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HAL Project Title:

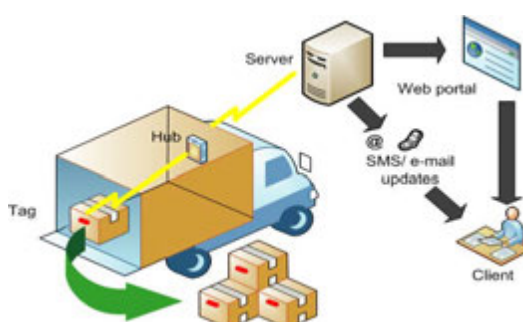
Opportunities and challenges faced with emerging technologies in the Australian vegetable industry.

(Technology Platform 2: Environmental Technologies)

Project VG08087

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## (Technology Platform 2: Environmental Technologies)

Horticulture Australia Project Number: VG08087

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### Purpose of Project:

This report was prepared as an outcome of Milestone 103 of project VG08087, "Opportunities and challenges faced with emerging technologies in the Australian vegetable industry". The project aims to provide a broad review of technologies that are influencing the competitiveness of the industry. This is the 2nd of five reports to be developed during 2009-2010 and reviews emerging technologies to solve environmental issues affecting the horticultural industry.

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## Media summary

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The objective of the project "Opportunities and challenges faced with emerging technologies in the Australian vegetable industry" is to provide a broad review of technologies that are influencing the competitiveness of the Australian vegetable industry.

This report is the second of five analyses to be developed in 2009-2010 and reviews emerging environmental technologies that can be implemented in the horticultural industry to tackle climate change challenges.

Some key findings of this analysis were:

- Biofuels, glasshouse energy technologies, smart demand management in cold chain operations, water generation technologies and smart irrigation are technologies where there is still technological uncertainty and R&D costs for the horticultural industry are not well defined yet. However, current pressures to mitigate and adapt to climate change and the quantum of savings on some of these areas may call for investment on early-stage technologies to shorten the research and development cycle. While the time frame to enter embryonic and growth areas is 30 years or more, the decision on the inclusion of agriculture in the projected ETS is only 4 years away.
- In available Government and industry reports discussing strategies for the development of smart irrigation, anaerobic digestion, biotechnology, biochar application and biofuels, horticulture is hardly mentioned. The fact that horticulture is considered a low emitter can benefit the industry through avoiding inclusion of this sector in a future ETS. However, it places horticulture in a disadvantage with respect to other sectors on receiving investment for innovation in climate related technologies. Strategic investment seems to be focused in broadacre crops and livestock, for example.
- The disadvantage mentioned above will be a greater hurdle when other larger emitters in horticultural supply chains (e.g. packaging, transport, retail) transfer the costs of mitigation and adaptation to growers instead of passing these costs to consumers. Given the perception of horticulture as a low emitter, it will be difficult to justify measures that lessen the impact of these ETS-derived costs.
- Biotechnology for adaptation of horticultural varieties is a contentious issue and there are major impediments to the commercialization of this technology in Australia, including development costs and political aspects. The use of transgenic crops should be evaluated from the perspective of ensuring food security under adverse climate conditions. In preparation to more favourable political conditions for the introduction of genetically modified crops as an adaptation strategy, assessments on the environmental effects of transgenic plants and their benefits in improving yields, aiding soil and water conservation and increasing the resilience of Australian vegetable chains should be undertaken.

## Technical summary

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The objective of the project "Opportunities and challenges faced with emerging technologies in the Australian vegetable industry" is to provide a broad review of technologies that are influencing the competitiveness of the Australian vegetable industry.

This report is the second of five analyses to be developed in 2009-2010 and reviews emerging environmental technologies that can be implemented in the horticultural industry to tackle climate change challenges.

Some key findings of this analysis were:

- Biofuels, glasshouse energy technologies, smart demand management in cold chain operations, water generation technologies and smart irrigation are technologies where there is still technological uncertainty and R&D costs for the horticultural industry are not well defined yet. However, current pressures to mitigate and adapt to climate change and the quantum of savings on some of these areas may call for investment on early-stage technologies to shorten the research and development cycle. While the time frame to enter embryonic and growth areas is 30 years or more, the decision on the inclusion of agriculture in the projected ETS is only 4 years away.
- In available Government and industry reports discussing strategies for the development of smart irrigation, anaerobic digestion, biotechnology, biochar application and biofuels, horticulture is hardly mentioned. The fact that horticulture is considered a low emitter can benefit the industry through avoiding inclusion of this sector in a future ETS. However, it places horticulture in a disadvantage with respect to other sectors on receiving investment for innovation in climate related technologies. Strategic investment seems to be focused in broadacre crops and livestock, for example.
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As a result of these observations, a three-tiered strategy for HAL funding in mitigation and adaptation technologies is suggested:

- Tier I encompasses technologies that are currently being commercialized and R&D decline expected in the next 10-20 years. This tier includes transgenic crops, CHP/CCHP, anaerobic digestion and photovoltaics/solar thermal energy. These technologies are mature, have well defined R&D predictability profiles and the investment levels are also highly predictable. Projects developed for this tier could include state-of-the-art and benchmarking projects. For example, analysis of financial and carbon reduction opportunities, solutions for specific uses in horticulture (e.g. alternative energy for water pumping, small CHP for cooling and heating for primary production, AD for reusing vegetable waste and composting) and pilot trials to test these concepts.
- Tier II encompasses technologies that are expected to be fully commercialized in the next 5-10 years and R&D decline expected in the next 40 years. This tier includes smart irrigation, production/use of biofuels for primary production machinery (e.g. forklifts, tractors) and glasshouse energy technology.
- Tier III encompasses technologies that have beyond 40 years for full R&D development. This category encompasses "blue sky" research and truly innovative solutions to pressing issues such as water generation and utilization of electricity grid information. Funding for this tier should be focused on accelerating the R&D cycle of these technologies.

Further, basic knowledge such as benchmarking projects, metrics and surveys to evaluate the environmental performance of horticultural enterprises is needed to advance on any of the abovementioned tiers. Such projects should encompass data from small, medium and large Australia operations that allow further targeting of technologies on the basis of capital costs, operational costs, training/education barriers and other parameters.

Finally, recent published studies challenging the assumption of local chains being more environmentally-friendly than imported products are a timely reminder of the need of reassuring consumers about the focus of horticultural chains in improving their environmental footprint. The industry can stand up to scrutiny if mitigation and adaptation technologies are investigated and adopted in a proactive manner.

## Executive summary

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The objective of the project "Opportunities and challenges faced with emerging technologies in the Australian vegetable industry" is to provide a broad review of technologies that are influencing the competitiveness of the Australian vegetable industry.

This report is the second of five analyses to be developed in 2009-2010 and reviews emerging environmental technologies that can be implemented in the horticultural industry to tackle climate change challenges.

The present report discusses the opportunities and challenges of emerging technologies for mitigation and adaptation of the Australian horticulture industry to climate change.

While there are several management measures that can be used for mitigation and adaptation, this report deals with measures supported by specific technology developments. We also provide a general discussion of cost and benefits for each technology investigated.

### *The Australia vegetable carbon footprint*

In comparison to other sectors such as livestock and broadacre crops, horticultural production can be regarded as a low emitter of greenhouse gases. A preliminary benchmark of the emissions from vegetables production was estimated by O'Halloran *et al.* (2008) and it is about 1 Mt CO<sub>2</sub>-e. While this estimate suits the purposes of carbon accounting from a sector-based perspective and is congruent with the requirements of an emissions trading scheme, this value does not reflect the entire lifecycle of vegetable products, which is the basis of a carbon footprint evaluation.

Taking into account glasshouse production and activities post-farm, in this report we estimate that the energy carbon footprint of the vegetable sector ranges from 7,600 to 9,000 GWh/year. This represents 6.1 to 7.25 Mt CO<sub>2</sub>-e per year, excluding transport. Cold chain operations represent about 70% of the total energy used. These values purely reflect energy consumption and do not include embodied energy, water and land use, packaging and waste generation from farm to consumption.

### *Energy and water use*

The environmental impacts of glasshouse production in relation to energy usage for heating, cooling and irrigation are of particular interest. The protected cropping industry is growing at a rate of 6% per annum and it is expected that the planted area will treble by 2017, with respect to 2007. Using data from the UK and New Zealand as a basis for the estimation of the Australian energy use for protected cropping of edible vegetables, we estimate that this could range from 1,700 to 3,000 GWh per annum. Thus, protected cropping alone could be contributing between 1.4 and 2.4 Mt CO<sub>2</sub>-e to the vegetable carbon footprint.

In regards to field cropping, the preliminary estimate of O'Halloran *et al.* (2008) indicates that electricity contributes 65% of the total emissions in Australian on-farm operations. This



finding disagrees with other international studies, which indicate that the most significant sources of carbon emissions in the production of vegetables are fuel and machinery, followed by fertilizers. These differences are explained by the fact that in the Australian study the authors attribute irrigation energy entirely to electricity. A more accurate estimate would require knowledge about the split between diesel-powered and electricity-powered pumps used in vegetable irrigation.

The relevance of the attribution of on-farm energy consumption to electricity is relevant to the estimation of saving opportunities through efficient irrigation. For example, in 2007 the average irrigation flow used for vegetable production was 430,649 ML. Pumping of this flow would have required 675 GWh, with an estimated annual cost of \$87.8 million (assuming an average electricity cost of \$0.13/kWh). This estimate, however, assumes that all pumps used for irrigation run in electricity.

### *Land use*

One critical issue in the environmental management of land for horticulture is the use of fertilizers and nutrients. In 2007 about 24% of all synthetic fertilizers was used for horticultural production. Further, it is estimated that as much as 72% of the total fertilizer applied is lost through leaching and runoff.

Management techniques to accurately account for fertilizer applications include the use of compost and poultry manure instead of conventional fertilizers. However, key technologies that can significantly impact the use of fertilizers are accurate measurements of the soil quality (and therefore fertilizer needs) and accurate delivery of fertilizers. These two aspects can be addressed through precision agriculture, which will be discussed in the last report of this project (production and harvesting technologies).

A concept that deserves further investigation is the thermal treatment of natural organic materials in an oxygen-limited environment (pyrolysis) to produce 'biochar'. A byproduct of the production of biochar is heat and power, which can then be used for irrigation and other energy-intensive operations. As a soil conditioner, biochar may improve the structure and fertility of soils and retention of fertilizers, thus decreasing run-off. However, these claims have not been sufficiently verified in horticultural applications.

The use of biochar as a sequestration strategy requires a national effort to be effective and therefore the benefits need to be estimated at a macro-level. Baseline studies on the potential biomass available from different horticultural residues in Australia could allow assessments of biochar facilities in a local, regional and national basis.

### *Adaptation to climate change*

The impacts of climate change in horticulture, which have been reviewed in detail in Australian and international studies include changes in growing seasons, poorer outturn quality and yields, higher risks / costs in the supply chain, and increasing on-farm and post-farm food safety risks. These technical impacts have not been accounted for in economic analyses on the impact of an emissions trading scheme on horticulture.

Although the Australian vegetable industry faces significant challenges on the environmental front, this report indicates that there are technologies that can help the industry to adapt to the reported climate change scenarios. However, the development and uptake of such technologies needs to begin now. After all, climate change will occur whether agriculture is included in the ETS or not.

One aspect of particular interest is the vulnerability of vegetable supply chains under climate change conditions. Recent experiences from Hurricane Larry the Victorian bush fires demonstrate that production, distribution and quality of fresh vegetables can be disrupted by extreme weather events. This makes the Australian industry more vulnerable to lose market share to imported products.

#### *HAL funding on environmental technologies*

Between 1998 and 2008, HAL funded 250 projects on environmental areas. About 37% of all environmentally-related projects were linked to the management of chemicals, followed by sustainability (23%) and water use-irrigation (29%).

A forecasting analysis using the historical performance of HAL in the development of adaptation and mitigation projects indicates that a decline in these platforms is expected to occur in 2012, if no factors influence current investment policies and strategies.

#### *Emerging technologies for mitigation and adaptation*

Estimates of financial savings related to mitigation strategies were calculated in the following areas:

- Energy efficiency in glasshouse production: \$41.6 million
- Energy efficiency in cold storage: \$12 million.
- Irrigation (water & energy): \$38 million.
- Waste avoidance: \$164.9 million.

There are several technologies that can improve energy efficiency in glasshouse production. However, it is important to select technologies that can be adapted and provide benefits in Australian conditions. For example:

- The costs of building, installing and servicing energy saving technologies for glasshouses can be high. DAFF grants such as FarmReady and the Regional Food Producers Innovation and Productivity Program provide some funding for the implementation of energy saving measures. However, a national effort to decrease energy in glasshouse production will need larger investments than what the Government has put aside for these two programs (\$35 million and \$26.5 million over four years, respectively).
- Economies of scale are important in glasshouse energy efficiency measures and only large operations could benefit from some available technologies. Therefore, surveys that provide details on the sizes of glasshouse operations in Australia would help to select technologies that can work for the majority of operators.

A current innovation in glasshouse production is the Seawater Greenhouse, a concept that combines air natural cooling and humidification and sunlight to distil fresh water from seawater. A 1,000 m<sup>2</sup> pilot project is under way in South Australia, with an aim to start operations by June 2010 and to add 3 or more hectares by 2011.

Improvements in protected cropping may be required to face competition from China, whose researchers have patented about 40% of the inventions in glasshouse technology in the past 30 years. The Chinese government is encouraging the development of large scale greenhouses through joint ventures with foreign companies and has recently introduced new cultivation techniques and cultivars.

General recommendations on the directions of R&D funding in the areas of adaptation and mitigation include:

- Biofuels, glasshouse energy technologies and smart irrigation are technologies in a growth stage, where there is still technological uncertainty and R&D costs are not well defined yet. Other technologies such as the Seawater Greenhouse and smart demand management in cold stores are still in embryonic stage. However, current pressures to mitigate and adapt to climate change and the quantum of savings on some of these areas may require HAL to evaluate investment on early-stage technologies to shorten the research and development cycle. While the time frame to enter embryonic and growth areas is 30 years or more, the decision on the inclusion of agriculture in the projected ETS is only 4 years away.
- In available Government and industry reports discussing strategies for the development of smart irrigation, anaerobic digestion, biotechnology, biochar application and biofuels, horticulture is hardly mentioned. The fact that horticulture is considered a low emitter can be of benefit in regards to avoiding inclusion of this sector in a future ETS. However, it places horticulture in a disadvantage with respect to investment for innovation in environmental technologies, because attention is on larger emitters such as broadacre crops and livestock.
- The disadvantage mentioned above will become evident when other larger emitters in horticultural supply chains (e.g. packaging, transport, retail) transfer the costs of mitigation and adaptation to growers (instead of passing these costs to consumers). Given the perception of horticulture as a low emitter, it will be difficult to justify measures that lessen the impact of these ETS-derived costs.
- Biotechnology for adaptation of horticultural varieties is a contentious issue and there are major impediments to the commercialization of this technology in Australia, including development costs and political aspects. The use of transgenic crops should be evaluated from the perspective of ensuring food security under adverse climate conditions. In preparation to more favourable political conditions for the introduction of genetically modified crops as an adaptation strategy, assessments on the environmental effects of transgenic plants and their benefits in improving yields, aiding soil and water

conservation and increasing the resilience of Australian vegetable chains should be undertaken.

*Recommendations for future R&D investments in adaptation and mitigation technologies*

As a result of these observations, a three-tiered strategy for HAL funding in mitigation and adaptation technologies is suggested:

- Tier I encompasses technologies that are currently being commercialized and R&D decline expected in the next 10-20 years. This tier includes transgenic crops, CHP/CCHP, anaerobic digestion and photovoltaics/solar thermal energy. These technologies are mature, have well defined R&D predictability profiles and the investment levels are also highly predictable. Projects developed for this tier could include state-of-the-art and benchmarking projects. For example, analysis of financial and carbon reduction opportunities, solutions for specific uses in horticulture (e.g. alternative energy for water pumping, small CHP for cooling and heating for primary production, AD for reusing vegetable waste and composting) and pilot trials to test these concepts.
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Further, basic knowledge such as benchmarking projects, metrics and surveys to evaluate the environmental performance of horticultural enterprises is needed to advance on any of the abovementioned tiers. Such projects should encompass data from small, medium and large Australia operations that allow further targeting of technologies on the basis of capital costs, operational costs, training/education barriers and other parameters.

Finally, recent published studies challenging the assumption of local chains being more environmentally-friendly than imported products are a timely reminder of the need of reassuring consumers about the focus of horticultural chains in improving their environmental footprint. The industry can stand up to scrutiny if mitigation and adaptation technologies are investigated and adopted in a proactive manner.

## Glossary, abbreviations and units

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### Environmental impact

CO<sub>2</sub>-e (Carbon dioxide equivalent). The amount of CO<sub>2</sub> that would have the same relative warming effect as the basket of greenhouse gases actually emitted.

Greenhouse Gases (GHGs) . Gases in the earth's atmosphere that absorb and re-emit infrared radiation. The Kyoto Protocol lists six major greenhouse gases: carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), HFCs (hydrofluorocarbons), perfluorocarbons (PFCs, a by-product of aluminium smelting) and sulphur hexafluoride (SF<sub>6</sub>).

### Energy

Kilowatt hour (kWh). The standard unit of electrical energy that represents the consumption of one kilowatt over the period of one hour.

Conversion factors for energy units

1 kilojoule (kJ) = 1000 Joule (J); 1 kWh (kilowatt-hour) = 3.6 MJ;

1 megajoule (MJ) = 1000 kJ; 1 MWh (megawatt-hour) = 3.6 GJ;

1 gigajoule (GJ) = 1000 MJ; 1 GWh (gigawatt-hour) = 3.6 TJ;

1 terajoule (TJ) = 1000 GJ; 1 TWh (terawatt-hour) = 3.6 PJ;

1 petajoule (PJ) = 1000 TJ;

Prefixes of SI-units

k =kilo  $10^3 = 1,000$ ;

M =mega  $10^6 = 1,000,000$ ;

G =giga  $10^9 = 1,000,000,000$ ;

T =tera  $10^{12} = 1,000,000,000,000$ .

Conversion factors of power units

1 kilowatt (kW) = 1000 W;

1 megawatt (MW) = 1000 kW;

1 gigawatt (GW) = 1000 MW;

1 megajoule per second (MJ/s) = 1 MW;

1 horsepower (HP) = 0.735 kW;

### Water

Eutrophic (a description usually applied to water) over enriched by nutrients, primarily nitrogen and phosphorus, stimulating excessive growth of organisms and depletion of dissolved oxygen.

Conversion factors

Megalitres (ML)= $1e^6$  litres (L); Gigalitres (GL) =1,000 ML.

# Project Background

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The vegetable industry is a truly multi-disciplinary business, particularly in the context of modern global supply chains. The industry draws knowledge from a variety of fields such as plant breeding and production, greenhouse technologies, irrigation, climate control, information technologies, product processing, packaging, logistics and consumer science, among others. Therefore, the growth of the vegetable sector is intertwined with the development and application of innovative solutions in the fields mentioned above. The use of molecular biology to produce new enhanced (but still non-genetically modified organisms) cultivars that increase yields, the introduction of pre-packed fresh vegetables and the development of track-and-trace systems that can improve transparency in food supply chains are some examples of how emerging technological trends can influence the competitiveness of the Australian vegetable industry.

The objective of the project "Opportunities and challenges faced with emerging technologies in the Australian vegetable industry" is to provide a broad review of current and emerging technologies that are influencing the competitiveness of the Australian vegetable industry. This review, carried out through the use of competitive intelligence analyses, provides a technology roadmap that shows: (a) where the Australian vegetable industry lies in the use of technology that benefits the competitiveness of the sector; and (b) what specific technological trends can affect the industry's competitiveness in the years ahead.

The application of competitive intelligence (CI) techniques in this report was used to explain how the exploitation of emerging technologies (or lack of thereof) can influence the profitability of the Australian vegetable sector. In this project, the application of CI was based on a two-staged approach:

- I) An analysis of the technological state-of-the-art in the Australian vegetable sector, *i.e.* what technologies are been applied commercially (as distinct from pilot trials) during the production, harvesting, processing and distribution of vegetables in Australia. This analysis includes hurdles faced by 'first-movers' in the implementation of new technologies and the benefits reaped from the uptake of new technologies.
- II) An analysis of emerging and potentially disruptive technologies with potential impact on the vegetables industry. The analysis included potential impediments for commercial implementation in Australia and potential benefits arising from the uptake of such technologies.

This project delivers competitive intelligence analyses in five key technological platforms relevant to horticultural industries:

- (1) Supply chain and logistics systems.
- (2) Technology for mitigation and adaption to environmental changes.

- (3) Technology for food safety and quality assurance.
- (4) Value addition processes (*e.g.* functional genomics, novel manufacturing processes).
- (5) Technology for production and harvesting (including glasshouse production, robotics, mechanization and precision agriculture).

The present report specifically delivers to the second technical platform: technologies for mitigation and adaptation to climate change.

## Climate change mitigation and adaptation

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The International Panel on Climate Change [5] defines *mitigation* as: “An anthropogenic intervention to reduce the anthropogenic forcing of the climate system; it includes strategies to reduce greenhouse gas sources and emissions and enhancing greenhouse gas sinks.”

*Adaptation* is defined as, “Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities” [5].

There are three types of adaptation:

- **Anticipatory:** adaptation that takes place before impacts of climate change are observed. Also referred to as proactive adaptation.
- **Autonomous:** adaptation that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. Also referred to as spontaneous adaptation.
- **Planned:** adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state.

While mitigation focuses on actions to eliminate or reduce the causes of climate change, adaptation refers to measures for adjusting systems (*e.g.* social, economic, natural) to climate change effects. Some authors make a distinction between mitigation and reduction measures in that the former uses external mechanisms to offset carbon footprints through some form of carbon capture, while the latter encompasses direct measures implemented within a business [6]. However, in this report “mitigation” represents direct or indirect measures for carbon reduction.

In the scientific and popular literature on climate change, technologies to reduce carbon emissions are interchangeably referred to as mitigation or adaptation technologies. One of the reasons is that strategies applied today to mitigate carbon emissions (*e.g.* energy and water efficiency measures) will eventually become adaptation strategies, as energy and water resources become scarcer.

Therefore, while we discuss separately the challenges of mitigation and adaptation technologies, the analysis does not classify measures and we simply include technologies that could help the Australian vegetable industry to mitigate and adapt to climate change.

Further, there are several management measures that can be used to mitigate and adapt to climate change, many of them are based on behavioural changes and not all of them are supported by a specific technology. In this report we have selected only measures that are supported by technological changes. A full discussion on management measures can be found in references [7-11].

This report does not provide detailed costs (e.g. costs of planning, facilitating, implementing and transitioning) and benefits (e.g. avoided damage or accrued benefits) of mitigation and adaptation measures. However, a discussion on these aspects is presented for each technology investigated.

## Mitigating the Impacts of Horticultural Supply Chains on the Environment

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Agriculture contributes 13.5 % of all human-induced greenhouse gas emissions (GHG) globally. In Australia, agriculture emitted 16.5% of the total national direct GHG in 2008 [12], up 0.2% with respect to the 2007 GHG accounting results. Comprehensive discussions on the issues that need to be attended in agriculture through the use of mitigation and adaptation technologies can be found in [8, 11, 13, 14].

The estimated GHG emissions from horticultural production between 1990 and 2005 are presented in Figures 1 and 2. The contribution of horticulture to the agricultural carbon footprint is estimated in 5 Mt CO<sub>2</sub>-e [15], with the vegetable industry contributing between 1 and 3 Mt CO<sub>2</sub>-e [16]. Based on these figures, horticulture can be regarded as a non-intensive industry in terms of emissions during production [17].



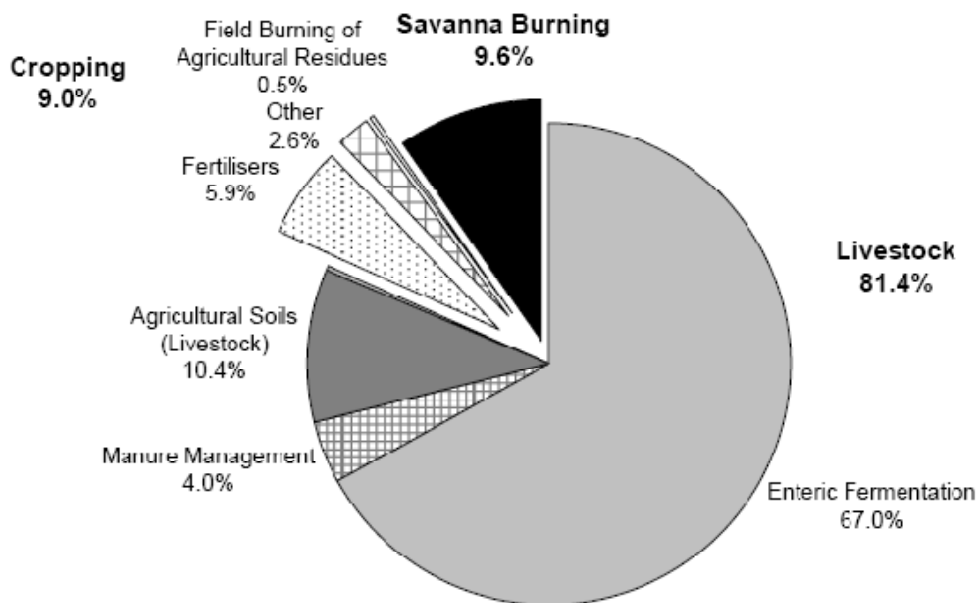


Figure 1. Components of agricultural emissions in Australia during 2005. Source: [18].

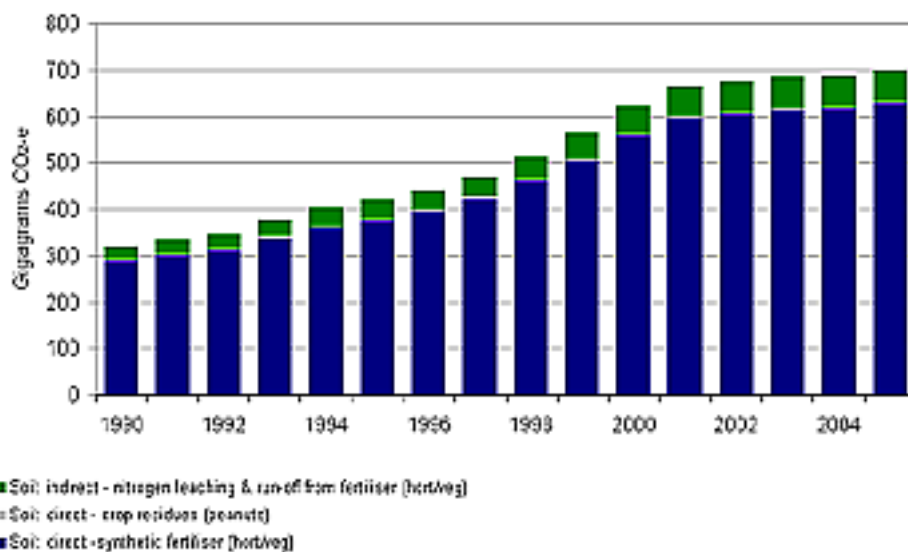


Figure 2. Estimated GHG emissions from horticulture (Gigagrams CO<sub>2</sub>-e). Source: National Land & Water Resources Audit. Signposts for Australian Agriculture. Available at: <http://www.nlwra.gov.au/products/pn21405>.

While in the context of an emissions trading scheme (ETS) it is perfectly acceptable to limit the environmental impact of horticultural production to the planting and growth of crops, the impact of downstream activities needs to be included in life cycle analyses (LCA) performed to determine carbon footprints of horticultural products. Figure 3 illustrates the impacts of agriculture using the LCA concept.

The concept presented in Figure 3 includes the environmental impacts of the following activities:

## ENERGY

- Direct energy use on-farm, during manufacture and cooking in households.
- Indirect energy use during storage, packaging and transportation throughout the supply chain.

## WATER

- Direct use of water for farming and processing.
- Indirect use of water for supplies manufacturing (e.g. packaging).
- Use of chemical agents and pollution of groundwater and waterways during farming and processing.

## LAND/VEGETATION/WILDLIFE

- Land use for agricultural production.
- Use of chemical agents and pollution of land.
- Controlled removal of vegetation.
- Controlled removal of wildlife.

## WASTE

- Food and packaging waste at each stage of the chain.

In an effort to capture all the aspects above, the concept of carbon footprint has been developed. A carbon footprint is expressed as the total amount of carbon dioxide equivalents (CO<sub>2</sub>-e) and other greenhouse gases (GHG), emitted over the full life cycle of the product. This lifecycle goes beyond production to encompass post-production and consumer impacts.

Carbon labelling is the expression of a product's carbon footprint in the form of a label. A carbon label (or eco-label) may have information such as grams of CO<sub>2</sub>-e, plus declarations of other GHG produced during the life cycle of the product. Carbon labelling has been adopted for non-perishable and perishable items. For example, Tesco is testing these labels in milk, potatoes, orange juice, detergent and light bulbs.

Eco-labelling is now part of the strategy of large supermarket chains, most notably Walmart in USA<sup>1</sup> and Tesco in the UK<sup>2</sup>. In Australia, an invitation by Planet Ark and the Carbon Trust to develop a carbon label has been extended to companies producing consumer packaged foods. It is expected that the first products bearing the label will hit Australian supermarket shelves in 2010<sup>3</sup>.

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<sup>1</sup> <http://walmartstores.com/FactsNews/NewsRoom/9279.aspx>

<sup>2</sup> <http://www.ausfoodnews.com.au/2009/05/04/tesco-expands-use-of-carbon-label-on-grocery-products.html>

<sup>3</sup> <http://www.ausfoodnews.com.au/2009/07/07/carbon-reduction-label-for-packaged-goods-launched-in-australia.html>

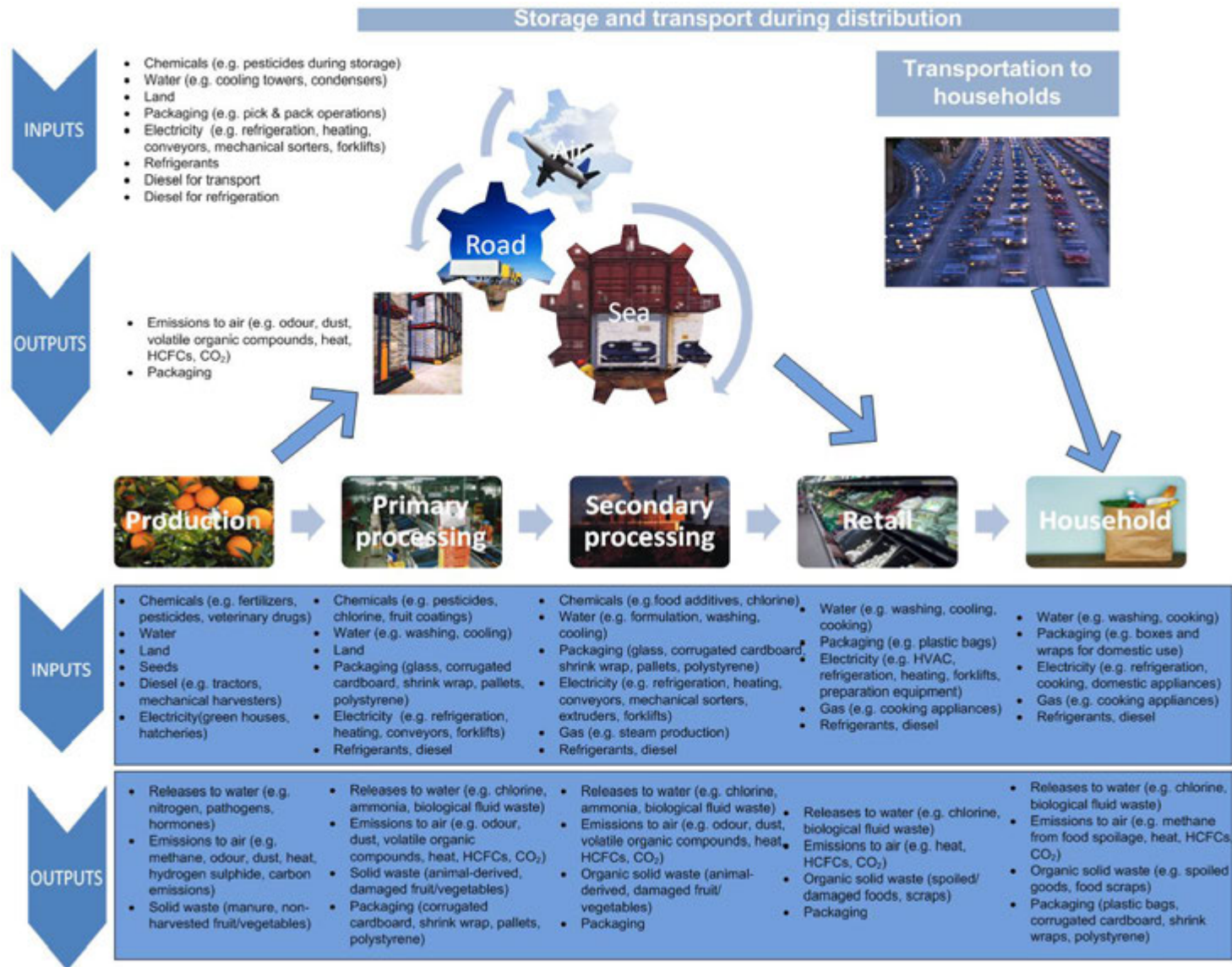


Figure 3. Environmental impacts of food supply chains [19].

If Australian supermarkets adopt carbon labelling, suppliers will have to declare their contribution to the total carbon footprint. Growers would then compete not only in price and quality, but also in environmental impact. Those with operations that minimise contributions to a product's carbon footprint could be selected as preferred suppliers over non-compliant/high environmental impact competitors.

Recently, the Food Ethics Council in the UK suggested including in food labels a statement showing the manufacturers' awareness in producing goods using water efficient processes. Rather than providing a specific "water footprint", the goal is to highlight companies engaging in "water stewardship"<sup>4</sup>. It is debatable whether this scheme would be successful in Australia. After all, farmers are already battling conditions of drought in several parts of the country. Growers that are not currently optimizing their water consumption are likely to be out of business in the near future.

Some specific mitigation aspects on energy, water, land and waste are discussed in the following sections.

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<sup>4</sup> [http://www.foodethicscouncil.org/files/waterlabels\\_0.pdf](http://www.foodethicscouncil.org/files/waterlabels_0.pdf)

#### CASE STUDY: ZESPRI AND THE NEW ZEALAND KIWIFRUIT EXPORT INDUSTRY

ZESPRI undertook a comprehensive study to measure the carbon footprint across the lifecycle of New Zealand Kiwifruit for export. The methodology followed aligns with the UK PAS 2050 (2008), acknowledged as the most robust carbon emission measurement standard available.

The study found that ZESPRI® kiwifruit shipped and consumed in Europe contributes 1.74 kg of carbon equivalents per 1.0 kg of kiwifruit across its lifecycle from orchard to consumer.

The emissions at each stage of the lifecycle of ZESPRI® Kiwifruit destined for Europe were:

- Orchard operations make up 17% of total emissions for EU exports.
- Packhouse and coolstore processes account for 11% of total emissions.
- Shipping accounts for 41% of total emissions.
- Repacking and retailer emissions amount to 9% of total emissions.
- Consumer consumption and disposal comprises 22% of total emissions.

ZESPRI is now working with the kiwifruit industry on a series of initiatives to reduce its carbon footprint, namely:

- Climate change adaptation – adjusting on-orchard practices to accommodate the changing environment. For example, one grower has converted a natural gully into two lakes which now serve as an efficient irrigation system for his orchard.
- Focus orchard network – sharing best practice to optimise orchard product quality, yield and efficiencies.
- Waste utilisation – turning kiwifruit waste into bio-plastics which can be used for packaging.
- Lean manufacturing - streamlining processes, reducing waste, increasing efficiency in the packhouse.
- Pack optimisation - allowing a greater quantity of fruit to be shipped at one time without compromising quality.
- Slow-steaming ships – reducing a ship’s speed by 2km/h at certain points in the season lowers diesel use by 17%.
- The potential future use of SkySails – harnessing the wind’s energy by flying a sail 100–300m off the front of cargo ships, reducing carbon emissions and lowering operating costs.

Source: <http://www.zespri.com/about-zespri/newsroom.html>

## Energy Use

### Protected (glasshouse) production

Glasshouse production consumes energy to maintain adequate ventilation, temperature and humidity for crops. Irrigation and CO<sub>2</sub> enrichment also contribute to the environmental impacts of glasshouse production.

HAL estimates that Australia has 1,600 ha of protected cropping systems for vegetables [20], although AUSVEG data indicates that in 2006-07 there were 870 ha of protected crops<sup>5</sup>. In any case, the protected cropping industry is growing fast, at a rate of 6% per annum. Given that the quality of products and prices meet the expectations of large retailers there is an interest in developing further this industry. It is expected that the planted area will treble by 2017 with respect to 2007 levels, particularly in SA and NSW. Protected vegetable production is currently focused on cucumbers, capsicums, hydroponic lettuces, herbs and tomatoes [20].

The vast majority of Australian farms operate with low to medium technology levels, lagging behind The Netherlands, US, UK and Canada, which have established best practice technologies and management systems in protected cropping systems.

The industry also lags in terms of its preparedness to climate change challenges. Although there is a limited area of protected crops, the industry's carbon footprint per hectare is significantly larger than field cropping. This is illustrated in Figure 4, which shows the estimated carbon footprint of protected horticultural production in the UK as compared with other systems.

Considering the farming area dedicated to field horticulture in the UK, one hectare of protected cropping consumes about 900 times more energy in items such as electricity and machinery than the same area in field cropping. The UK has an estimated 1,800 ha of protected cropping with an estimated annual energy use of 1.84 GWh/ha.

This result is surprisingly lower than the annual energy use for protected cropping in New Zealand, estimated in 3.14 GWh/ha [21]. The opposite would be expected, given that in the UK the need for heating is higher than protected cropping under the mild NZ climate. However, the uptake and development of energy-efficient technology is likely to be higher in the UK than in NZ.

Using the UK and NZ data as a basis for the estimation of the Australian energy use for protected cropping (edible vegetables only), we estimate that this could range from 1,700 (for 870 ha planted) to 3,000 GWh (for 1,600 ha planted) per annum.

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<sup>5</sup> <http://www.ausveg.com.au/assets/contentitems/public/7048/VegetablesGrownUndercover.pdf>

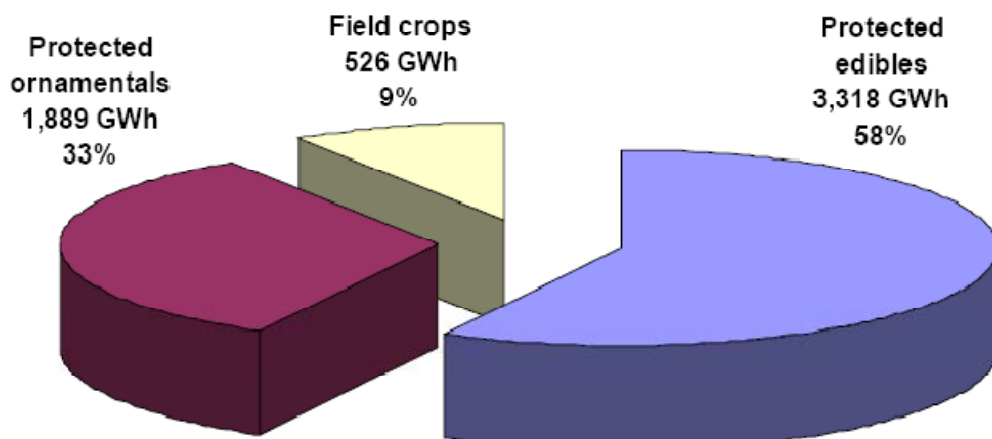


Figure 4. Breakdown of primary energy use in UK horticultural production. Sources: [2]; Carbon Trust, 2009<sup>6</sup>.

While the UK and New Zealand require more heating to maintain appropriate environmental conditions for protected crops than Australian operations, it has been established that the UK is likely to use more energy efficient glasshouse systems than those used in Australia. Further, Australian production may require additional cooling and irrigation to counteract warm summer conditions.

### Field horticulture

HAL has defined the following main areas of energy use at farm level [7]:

- Irrigation (water pumping)
- Vehicles and equipment.
- Forklifts, tractors and other machinery.
- Lighting.
- Cold storage and packing lines (if it is a grower-packing operation).

The total primary energy use during the production of crops includes direct energy input (e.g. diesel, petrol, electricity) and indirect energy input (e.g. embodied energy in machinery, buildings, agrichemicals and fertilizers).

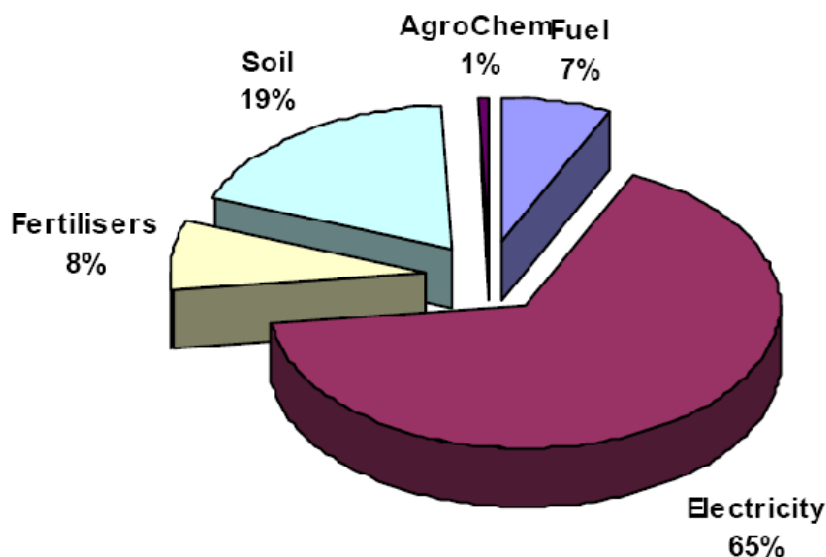
Irrigation and cold chain operations are electricity-intensive operations. In the former, the choice of the irrigation system among border check, subsurface drip, centre pivot and others is a key factor that determines the operational energy required to run the system. From these systems, subsurface drip is the most energy intensive irrigation system.

Refrigeration is a significant energy spending operation in horticulture enterprises. At facilities with no packing line, refrigeration can use between 90% and 95% of the total energy use. With a packing line, refrigeration energy use can range from 70% to 80% of the total, with the balance used by packing lines and lighting [22]. In the section "cold chain

<sup>6</sup> [http://www.carbontrust.co.uk/energy/startsaving/sectorselector/agricultureandhorticulture\\_2.htm](http://www.carbontrust.co.uk/energy/startsaving/sectorselector/agricultureandhorticulture_2.htm)

operations" an estimate of the energy expenditure to maintain cold chain conditions for the vegetable industry is presented.

A recent Australian report [16] presented estimates of on-farm (direct) greenhouse gas emissions. Figure 5 shows a snapshot of the proportion of greenhouse gas emissions for the Australian vegetable industry.



*Figure 5. Proportion of greenhouse gas emissions from the Australian vegetable industry. Source: [16].*

Figure 5 suggests that decreasing the use of electricity pre-farm, on-farm and post-farm operations would have the largest impact on the total emissions from the Australian vegetable industry.

However, this finding disagrees with other international studies. For example, an assessment for iceberg lettuce production in Salinas (USA) published by Pimentel in 1980 [23] found that electricity was only 14% of the total, while diesel represented 36%. The most significant sources of carbon emissions in the US production of lettuce are fuel and machinery, followed by fertilizers.

These differences are explained by the fact that in the US studies the energy used in irrigation is attributed to fuel, whereas in the Australian study [16] the authors attributed irrigation energy to electricity. A more accurate Australian estimate would require knowledge about the split between diesel-powered and electricity-powered pumps used in vegetable irrigation. This correction would certainly affect the energy source attribution in Figure 5.

New Zealand data [24] indicates that, while electricity represents 46% of the total energy inputs in irrigated arable operations, electricity is a minor input for onion and potato (1.3 and 4.9% of the total energy use, respectively).



For each type of crop there is an overall energy ratio (OER) which determines the relationship between energy inputs and outputs. This ratio is essential to understand the energy efficiency of cropping operations in relation to production (i.e. productivity). A New Zealand study [24] found that the energy productivity for onions was 850 MJ/tonne, while for potatoes this index increased to 1, 200 MJ/tonne. Therefore, in this study the production of 1 kg of potato used 40% more energy than producing 1 kg of onion.

Further, the energy intensity for an onions operation was 50,100 MJ/ha, with 26% of the total energy inputs representing fertilizers. For potato, the energy intensity was 60,000 MJ/ha, of which fertilizers represented 42%.

Therefore, differences between energy expenditure for different vegetables and annual mixes of crops should be expected. To obtain an accurate representation of the vegetable industry's carbon footprint, the seasonal variation in crops produced by vegetable farms should be accounted for.

### Manufacturing

In terms of volume and value, the fresh domestic segment is the main market for vegetables. However, the vegetable manufacturing sector is estimated to process about 920,000 tonnes per year<sup>7</sup>. A growing segment is represented by fresh cuts, washed salads and the range of pre-packed fresh products, which had an estimated retail value of \$3.4 million in Australia and New Zealand during 2008.

Processed vegetables traded in significant volumes and on a commodity basis include frozen (e.g. fries, peas, beans, mixed vegetables), canned and dried vegetables and ingredients for other food products.

The annual energy and water use estimated for some processed vegetables in Australia are presented in Table 1. These values were based on current production volumes reported by AUSVEG and energy use data reported in source [1].

*Table 1. Estimated annual energy and water use for some vegetables during processing.*

<b>Product</b>	<b>Production (tonnes)</b>	<b>Energy use (GWh)</b>	<b>Water use (kL)</b>
French & runner beans	10,897	9	67
Peas	15,232	12	93
Potatoes	745,017	584	4,560
Sweet corn	31,956	25	196
Tomatoes	116,933	92	716

Table 1 indicates that potato processing (mostly frozen pre-cooked chips) is the most significant segment in terms of energy and water use. Potato manufacturing requires cooling (i.e. freezing), heating (i.e. blanching, frying) and a cold chain, as in the case of other manufactured vegetables. Freezing consumes between 9% and 17% of the total energy required to process frozen chips [25].

<sup>7</sup> <http://www.ausveg.com.au/statistics.cfm?CID=7048>

In any processing alternative, the transport and storage of raw materials (i.e. fresh produce) requires optimum temperature maintenance. Processes such as canning or drying require energy inputs during relatively short time frames, while chilled or frozen goods need to be maintained under refrigeration for days or even months, depending on the product characteristics. Therefore, cold chain systems are likely to use the largest proportion of the post-harvest energy.

### *Cold chain operations*

Figure 6 shows the five broad areas of cold chain operations required during the entire vegetables supply chain: (a) Initial cooling of fresh produce in the stages of production and primary processing; (b) chilling and freezing of products during the secondary processing stage; (c) refrigerated storage and distribution; (d) retail; and (e) domestic refrigeration in the consumer's household.

Figure 6 shows a national estimate of electricity usage for the domestic cold chain of vegetables at each of the stages above, calculated according to the methodology developed in reference [26].

The calculation of electricity usage for refrigeration purposes used the following assumptions:

- (a) The vegetable production at farm level for 2005-06 was obtained from reference [27]. The values for frozen fruit and vegetables production and the consumption at household level were obtained from published market reports [28, 29].
- (b) Essentially, cold chain operations during primary processing are related to produce precooling. Although primary processing can include storage, all energy used during storage is considered in the "distribution and handling" sector.
- (c) While good cold chain practices dictate that sensitive products should be immediately cooled after harvest, the reality is that many products are collected, stored and shipped at ambient conditions when these periods are short enough to avoid significant quality losses. Other products are simply not refrigerated (e.g. onions, fresh potatoes). Therefore, the scenario for energy usage assumes that only 50% of the vegetable production is precooled.
- (d) The calculation of the total energy usage during cold storage and retail phases was based on the assumption that vegetables use only 20% of the total energy used in cold storage operations in Australia. Again, this is a very conservative estimate. The total energy use was obtained from [26] and [30].
- (e) The estimation of the energy used for domestic refrigeration took into account that about 30% of the refrigerator is used for holding chilled and frozen vegetables, as illustrated on the "consumer's household" section of Figure 6.

The estimated total emissions during the transport of fresh and processed vegetables [1, 19, 31, 32] are also presented. The emissions value for transport assumes that 20% of the total emissions from food distribution in Australia can be attributed to the vegetables segment.

This is a conservative value, but there is a lack of more accurate estimates for food transportation.

Figure 6 indicates that energy consumption increases dramatically towards the final stages of the chain. From a whole-of-the-chain point of view, energy saving technologies that target retail and domestic refrigeration are likely to have more impact than other sectors. However, in this report we are particularly interested in technologies to save energy at farm level.

### Summary of energy use in vegetable supply chains

Figure 7 summarises the estimated energy used during the production, manufacture and distribution of vegetable products. The total emissions contributed by all the elements shown in Figure 7 is estimated to be 6.1 to 7.3 Mt CO<sub>2</sub>-e.

The major opportunity for energy reduction at farm level is in glasshouse production, which should be a key concern for companies operating on this space. More accurate statistics on the size of the industry and the energy spent during production are required.

Using available data, this preliminary assessment indicates that the energy consumption from protected cropping is significant and should be included in the evaluation of horticulture carbon footprints. This aspect appears to be neglected in available evaluations of the Australian vegetable carbon footprint.

#### SIZING THE OPPORTUNITY: ENERGY EFFICIENCY IMPROVEMENTS IN GLASSHOUSE OPERATIONS

Prospects for energy savings in the protected crops sector were investigated in the UK [2]. Energy saving strategies ranged from simple measures such as improving lighting efficiency (with savings on 0.2%) to adopting combined heat and power, also known as CHP or cogeneration (with savings of 20%). In Australian glasshouse vegetable production, reducing 20% of a total energy usage of 1,600 GWh/year would represent about \$41.6 million per year (assuming an average electricity cost of \$0.13/kWh).

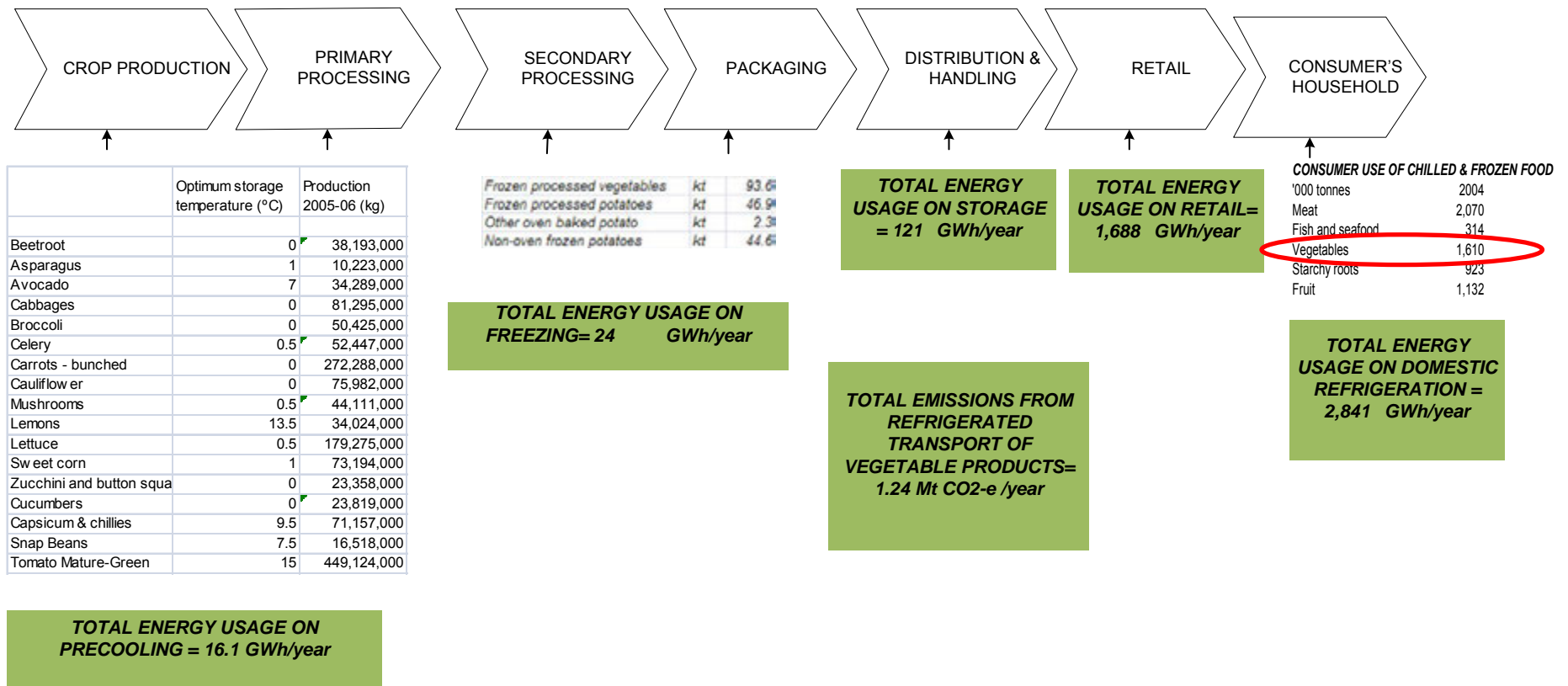
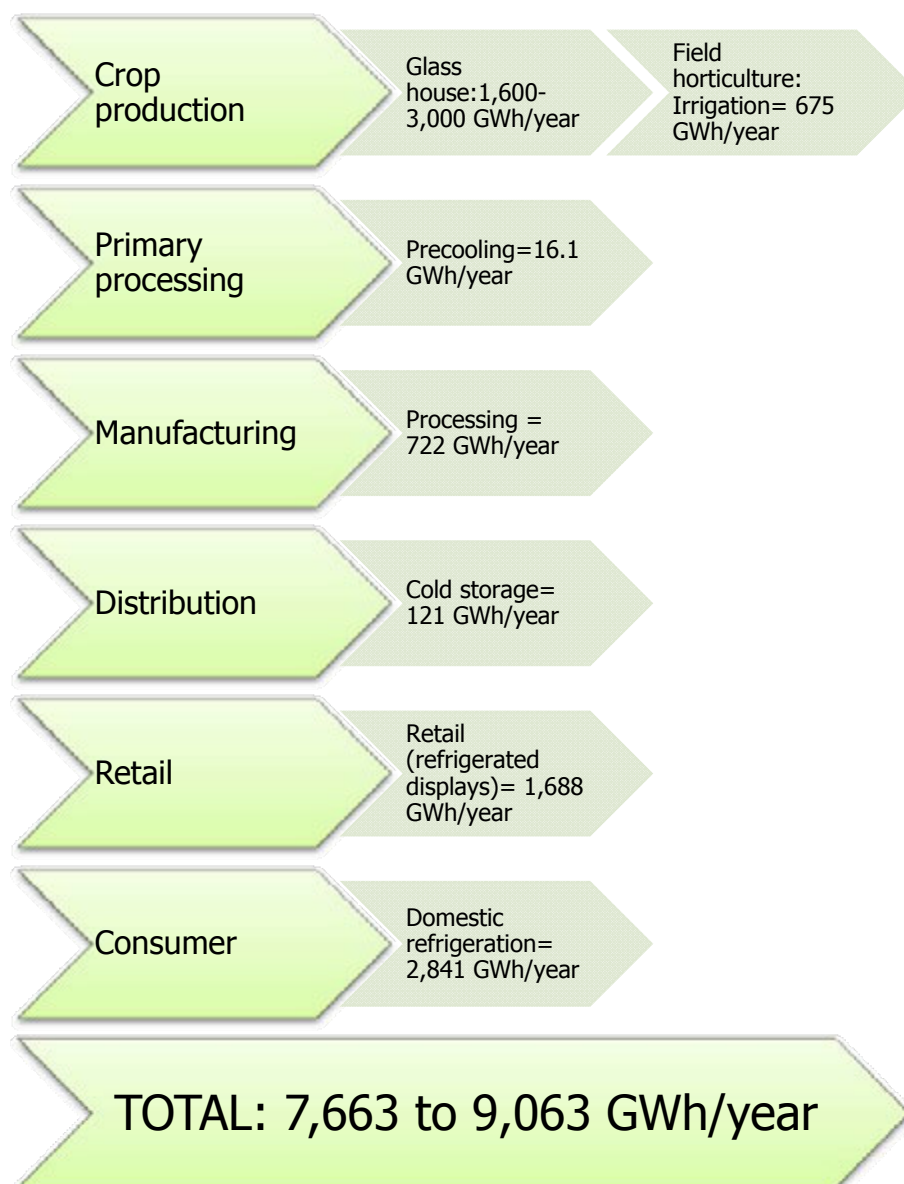


Figure 6. Estimated energy expenditure during the domestic cold chain of fresh and frozen vegetables.



*Figure 7. Summary of estimated energy expenditure during the production, manufacture and distribution of vegetable products.*

Cold chain management is essential for fruit and vegetable supply chains and the contribution of these operations should be included in the estimation of horticulture carbon footprints. A CSIRO report identified several strategies to decrease energy consumption in precooling and postharvest storage [26]. Some of these are summarized in Appendix 1. Most of the proposed measures relate to selection of refrigeration equipment and maintenance measures (e.g. keep insulation effectiveness and air tightness). Savings resulting from these measures are estimated to be in the range of 1-15% [33, 34].

Smart demand management, an intervention based on new control strategies, will be discussed later in this report.

### SIZING THE OPPORTUNITY: ENERGY EFFICIENCY IMPROVEMENTS IN COLD STORAGE OPERATIONS

A 15% reduction in the electricity spent in primary cold storage, manufacturing (including freezing, canning and production of salads) and subsequent refrigerated warehousing in the vegetables supply chains would save \$12 million per year (assuming an average electricity cost of \$0.13/kWh).

It is important to highlight that indirect emissions from electricity (or diesel in the case of refrigerated transport) contribute with 70%- 90% to the total carbon footprint of refrigeration systems. Direct emissions from leakage of refrigerant into the atmosphere represent 10-30% of the total emissions from refrigeration.

Naturally, refrigerant leakage also has a cost. Reporting of leakage rates has always been a contentious issue in the Australian refrigeration industry. In the UK, a recent survey in 39 refrigeration plants showed leakage rates ranging from 10% to 500% of the original refrigerant charge<sup>8</sup>. To our knowledge, no surveys undertaken in Australia have been published<sup>9</sup>.

Additionally, it has been estimated that transport of vegetable products contributes with 1.24 megatonnes (Mt) of CO<sub>2</sub>-e. Transport represents between 15% and 17% of the total carbon emissions of the activities depicted in Figure 7 and it also has a fugitive emissions component. Therefore, alternatives to decrease the impact of transport such as the new distribution models addressed in the previous report [35] could significantly decrease the environmental impact of vegetable distribution.

A study supported by the Victorian Eco-Innovation Lab (VEIL), CSIRO and the Victorian Department of Innovation, Industry and Regional Development aims to establish a benchmark on the carbon footprint of fruit and vegetables distribution, assess the resilience of these chains to variations in fuel prices and availability, and suggest ways to decrease the impact of fruit and vegetables transport<sup>10</sup>. This project is expected to be completed by February 2010.

<sup>8</sup> <http://www.frperc.bris.ac.uk/defraenergy/docs/Dissemination03Apr09/RefrigerantLeakage.pdf>

<sup>9</sup> <http://www.climatechange.gov.au/greenpaper/consultation/pubs/0714-green-cooling-council.pdf>

<sup>10</sup> Food Chain Intelligence will provide consultancy services to VEIL, CSIRO and DIIRD on this project.

## Water Use

Irrigation is fundamental to sustain the productivity of horticulture in Australia: irrigated fruit and vegetables (excluding grapes) accounted for over \$9 billion or nearly 40% of the gross value of irrigated production in Australia in 2004-05 [36].

The efficiency of different irrigation technologies has led to the adoption of drip irrigation, which delivers water to individual plants through plastic pipes and uses 30% to 50% less water than surface irrigation [37]. However, these systems are expensive, energy intensive and require clean water to avoid pipe blocking. The latter aspect can be an issue with recycled water [38].

Different annual water consumption values per hectare to irrigate vegetable crops in Australia have been published, ranging from 477,000 ML in 2005 [39] to 607,800 ML [16]. An average value of 430,649 ML per annum [40] requires about 675 GWh/year for water pumping [16], with an estimated annual cost of \$87.8 million (assuming an average electricity cost of \$0.13/kWh). This estimate, however, assumes that all pumps used for irrigation run in electricity.

In comparison to surface-irrigated pastures and crops, horticulture uses smaller volumes of water but with more frequency. Therefore, horticulture irrigation relies on piping delivery systems for on-demand, pressurised water supplies for sprinkler and drip irrigation.

Unfortunately, about 29% of the irrigation water is lost between the irrigation district inlet and the farm water meter [41]. On-farm losses are largely attributed to poor irrigation timing from manual water scheduling systems on supply canals. Also, most distribution losses occur due to water oversupply as a method of avoiding adverse yield effects. Oversupply can mean significant water losses, as water is no longer available for irrigation supply [42].

The scope for water efficiency improvements from irrigation technologies is thus estimated to be significant. For example, a recovery of the 29% loss estimated before would represent a savings potential of 124,888 ML per year for the vegetable industry. Further, the benefits would be also reflected in a decreased use of energy for water pumping.

### SIZING THE OPPORTUNITY: SAVINGS THROUGH BETTER IRRIGATION TECHNOLOGIES

Assuming that water supply costs are \$100/ML, recovering the water transmission losses mentioned above would represent savings of \$12.5 million per year for the vegetable industry. Most importantly, savings due to decreased energy consumption in water pumping would amount to \$25.5 million per year, assuming power costs of \$0.13 kWh.

Horticulture Australia is addressing water use efficiency within the Horticulture Water Initiative. Other aspects addressed in this initiative include water rights and reliability, supply, environmental performance and industry performance against “triple bottom line”<sup>11</sup>.

While the focus of this report is on technologies aiding water efficiency and environmental performance, all issues above are interconnected. For example, irrigation-induced salinity can be an outcome of over-irrigation or under-irrigation, which in turn impacts water use efficiency.

Technical solutions to address water efficiency include the use of subsurface drip irrigation coupled with GPS systems to ensure accurate irrigation. Water savings through these systems are estimated between 16% and 26%, as compared with overhead irrigation <sup>12</sup>.

### *Manufacturing and cold chain*

Table 1 indicates that about 5.6 ML of water are used for manufacturing of processed vegetables every year. However, savings from an increase in water efficiency during vegetable manufacturing are more modest than the quantum of savings to be achieved through irrigation efficiency during primary production.

In cold storage, large amounts of water are consumed by evaporative condensers used in industrial refrigeration plants to eject extracted heat into the outside air. It is not known exactly how many evaporative condensers are installed in Australia. However, innovative systems such as the rainwater harvesting system developed by Oxford refrigeration can lead to estimated savings of up to 100,000 litres per day from a collecting area of 47,250 m<sup>2</sup>. Investment on these rainwater harvesting systems need to have a long-term view (i.e. payback is expected between 10-15 years). However, these systems would enable refrigeration plants using evaporative condenser to operate under stringent water restrictions in place.

### *Land Use*

Land use has a major effect on natural resources through its impact on water, soil, nutrients, plants and animals. There is also a strong link between changing patterns of land use and economic and social conditions, particularly in regional Australia<sup>13</sup>.

Figure 8 shows the land use by horticultural production in 2002. The Australian Bureau of Statistics estimated that the proportion of land dedicated to grow irrigated vegetables and herbs in 2007 was 0.06% (113,753 ha) of the total irrigated agricultural land.

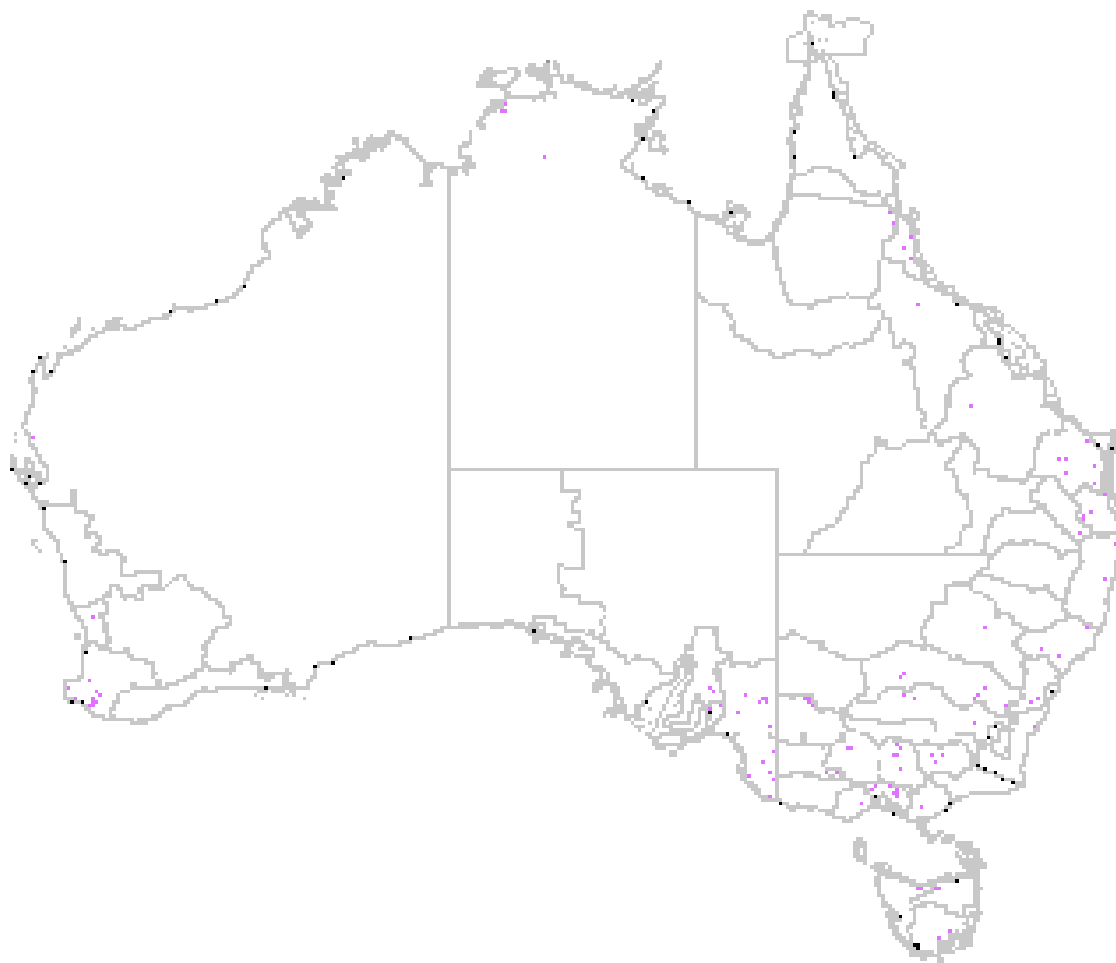
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<sup>11</sup> [http://www.horticulture.com.au/delivering\\_know-how/Environment/Water/Water\\_Initiative.asp](http://www.horticulture.com.au/delivering_know-how/Environment/Water/Water_Initiative.asp)

<sup>12</sup> [http://www.horticulture.com.au/librarymanager/libs/51/Vegetable%20Industry\\_a4final.pdf](http://www.horticulture.com.au/librarymanager/libs/51/Vegetable%20Industry_a4final.pdf)

<sup>13</sup> [http://adl.brs.gov.au/mapserv/landuse/pdf\\_files/Web\\_LandUseataGlance.pdf](http://adl.brs.gov.au/mapserv/landuse/pdf_files/Web_LandUseataGlance.pdf)





*Figure 8. Land used by horticulture in 2002 (purple dots). Source: Australian Collaborative Land Use Mapping Programme .Website: <http://adl.brs.gov.au/mapserv/landuse/index.cfm?fa=>. Accessed on 3 August 2009.*

### Peri-urban horticulture

Increasing urban pressure on farming in urban fringes, continues to create rural land use conflicts. For horticultural operations located in peri-urban areas, increasing demands are being placed to meet the environmental expectations of the urban lifestyle, which may not be compatible with continued profitable farming [43].

Further, farming enterprises may be impacted by residents who want the lifestyle of acreage properties but are not prepared to accept that normal farming practices need to be carried on around them.

Also, higher land prices, land taxes and Council rates induced by development and lifestyle investors make it increasingly difficult for farms to remain viable or to further develop or expand to maintain or improve profitability.

Rather than technical solutions, policy planning and social solutions must be put forward. The HAL project AH07031 "Peri-urban horticulture and land use planning: literature review & tool-kit" [44] was developed to address this aspect.

### Fertilizers and nutrients

Irrigated crops and particularly summer crops typically receive high rates of nitrogen fertiliser (i.e. up to 300 kg N/ha), in conditions which favour denitrification. Nitrogen fertilizer that is not used by plants can be leached from the soil or dissolved in runoff water soon after application. This excess nitrogen can increase soil degradation, pollute surface waters, increase soil acidity, reduce nutrient availability to plants and increase GHG emissions in the form of nitrous oxide [45].

In the National Greenhouse Gas Inventories Accounts 2007, the fertilizer application rate assigned to horticultural crops and vegetables was 125 kg N/ha, the highest value of all significant agricultural crops [12]. However, higher application rates of 173 kg/ha have been reported [45].

In 2007, horticulture used about 24% of all synthetic fertilizers for crop production [12]. Further, the fraction of fertiliser available for leaching and runoff is estimated as 72% of the total fertilizer applied.

Phosphorus is another macronutrient that is added to the soil through the application of phosphate fertilizer. Only between 1% and 4% of the phosphate added can be absorbed by plants and its availability is highly correlated to the soil acidity. The average application rate is estimated in 100 kg/ha [45]. The negative consequences of over-fertilisation with phosphorus are its accumulation over time and the potential contamination of water bodies if transported by wind or water currents. An increase of phosphorus in water bodies affects the water quality and increases the risk of algal blooms.

Several management techniques to accurately account for fertilizer applications have been recommended [9], including the use of compost and poultry manure instead of conventional fertilizers. Recent trials in NSW show that the use of compost provides equivalent yields to a mixed treatment of poultry manure and urea for broccoli, eggplant, cabbage and leek. For capsicum, compost provided yields 22% higher than the conventional fertilizer treatment <sup>14</sup>.

However, the technologies that can make a significant impact on the use of fertilizers are accurate measurements of the soil quality (and therefore fertilizer needs) and accurate delivery of fertilizers. These two aspects can be addressed by precision agriculture, which will be discussed in the last report of this project (production and harvesting technologies).

### Carbon capture and storage (sequestration)

Most farming operations which incorporate post-harvest crop residues, wastes, and byproducts back into the soil will provide a carbon storage benefit. This is the case for practices such as field burning of stubble - rather than releasing almost all of the stored CO<sub>2</sub> to the atmosphere, tillage incorporates the biomass back into the soil where it can be

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<sup>14</sup> <http://www.compostforsoils.com.au/uploads/file/pdfs/vegetables%20-%20cost%20benefit%20trial%20for%20using%20compost%20in%20vegetable%20growing.pdf>

absorbed and a portion of it stored permanently<sup>15</sup>. Some agricultural soils can be efficiently exploited as carbon sinks through reduced tillage, cover cropping and organic systems with better manure management.

However, the use of plantations acting as carbon sinks has attracted controversy. For example, a study published in 2006 reported for the first time that plants can directly emit methane [46]. Suggestions that plantations could in fact increase GHG emissions through methane emissions rather than decreasing these by sequestering carbon dioxide were made. Later, various scientific papers and communications stated that methane by terrestrial plants under aerobic conditions was insignificant<sup>16,17</sup>.

A second relevant study [47] found that plantations can reduce stream flow and increase salinisation of soils more than previously thought. Newspapers such as *The Australian*<sup>18</sup> questioned the effect of forests on water reserves. While these claims were later dismissed, the aforementioned study did provide a basis for predicting where trade-offs in water availability and soil quality are likely, thus improving decisions on what plants are to be planted and where. In particular, it focused attention on the potential problems of growing plantations in drier regions on lands naturally occupied by grasses and shrubs.

While these two studies do not undermine the benefits of carbon sequestration in forests<sup>19</sup>, they do highlight the evolving nature of carbon sink studies. Horticultural plantations as carbon sinks are likely to have a minimum benefit as compared with dedicated forestry plantations and do have negative impacts on the soil's health. Carbon sequestration in agriculture depends on microclimates, soil types, management practices and crop choices. And all of these factors vary over agricultural regions, thus region-specific research is needed to make policy decisions about the effectiveness of carbon sequestration.

Having said this, a Californian study [48] investigated several management practices to aid carbon sequestration in Yolo County. The results indicated that conservation-tillage practices in tomato growing can significantly reduce greenhouse-gas reduction. The authors contend that (a) the combination of economic and biophysical models is required to develop regional carbon sequestration supply curves for agriculture; (b) farmers could change their crop technologies in response to reasonable carbon-sequestration payments; and (c) the cost of carbon sequestration changes with soil and crop type.

Therefore, more research on the role of Australian horticulture is required in a regional basis, before estimating any potential savings/losses in the uptake of carbon sequestration technologies.

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<sup>15</sup> [http://en.wikipedia.org/wiki/Carbon\\_sequestration](http://en.wikipedia.org/wiki/Carbon_sequestration)

<sup>16</sup> <http://www.csiro.au/resources/PlantationsValidCarbonSinks.html>

<sup>17</sup> [http://www.isolife.nl/example\\_plant%20physiology.php](http://www.isolife.nl/example_plant%20physiology.php)

<sup>18</sup> <http://www.climateark.org/shared/reader/welcome.aspx?linkid=50074>

<sup>19</sup> <http://www.nicholas.duke.edu/institute/methanewater.pdf>

### *Pyrolysis-assisted charcoal production (biochar)*

A recent concept that deserves further investigation is the processing of agricultural waste into charcoal. Biochar results from the thermal treatment of natural organic materials in an oxygen-limited environment (pyrolysis)<sup>20</sup>. As a by-product, the process also creates a mixture of gases (called syn-gas) which can be used to produce heat and power.

The concept of locking carbon through biochar is further explained in Figure 9. Biochar production has lower risks of releasing the stored carbon to the atmosphere than other sequestration options. For example, forests planted to sequester carbon can burn, non-tillage crops can reverse to conventional tillage. However, once biochar is created, there are virtually no possibilities of releasing this captured carbon into the atmosphere [49].

There are other potential benefits in using biochar as a soil conditioner. Some of the claims include:

- Mixed with manure or fertilizers, biochar can be added in no-tillage methods without the need for additional equipment.
- It can improve the structure and fertility of soils, thus improving production. Experiments in India and Japan with crops of peas, mung beans and soybeans have shown biomass productivity increases from 29% to 160%, as compared with conventional crop production<sup>21</sup>.
- It can enhance retention of fertilizers, thus decreasing run-off.

Biochar requires a national framework to work as a sequestration strategy and the benefits need to be estimated at a macro-level. For example, in the US a baseline of the calculated biomass available from crop residues is about 5.5 tonnes per hectare, mostly from broadacre crops. Using this baseline and supply chain theory, comparisons of centralised approaches (e.g. large biochar facilities that receive waste from several farms in a US regional basis) with distributed approaches (e.g. small biochar reactors installed in each farm) are possible. Similar calculations are needed in Australia.

The costs of producing biochar also needs to be considered: in 2007, it was estimated that the costs of pyrolysis were about \$4/GJ, mostly in the form of machinery and energy for heating [49].

It is likely that horticulture would be at the consumer's end of this technology, because horticultural waste is not the best raw material for biochar production, which benefits more from low moisture materials with high energy content.

Nevertheless, biochar itself could mitigate the environmental footprint of vegetables and decrease safety risks to consumers by reducing pesticides applications. A recent study [50] investigated the effectiveness of two types of biochar in reducing the bioavailability of

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<sup>20</sup> <http://www.csiro.au/files/files/pnzp.pdf>

<sup>21</sup> <http://www.bio2001.csiro.au/files/files/poei.pdf>

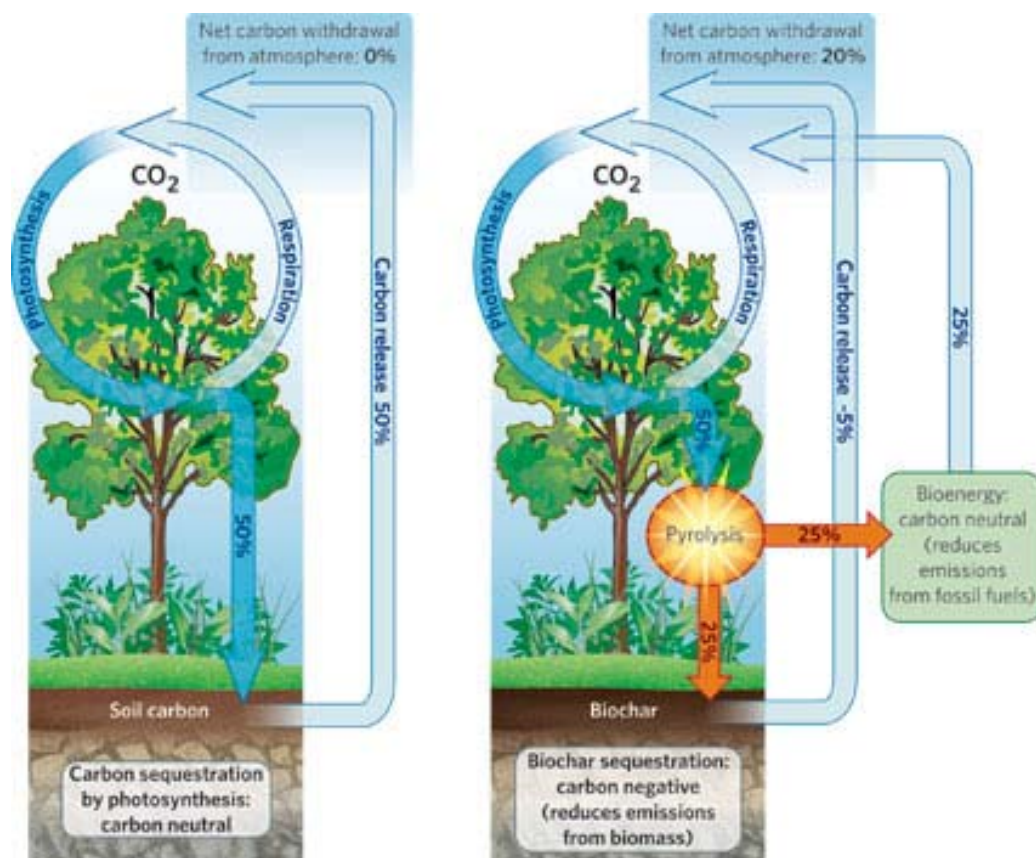


Figure 9. The concept of biochar: the left hand side present the natural process of carbon sequestration. The right hand side presents the pyrolysis-aided process, which can reduce emissions from biomass and produce energy. The biochar net effect is the sequestration of 20% of CO<sub>2</sub> that would be otherwise released into the atmosphere [49].

two soil-applied insecticides (chlorpyrifos and carbofuran) to spring onion. This study found that pesticide runoff decreased significantly with increasing amounts of biochar in soil. For example, 86–88% of the pesticides were lost from the control soil (i.e. no biochar), whereas only 51% of carbofuran and 44% of chlorpyrifos were lost from the soil amended with 1.0% biochar. Despite greater persistence of the pesticide residues in biochar-amended soils, the plant uptake of pesticides decreased markedly with increasing biochar content of the soil. With 1% of biochar soil amendment, the total plant residues for chlorpyrifos and carbofuran decreased to 10% and 25% of that in the control treatment, respectively.

Other non-refereed reports claim that biochar increased in 10% the yield of a sweet corn crop over 2006-07, saved 30 lb/acre in nitrogen for Irish potatoes (2006) and increased in 22% to 47% the yield of a tomato crop over a year<sup>22</sup>. There is a lack of published scientific reports on large scale trials for horticulture. However, some efforts are now under way to address this knowledge gap<sup>23,24</sup>.

<sup>22</sup> <http://www.carbonchar.com/biochar-research>

<sup>23</sup> [http://www.ars.usda.gov/research/projects/projects.htm?accn\\_no=414740](http://www.ars.usda.gov/research/projects/projects.htm?accn_no=414740)

<sup>24</sup> <http://www.swan.ac.uk/geography/PostgraduateStudy/ResearchTopics/BiocharProduction/>

In May 2009, CSIRO received \$1.4 million for a 3-year project that will assess the opportunities to reduce greenhouse gas emissions and boost farm productivity through the use of biochar. However, this project is largely focused on grains agriculture and forestry<sup>25</sup>.

HAL may wish to evaluate the case for horticulture as a provider of raw materials (i.e. feasibility of vegetable waste for biochar production) and as a recipient of the biochar production (i.e. evaluation of biochar-related improvements in productivity and fertilizer runoff).

## Waste Generation

Waste in horticultural supply chains is generated in the forms described below.

At farm level:

- Unused pesticide residues and inorganic fertilizers.
- Seed and fertilizer bags, chemical containers, ground covers.
- Plastic liners and cardboard boxes from packaging operations.
- Unused tractor oil, grease and fuel.
- Non-marketable fruit.

At manufacturing level:

- Rejected produce.
- Pomace and peels from juice/canning/freezing.
- Unused cut vegetables.
- Solids discarded with water.
- Plastic, rubber, EPS boxes, films, glass.
- Wood from pallets.

There is a scarcity of information on food waste (including fruit and vegetables) in Australia. Food waste from households, commercial and industrial sources comprises between 10% and 15% of the 20 million tonnes of waste that ends in landfill in Australia each year [51] [52]. The current recycling rate for food waste is only 10%.

The Australia Institute report "Wasteful consumption in Australia" [53] estimated that consumers threw away \$5.3 billion worth of food in 2004. Half of this value was fresh food, such as fruit and vegetables.

Other available data on waste of fruit and vegetable products from farm to retail indicates that the proportion of products lost in developed countries is 15% [54]. The percentage loss attributed to food wastage at household level is 20 to 25%, due to poor purchasing habits and poor storage practices [53].

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<sup>25</sup> Dr. Evelyn Krull, personal communication, August 2009.

Some on-farm practices can also contribute to waste. For example, a farmer may choose not to harvest a crop in a given year because the harvesting and marketing costs are likely to be greater than the earnings [52].

Extreme or unusual weather events can also damage a crop at the farm level. For example, in March 2006 Cyclone Larry ruined 200,000 tonnes of bananas, worth and estimated \$300 million. In addition to the crop loss, the impact of Cyclone Larry on the Australian banana industry left thousands of Queenslanders out of work and caused banana prices to skyrocket. Damages to field and protected crops were also registered during the 2009 Victorian bushfires<sup>26</sup>.

Unfortunately, a potential outcome of climate change in Australia would be an increase in the frequency of extreme weather events. Therefore, strategies to predict their frequency, the types of risks involved, the consequences on production and distribution of vegetable crops and emergency plans to deal with these events are required to protect the horticulture industry.

#### SIZING THE OPPORTUNITY: VEGETABLE WASTE LOSSES

The 2007 Australian vegetable production was 3,100 kilotonnes. Assuming a 5.5% product loss between farm and retail, the estimated annual waste due to supply chain issues would be about 170 kilotonnes. This represents a lost value of \$52.6 million at farm level<sup>1</sup> or \$160.7 million per year at retail level<sup>2</sup>.

In manufacturing, waste recycling levels in the industry are estimated in 86% [1]. Assuming that 14% of waste goes into landfill and considering an annual input of 920 kilotonnes of vegetables per year<sup>3</sup> (with about 10% of this input representing processing waste), 12,880 tonnes of waste would go to landfill every year. At a disposal cost estimated as \$114 per tonne, landfill of vegetable waste represents a loss value of about \$1.5 million per year.

<sup>1</sup>Based on 2006-07 data from AUSVEG that reports an average gross value of \$309/tonne. The average includes data from French and runner beans, peas, potatoes, sweet corn and tomatoes.

<sup>2</sup>Based on 2006-07 data from DAFF that reports a total value of agricultural production of \$2,931 m.

<sup>3</sup>These costs include \$198 for an 8 tonne skip hire and removal, \$70/tonne in disposal fees and \$20/tonne in landfill levy. Costs taken from: Hyder Consulting, 2008. Waste and recycling in Australia. A report prepared for the Department of Environment, Water, Heritage and the Arts. 141 p.

<sup>26</sup> <http://www.foodmag.com.au/Article/Natural-disasters-destroy-food-crops/437366.aspx>

# Adapting to the Impacts of Climate Change on Horticulture

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The symbiotic relationship between food production and climate change means that the latter is now having a drastic impact on agricultural production worldwide.

The impacts of climate change in horticulture were reviewed in detail in the reports "Defining the impacts of climate change on horticulture in Australia" [8], "Climate Change 2007" [55] and "Global Climate Change Impacts in the United States" [56]. Some of these expected impacts are summarized below.

## Changes in Crop Production

- Changing/shorter growing seasons.

Higher temperatures would mean a longer growing season for crops that do well in the heat, such as melon, okra, and sweet potato, but a shorter growing season for crops more suited to cooler conditions, such as potato, lettuce, broccoli, and spinach. An example is the cycle of the winter lettuce and brassica season (mid-April to October) in south-east Queensland, which would be shortened by several weeks to a month by 2030. For citrus, grapes, sweet corn and rockmelons in the Riverina, crops would mature earlier by about 10-14 days.

Earlier ripening and reductions in grape quality and value are likely to lead to a price drop of 4 - 10% per tonne in the Yarra Valley and 16 - 52% in the Riverina by 2030.

- Changes in dormancy periods.

Grapes, oranges, apricots, almonds, artichokes, figs, kiwis, olives, walnuts and other specialty crops require a minimum time of exposure to chilling temperatures during winter to induce a dormant state and be ready for fruit bearing in the next harvest season<sup>27</sup>. However, these periods are already shortening in several parts of the world.

In Australia, it has been estimated that for citrus in the Central Burnett (Queensland), the effects of heat accumulation under climate change conditions would be equivalent to adding an additional month to the yearly water requirement for citrus in this region.

For the pome fruit growing regions of Manjimup (WA) and the Granite Belt (Qld), a 1°C warming would significantly decrease the number of years when sufficient chilling would be achieved. A 2°C warming may make apple production at these sites unfeasible for traditional high chill cultivars such as Red Delicious. Plantings would need to concentrate

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<sup>27</sup> Also known as vernalisation.



on varieties such as Gala and Pink Lady, which have chilling requirements below 1,000 hours.

Cranberries have a particularly high chilling requirement and there are no known low-chill varieties.

- Changes in outturn quality and yield.

Even crop species that are well-adapted to warmth (e.g. tomatoes) can have reduced yield or quality when daytime maximum temperatures exceed 32.2°C, for even short periods during critical reproductive stages. Other example of potential quality reduction is the decrease in production of anthocyanins in apples, which is reduced by high temperatures. Similarly, in capsicum red colour development during ripening is inhibited above 27°C.

Currently, unseasonal high temperatures cause premature seed head production (bolting) of lettuce and celery, resulting in poor quality heads, and reduced yields. Lettuce tipburn, a disorder occurring under low humidity and temperatures greater than 30°C, would become more prevalent.

Crops that depend in cooler night time temperatures, such as snap beans, would undergo a substantial yield reduction when night time temperatures exceed 26.7°C.

## Water Use

- Changes in evaporation rates.

Higher temperatures cause plants to use more water to keep cool. But fruits and vegetables can suffer even under well-watered conditions: if temperatures exceed the specific maximum level for pollen viability in a plant, the plant would not produce seed and therefore it would not reproduce.

Higher potential evaporation from the soil and accelerated transpiration in the plants themselves would cause moisture stress. The use of overhead irrigation may increase for cooling lettuce and other leafy vegetables, contrasting with potentially reduced availability and quality of water for irrigation.

Further, higher evaporation rates would also affect losses from farm dams. These losses have been identified as a major issue in the Northern Murray-Darling Basin. Evaporation mitigation technologies that would need to be introduced are impermeable covers or chemical monolayers to avoid evaporation for the surface of water bodies, shade cloths and modular covers [57].

- Competition for irrigation water.

This is now a common occurrence and as a consequence the cost of water has increased. Water for irrigation in horticultural crops would be diverted from other uses as

long as the economic returns are sufficient. Water irrigation is sometimes used to maintain adequate temperature conditions for the growth of cool season plants (such as many vegetables). With increasing competition for freshwater supplies, the water supply needed for maintaining these crops may not be available.

## Supply Chain

- Uncertainty in crop yield and increased risks associated to location.

Predicting the optimum planting date for maximum profits would be more challenging under increased climate uncertainty. This uncertainty applies for both local production and supply from competing regions.

Extreme weather events such as spells of high temperature, heavy storms, or droughts are likely to occur with more frequency. Disruptions in crop production, transport and distribution systems are likely consequences. Also, the predicted sea level increases ranging from 3 to 17cm by 2030 mean that crops planted near coasts would be exposed to increasing risks, including coastal erosion.

The quality of soils may be affected and in some cases landslides and erosion phenomena due to run off can occur. Increased temperature and altered precipitation patterns might result in increased losses of soil minerals, especially by leaching and erosion [58]. The direction of the net change in plant-available soil minerals is still unclear, but large local variations are to be expected.

- Operational costs.

Climate change conditions would increase the cost of labour for harvesting, especially in northern regions, as fewer people (predominantly backpackers) would find the regional climate favourable in which to work. Increasing travel costs would exacerbate this.

The costs of freight, packaging, pesticides, petrol and fertilisers would increase as a result of greenhouse gas mitigation activities. Insurance premiums are likely to rise in conditions where extreme weather events occur more frequently.

Quality issues such as re-greening in citrus due to higher night temperatures may require longer periods of de-greening to satisfy consumers' expectations. Increased costs of grading and marketing for susceptible fruit and vegetables would occur for removing increased amounts of blemished product. Reduced marketable yields associated with damage from sunburn and poor pollination would also occur.

Post-harvest cooling costs for most vegetable crops would increase, as additional field heat would need to be removed prior to transport to market and additional cooling would be required to maintain optimum cold chain conditions. Also, additional cooling needs would be registered for protected (greenhouse) production.

In the future, horticultural growers may need to consider carbon trading costs if agriculture is included in the ETS. If it is included, emissions costs related to the product

of emissions permit price and the difference between actual emissions and allocated free permits need to be included.

Modelling of impacts on farm revenue developed by the Centre for International Economics [17] indicates that emissions costs for horticulture could lead to a decrease in farm revenue of up to 1.5% in fruit and up to 0.65% in processed vegetables. These results are based on the HI\_LINK model, which is a disaggregated, value chain model of the Australian horticultural industry. Its database covers the production, consumption and trade flows of 48 horticultural commodity groups in Australia.

In the HI\_LINK model, production from protected cropping is not treated differently from field horticulture and the underlying assumption of “low emitter of GHG” is used for both types of production. This approach may need to be reviewed on the basis of the estimated large emissions from protected cropping, as established previously in this report.

## Pest and Crop Diseases

- Proliferation.

Many insect pests and crop diseases thrive due to warming, increasing losses and necessitating greater pesticide use. Additionally, higher temperatures are known to reduce the effectiveness of certain classes of pesticides. Pesticide spraying would be needed more frequently or in higher doses.

Higher temperatures would provide opportunities for pests that are currently not able to survive during winter. Examples include the Silverleaf Whitefly, which may extend into southern regions. Also, proliferation the Queensland fruit fly *Bactrocera tryoni* can become a significant threat in southern Australia. Growers in endemic Queensland fruit fly areas are likely to have cost increases of 42 to 82%, and 24 to 83% in the current fruit fly-free zone.

Higher temperatures, combined with lower humidity can compromise the effectiveness of some biological pesticides, such as the Nuclear Polyhedrosis Virus (NPV) used extensively in sweet corn and tomatoes for managing heliothis.

## Food Safety

A report by the Food and Agriculture Organization (FAO) [59] emphasizes several areas of concern at primary production level, including:

- The effect of climate change on the range of pathogenic vectors (e.g. pests) and their transmission cycle in crops, animal production and fisheries.
- The effect of climate change and extreme weather events on water and soil contamination (e.g. the effect of flooding on areas of horticultural production).
- The development of microbial adaptation to environmental stressors and evolution towards resistant pathogenic strains.

The FAO report also emphasizes on the links between warmer weather and the incidence of salmonellosis [60], campylobacter [61, 62], rotavirus [63] and cholera [64].

However, potential risks due to climate change can also include toxicological risks. For example [65]:

- Altered residues of pesticides and toxic trace elements in crops.
- A different environmental dispersion of polycyclic aromatic hydrocarbons giving rise to residues in both edible crops and animal products.

There are other areas that need further investigation [19]. For example:

- The flow-on effect of contaminated food raw materials on processing, distribution, retailing and foodservice. For example, 'hurdle' technologies that are normally effective in dealing with current pathogen populations in produce may not be so with larger pathogen concentrations.
- Retailers and consumers may find that product shelf lives become shorter, as products are subjected to more frequent or severe temperature abuse. The relationship between spoilage mechanisms and pathogenic contamination would probably lead to higher risks at the consumers' end.
- Current safe temperature regulations during transport, storage, retail and at catering level may need to be reviewed, both in specifications and level of compliance.
- Safe temperature guidelines during manufacture and distribution of foods may also need to be harmonised with energy performance standards for refrigerated equipment. Ensuring food safety through optimum temperature maintenance while maintaining low energy consumption may be perceived as conflicting demands by equipment manufacturers and users. A harmonised approach would ensure that a balance between the two goals is achieved [66].

Conflicting demands between food safety and mitigation measures are also evident when growers adopting practices to protect the environment result in lower quality crops and the rejection of these by buyers. In California, some growers are being encouraged

to or are actively removing conservation practices for water quality, and most growers take action to discourage or eliminate wildlife from croplands and areas adjacent to these.

Some of the measures recommended to enhance food safety in vegetable crops include the elimination of non-crop vegetation and the avoidance of ponds/water reservoirs near crops. These practices may result in wildlife habitat loss, degradation and continued water-quality impairment. The removal of non-crop vegetation, for example, can include common conservation practices such as filter or buffer strips, grassed waterways, natural lands, hedgerows and windbreaks. Discouraging or actively removing these features would have negative environmental impacts and, in some cases, could actually increase the risk of crop contamination [67].

There are concerns over the safety of using recycled water in Australia [68, 69], particularly in view of emerging food safety threats [70]. The risks to human health depends on several factors such as the concentration of pathogens in the source water, water treatment efficiency, volume of water contacting the crop, die-off rate of pathogens in the environment and the amount of food consumed. Consumers would need to be reassured that environmental management practices taken up by growers would not increase risks at their table.

## Opportunities and Barriers to the Adoption of Mitigation and Adaptation Technologies

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Table 2 summarises the social, technological, economic, ecological and political/legal factors affecting the uptake of emerging mitigation and adaptation technologies. This table was compiled from views expressed in a variety of industry reports and forums, which are included in the References section.

Table 2. Environmental (STEEP) analysis showing the opportunities, challenges and threats affecting the diffusion of emerging mitigation and adaptation technologies.

VARIABLE	TREND	OPPORTUNITY	CHALLENGE
Social	Some regional areas (e.g. Lockyer Valley) are driven by economic development in horticultural regions.	Adaptation technologies can help to minimize climate change impacts in horticulture-based regional economies.	Unequal distribution of costs and benefits of adaptation technologies can lead to community concern on the fairness of adaptation processes. COST BARRIER.
	Land use planning processes generally consider peri-urban land, where significant areas of horticulture occur, to be a resource for future urban development.	Integration of horticultural production in urban settings.	Growers in peri-urban areas are unlikely to invest capital in upgrading infrastructure (e.g. irrigation systems) due to their inability to recover this investment when they sell their land for urban development. Competition between land for urban uses and for horticultural crops is likely to be won by the former, due to higher prices paid and less risk for land owner involved. COST/REGULATORY BARRIER.
	Emergence of environmental concerns such as "food miles" and food carbon footprints.	The industry can proactively develop cooperation schemes to share transport, cold storage and packing houses. This strategy also increases the profitability of the industry.	Competition and fragmentation may make communication and trust-building difficult. COMPETITIVE POSITIONING BARRIER.
	By 2050, about 80% of the human population will live in urban centres <sup>28</sup> .  Increase in local and regional sourcing of foods (the rise of the 'locavores')	Start new supply chains for urban settings (e.g. "vertical farms" and city-based glasshouses under contract with retailers).  Start direct marketing channels between growers and urban consumers and drive 'local chains' marketing campaigns.	These trends may have passed undetected in strategic plans. AWARENESS BARRIER.  <b>THREAT: Growers that are not prepared to take on more risks on the supply chain will miss on these opportunities.</b>

<sup>28</sup> <http://www.verticalfarm.com/>  
Food Chain Intelligence

<p>Technological</p>	<p>Use of biotechnology for developing climate change resistant varieties.</p>	<p>When applied successfully, biotechnology can substantially improve productivity and reduce costs for growers (see cost-benefit aspects for biotechnology).</p> <p>Climate change resistant varieties can prepare the industry to survive in difficult farming conditions.</p>	<p>Horticulture includes hundreds of distinct plants, the majority of which are grown on small acreages and which individually represent relatively small market values. This makes it more difficult to recover R&amp;D costs.</p> <p>High costs to gain access to patented genetic-engineering methods and meeting the regulatory requirements for testing and registration of biotech crops.</p> <p>Negative consumer perception and reluctance of food processors and marketers to accept new biotech commodities.</p> <p>Due to disappointing past commercial results and current market outlook, many horticultural seed and nursery companies are reducing their investments in genetic engineering research.</p> <p>REGULATORY/COST/COMPETITIVE POSITIONING BARRIERS.</p> <p>THREAT: USA is already using biotechnology as a competitive advantage in export markets and other Asian countries are likely to follow. Australian horticulture can be disadvantaged if biotechnology is not developed for Australian-specific climate change challenges.</p>
	<p>Use of alternative energy sources (biomass, solar, eolic and geothermal power) is increasing worldwide (e.g. solar power capacity grew 62 %, while wind capacity rose 29 % in 2008 as compared with 2007)<sup>29</sup>.</p>	<p>Opportunity to decrease the carbon footprint of vegetables through adoption of renewable energy.</p>	<p>Government policy for farming needs to encourage uptake of environmental technologies that are adequate for Australian conditions.</p> <p>AWARENESS BARRIER.</p>

<sup>29</sup> <http://www.canada.com/technology/Renewable+energy+outperforms+nuclear/1724258/story.html>  
 Food Chain Intelligence

	Carbon sequestration and storage strategies may call for changes in land use to favour 'carbon forestry'	Horticulture –dedicated land can be combined with 'carbon forestry', thus allowing growers to be integrated into a carbon economy.	Horticulture –dedicated land may switch to 'carbon forestry' uses. <b>THREAT: Decrease of productive land may threaten the sustainability of domestic chains to supply the Australian market, forcing to increase imports.</b>
Economic	Increased energy / fuel costs.	Improvement of cold chain equipment and protected horticulture technology to decrease energy consumption.	There is little investment in developing these areas. AWARENESS AND COST BARRIERS.
	Although agriculture is not yet considered in the future emissions trading scheme, this will be reconsidered by 2015.	Incentive for increasing the uptake of environmental innovations.	While field horticulture is likely to have the smallest costs rises from agricultural enterprises, glasshouse horticulture may not be equally spared of ETS impacts.  Costs of abatement in ETS can lead some growers out of business.  Potential for horticultural over production as farmers in energy intensive industry (e.g. livestock) switch to less ETS exposed farming. REGULATORY BARRIER.
	Increasing fuel costs and concerns over peak oil <sup>30</sup> timing.  Domestic grocery supply chains continue to undergo significant consolidation to take advantage of scale economics.  Vegetable supply chains are becoming longer (i.e. more links).	Incentive to adopt technologies that can reduce cost and energy use of supply chain activities.	Cost of adoption of new transport technologies is likely to be passed on to growers.  Cost of transport is already a significant proportion of costs for the vegetable supply chain. Any technology that increases capital costs without decreasing operational costs is unlikely to be implemented.  COST/VALUE CHAIN BARRIER.
Ecological	Prolonged drought conditions in many growing areas.	Incentive to uptake of technologies to improve water efficiency and generation	Investment in developing water efficient crops is still insufficient.

<sup>30</sup> Peak oil is the point in time when the maximum rate of global petroleum extraction is reached, after which the rate of production at competitive prices enters terminal decline.



of alternative water sources.

**THREAT:** Restrictions on water use can disadvantage Australian vegetable exporters with respect to competitors, due to the unreliability of supply.

Vulnerability of food distribution systems can increase under climate change.

The vegetable industry can develop new local and regional distribution models that decrease the environmental impact of vegetable chains.

No assessments on the consequences of disruptions due to extreme weather events and bush fires have been undertaken for the vegetable industry. AWARENESS BARRIER.

Disruptions due to natural disasters (*e.g.* bushfires, hurricanes) can be better managed with alternative distribution systems.

Perishable supply chains to become more dependent on cold chain maintenance, thus potentially increasing costs and food safety risks. AWARENESS BARRIER

No immediate benefit seen in the uptake of new environmental technologies. COST/PRIORITY BARRIER.

**THREAT:** Recent experiences from Hurricane Larry and the Victorian bush fires demonstrate that both supply and quality of fresh vegetables is disrupted. This makes the Australian industry more vulnerable to lose market share to imported product.

The diversity of climatic regions has led to a diverse horticulture industry, ranging from annual to perennial crops through to amenity and urban horticulture.

Australia is capable of producing about 159 different crop varieties, which other competitors in the southern hemisphere can't provide.

Horticulture is spread across most major catchments, with variations in irrigation infrastructure and competing uses between and within these catchments. Differences in regulatory and management regimes between states and catchments create unequal conditions for the development of horticulture. REGULATORY/COMPETITIVE POSITIONING BARRIER.

<p>Political/ regulatory</p>	<p>Reclaimed water can help polluting industries to comply with EPA standards for outfall discharge [69].</p>	<p>Opportunity for uptake of recycling technologies in agriculture and urban irrigation.</p> <p>New technologies (e.g. precision agriculture) can reduce inputs at farm level.</p>	<p>The implementation of reclaimed water schemes for agricultural use carries food safety concerns and potential environmental risks such as rising water tables, salinity and/or water logging.</p> <p>Potential impact on the environment through the emission of GHG during reclaiming processes.</p> <p>Some precision agriculture solutions are perceived as costly.</p> <p>Reclaimed water costs need to be competitive with self supply water costs (e.g. \$0.07–\$0.10 /kL in Western Australia). COST/REGULATORY BARRIERS.</p>
	<p>Under the carbon pollutions scheme, waste water streams from vegetable processing will be monitored for high organic content.</p>	<p>Opportunity for uptake of water treatment technologies.</p>	<p>Increased manufacturing costs. COST BARRIER.</p> <p><b>THREAT: Decrease of profit margins due to new regulatory burdens around water use for vegetable processors.</b></p>
	<p>FSANZ is currently developing Primary Production and Processing Standards for seafood, dairy, eggs, poultry and seed sprouts. It is likely that fruit and vegetables will be also included in the future.</p>	<p>Adaptation technologies to deal with food safety issues arising from climate change can help reduce the impact of regulations on the industry.</p>	<p>Changes in the use of recycled water can lead to increased food safety risks and produce-related outbreaks. This can in turn lead to over-regulation of the horticultural sector. REGULATORY BARRIER.</p> <p><b>THREAT: Decrease of profit margins due to new regulatory burdens around food safety for vegetable processors.</b></p>

# HAL-Funded Projects in Adaptation and Mitigation Technologies

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To detect the major focus of investment in HAL projects, a list of the titles of all vegetable funded projects<sup>31</sup> in the area of adaptation and mitigation technologies was analysed to extract the frequency distribution of keywords within the title.

Titles of projects and start dates were extracted from the HAL database by performing a keyword search that reflected adaptation and mitigation technologies, *i.e.* project titles with concepts such as:

- |                             |                               |
|-----------------------------|-------------------------------|
| -Climate change, adaptation | -Environmental impacts        |
| -Water use                  | -Irrigation                   |
| -Pollution                  | -Erosion                      |
| -Chemicals                  | -Carbon footprint             |
| -Emissions                  | -Sustainable (sustainability) |

This search led to a sub-sample of 251 projects funded between 1998 and 2008<sup>32</sup>. The analysis considered both fruit and vegetable types of projects, as it is believed that diffusion of technological developments is common between these areas, particularly in the context of HAL's activities.

Figure 10 shows the most frequent keywords associated to HAL funded projects, which suggest a strong focus on the management of chemicals during production and water management (including irrigation).

Figure 11 shows two growth curves: (a) projects developed from 1988 to 2003, which focused on minor use permits (a program that run from 2000 to 2003) and controlling chemicals in soil; and (b) post-1996 projects, which focused on irrigation, water use and benchmarking of environmental impacts to respond to the potential inclusion of agriculture in the projected ETS. Both waves of adaptation and mitigation projects are now in decline, with the 1<sup>st</sup> wave reaching maturity in 1994 and the 2<sup>nd</sup> wave reaching maturity in 2004.

Logistics growth curve theory dictates that the inflection point is normally found in the middle of the trend life-cycle. This suggests that the peak number of projects in the HAL climate change platform would appear in 2012, if no factors influence current investment policies and strategies in this platform.

This analysis is based on the number of projects, as distinct to the financial investment made on the area. HAL has an average spend per project of around \$72,000 per year [71], which is relatively small. If future HAL strategies switch to fund fewer (but larger) projects in this and other areas, future analyses should be performed in terms of investment.

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<sup>31</sup> This list was provided by Karen Symes, HAL, on April 2009.

<sup>32</sup> The search of keywords in the HAL project database was performed by Dr Helen Sargent (HAL) on June 2009.

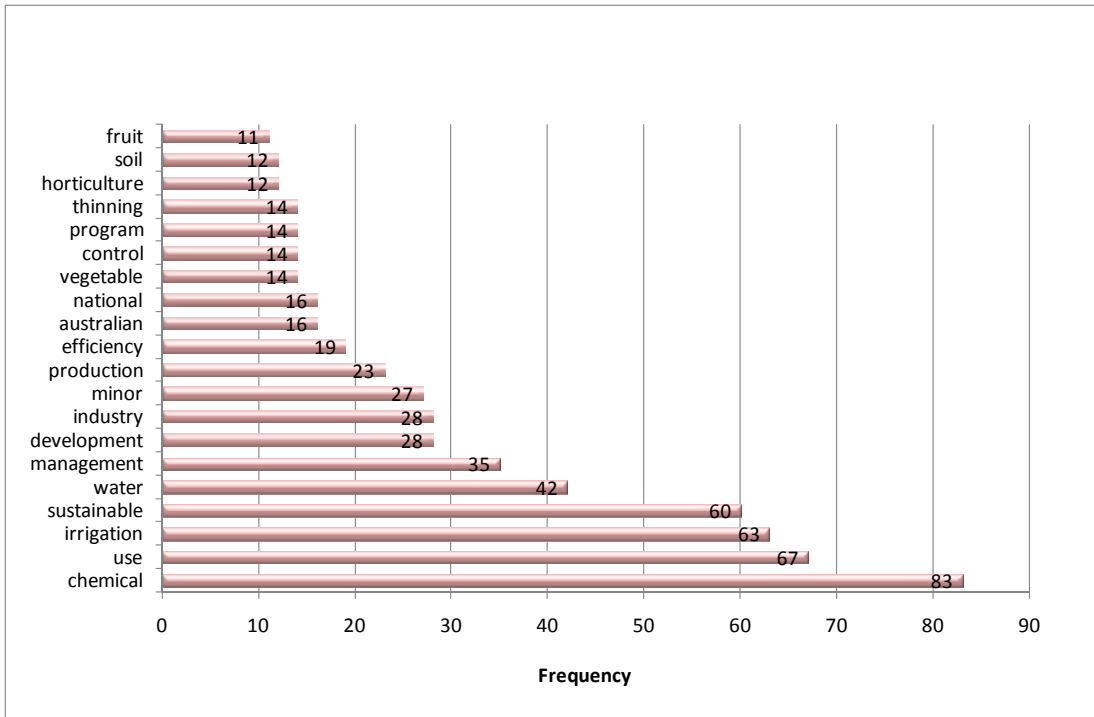


Figure 10. Analysis of keywords found in the titles of HAL-funded projects for the vegetable industry in the area of climate change. Only the 20 groups with the largest frequencies of appearance on the titles are shown.

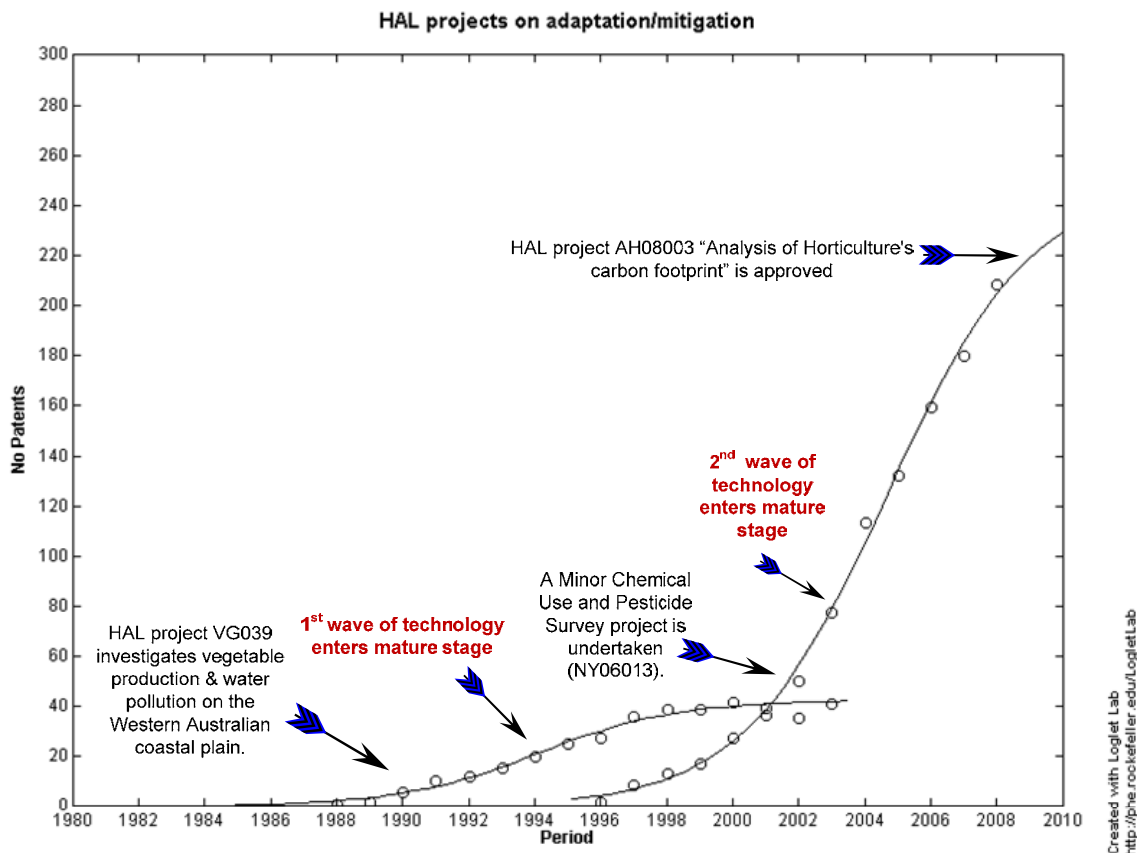


Figure 11. Historical cumulative number of projects developed with HAL funding in adaptation and mitigation technologies.

Figure 12 shows that about 37% of all projects developed in environmental-related topics have been in the area of chemicals, followed by sustainability (23%) and water use-irrigation (29%). All other areas have a minimal contribution.

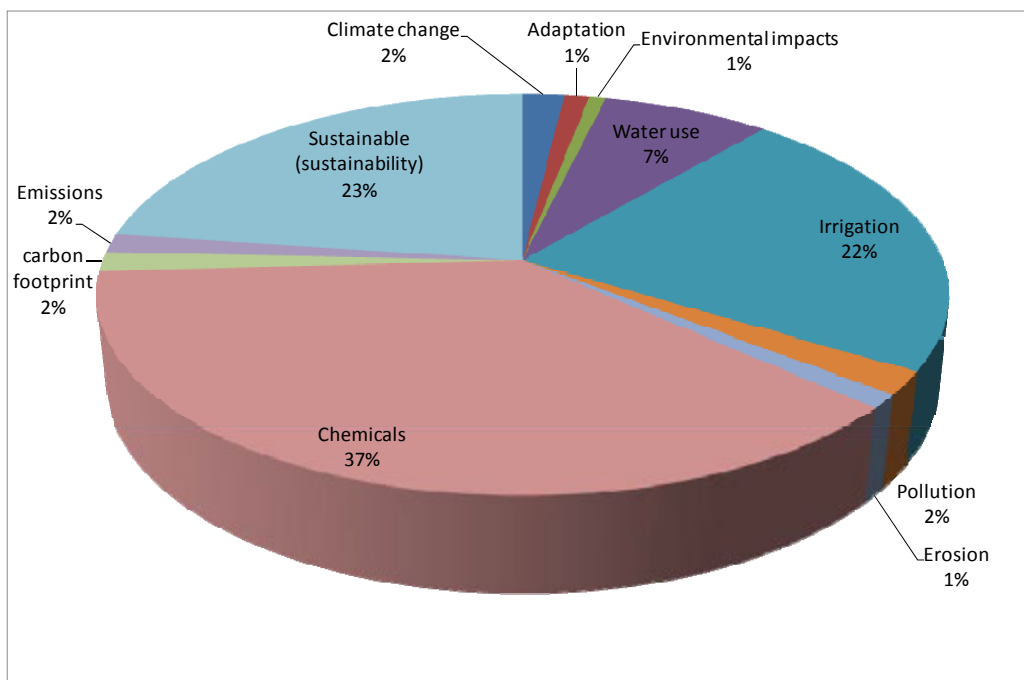


Figure 12. Percentage contribution of key words on adaptation and mitigation areas in 251 HAL funded projects in the climate change platform.

## Emerging Technologies for Adaptation and Mitigation

The quantum of financial savings related to mitigation strategies are the largest in the sectors presented in Figure 13.

While waste avoidance represents the largest opportunity for energy and carbon emissions, waste generation and cold chain operations are activities shared by all partners in vegetables supply chains. The management of irrigation and energy efficiency in glasshouse production are savings that can benefit directly vegetable growing operations.

Figure 14 shows the technological areas that were detected as having the greatest development and opportunities for horticultural supply chains. The following sections investigate the flagged options and provide some insights on cost-benefit aspects of these technologies.

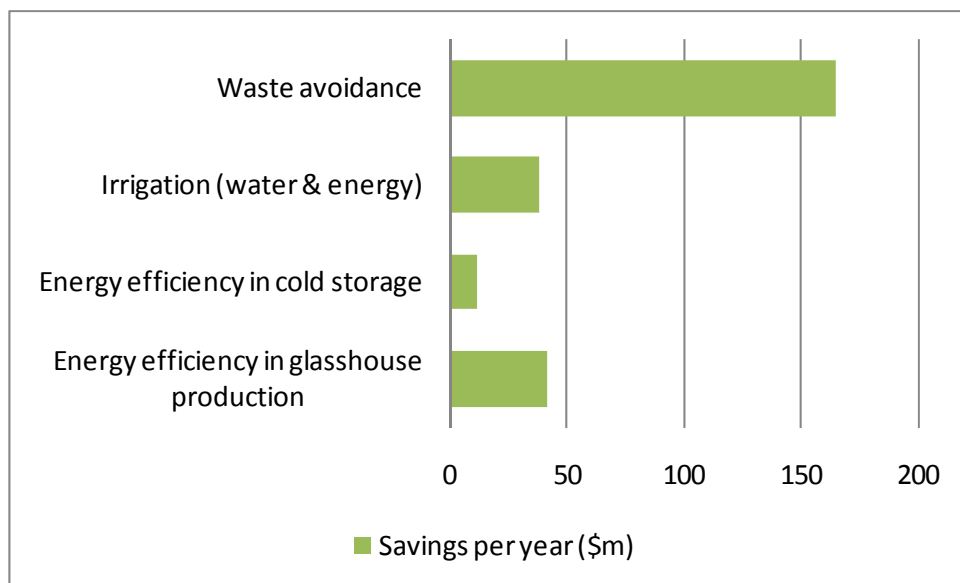


Figure 13. Savings estimated per type of mitigation measure for the vegetable industry.

### Energy Generation

There are several technologies that are currently being investigated for energy production, both for distributed and centralized plants. The technologies selected here take the view of a distributed strategy, whereby individual farms or networks of farms install their own plant for energy generation.

As a general comparison of the cost-benefit of various energy generation options, Table 3 presents estimated capital and operational costs and performance parameters for different energy generation technologies. Table 3 indicates that, while solar photovoltaics and wind energy have high capital costs, their operating costs are the lowest of all alternatives.

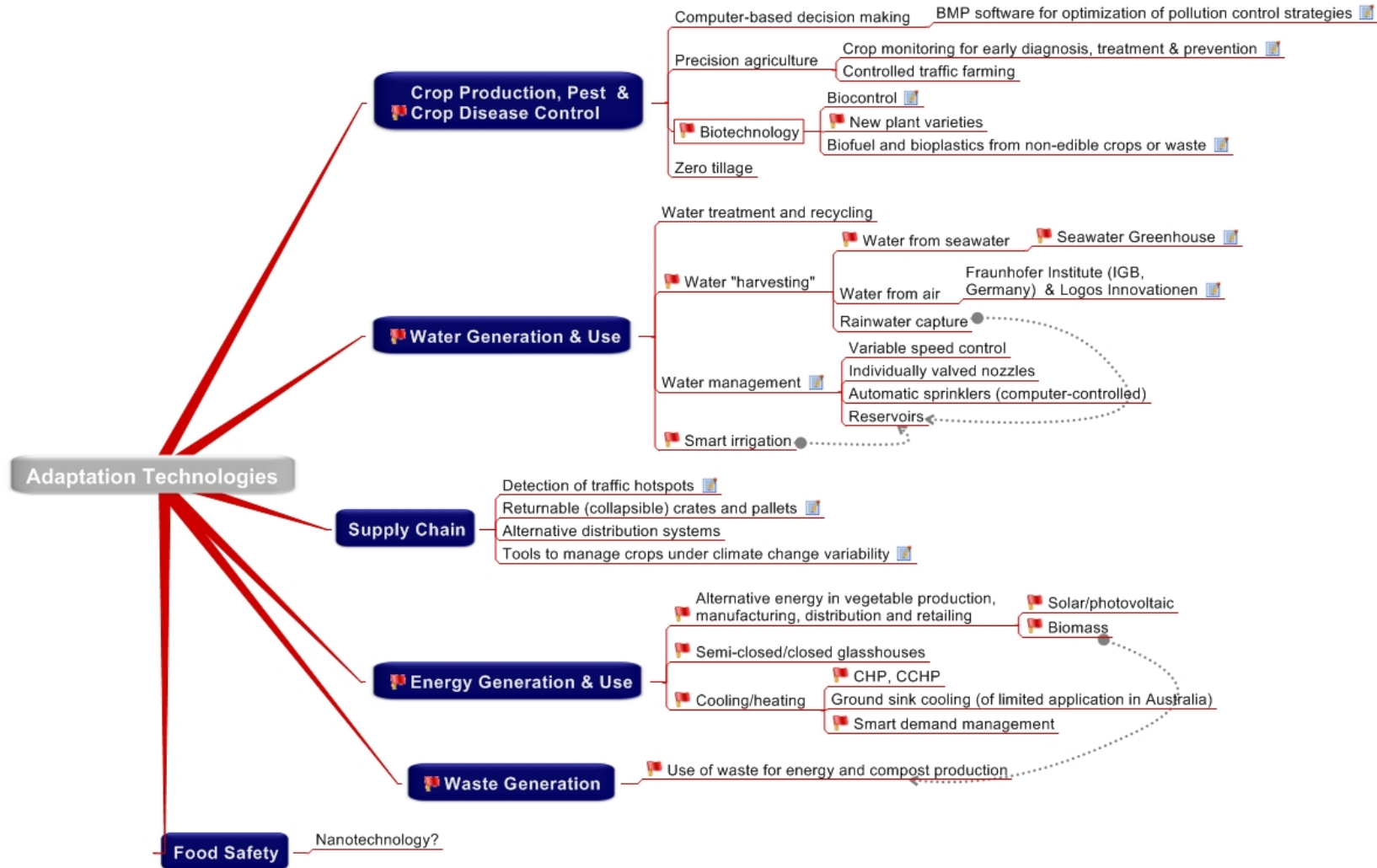


Figure 14. Mitigation and adaptation technologies. The red flags identify the technologies investigated in this report.

Table 3. Technology costs and performance indicators of distributed generation options. Source: [72].

Technology	Installed Capital cost (A\$/kW) (2010)	Capacity factor	O&M cost (A\$/MWh)	Fuel cost (A\$/MWh)	Energy Efficiency	Plant life (years)
Internal combustion diesel	920	0.30	45	120	0.45	15
Internal combustion natural gas	1260	0.30	50	57	0.28	15
Gas turbine	800	0.30	45	57	0.28	20
Gas micro turbine	1175	0.30	45	57	0.28	15
Gas CCGT (CHP)	1350	0.30	10	19	0.85	20
Biomass CHP	3125	0.30	10	10	0.55	20
Gas micro turbine CHP	1495	0.30	50	24	0.68	15
Gas reciprocating engine CHP	1375	0.30	55	22	0.75	15
Biomass	2150	0.30	10	19	0.28	20
Solar Photovoltaic	7275	0.20	2	na	na	20
Wind	3625	0.28	2	na	na	20
Biogas reciprocating engine	1265	0.30	50	neg	0.30	20
Fuel cell hydrogen	3130	0.50	70	72	0.50	20
Fuel cell natural gas	3130	0.50	70	22	0.50	20

Notes:

Compared to data for centralised generation, data for the distributed generation sector is generally poorer in quality.

The data is from a wide variety of sources.

Capacity factor is generally assumed to be 30% unless specific information suggests otherwise. Where information is available, capacity factors differ slightly across States.

Energy efficiency refers to the ratio of useful energy output to non-renewable energy input based on gross calorific value (higher heating value). These ratios are only recorded if they use a fuel.

## Biomass for energy production

The use of organic materials to produce fuel is a mitigation strategy present in most Government environmental agendas worldwide. Wood, straw, animal waste, pulp/paper waste, landfill gas, biodegradable industrial and municipal waste, willow, poplar, coppice and miscanthus can all be used to produce energy.

The concept of plant-based biomass is the capture of solar energy as fixed carbon via photosynthesis, which is the key initial step in the biomass growing. Degrading the green material through microbial decomposition or burning the biomass returns the CO<sub>2</sub> that was absorbed as the plants grew to the atmosphere. There is no "net release" of CO<sub>2</sub> if the cycle of growth and harvest is sustained<sup>33</sup>. As in the case of biochar, the resulting fuel is syn-gas. Figure 15 shows the variety of products that can be obtained from biomass and its intermediary syn-gas.

Biomass can result in very low emissions compared to fossil fuels. The ash content of biomass is much lower than that of coal, and is generally free from heavy metals, allowing environmentally friendly uses for the ash such as soil conditioner, instead of landfill.

<sup>33</sup> [http://ec.europa.eu/research/energy/nn/nn\\_rt/nn\\_rt\\_bm/article\\_1110\\_en.htm](http://ec.europa.eu/research/energy/nn/nn_rt/nn_rt_bm/article_1110_en.htm)



### Gasification – Options for Bio-based Products

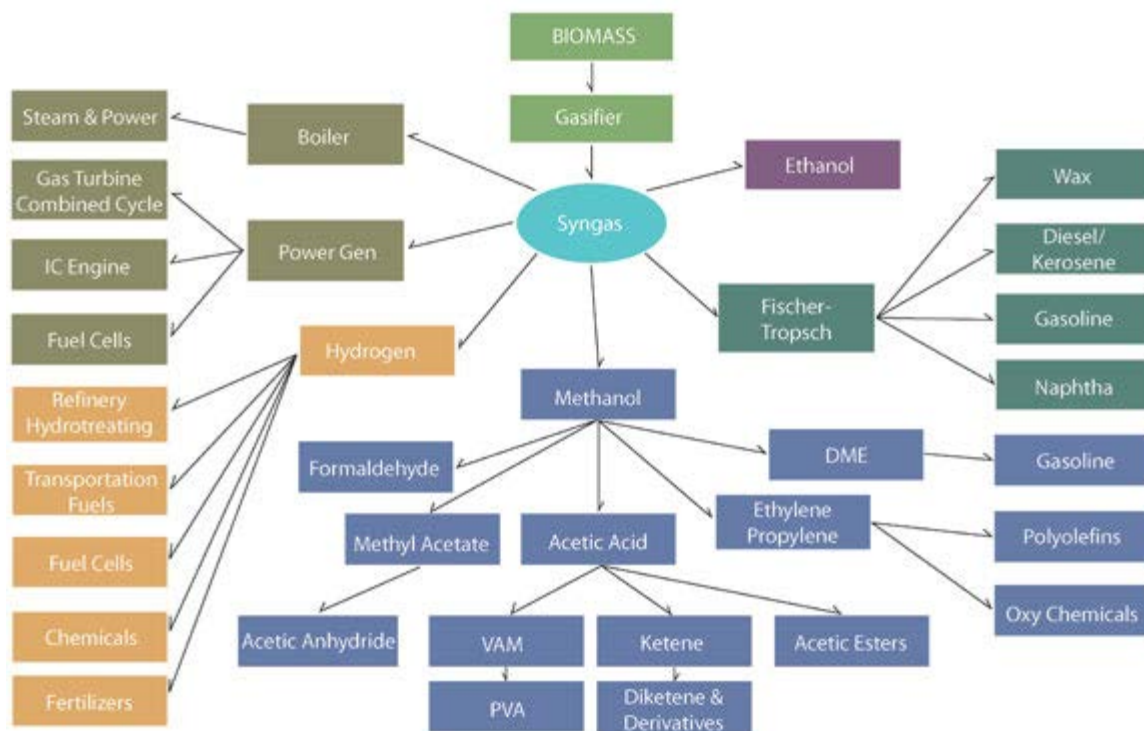


Figure 15. Alternative products for biomass. Source: Ebert, J. 2008. Syngas 101. Biomass Magazine<sup>34</sup>.

As a result of the first generation of biofuel research, energy crops such as corn, sugar beet and rapeseed are being used to produce biofuel (e.g. ethanol and diesel). This 1<sup>st</sup> wave of biofuel trials led to an ongoing debate on the competition between agricultural land (and products) dedicated to biofuel production and animal and human consumption.

Biomass for energy production is now in its second generation of research. The goal of these new processes is to use residual non-food crops and residues such as stems, leaves and husks that are left behind once the food crop has been extracted. Crops not used for food purposes include some types of grass, jatropha and cereals that bear little grain. Industry waste such as wood chips, skins and pulp from fruit and vegetable processing are also being considered [73].

This new wave of biomass technologies has not resolved the conflict between using land for biofuel production instead of food production. Theoretically any vegetable crop can be used as raw material for biofuel production, although with varying degrees of fuel production rates, financial returns and sustainability. If the conversion of crops to biofuel offers substantial financial rewards, the temptation to do so despite the threat of food insecurity will be high for growers.

<sup>34</sup> [http://www.biomassmagazine.com/article.jsp?article\\_id=1399](http://www.biomassmagazine.com/article.jsp?article_id=1399)

Some Australian companies that have started to work on the commercialization of bioenergy technologies include:

- BEST Energies Australia Pty Ltd: biodiesel, pyrolysis technologies.
- Plantation Energy: industrial and domestic grade fuel pellets from timber.
- Syngas: start-up in pre-processing stage. Syngas plans to establish a large clean premium diesel facility in South Australia, using a combination of coal and non-food biomass (e.g. straw).
- Syngenta Australia: currently partnering with QUT to develop cost effective conversion of sugarcane waste to ethanol, including the delivery of plant-expressed enzymes.
- PNP Energy Pty Ltd: design and construction of anaerobic processes, biogas (methane) harvesting, cogeneration, aeration systems, membrane liners and covers.

Further, RIRDC is investing in the evaluation of opportunities for several non-edible plant materials through its Bioenergy, Bioproducts and Energy program <sup>35</sup>.

A general search for patents related to the production of biofuels worldwide provided a sample of over 6,000 inventions. Figure 16 shows that the five countries with the highest number of biofuel patents<sup>36</sup> are US, China, Germany, Russian Federation and France.

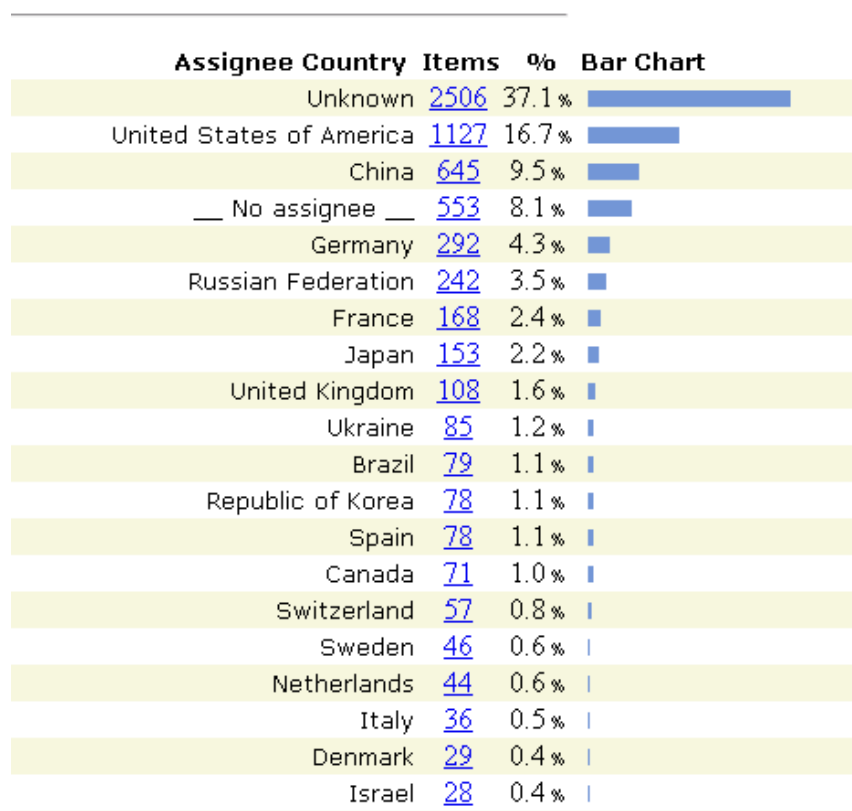


Figure 16. Countries with the highest numbers of biofuel patents (1988-2008).

<sup>35</sup> [http://www.rirdc.gov.au/programs/new-rural-industries/bioenergy-bioproducts-and-energy/rirdc-projects-and-results/rirdc-projects-and-results\\_home.cfm](http://www.rirdc.gov.au/programs/new-rural-industries/bioenergy-bioproducts-and-energy/rirdc-projects-and-results/rirdc-projects-and-results_home.cfm)

<sup>36</sup> Assessed by location of the patent owning entity.

Given the focus of this report on vegetable production, a search for any technologies developed using the most significant vegetables<sup>37</sup> of interest to HAL as raw material for biofuel production was undertaken.

Figure 17 shows the logistics growth curve of inventions that specifically use vegetables as raw materials for biofuel production. This figure indicates that this area is growing and its maturity is expected in 2020.

Horticultural crops are not a first choice for biofuel production, due to the high moisture content and generally low energy content. There are some exceptions such as cassava or sweet potato. In particular, sweet potatoes can yield two to three times as much carbohydrate for fuel ethanol production as field corn, approaching the amount that sugarcane can produce<sup>38</sup>. However, cassava and sweet potato have economic disadvantages compared to sugarcane or corn, such as higher labour costs at planting and harvesting.

This author does not advocate using edible vegetables for the production of biofuel. However, the use of vegetable waste for biofuel production can be a useful alternative for waste recycling. This option needs to be considered in parallel to other potential uses for vegetable waste, such as cogeneration and anaerobic digestion technologies, further explored in this report. Also, there is potential for extraction of valuable bioactives from waste, which is an option currently explored by HAL [74].

Cost benefit aspects also need to be explored in the context of the technology used to exploit vegetable waste as an energy source. This aspect is further explored in the "Waste Generation" section in this report.

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<sup>37</sup> Selected from a list provided by Karen Symes, HAL, on April 2009. Potatoes and tomatoes excluded.

<sup>38</sup> <http://www.ars.usda.gov/is/pr/2008/080820.htm>

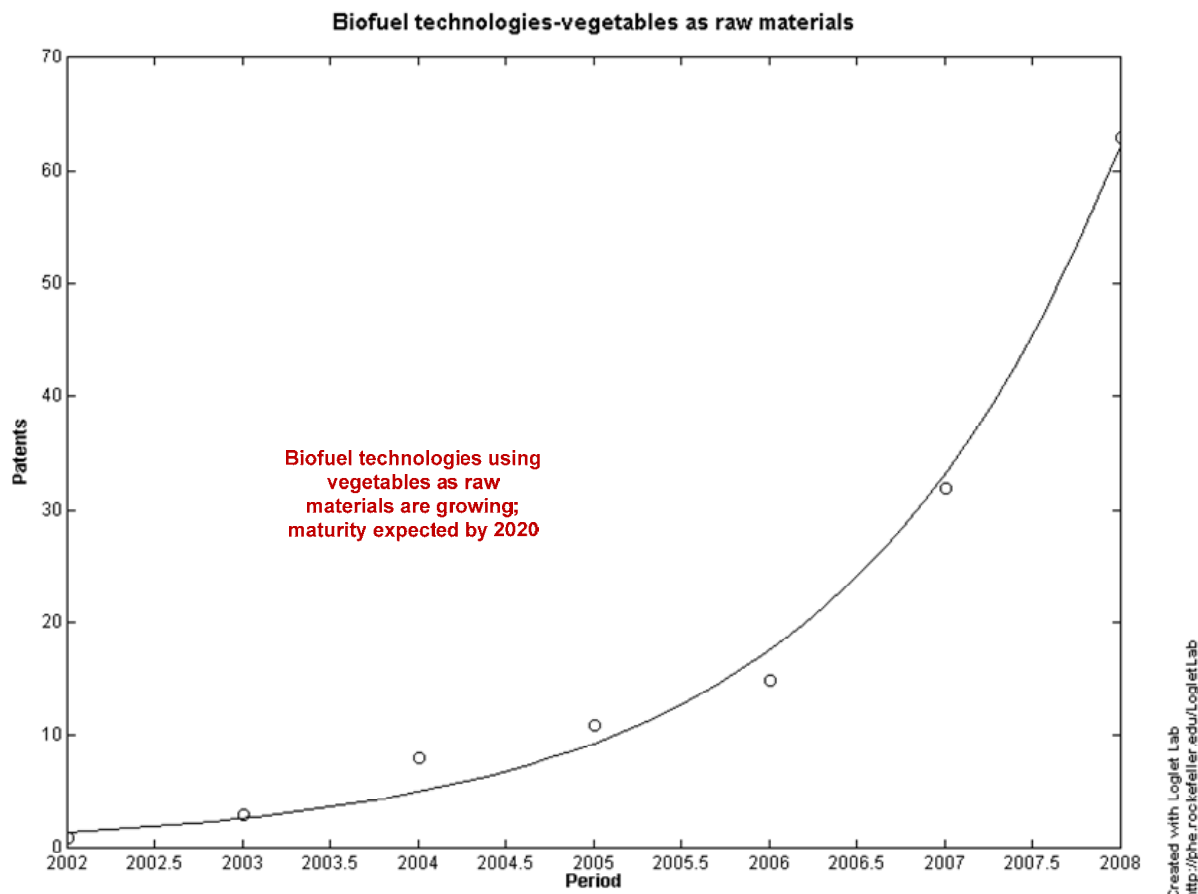


Figure 17. Growth curve of biofuel patents using vegetable crops as raw materials.

### Anaerobic digestion

Although anaerobic digestion (AD) is a mature technology<sup>39</sup>, it is receiving renewed attention worldwide as a means to produce bioenergy from organic waste. AD harnesses the natural bacterial decomposition of organic waste in the absence of oxygen to produce biogas and digestate, an organic composting material that can then be reused in agriculture as a fertilizer and soil conditioner.

Anaerobic digestion of food waste has three desirable effects:

1. It reduces the volume of residues in 50% of their original volume.
2. It results into more biodegradable and useful materials.
3. It has the potential to produce methane, which can then be used for energy production. Food waste can produce about 376 m<sup>3</sup> methane per tonne, which is 15 times more than the production of methane from a tonne of cattle manure<sup>40</sup>.
4. EPA (USA) estimates that about 6.2 tonnes of food waste could produce enough energy to power one American household for a year.

<sup>39</sup> [http://www.waste-management-world.com/display\\_article/339836/123/ARCHI/none/none/1/State-of-the-art-2008---Anaerobic-digestion-of-solid-waste/](http://www.waste-management-world.com/display_article/339836/123/ARCHI/none/none/1/State-of-the-art-2008---Anaerobic-digestion-of-solid-waste/)

<sup>40</sup> <http://www.epa.gov/epawaste/rcc/resources/meetings/rcc-2008/sessions/msw/food/foodwaste/peck.pdf>

The UK has now a goal of establishing AD as a key technology to reduce the environmental impact of food waste<sup>41</sup>. They foresee its development through the involvement of relevant waste producers and users (e.g. waste management and recovery, energy, transport, water and agriculture sectors).

Several studies on the technical feasibility of fruit and vegetable waste as raw materials for AD have been undertaken [75-77]. Table 4 shows some published examples of biogas production from agricultural and horticultural waste streams.

The horticultural industry would be likely positioned as a user of the digestate for fertilizing and soil conditioning purposes. Use of compost in the viticulture, horticulture, cut flower, and nursery industries has been estimated to increase typical yields by about 12%, mostly through an increase in water efficiency of the conditioned soil<sup>42</sup>.

However, trials to test small-scale AD to dispose of industrial vegetable waste are under way in the UK. See example below.

#### CASE STUDY: ANAEROBIC DIGESTOR FOR 'STAPLES VEGETABLES', UK

Staples Group farm 10,000 acres of brassica crops for the major retailers in Lincolnshire and on the Isle of Wight. The company is proposing to install a thermophilic AD facility on their vegetable processing site in Wrangle (Lincolnshire) to process the out-of-specification material and trimmings generated by their retail contracts. The electricity generated will be used on site, with a small amount being purchased by a major retailer providing a valuable income stream for the group. Heat will be used to chill the preparation and pack houses and possibly also for a district heating system. The digestate will become a key part of the nutrient budgeting undertaken by the group to ensure effective soil management, reduced dependency on inorganic fertilisers and improved yields.

From: <http://www.defra.gov.uk/news/2009/090608a.htm>

<sup>41</sup> <http://www.defra.gov.uk/environment/waste/ad/pdf/ad-sharedgoals-090217.pdf>

<sup>42</sup> [http://www.epa.sa.gov.au/pdfs/organic\\_waste.pdf](http://www.epa.sa.gov.au/pdfs/organic_waste.pdf)

Table 4. Biogas production technologies for various agricultural wastes [78].

Reference	Commodity	Reactor Type/ Size	Temperature	Biogas Production	Methane fraction
[79]	Raw fruit & vegetable waste (shredded)	Tubular/ 18L	Psychrophilic Mesophilic Thermophilic	0.64-1.05 l/l/d 0.83-2.34 l/l/d 1.7 -3.17 l/l/d	56-58% 54-65 % 58-62%
[80]	Cherry stillage	Sequencing Batch Reactor / 1.8 L	Low mesophilic (30°C)		58-71%
[81]	Bananas (fruit and stem) Potatoes (peelings, rejects) Oats	Continuous/ 20 L	Mesophilic	497 L/kg TS 350-410 L/kg TS 227-257 L/kg TS	53% 44-50% 51-54%
[82]	Palm oil mill effluent	Closed digester/ 500 m <sup>3</sup>	High mesophilic (37-42°C)	650-1000 kg/d	?
[83]	Olive pomace	Semi-continuous/ 1 L	Mesophilic	0.39-0.69 l/l/d	79.5-84%
[84]	Sequential feedings: mango, orange, pineapple, tomato processing, jackfruit and banana waste	Semi-continuous/ 45 L	Low mesophilic (30°C)	0.61-1.96 l/l/d	22-61.2%
[85]	Carrot processing wastewater. Potato and swede processing wastewater	UASB/ 2-3 L	Thermophilic (55°C)	7.3 l/l/d (315 cm <sup>3</sup> /g COD) 347 cm <sup>3</sup> /g COD	49% (carrots)

Table 5 . Economic analysis for the use of maize a raw material for an anaerobic digester.

crop: maize	11,000 tonnes FM	
	275 ha at €1098 / ha	€302,000 / year
digester	500 kW	
investment	3,500 €/kW	€1,750,000
	25 year life span	€70,000 / year
cost of operation	4,161,000 kWh <sub>el</sub>	
	3.25 ct/kWh <sub>el</sub>	€135,232 / year
<b>total</b>		<b>€507,232 / year</b>
electricity produced	4,161,000 kWh <sub>el</sub>	
	14.5 ct/kWh <sub>el</sub>	<b>€603,345 / year</b>

#### CASE STUDY: ANAEROBIC DIGESTORS OF BIOWASTE IN SWITZERLAND

A 9,000 tonne per year plant in Rümlang uses a dry, horizontal plug-flow process which operates at temperatures around 55°C. The investment to build the plant back in 1992 was £2.8 millions, including the costs of land in an industrial zone. Treatment costs are around £62b per tonne.

Although the plant serves a community of around 45,000 inhabitants, 50% of the capacity is used to digest waste from the catering, retail and agricultural industries in the area.

The plant produces around 350 kg of solid residue and 450 L of liquid per tonne of waste, though these figures vary according to the moisture content of the feedstock. Around 50% of the output is liquid fertiliser. The solid waste is subjected to a simple composting process. Both solid and liquid products are used for agricultural purposes and more than 90% is used by farmers.

The plant also produces around 100 m<sup>3</sup> of biogas per tonne of input, of which around 60% is methane. Further, cooperation with the retailer Migros has led to Migros sending their vegetable waste to Kompogas and using the biogas to power their trucks ('salad as fuel').

A similar plant has been installed in Basel, with a capacity of 15,000 tonnes/year. More than 60% of the composted product is used for horticultural purposes, particularly in glasshouse production. Farmers pay between 0.86 to £1.72/m<sup>3</sup>. Leureko, the company marketing the compost products, has been successful in selling these for more than 10 years. The resulting biogas fuel is used to power cars.

Source: [www.kompogas.ch/en/index.html](http://www.kompogas.ch/en/index.html)

## Cogeneration/Trigeneration

*Steam-injected gas turbines (STIG) can absorb excess steam, e.g. generated due to seasonal reduced heating needs, to boost power production by injecting the steam in the turbine. Steam injection boosts the power output of the turbine. Currently, over 100 STIGs are found around the world, especially in Japan, as well as in Europe and the U.S. Examples: STIGs at Sunkist Growers in Ontario (CA, 1985); Frito Lay (Bakersfield, CA, 2004) and Hershey Foods (Oakdale, CA, 2004)*

*CHP Integration allows increased use of CHP in industry by using the heat in more efficient ways. This can be done by using the heat as a process input for drying or process heating (see also above) or through tri-generation through supply of power, heating and cooling. The fluegas of a turbine can often be used directly in a drier. This option has been used successfully for the drying of minerals as well as food products. Example: The Avebe starch plant in Gasselternijveen (The Netherlands) uses a steam-injected gas turbine (STIG) installation to provide both power and heat for the plant.*

*Pressure recovery turbines are an opportunity to recover power from the decompression of natural gas on industrial sites. Natural gas is transported in pipelines at a pressure of 700 psi, and large industrial facilities receive gas with pressure up to 650 psi. No examples in the food industry were found in this case.*

*Source: [4]*

Cogeneration and trigeneration systems (CHP and CCHP, respectively) combine heat and power (in the former) or are integrated with a thermally driven refrigeration system to provide cooling as well as electrical power and heating (in the latter). CHP plants are currently available in a variety of capacities and can use a variety of fuels such as coal, light fuel oils, natural gas, waste fuels and solid or gaseous biomass.

CHP and CCHP systems have been in operation for many years. In fact, the first commercial power plant in 1882 built by Thomas Edison was also the first cogeneration power plant in history. Therefore, cogeneration hardly classifies as an emerging technology. The novelty of the CHP concept now relates to:

- The accelerated uptake of this technology in industrial sectors that previously preferred conventional heating and cooling systems (i.e. based on direct use of fuel or electricity), in view of the environmental challenges faced.
- The use of biofuel or other alternative energy sources to power cogeneration and trigeneration systems.

Large scale (above 20 MW) and medium scale (between 1 and 20 MW) cogeneration applications are well developed and established in paper, chemicals, food, primary metals, and petroleum refining. However, trigeneration systems from 4 MW to 9 MW and small plants (less than 1 MW) are less established. Plants that have variable (and large) heating and refrigeration needs are especially attractive for trigeneration, including margarine and vegetable oils, dairy, vegetable and fruit processing and freezing, and meat processing [4].

CHP development in recent years has focused on power systems, heat recovery systems, thermally driven refrigeration machines and integration and control. The improvement in micro-turbine technology and the development of cheaper fuel cells are the most exciting innovations in small-scale CHP technology.

Trigeneration is currently used in a small proportion of supermarkets in the USA, the UK and Japan, mainly for air-conditioning. These systems are based on internal



combustion engines or micro-turbines and lithium-bromide-water absorption refrigeration systems.

Figure 18 shows some opportunities, barriers and research needs for CHP and CCHP for their application in agriculture and food.

Figure 19 suggests that most of the patents developed worldwide in CHP and CCHP are owned by technology and energy services companies. Figure 20 shows that the inventions patented have mostly developed in the USA. Australia has five patents, mostly about cogeneration in metallurgy.

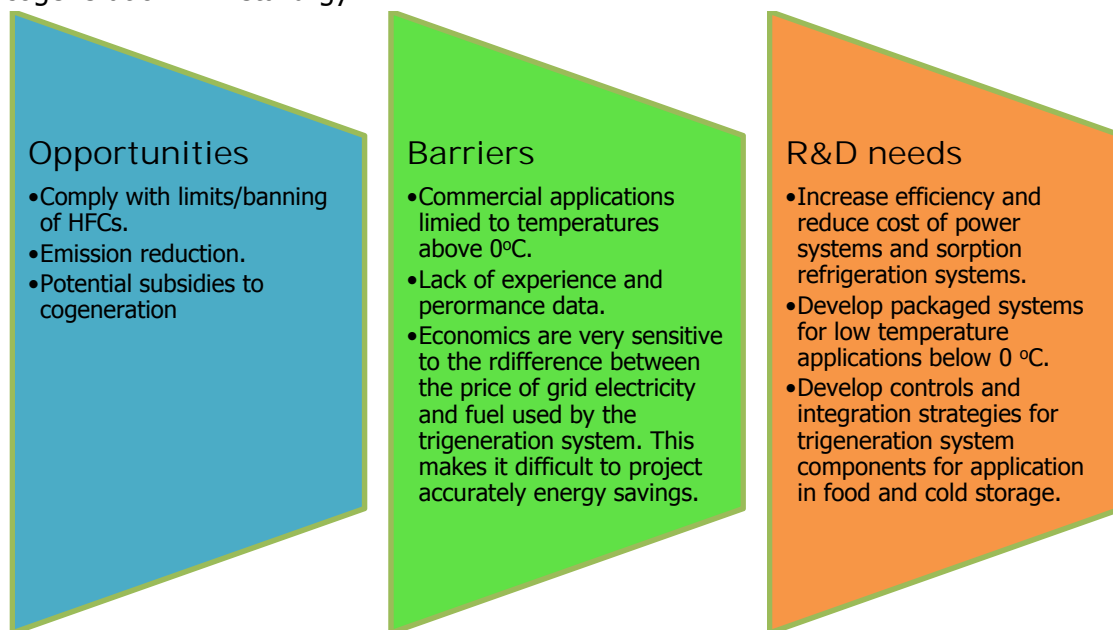


Figure 18. Summary of opportunities, barriers and research needs for CHP and CCHP for their application in agriculture and food.

Assignee	Items	%	Bar Chart
GENERAL ELECTRIC COMPANY	98	8.3%	■
OSAKA GAS CO LTD	95	8.0%	■
___ No assignee ___	80	6.7%	■
TOHO GAS CO LTD	26	2.2%	■
NORITZ CORP	18	1.5%	■
THE MEAD CORPORATION	16	1.3%	■
SPRINT COMMUNICATIONS COMPANY L.P.	15	1.2%	■
TOSHIBA CORP	15	1.2%	■
TOKYO GAS CO LTD	14	1.1%	■
AISIN SEIKI CO LTD	11	0.9%	■
SEIBU GAS CO LTD	11	0.9%	■
WESTVACO CORPORATION	11	0.9%	■
APPLIED ENERGY SYSTEMS OF OKLAHOMA, INC.	9	0.7%	■
CHOFU SEISAKUSHO CO LTD	9	0.7%	■
HITACHI LTD	9	0.7%	■
HONDA GIKEN KOGYO KABUSHIKI KAISHA	9	0.7%	■
ISHIHARA TAKAO	9	0.7%	■
LG ELECTRONICS INC.	8	0.6%	■
MATSUSHITA ELECTRIC IND CO LTD	8	0.6%	■
mitsubishi heavy ind ltd	8	0.6%	■

Figure 19. Representative companies that own patents in cogeneration and trigeneration (1989-2008).

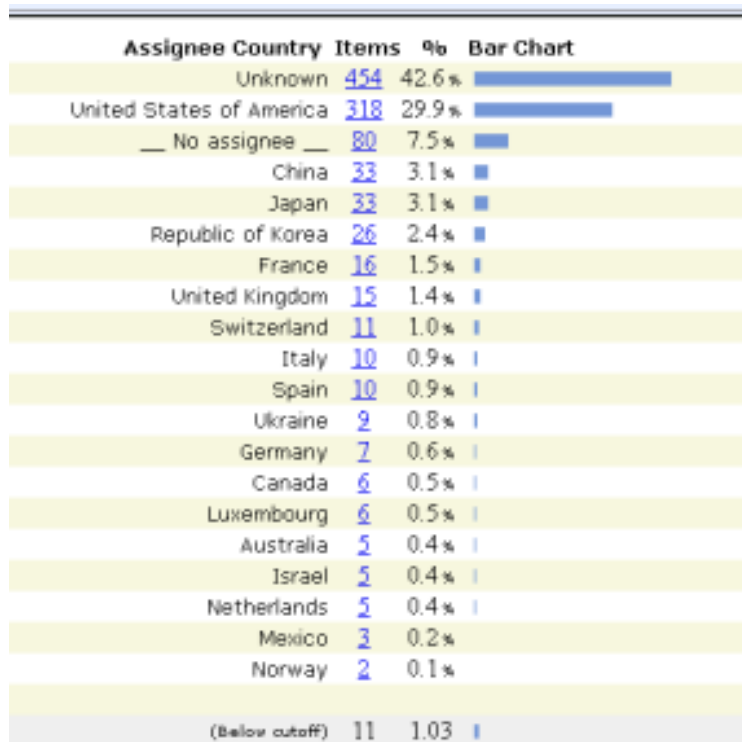


Figure 20. Countries that have developed CHP and CCHP inventions (1989-2008).

A formal analysis of patent trends was not performed, given that from over 1,000 patents in cogeneration and trigeneration, only 10 refer to cogeneration for agricultural/farm purposes. This does not necessarily mean that the area of cogeneration for food and agricultural purposes has not been developed. It is most likely that technology transfer between food industry and applications in other fields (e.g. chemical, refineries, minerals) does not require specific changes that need to be covered in a patent.

*Specific cost-benefit aspects*

The cost-effectiveness of CHP depends on the price differential between electricity and fuels (mainly natural gas). This means that the cost-effectiveness will vary by region, site and over-time and that each case needs to be individually assessed.

Figure 21 shows a comparison between cogeneration technologies as a function of the investment costs per kW, as estimated to occur in 2015. This figure should be used for comparison purposes only, given that the costs were calculated using an electricity price of 4-5 US cents/kWh and a natural gas price of US\$3.4/MMBtu (AUD\$3.75/GJ), which are normally higher than the costs paid in Australia.

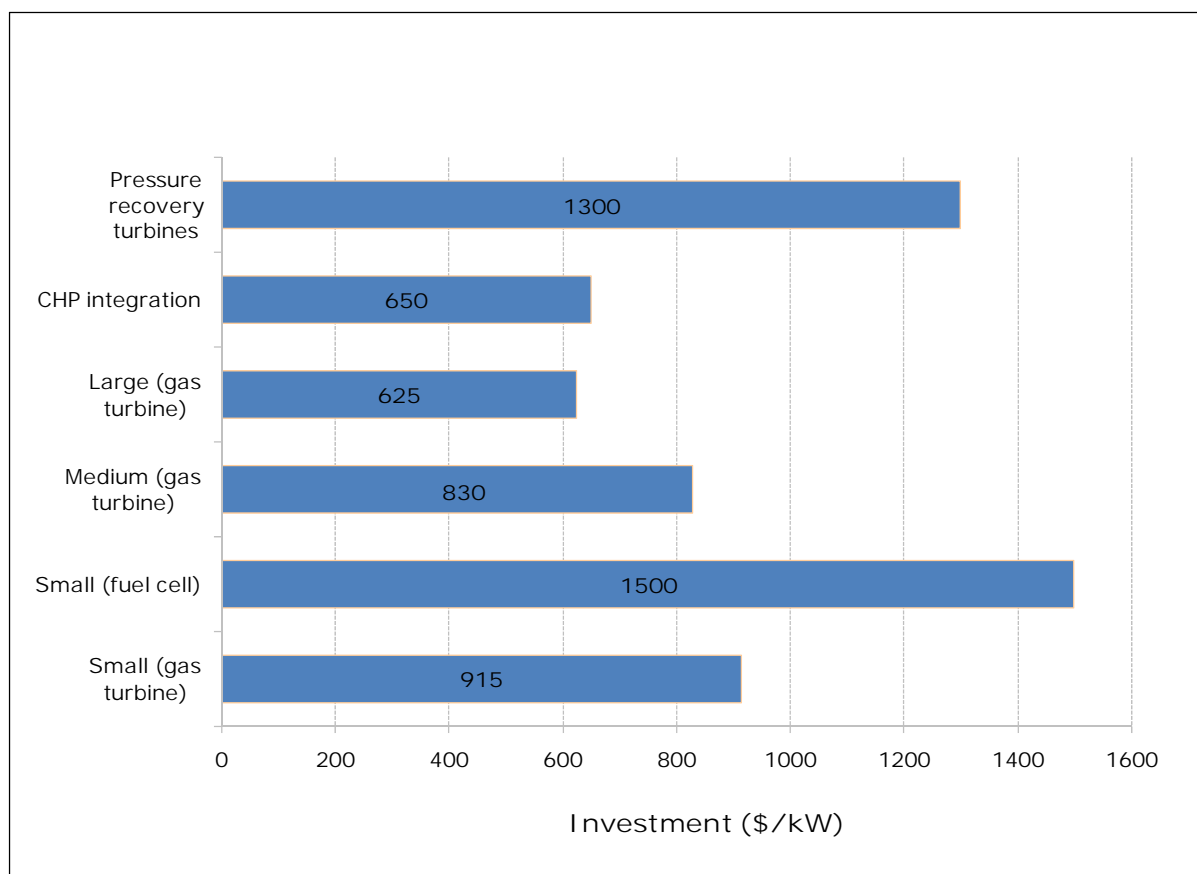


Figure 21. Comparison of investment per kW of different cogeneration technologies in the US in 2015. Source: [4].

### Photovoltaics and solar thermal energy

Photovoltaics (PVs), is the term used for all technologies which convert incident light (e.g. solar) directly into electricity by a semiconductor junction device. Photovoltaic cells are the smallest unit in a PV power producing system, typically available in different square sizes between 12.5 and 20 cm [86].

Solar thermal systems use solar collectors to “store” energy that can be later used to directly heat fluids (i.e. water, air) or to indirectly power absorption refrigeration systems. Common applications of solar energy in farms include space and water heating, greenhouse heating and crop drying. But interest on the use of PV and solar energy to generate electricity is increasing. The application of this electricity to water pumping, electrical fencing, lighting and cooling/heating can make a significant difference in the operating costs of vegetable farms.

The most common types of collector for smaller scale applications are the non-concentrating flat plate and evacuated tube collectors [87]. The average sales annual growth rate of these systems between 1999 and 2007 was 23.6% in China and Taiwan, 20% in Europe, and 16% in Australia and New Zealand [88].

There are over 38,000 patents registered in the fields of photovoltaics and the use of solar energy. Most of these were patented between 2005 and 2008, with 41% of these developed in China. Only 289 patents refer exclusively to the use of photovoltaics and solar energy to agriculture and half of these inventions have been developed in China (Figure 22).

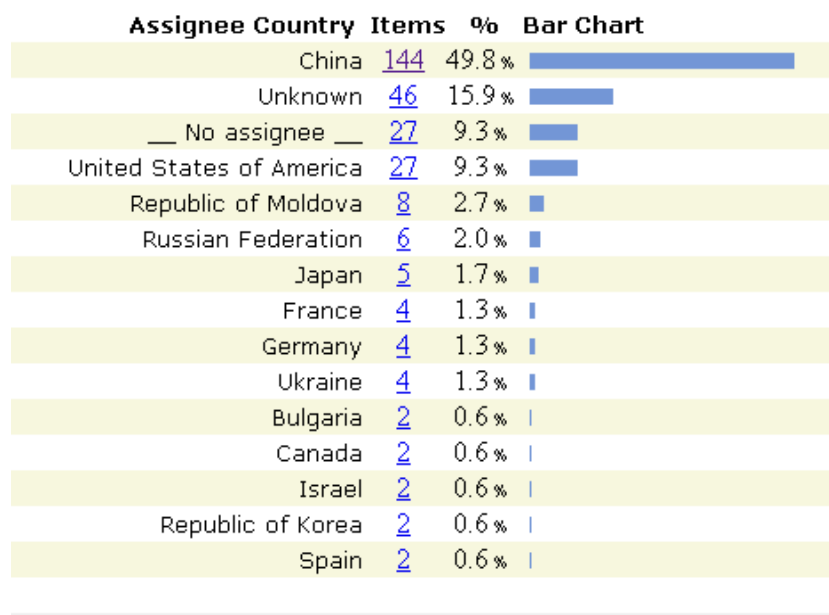


Figure 22. Countries with the highest numbers of patents in the fields of photovoltaics and solar thermal energy (1975-2008).

Examples of inventions related to the use of solar energy patented in recent years are presented in Appendix 2.

It is estimated that in 2007, the emissions avoided through the use of solar plants in Australia were 1,052,261 tonnes CO<sub>2</sub>-e, from a total collector area of 5,753,000 m<sup>2</sup> installed around the country.

However, the future of solar energy in Australia remains uncertain. While the government allocated \$1.35 billion to part-fund construction of up to four solar power stations generating as much as 1000MW each in the 2009-10 budget, \$2 billion are to be spent in carbon capture and storage (CCS) technology, even though it is predicted that CCS will not be commercially viable until 2033<sup>43</sup>.

*Specific cost-benefit aspects*

It is difficult to give a generic price for PV solar modules and systems, since this depends on several factors such as system size, location, grid connection and technical specifications. The price of PV modules and systems decreased strongly until 2004 but has begun increasing slightly over the last two years due to the present shortage of silicon. In 2003,

<sup>43</sup> <http://business.smh.com.au/business/solar-power-faces-early-sunset-in-australia-20090626-czu5.html?page=-1>

module prices in the UK were in the range £2.5-3.7/W [86]. Specific examples of solar energy applied to glasshouse production are presented in the following section.

## Energy Use

### Glasshouse production

It has been established that the major input in glasshouse production is energy. Figure 23 shows the patenting trends of technologies for energy management in glasshouse crops.

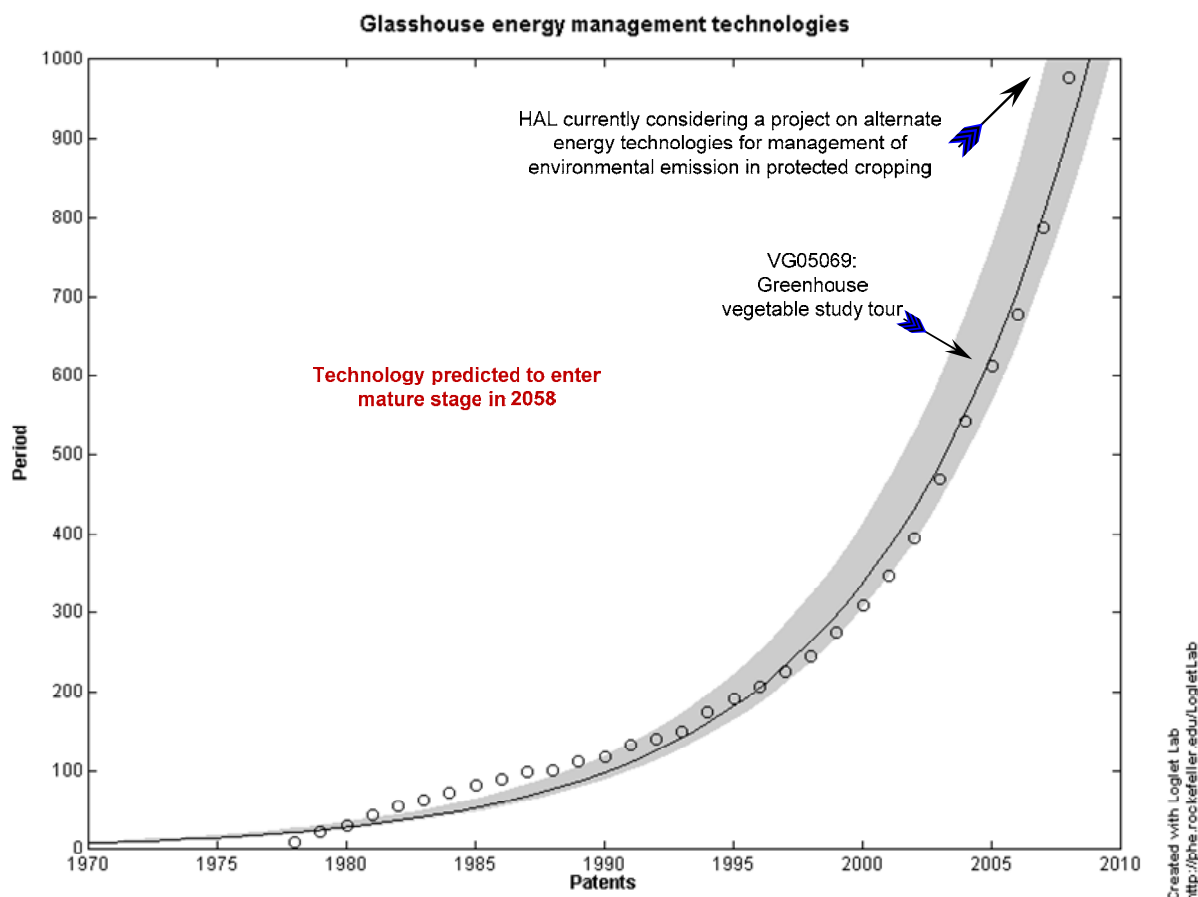


Figure 23. Growth curve of patented glasshouse energy technologies worldwide (1978-2008). Some HAL milestones in the area are shown as a reference.

The application of a logistic growth model in this data indicates that glasshouse energy technologies are still in the growth phase. Maturity is expected to occur post 2050.

Appendix 2 shows some of the patent titles related to glasshouse energy technology.

Temperature and humidity glasshouse conditions can be managed through the use of thermal screens, heat pumps, adsorption chillers, CHP, liquid desiccants, desiccant wheels, zeolites and inter-season heat storage<sup>44</sup>.

<sup>44</sup> <http://www2.warwick.ac.uk/fac/sci/whri/research/climatechange/mitigate/glasshouses/>

However, it is important to discern which of these technologies are likely to provide most benefit in Australian conditions. For example, a study in New Zealand [89] detected the following issues:

- Modern energy saving technology is mostly imported from Europe. It is often very expensive to get it built, installed or serviced outside Europe. Further, growers in NZ receive no financial support from the government, while in many European countries the governments provide considerable subsidies or tax deduction for investments in energy saving technology in greenhouses.

In Australia, FarmReady and the Regional Food Producers Innovation and Productivity Program provide some funding for the implementation of energy saving measures<sup>45</sup>. However, energy improvements in glasshouse production are likely to need larger investments than what the Government has put aside for these two programs (\$35 million and \$26.5 million over four years, respectively).

- Energy-saving solutions such as thermal screens have high investment costs, some adverse side-effects on plants, and the mild NZ climate means that costs savings are limited. This solution would need to be properly evaluated in Australian climate.
- Mild weather also means that energy savings through current technical solutions are modest and the implementation costs often outweigh the benefits. Australia and NZ do not stand to achieve the large energy savings observed in many European countries, which have larger heating needs. Having said this, Australia may have more cooling needs than NZ.
- A number of greenhouses in NZ are not suitable for installing modern technology. Moreover, the low production level in such greenhouses makes it impossible to recover the investments in energy saving technology. Only large operations stand to benefit from energy saving technologies. These observations are likely to apply in Australia as well.
- In mild climates, a large proportion of energy is dedicated to the control of humidity (as distinct from temperature control only). Smart energy controllers need to be designed on the basis of both humidity and temperature control and this requires engineering knowledge as well as physiology knowledge of the crops grown. Such specialized skills are not always available and come at a cost.

A novel technology is the development of closed and semi-closed greenhouses, which are being tested in The Netherlands. In a semi-closed greenhouse, air exchange is controlled to encourage an increase in CO<sub>2</sub> and humidity up to a specific threshold that depends on the crop being produced. In some varieties, this practice ensures a maximum opening of stomata, maximum CO<sub>2</sub> fixation and higher production. Decreased ventilation leads to excess heat, which can be stored in aquifers<sup>46</sup> and later used for cooling (through a heat pump) or heating the greenhouse<sup>47</sup>.

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<sup>45</sup> [http://www.daff.gov.au/about/grants\\_and\\_assistance#ag](http://www.daff.gov.au/about/grants_and_assistance#ag)

<sup>46</sup> Aquifer is a formation of water-bearing sand material that can contain and transmit water.

<sup>47</sup>

<http://www.greenportkas.nl/uploads/greenportkasvenlo/File/Pers/FlowerTech%20Greenportkas%202008%2011.pdf>

HAL has not funded projects in glasshouse production technologies that specifically target energy consumption, although a proposal that tackles this aspect is currently under consideration. These types of investment are timely, given the quantum of savings estimated in this report through better energy management in glasshouse production.

To further illustrate the importance of this research area, the number of patents per country in glasshouse energy technologies were analysed (Figure 24). While the USA and European countries rate high in the list, China has patented about 40% of the total number of inventions.

China has signalled its intentions to develop their glasshouse industry. Some industry analysts indicate that the Chinese government is encouraging the development of large scale farms. Foreign companies are becoming active providing technology and joint venturing in farming. Further, the large number of growers has driven innovation in vegetable production with new cultivation techniques and cultivars<sup>48</sup>.

In 2001, China had about 1.6 million hectares of protected crops, using a combination of plastic tunnels and rustic solar greenhouses [90]. Recent estimates suggest that China now has 2.1 million ha of greenhouses [91]. Based on a study tour to Beijing and Shandong in 2003<sup>49</sup>, researchers from Wageningen University (The Netherlands) indicated that China had the potential to expand their role significantly in the area of protected cropping.

However, there are significant issues that are slowing down their expansion, such as limited availability of water and land, low irrigation efficiency, limited measures to ensure food safety and supply chain issues (e.g. inadequate cold chain practices and infrastructure).

Notwithstanding these issues, China's presence as a horticultural exporter is increasing (Figure 25). New Zealand and China are the major suppliers of imported fresh vegetables into Australia. Imports of processed and frozen vegetables, which are direct substitutes of fresh vegetables, rose 23% in 2007/08 with respect to the previous period.

Therefore, China's glasshouse horticulture can become a strong competitor to Australian local growers in the future.

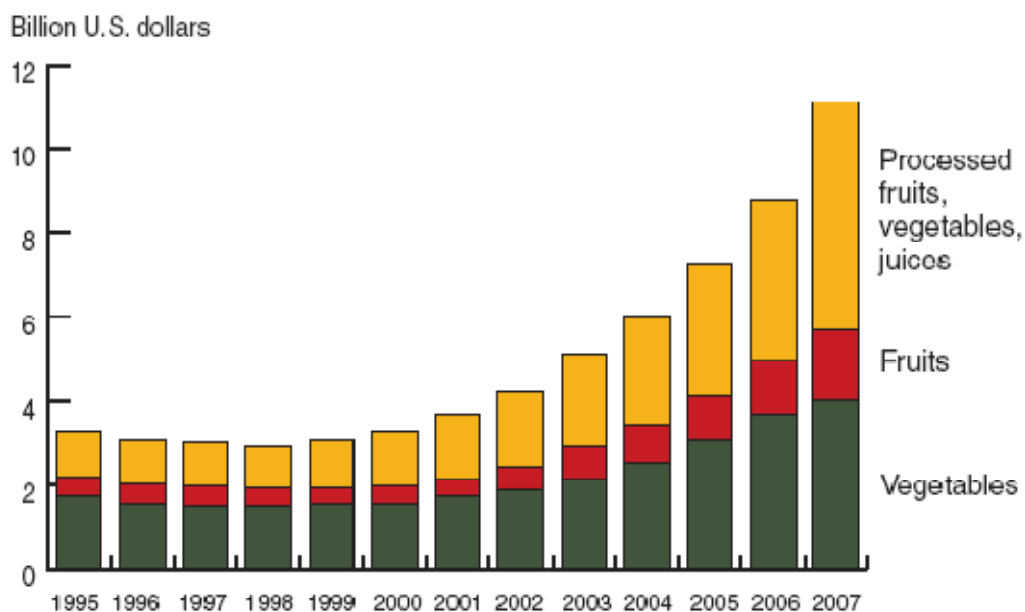
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<sup>48</sup> <http://www.nzcta.co.nz/articles/33/the-fruits-of-chinese-innovation/>

<sup>49</sup> <http://www.hpc.wur.nl/UK/Publications/Other+HPC-publications/Report+China+2003/>

Assignee Country	Items	%	Bar Chart
China	423	39.9 %	
Unknown	189	17.8 %	
United States of America	175	16.5 %	
__ No assignee __	121	11.4 %	
France	25	2.3 %	
Netherlands	20	1.8 %	
Canada	13	1.2 %	
Germany	13	1.2 %	
Japan	8	0.7 %	
Republic of Moldova	8	0.7 %	
Republic of Korea	7	0.6 %	
United Kingdom	7	0.6 %	
Denmark	6	0.5 %	
Bulgaria	5	0.4 %	
Australia	4	0.3 %	
Russian Federation	4	0.3 %	
Spain	4	0.3 %	
Italy	3	0.2 %	
Switzerland	3	0.2 %	
Austria	2	0.1 %	
(Below cutoff)	20	1.89 %	

Figure 24. Countries with the highest numbers of glasshouse energy technology patents (1989-2008).



\*Date of China's WTO accession.

Source: Economic Research Service calculations based on China customs statistics.

Figure 25. China's exports of horticultural products between 1995 and 2007. Source: [92]



### *Cost-benefit considerations*

It has been stated before that a 20% energy savings in the Australian vegetable glasshouse production could save \$41.6 million per year to the industry. However, only selected technologies can achieve these savings. For example, a cost-benefit analysis on the use of thermal screens in NZ revealed that using an energy screen with a saving factor of 50% did not save enough energy in winter to compensate the investment, capital and maintenance costs at the coal and gas prices paid in 2006. Only higher fuel prices could justify the investment [89]. Accurate climate control was suggested as a more effective alternative to decrease energy consumption, but this measure alone is likely to lead to savings ranging from 5 to 10% only.

More radical innovations will be required to achieve energy savings, perhaps through the semi-closed and closed glasshouse systems mentioned before. The Dutch horticultural sector aims to reduce CO<sub>2</sub> emissions by at least 30% in 2020, compared to 1990 levels. The implementation of semi-closed and closed glasshouse systems is part of their strategy to achieve this goal <sup>50</sup>.

#### CASE STUDY: A + G van den Bosch B.V. Vleestomaten

Tomato growing company Van den Bosch B.V. uses thermal energy to meet all its heating needs. Water at a temperature of 65°C is pumped up from a water-soaked sand layer located 1,750 m underground. A heat pump is used to convert heat to various types of energy. The water is then pumped back into the sand layer at around 30°C. Other features include the use of energy screens, a CO<sub>2</sub> pumping system and modifications to the heating system, which ensure good indoor climate for growing tomatoes [3].

### Smart Demand Management for Cold Storage

Several demand management strategies for energy savings in cold storage can be implemented. The 'smart' use of alternative energy sources (e.g. CHP, CCHP, ice banks, eolic, solar, phase change materials) to power cold stores requires:

- (a) The application of data collected from electricity grids to optimize the performance of refrigeration systems based on electricity rates;
- (b) Controllers that balance product quality, cooling demands and power available.

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[http://www.nwo.nl/files.nsf/pages/NWOA\\_7QWC3X/\\$file/Energy%20Innovation%20Agenda%2009-09-2008\\_tcm24-281800.pdf](http://www.nwo.nl/files.nsf/pages/NWOA_7QWC3X/$file/Energy%20Innovation%20Agenda%2009-09-2008_tcm24-281800.pdf)

A recent example of 'smart' controllers is the system created for the Night Wind project (The Netherlands), which combines eolic energy and grid electricity to power cold stores. The idea is to sub-cool refrigerated facilities using wind energy produced at night and avoid energy expenditure during daytime peak hours<sup>51</sup>.

A novel demand management strategy has been successfully tested for CA commercial apple storage in Australia [93] [94]. This technology consists in sub-cooling the cold stores during cheap energy rates periods to a threshold established in terms of the physiological response of apples under CA conditions. The power is switched off for some hours during expensive electricity rates periods, allowing a calculated warming period before switching the power on again. The temperature oscillations in the cold store are managed through the careful evaluation of apple quality during these variable conditions.

Preliminary calculations indicate that shifting refrigeration to off-peak periods results in product temperature oscillations of less than  $\pm 0.5^{\circ}\text{C}$ , with savings amounting to 40% of refrigeration energy costs. In this study, no significant detrimental effects on apple quality were found.

Similar demand management strategies may offer substantial energy savings during the cold storage of vegetables with postharvest shelf-life that extend over months, rather than weeks. Examples include carrots, celeriac, celery, parsnips and radish. Peak shifting strategies are expected to provide little or no benefit for vegetables with short shelf-life (e.g. days and weeks).

It is difficult to evaluate patents that specifically address the use of demand management in cold storage. The reasons are:

- Demand management strategies require a combination of technologies, including software, controllers and monitoring systems for electricity input, temperatures and depending on the product, some sensing capabilities for humidity and atmosphere inside the cold store.
- Demand management is used for a variety of cooling technologies (as specified before).

HAL has started to investigate the opportunities of electricity management through project AP06063 "Influence of electricity load shifting strategies on controlled atmosphere stored apples". The methodology followed for apples can be implemented for other crops, prior investigation of the specific effects of variable temperature, gas and humidity levels on these crops.

Other technologies for decreasing energy use in cold storage are provided in reference [95] and in Appendix 1.

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<sup>51</sup> [http://www.nightwind.eu/mediapool/48/485045/data/Cold\\_Storage\\_of\\_Wind\\_Energy.pdf](http://www.nightwind.eu/mediapool/48/485045/data/Cold_Storage_of_Wind_Energy.pdf)

### *Cost-Benefit Aspects*

In theory, demand management in cold stores can be achieved with no additional technology and at virtually no extra cost for cold store operators. For example, switching off the refrigeration plant for some hours during the day and sub-cooling the cold store during the night can be achieved manually by a trained operator, once the thresholds of product temperatures and conditions have been established through experiments.

However, automation of these operations through smart controls can benefit from the use of real-time information from the electricity grid to time on and off periods according to electricity prices. Also, automated demand management eliminates human errors in the timing of these periods, which can be costly if the cold store is left out of power (or sub-cooled) too long and the stored products are damaged.

As an example of investment costs for smart controllers, the Night Wind Control System (NWCS), which is the 'brain' of the Night Wind demand management system, costs about AUD\$22,000. This cost covers some changes in the existing refrigeration control system and the software to detect the best moments to switch on and off the refrigeration system. The input for the NWCS is provided by the day-ahead energy price prediction of the energy spot market (the APX in the Netherlands). This price reflects the excess or shortage of energy on the grid and is correlated to the wind energy production<sup>52</sup>.

However, the NWCS could be adapted to operate without an eolic system and can be used instead to coordinate other alternative energy sources or the heuristics dictated by product quality as per the HAL project AP06063, for example.

The demand management strategy of project AP06063 represents an energy reduction of 40-45% over the normal cold store operation [94]. However, these savings need to be tempered with the fact that not all fruit and vegetables can withstand the temperature variations that occur in the implementation of these strategies.

The combination of alternative energy sources (e.g. eolic, ice storage, solar) with smart demand management particularly benefits frozen vegetables (e.g. potatoes, carrots, vegetable mixes). However, the specific cost-benefit cannot be stated until a full investigation on the effects of product quality under variable energy sources is carried out.

For example, the Night Wind project investigated the effect of eolic + electricity power generation and electricity-only power generation in the quality of frozen goods. The products tested were bacon, smoked mackerel fillet, fruit pies, strawberries, tomatoes, melons and ice cream. The control products were left at a steady temperature of -19 °C while the eolic + electricity temperatures varied between -16 °C to -28 °C.

The results showed that the quality of foods stored at variable temperatures was comparable, but generally inferior to products maintained at a constant temperature. The actual impact on shelf-life and consumer acceptance was not measured.

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<sup>52</sup> [http://www.nightwind.eu/pageID\\_4054663.html](http://www.nightwind.eu/pageID_4054663.html)

## Water Generation

### The Seawater Greenhouse

The Seawater Greenhouse is a concept that uses seawater to cool and humidify the air of a greenhouse and sunlight to distil fresh water from seawater. The Seawater Greenhouse is an alternative for sustainable provision of water for agriculture in arid, coastal regions<sup>53</sup>.

Figure 26 shows a diagram that summarises the process of water generation. The greenhouse is driven by solar and wind energy. Sunlight is separated into visible and infrared light. Visible light that passes through the roof drives photosynthesis, while infrared light trapped in the roof canopy and ducted to the seawater evaporator converts seawater into water vapour.

The structure acts as a 'wind-catcher', facing into the prevailing daytime wind to assist ventilation. Fans are required under most conditions. The wind-fan combination moves air through the front evaporator and chills the sea water, which then provides cooling for the rear condenser. The condenser in turn generates fresh water.

The overall process is extremely energy efficient. For example, 1 kW of electricity expended on pumping will remove 500 kW of heat. Water can be produced at low energy costs (<3 kWh/m<sup>3</sup>).

Projects of this type have been completed in Oman, the United Arab Emirates and Tenerife (Spain). The design of each solution involves heavy use of mathematical models to evaluate the most adequate parameters for operation.

Charlie Paton is the Managing Director of the Seawater Greenhouse Ltd. In a recent conversation<sup>54</sup>, Mr Paton mentioned that they are about two weeks away from selecting a site on which they will showcase the first Australian Seawater Greenhouse. Mr Paton has been studying the Australian market over the past months. While there is no shortage of suitable locations, especially in Western Australia, they decided to locate their first project in South Australia for a variety of practical reasons. Their goal is to have a 1,000 m<sup>2</sup> pilot greenhouse operating there by June 2010 with an additional 3-5 hectares operating by no later than 2011.

### *Cost-Benefit Aspects*

The cost information in Table 6 was calculated for the Oman project. Capital costs in 2001 for a greenhouse area of 1,080 m<sup>2</sup> (for temperate and tropical models) and 1,530 m<sup>2</sup> (for the Oasis model) ranged from AUD\$65,700 to AUD\$83,000.

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<sup>53</sup> <http://www.seawatergreenhouse.com/>

<sup>54</sup> Personnal communication, 2 Sept 2009

The capital costs in this project ranged from AUD\$55.50/m<sup>2</sup> and AUD\$61.50/m<sup>2</sup> and were lower than the current average costs in Australia, which range from \$100/m<sup>2</sup> to \$300/m<sup>2</sup>, depending on the sophistication of the greenhouse and the level of equipment being included<sup>55</sup>. Further, while viable glasshouse production units in Australia need a minimum of 1,500 m<sup>2</sup>, the lower operating costs for the seawater greenhouse (i.e. energy and water) would lower the area requirements to achieve a viable production.

The Seawater Greenhouse presents interesting possibilities for Western Australia<sup>56</sup>, which has the longest coastline of any state. However, some inland regions below the sea level could be potentially used. Inland areas present lower relative humidity, which leads to greater potential for water extraction [91].

*Table 6. Summary of costs and performance of three seawater greenhouse designs. Source: [96].*

	Temperate model	Tropical model	Oasis model
<b>Area, water production and cost</b>			
Greenhouse length (m)	60	60	85
Greenhouse area (m <sup>2</sup> )	1,080	1,080	1,530
External irrigated area under shade netting (m <sup>2</sup> )	1,030	590	1,690
<b>Total cultivated area (m<sup>2</sup>)</b>	<b>2,110</b>	<b>1,670</b>	<b>3,220</b>
<b>Average water production (m<sup>3</sup> day<sup>-1</sup>)</b>	<b>6.03</b>	<b>3.42</b>	<b>9.86</b>
<b>Capital cost (£)</b>	<b>34,379</b>	<b>34,379</b>	<b>43,902</b>
<b>Capital cost per hectare (£)</b>	<b>318,326</b>	<b>318,326</b>	<b>286,939</b>
<b>Annual crop sales, costs and profit</b>			
<b>Total annual income (£)</b>	<b>22,330</b>	<b>19,250</b>	<b>33,250</b>

<sup>55</sup> <http://www.ahga.org.au/about/>

<sup>56</sup> <http://www.futurewa.com.au/post/Solar-plant-yields-water-and-crops-from-the-desert-Perfect-for-Western-Australia.aspx>

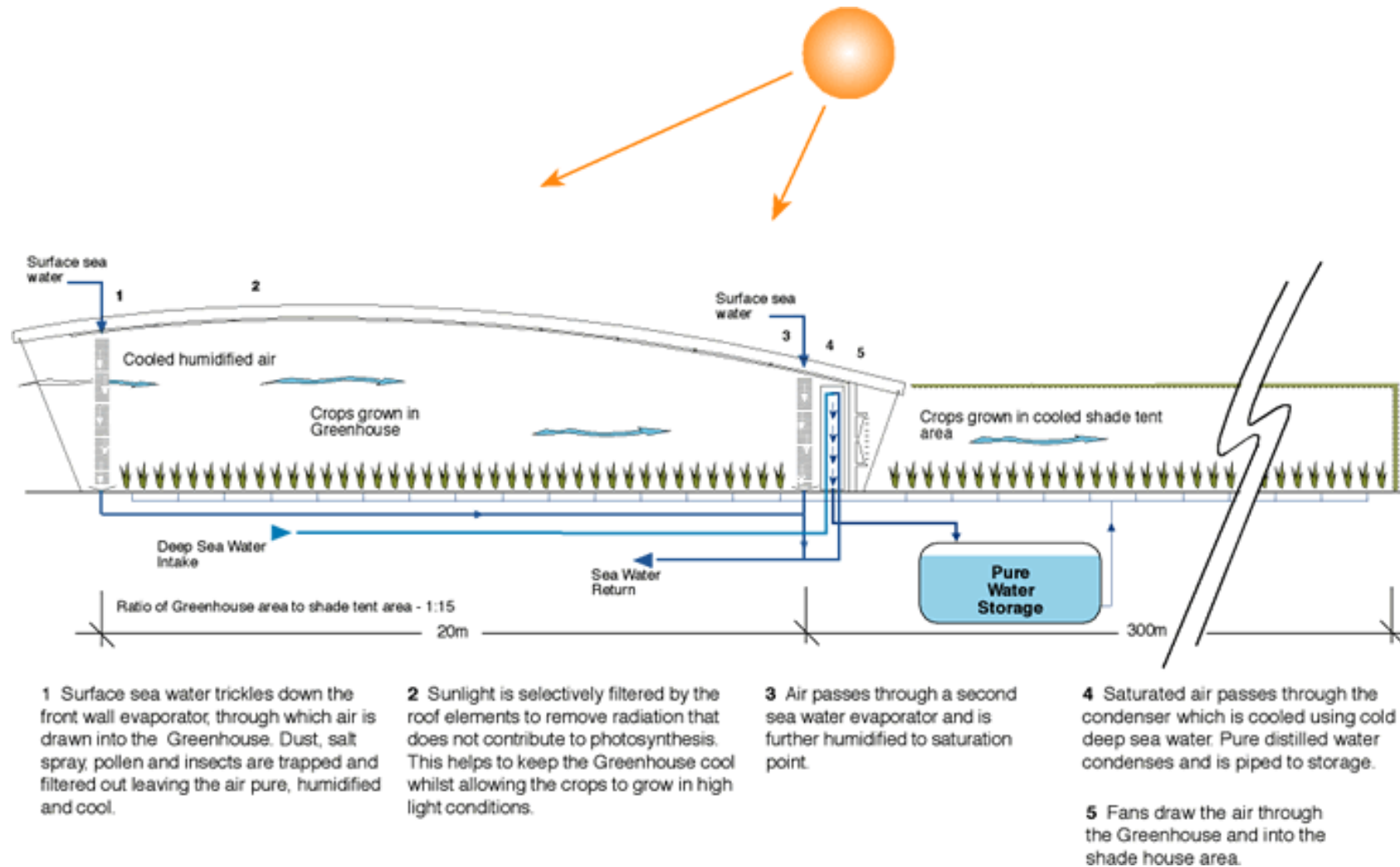


Figure 26. The concept of a seawater greenhouse, which works using a natural hydrological cycle within a controlled environment. Source: [http://www.seawatergreenhouse.com/the\\_process.htm](http://www.seawatergreenhouse.com/the_process.htm)

## Water Use

### Smart irrigation

More efficient irrigation, shifts in cropping patterns and the use of groundwater are all no-cost or low-cost options for taking advantage of a longer growing season or avoiding crop exposure to high temperature stress or low rainfall periods. Effectiveness will depend on the region, crop, and the rate and amount of warming [97].

Intelligent systems have been developed that enable the water flows within an irrigation system to be coordinated much more effectively, so that near 'on-demand water supply' can be achieved [42]. An example is the Water Information Networks (WIN) project from the National ICT Australia Limited (NICTA), which focuses on innovative methods for controlling and integrating channel networks with on-farm irrigation systems so that these channels themselves become a water reserve for 'on-demand' water supply<sup>57</sup>.

NICTA designed and built NICTOR™, a wireless sensing and control platform based on the ZigBee™ protocol<sup>58</sup>. NICTOR devices are used to measure crop water requirements in real time and use this data to control canal gates and pumps and deliver the right volume of water to the plant when it requires it.

In trials employing drip irrigation for 'Pink Lady' apple orchards controlled by NICTOR the results were extremely positive, with 73% increase in gross returns (in dollars earned per hectare) and 74 % increase in economic water productivity (in dollars earned per ML of irrigation water) [98].

Figure 27 shows the growth curve of irrigation technologies. An analysis of patents on irrigation systems indicates that technological development in irrigation is in a growth stage and not likely to reach maturity until 2050.

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<sup>57</sup>

[http://www.dbcde.gov.au/digital\\_economy/future\\_directions\\_of\\_the\\_digital\\_economy/australias\\_digital\\_economy\\_future\\_directions/final\\_report/appendix\\_case\\_studies/national\\_ict\\_centre\\_of\\_excellence\\_improving\\_water\\_use\\_efficiency#footnote-221](http://www.dbcde.gov.au/digital_economy/future_directions_of_the_digital_economy/australias_digital_economy_future_directions/final_report/appendix_case_studies/national_ict_centre_of_excellence_improving_water_use_efficiency#footnote-221)

<sup>58</sup> An international standard for wireless mesh networks.

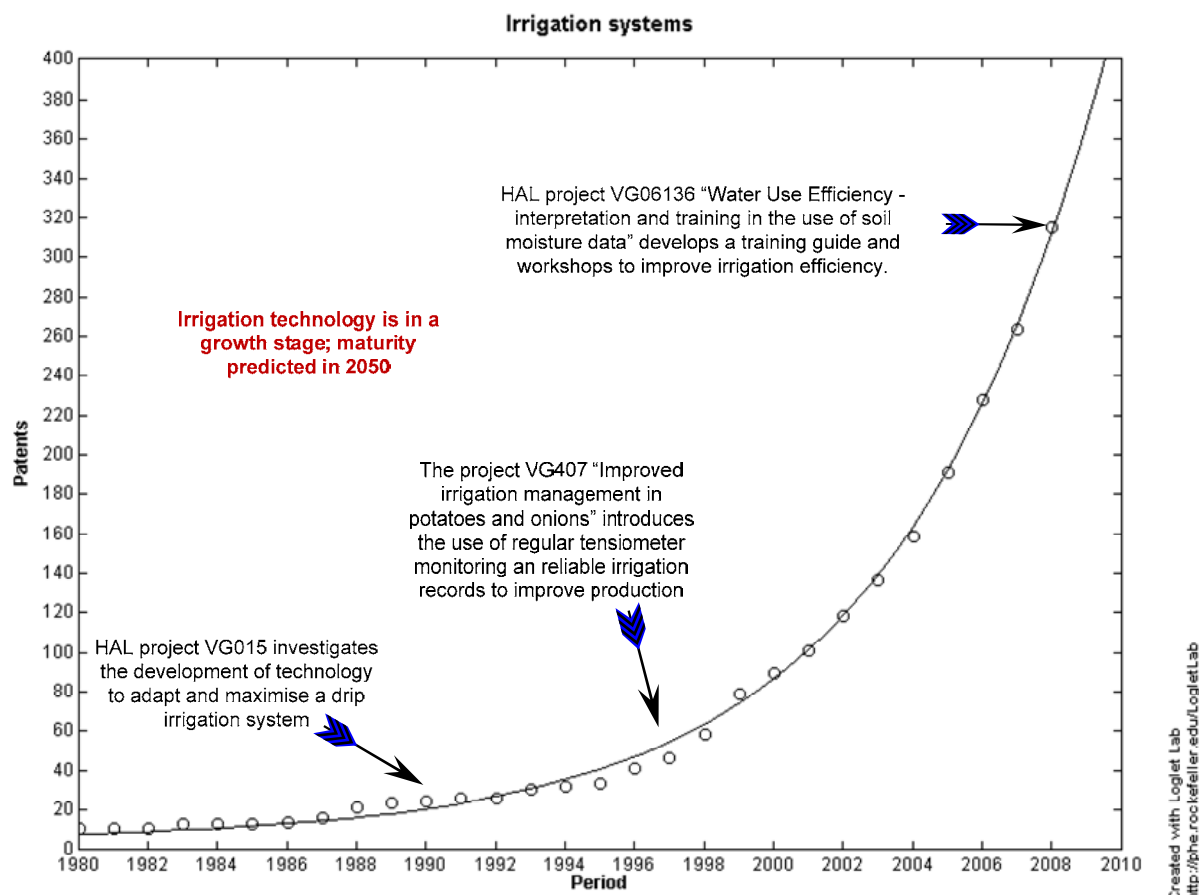


Figure 27. Growth curve of patented irrigation technologies worldwide (1980-2008). Some HAL milestones in the area are shown as a reference.

### Cost-benefit aspects

Smart irrigation systems have been tested in a number of pilot projects in Victoria, with excellent outcomes in terms of overall water savings and quality of service. Examples of outcomes include water distribution efficiency of better than 90% (essentially only the unavoidable losses due to evaporation and seepage remain), compared to 70% achieved under manual operations. This was combined with an ability to meet water requests on-demand in better than 90% of all water orders. The State Government of Victoria identified savings of 400 Mm<sup>3</sup> of water per year with the application of advanced control technologies, if implemented across all Victorian irrigation districts [99].

A report by Access Economics estimated that an investment of \$200 million would be sufficient to introduce intelligent technologies in all the Murray Darling Basin irrigation areas. The expenditure was assumed to be spread evenly in a 5-year period (e.g. 2009-2014). The authors estimated that this investment could lead to savings of 15% per hectare, representing a net increase in GDP of \$108 million by 2018. At a discount rate of 7%, the net present value (NPV) of the investment would range from \$428 million to \$530 million in the period 2009-2018. Further, it was estimated that the uptake of smart technologies for irrigation would create 800 new jobs by 2016 [42].



In terms of irrigation systems, a recent study compared the costs of different system conversion in horticulture in the Northern Murray-Darling Basin [57], including drip irrigation and centre pivots. Existing systems used in horticulture include travelling boom, solid set, surface, hand shift and travelling gun.

The economic evaluation of irrigation application systems in Table 7 encompassed capital, labour, pumping, maintenance and other operating costs over a 20-year investment cycle at a discount rate of 5%. The lifetime of various irrigation systems was assumed to be 20 years, except for surface drip (5 years) and subsurface drip (10 years). The variable costs (i.e. operating, repairs and maintenance and labour) varied depending on the amount of water applied to the crop.

*Table 7. Comparison of system conversion options for horticulture. The shaded square indicates options where the breakeven cost of water saved is uneconomical. Source: [57].*

System Conversion	Annual Cost (\$/Ha)	Breakeven costs (\$/ML saved) for improved volumetric efficiency		
		10%	20%	30%
Furrow to Surface Drip	490	1224	612	408
Furrow to Centre Pivot	251	628	314	209
Travelling Gun to Surface Drip	219	548	274	183
Travelling Gun to Centre Pivot	-19	-	-	-
Travelling Boom to Surface Drip	266	665	332	222
Solid Set to Surface Drip	385	963	481	321
Handshift to Surface Drip	287	718	359	239
Handshift to Centre Pivot	49	122	61	41

From the options in Table 7, conversion of travelling guns to centre pivots is the most economical investment which results in a profit. The second best option occurs when converting from hand shift sprinklers to centre pivots.

## Land use

It has been stated that issues around land use need to be solved through social studies and policy rather than through technology. This is further emphasized by a recent CSIRO study [100], which identified the attainable carbon storage and mitigation and ease of implementation for several rural land use options. The options investigated are presented in Figure 28.

The CSIRO study concluded that forestry-based solutions (e.g. carbon forestry, biodiversity, plantations, reduction of land clearing and re-growth) can achieve higher emissions reductions/storage over agriculture-based solutions (e.g. mitigation of emissions from savannah burning, build soil carbon storage and mitigate N<sub>2</sub>O emissions for cropped land) and bioenergy-based solutions (e.g. biofuels, biochar).

The report supports the results from the Garnaut Review in that Australia can significantly offset its GHG emissions by storing carbon in the landscape and changing the emissions profile from rural land use. The national estimate of carbon savings from switching land use to forestry-based mitigation is 750 Mt CO<sub>2</sub>-e per year.

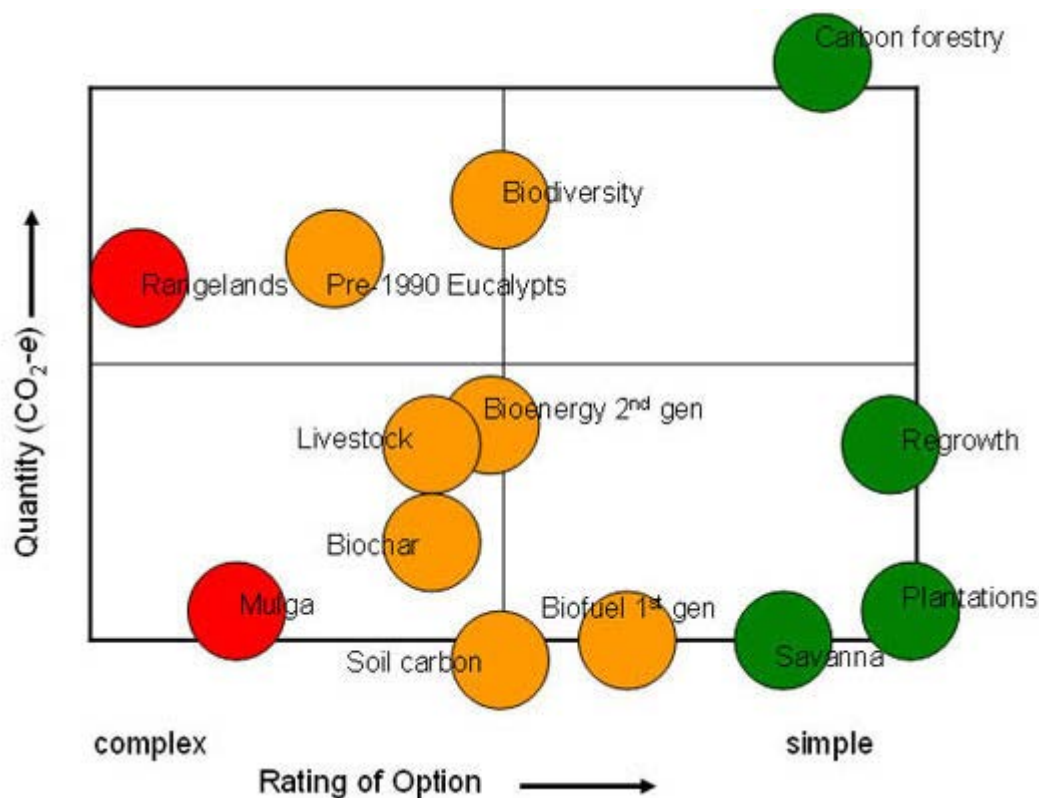


Figure 28. Attainable carbon storage/mitigation and ease of implementation for each of the rural land use options.

There can be serious issues if this strategy is adopted without considering that a shift of land use to carbon forestry implies that other land-based industries (e.g. livestock, crops production, horticulture) would be affected. The economic impacts of this switch and the consequences on food production were not addressed in this report.

This problem is acknowledged by the authors in page 29: "The potential perverse outcomes range from diversion of food production lands at a time where food security is a growing priority to impacts on environmental values such as biodiversity, weed and feral animal control and off-site changes."

This emphasizes the need for approaching mitigation and adaptation strategies for agriculture in a holistic manner. For example, while biochar, anaerobic digestion of waste and many other agricultural-based mitigation technologies may lead to smaller volumes of carbon sequestration, they could provide a better balance between CO<sub>2</sub> sequestration and food production.

There will also be technological tradeoffs in a massive change in land use. For example, land use lost for food production may mean that technologies such as biotechnology, intensive farming and others need to be implemented to counteract the production losses.

### Biotechnology for adaptation

The OECD defines biotechnology as “the application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services” [101]. In this report we review biotechnology applications that specifically aim to adapt horticulture crops to the climate challenges expected to occur in Australia in the near future (e.g. increased temperatures, stronger viral and pest attacks, drought) .

Genetically modified (GM) crops for feed, fibre and food have been grown, traded and consumed in Australia since 1996<sup>59</sup>. In some industries, the uptake of GM crops has been swift. An example is the case of GM cotton, which made 90% of the Australian cotton crop in 2007<sup>60</sup>.

Figure 29 shows the growth curve of biotechnology patents applied to the development of transgenic vegetable crops, worldwide.

The developments in Figure 29 include traits that can help horticulture to adapt to climate change and also ‘output’ or product quality traits. It is important to remember that some issues raised in regards to warmer temperatures during production relate to product quality, therefore ‘output’ traits can act as adaptation biotechnologies. We will expand on the use of biotechnology on improving product quality in the forthcoming report “Technologies for product quality and safety”.

Australia currently has about 0.4% of the arable land planted with GM crops (or 0.2 million ha) [101], but it is estimated that only a minor portion of this represents horticulture trial crops. GM crops accepted by FSANZ and of interest to HAL include:

- Potatoes resistant to the Colorado beetle, potato leafroll virus and the virus Y.
- Carnations with genetically modified flower colour.

It is estimated that in 2006, Australia had 527 biotech firms of which about 35% were dedicated to agricultural applications [101]. However, several biotech firms left the business during 2007-2009.

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<sup>59</sup> [http://www.afa.com.au/news/news\\_pdf\\_063\\_AFAA\\_Media\\_Release\\_19-08-09.pdf](http://www.afa.com.au/news/news_pdf_063_AFAA_Media_Release_19-08-09.pdf)

<sup>60</sup> [http://www.health.gov.au/internet/ogtr/publishing.nsf/Content/gmofactsheets-3/\\$FILE/gmstockfeed.pdf](http://www.health.gov.au/internet/ogtr/publishing.nsf/Content/gmofactsheets-3/$FILE/gmstockfeed.pdf)

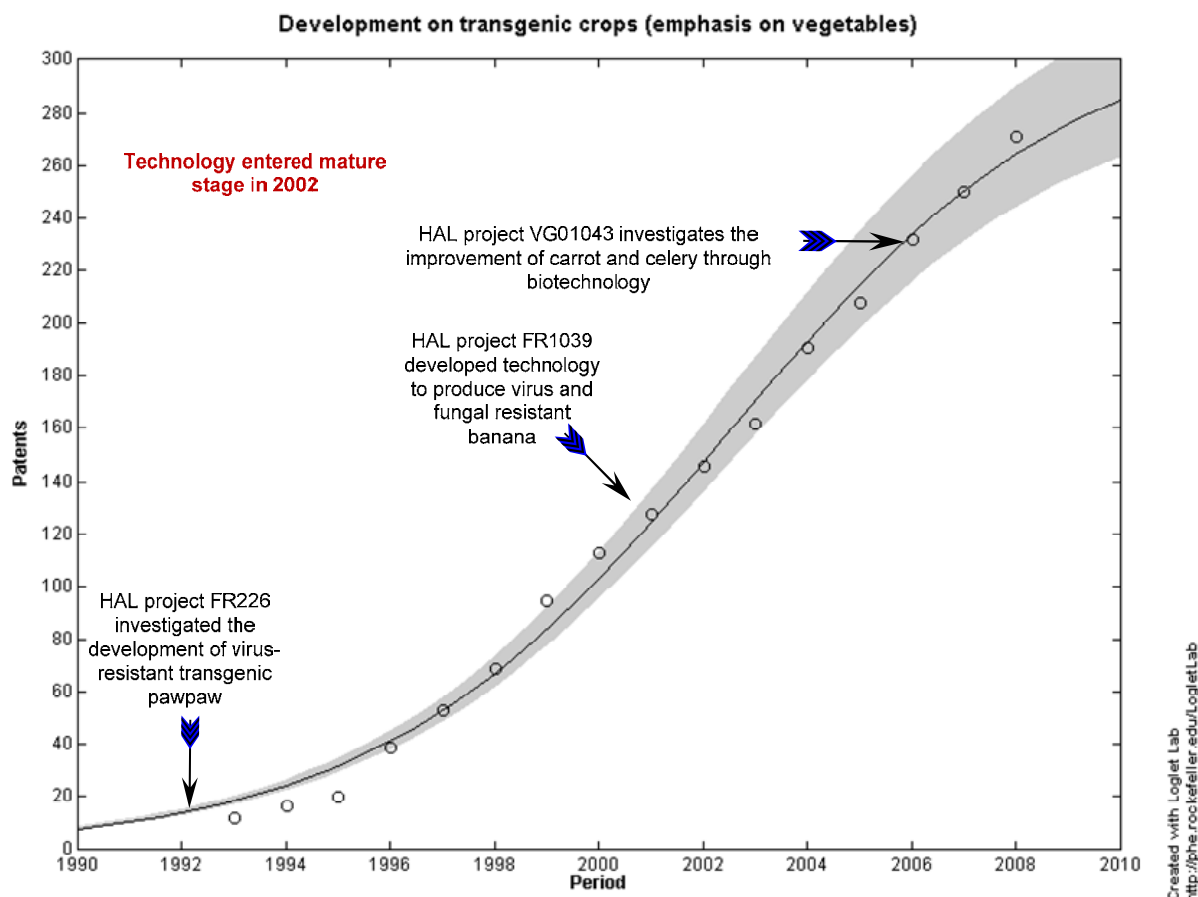


Figure 29. Growth curve of patented transgenic technologies with application to vegetables worldwide (1989-2008). Some HAL milestones in the area are shown as a reference.

Between 2006 and 2008, over 3,800 field trials for plant varieties were conducted by private firms or research institutes in Australia, Canada, the European Union, Japan, Mexico, New Zealand, Switzerland and the United States combined. The trials focused on herbicide tolerance (27% of the total trait trials), agronomic traits (24%), pest resistance (17.3%) and product quality (12.9%) [101].

In the period 2006-2008, agronomic and product quality traits trials accounted for 37.5% and 21.9% of the total GM field trials for specific traits (i.e. 32) in Australia. About 56% of these were conducted by the private sector [101].

Key players in the development of GM crops are Seminis Seeds and its parent company Monsanto (Figure 30). While these companies do not have a head office in Australia, they have been involved in some Australian horticultural GM trials (Table 8).

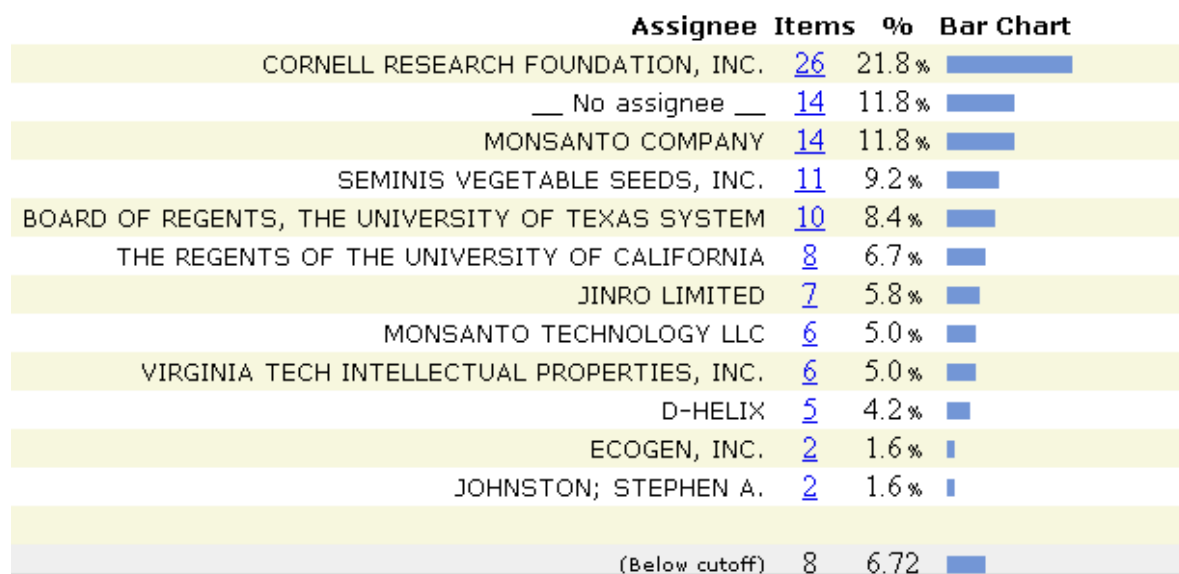


Figure 30. Companies/individuals with ownership of IP in transgenic horticulture crops.

*Cost benefit aspects*

A recent report on climate challenges for US agriculture concluded that using varieties with improved tolerance to heat or drought or that are adapted to take advantage of a longer growing season is a measure that can be successful for some crops. However, it is less likely to be cost-effective for perennial crops, for which changing varieties is extremely expensive and new plantings take several years to reach maximum productivity [97].

Even for annual crops, changing varieties is not always a low-cost option. Planting stress-tolerant varieties often requires new farming equipment or a wide range of adjustments. In some cases, it is difficult to breed for genetic tolerance to elevated temperature or to identify an alternative variety that is adapted to the new climate and to local soils, practices, and market demands.

This adds to other significant challenges faced by transgenic crops in horticulture, including [102]:

- Lack of economies of scale due to the diversity of specialty crops and the variety of target traits in specialty crops research.
- Each specialty crop occupies a relatively small market niche, compared to the vast acreage of commodity crops. Just one specialty crop, such as apples, may have dozens of diverse varieties, increasing research and development costs.
- Traits that modify physiology in some way and that may be especially appealing for specialty crop producers tend to be more complex than the simple gene-phenotype relationship of herbicide tolerance or pest resistance engineered into commodity crops.
- In the US, the Food and Drug Administration requires that each new GM plant line or event in the same crop go through the regulatory system. In Australia and New Zealand, FSANZ takes a similar position.

- The greatest hurdle for GM in Australia is the fact that federal states have control over whether and where GM organisms may be used. Therefore, despite approvals for other GM plants given by the National Office of the Gene Technology Regulator (OGTR), genetically modified cotton and carnations remain the only commercial GM plants grown of Australia at this time. Furthermore, they are confined to specific regions<sup>61</sup>. Just recently, SA, WA and Tasmania confirmed their moratoria to GM canola crops. NSW and VIC are the only states pursuing GM canola trials<sup>62</sup>.

Having said this, the financial rewards from the commercialization of GMs can be significant, as illustrated by the results of the second decade of biotechnology-derived crops in the US.

*Table 8. Some advances in the development of climate change resistant vegetables through biotechnology. Sources: [103]*

DEVELOPMENT	INSTITUTION/COMPANY	WEBSITE
Tomatoes and Chinese cabbage with adaptation to hot & humid environments and low-input cropping systems.	The World Vegetable Center	<a href="http://www.avrdc.org/">http://www.avrdc.org/</a>
Tolerant tomato germplasm.	The Tomato Genetics Resource Center (TGRC) at the University of California, Davis	<a href="http://tgrc.ucdavis.edu/">http://tgrc.ucdavis.edu/</a>
Environmental stress tolerance in tomato to enhance performance under soil water deficit.	Department of Plant Science, College of Agriculture and Natural Resources, University of Connecticut.	<a href="http://plantscience.uconn.edu/">http://plantscience.uconn.edu/</a>
IR, VR bell pepper (India, USA).	Seminis Vegetable Seeds (Monsanto)	<a href="http://www.geaction.org/truefood/crop/pipeline_rdveg.html">http://www.geaction.org/truefood/crop/pipeline_rdveg.html</a>
HT,VR cabbage (India, The Netherlands, Finland, USA)	Seminis Vegetable Seeds (Monsanto), Aventis (Proagro/Plant Genetic Systems), American Takii, Cornell University	<a href="http://www.geaction.org/truefood/crop/pipeline_rdveg.html">http://www.geaction.org/truefood/crop/pipeline_rdveg.html</a>
VR Cassava (Africa)	Monsanto	<a href="http://www.monsanto.com/pdf/pubs/2007/pledge_report.pdf">http://www.monsanto.com/pdf/pubs/2007/pledge_report.pdf</a>
HT (glyphosate), IR, VR, FR lettuce (Italy, France, Australia, Japan, USA)	Seminis Vegetable Seeds (Monsanto), Exelixis (Agritope), Harris Moran (Limagrain), Queensland Department of Primary Industries, University of Florida, others.	<a href="http://www.geaction.org/truefood/crop/pipeline_rdveg.html">http://www.geaction.org/truefood/crop/pipeline_rdveg.html</a>

Codes: HT =Herbicide Tolerance; IR =Insect Resistance; VR =Virus Resistance; BR=Bacterial resistance; FR =Fungal Resistance; PQ =Product Quality.

In 2006, the US planted acreage concentrated in herbicide-resistant alfalfa, canola, corn, cotton, and soybean; virus-resistant squash and papaya; three applications of insect-

<sup>61</sup> [http://www.gmo-compass.org/eng/news/stories/285.gm\\_crops\\_australia\\_will\\_moratoria\\_end.html](http://www.gmo-compass.org/eng/news/stories/285.gm_crops_australia_will_moratoria_end.html)

<sup>62</sup> [http://www.ausgrain.com.au/Back%20Issues/186magrn09/10\\_Adviser's.pdf](http://www.ausgrain.com.au/Back%20Issues/186magrn09/10_Adviser's.pdf)

resistant corn; two applications of insect-resistant cotton; and insect-resistant sweet corn. Compared to 2005, planted acreage in biotechnology-derived crops increased 12.7 % [104].

This relatively modest increase led to an improved crop production of 3.5 million tonnes, production savings of approximately US\$1.9 billion and reduced pesticide use in 50 million tonnes. Increased revenue from higher yields and reduced production costs improved net returns to growers by US\$2.6 billion with respect to 2005. To put these numbers in perspective, net farm income for US agriculture was \$69.8 billion in 2007.

However, most of the economic benefits above were derived from the non-horticultural crops. Biotechnology has had limited commercial success to date in fruits, vegetables, flowers and landscape plants. While sweet corn, potato, squash and papaya varieties engineered to resist insects and viruses have been approved for commercial use and marketed, only papaya transgenic varieties have achieved a significant market share (about 70% of the Hawaiian crop shipped to the continental United States is transgenic) [105].

In Australia, a recent report [106] investigated the benefits of GM technologies in the productivity of broadacre crops including cotton, canola, soybeans, maize, wheat and rice. The study found that the cumulative benefits of adopting all five prospective GM crops over 2008-09 to 2017-18 would be \$174 million in Queensland, \$551 million in the Murray Catchment Management Area, \$1.1 billion in Victoria, \$1.4 billion in South Australia, \$2.4 billion in Western Australia and \$2.9 billion in the Rest of New South Wales (all in 2006-07 dollars). To this author's knowledge, no similar studies have been undertaken for GM in horticulture crops.

Adoption costs associated with the use of biotechnology encompass royalty technology fees and/or seed premiums. For example, average costs of conventional and biotechnology-derived virus-resistant squash varieties in 2006 were US\$406 and US\$254 for 10,000 seeds per acre, respectively. Adoption costs were US\$152 per acre (or US\$61.53/ha).

## Implications and Recommendations

The trends of HAL-funded projects in environmental technologies suggest that the peak investment in this area will occur in 2012 and that most projects have focused on the management of chemicals and fertilisers.

Figure 31 shows that the number of project related to environmental aspects developed in HAL is higher than the number of projects developed under the "Supply Chain and Logistics" platform analysed in the previous report.

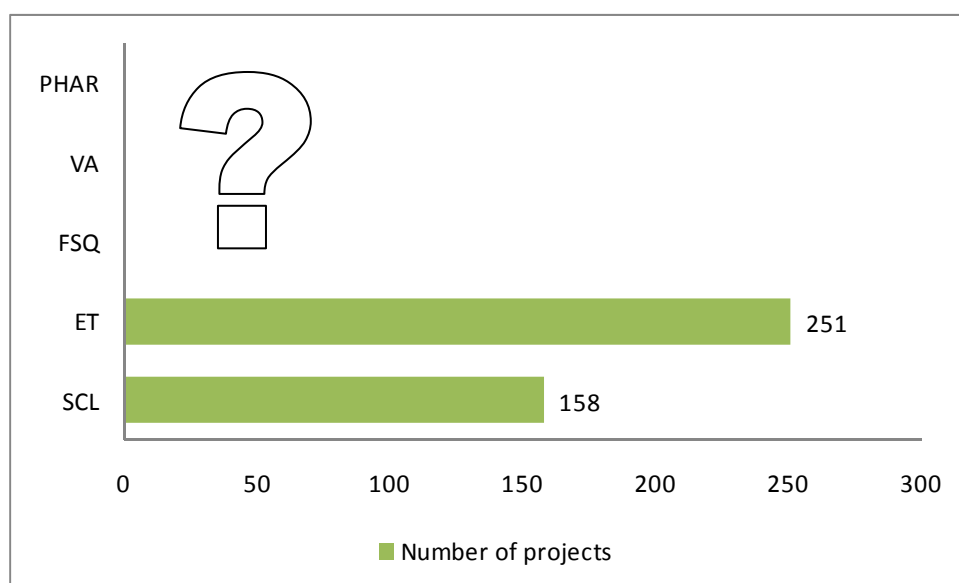


Figure 31. Comparison of projects developed in the five emerging technology areas investigated in project VG08087. Codes: SCL= supply chain & logistics; ET= environmental technologies; FSQ= food quality & safety; VA= value addition; PHAR= production and harvesting.

There may be external factors that influence current investment policies on environmental projects related to mitigation and adaptation. This section provides some 'food for thought' in the areas that are impacting the profitability of vegetable growing operations and some key areas of future technological development.

### Summary of technologies and recommendations for future R&D funding

Table 9 summarises the analyses performed for five categories discussed. From this table, the following observations can be drawn:

- Biofuels, glasshouse energy technologies and smart irrigation are technologies in a growth stage, where there is still technological uncertainty and R&D costs are not well



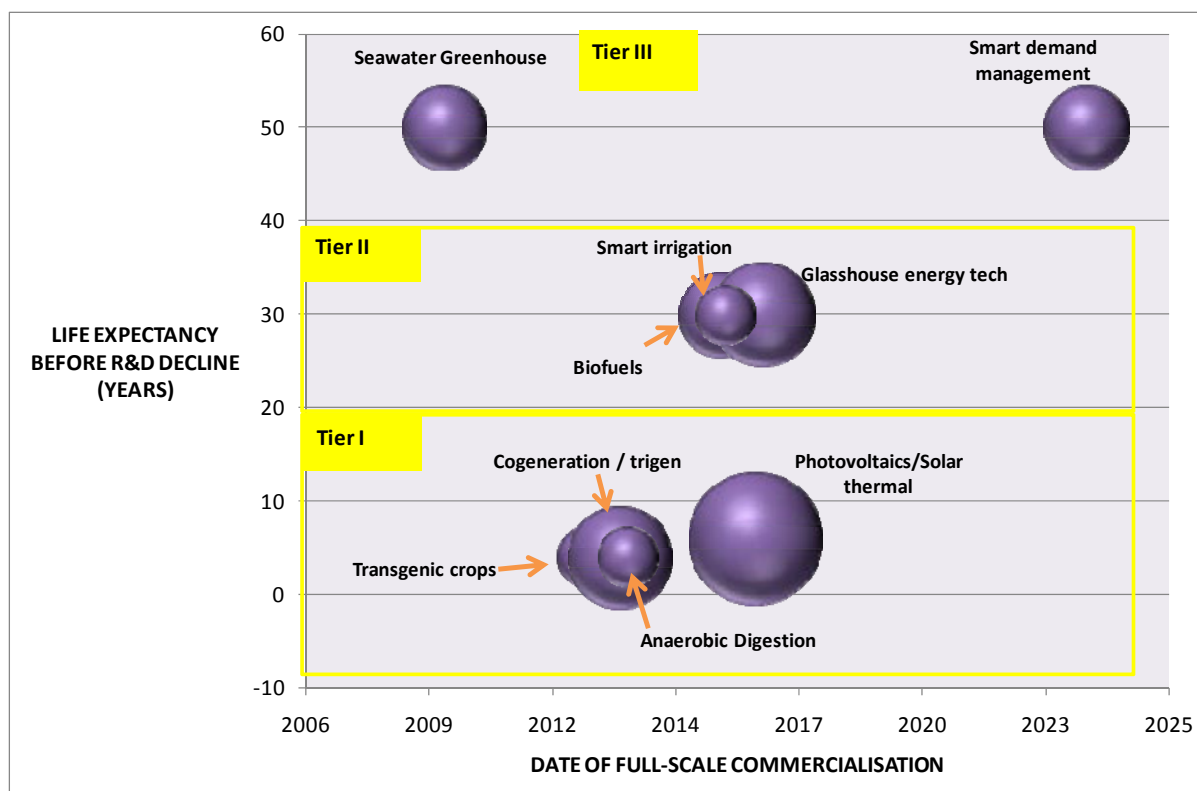
defined yet. Other technologies such as the Seawater Greenhouse and smart demand management in cold stores are still in embryonic stage. However, current pressures to mitigate and adapt to climate change and the quantum of savings in some of these areas may require HAL to evaluate investment on early-stage technologies to shorten the research and development cycle. While the time frame to enter embryonic and growth areas is 30 years or more, the decision on the inclusion of agriculture in the projected ETS is only 4 years away.

- Excepting the technologies above where basic knowledge and designs are still being developed, investment in all other areas should emphasize demonstrations applicable to the horticultural industry and commercial improvements.
- In available Government and industry reports discussing strategies for the development of smart irrigation, anaerobic digestion, biotechnology, biochar application and biofuels, horticulture as a recipient of these strategies is hardly mentioned. The fact that horticulture is considered a low emitter can benefit growers in regards to avoiding inclusion of this sector in a future ETS. However, it places horticulture in a disadvantage with respect to investment for innovation in climate related technologies. The Government's attention seems to be on larger emitters, such as broadacre crops and livestock.
- The disadvantage mentioned above will become even more evident when other larger emitters in horticultural supply chains (e.g. packaging, transport, retail) transfer the costs of mitigation and adaptation to growers, instead of passing these costs to consumers. Given the perception of horticulture as a low emitter, it will be difficult to justify measures that lessen the impact of these ETS-derived costs.
- Biotechnology for adaptation of horticultural varieties is a contentious issue and there are major impediments to the commercialization of this technology in Australia, including development costs and political aspects. However, the US and countries in Asia are already using transgenic crops. Australia is in danger of losing both domestic and international markets to these countries. Moreover, the use of transgenic crops should be evaluated from the perspective of ensuring food security under adverse climate conditions. In preparation to more favourable political conditions for the introduction of genetically modified crops as an adaptation strategy, evaluations of the environmental effects of transgenic plants and their benefits in improving yields, aiding soil and water conservation and increasing the resilience of Australian vegetable chains needs to be undertaken.

The bubble chart in Figure 32 places some context of the life expectancy and expected commercialization window for the technologies analysed in this report. The size of the bubble indicates the level of adoption.

TABLE 9. Summary of the status of emerging technologies selected as examples on five environmental technology areas.

CATEGORY	EMERGING TECHNOLOGY	STAGE OF TECHNOLOGICAL DEVELOPMENT	PREDICTABILITY		LIFE CYCLE (Benchmark: 2009)		INVESTMENT	HAS HAL INVESTED ON THIS AREA?	LEVEL OF ADOPTION
			Technical	R&D costs	Time to commercialization	Time to R&D decline			
ENERGY GENERATION	Biofuels	GROWTH	FAIR	HIGH	2-7 years	30 years	2,150 A\$/kW	NO	MEDIUM
	Anaerobic Digestion	MATURE	HIGH	HIGH	1-4 years	3-4 years	UNKNOWN	NO	Centralised: MEDIUM-HIGH/ Distributed: LOW
	Cogeneration/Trigeneration	Large systems: MATURE	HIGH	MODERATE	1-4 years	3-4 years	1,350 - 3,125 A\$/kW	NO	MEDIUM
	Photovoltaics/Solar thermal	MATURE	HIGH	HIGH	Depends on Government's policy (2-7 years)	6 years	UNKNOWN (retail level)	NO	MEDIUM
Energy use	Glasshouse energy technologies	GROWTH	FAIR	HIGH	2-7 years	Over 30 years	Seawater greenhouse: \$55.50-\$61.50/sq m	NO	LOW-MEDIUM
	Smart demand management	EMBRYONIC	POOR	POOR	7-15 years	Unknown	\$22,000 per cold store	NO	LOW
Water generation	Seawater Greenhouse	EMBRYONIC	POOR	POOR	Under way	Unknown	Seawater greenhouse: \$55.50-\$61.50/sq m	YES	LOW
Water use	Smart irrigation	GROWTH	FAIR	HIGH	2-7 years	30 years	\$200 million for all the MD Basin	YES	LOW-MEDIUM
Biotechnology for adaptation	Transgenic crops	MATURE	HIGH	HIGH	1-4 years	3-4 years	Squash: \$61.53/ha	YES	MEDIUM



*FIGURE 32. Bubble chart identifying a three-tiered strategy for HAL investment in environmental projects: (a) Tier I- technologies that are currently being commercialized and R&D decline expected in the next 10-20 years; (b) Tier II- technologies that are expected to be fully commercialized in the next 5-10 years and R&D decline expected in the next 40 years; and (c) Tier III- technologies that are expected to be fully commercialized in the next 10-15 years and R&D decline expected in the next 40-70 years.*

Figure 32 suggests a three-tiered strategy for HAL funding in mitigation and adaptation technologies:

- Tier I encompasses technologies that are currently being commercialized and with an expected R&D decline in the next 10-20 years. This tier includes transgenic crops, CHP/CCHP, anaerobic digestion and photovoltaics/solar thermal energy. These technologies are mature, have well defined R&D predictability profiles and the investment levels are also highly predictable. Projects developed for this tier could include state-of-the-art and benchmarking projects. For example, analysis of financial and carbon reduction opportunities, solutions for specific uses in horticulture (e.g. alternative energy for water pumping, small CHP for cooling and heating for primary production, AD for reusing vegetable waste and composting) and pilot trials to test these concepts.
- Tier II encompasses technologies that are expected to be fully commercialized in the next 5-10 years and R&D decline expected in the next 40 years. This tier includes smart irrigation, production/use of biofuels for primary production machinery (e.g. forklifts, tractors) and glasshouse energy technology. Projects funded on this tier should include well-developed business cases specifically prepared for horticulture.

There is a scarcity of reports that present clear cost-benefit cases for the industry. Surveys to assess the size of the glasshouse industry and the calculation of environmental impacts through energy surveys in these operations are much needed.

- Tier III encompasses technologies that have beyond 40 years for full R&D development. This category encompasses “blue sky” research and truly innovative solutions to pressing issues such as water generation and utilization of electricity grid information. Funding for this tier should be focused on accelerating the research and development cycle of these technologies.

For the technologies close to full commercialization, there is an expectation that service providers collaborate to develop case studies in the horticultural industry as part of their marketing effort. However, horticulture is perceived as a small market compared to broadacre crops, livestock industries and other sectors. Only providers specialized in the sector will be willing to invest in horticultural cases.

Benchmarking projects that establish metrics and measure the environmental performance of horticultural enterprises would be highly desirable. Benchmarking studies should encompass data from small, medium and large Australia operations that allow further targeting of technologies on the basis of capital and operational costs and other parameters.

A closing remark: a recently published case study from the UK found that imported products from Spain and New Zealand could be more environmentally-friendly than the same food produced in the UK. The study compared factors such as energy use, global warming potential, pesticides use and land requirement of seven foods, including potatoes, beef, lamb and strawberries<sup>63</sup>.

The aforementioned study challenges the concept of local food chains as being more environmentally friendly than imports. More importantly, it raises questions as to how local supply chains in Australia compare with imports. Australian horticultural chains can only stand up to scrutiny in the environmental area if technologies that reduce and prepare the industry for climate change are investigated and adopted in a proactive manner.

## Acknowledgements

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<sup>63</sup> <http://www.apal.org.au/assets/content/3621/APWN%20Vol12%2027.pdf>

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# Appendix 1. Energy saving measures in the cold chain of vegetables

**Table A1. Summary of electricity saving strategies for cold chain operations of fruits and vegetables.**

Sector	Focus of electricity saving strategies	Temperature-related heuristics for quality preservation
Primary production- Precooling of fruits and vegetables	<ul style="list-style-type: none"> <li>• Matching of compressor capacity with refrigeration load (in air forced cooling)</li> <li>• Decreasing evaporator capacity towards the end of precooling.</li> </ul>	<p>The objective in this operation is to achieve cooling as fast as possible. Any strategy that leads to slow cooling will have detrimental effects on the quality of the product.</p> <p>Wide optimum storage temperature variations exist between commodities. Optimum temperatures are commodity-dependant and temperature variations above or below the recommended temperature will have a significant impact on quality. Therefore, the use of peak load shifting/sub-cooling should be carefully assessed in laboratory and pilot trials.</p>
Freezing processes in secondary processing	<p>In continuous freezers:</p> <ul style="list-style-type: none"> <li>• Intelligent matching of freezing capacity and freezing loads</li> <li>• Adaptive defrost</li> </ul> <p>In batch freezers:</p> <ul style="list-style-type: none"> <li>• Peak avoidance techniques</li> <li>• Turning off freezer during weekends, if not in use.</li> </ul>	<p>The objective in this operation is to achieve freezing as fast as possible. Any strategy that leads to slow freezing will have detrimental effects on the quality of the product.</p>
Chilling processes in secondary processing	As per precooling.	As per precooling.

**Table A2. Summary of electricity saving strategies for refrigerated storage**

Sector	Focus of electricity saving strategies	Temperature-related heuristics for quality preservation
Refrigerated storage sector	<p><u>In frozen products:</u></p> <ul style="list-style-type: none"> <li>• Peak avoidance techniques</li> <li>• Sub-cooling of the warehouse during weekends</li> <li>• Intelligent matching of load (variable and fixed compressor’s capacity)</li> <li>• Adaptive defrost</li> </ul> <p><u>In chilled products (dedicated storage):</u></p> <ul style="list-style-type: none"> <li>• Peak avoidance techniques (see heuristics)</li> <li>• Intelligent matching of loads</li> </ul> <p><u>In CA storage:</u></p> <ul style="list-style-type: none"> <li>• Increasing evaporation temperature above the recommended storage temperature is a possibility (see heuristics)</li> </ul>	<p><u>In frozen products:</u></p> <ul style="list-style-type: none"> <li>• Peak avoidance and sub-cooling techniques should maintain product temperatures within -18 and -25 °C</li> </ul> <p><u>In chilled products:</u></p> <ul style="list-style-type: none"> <li>• Sub-cooling to temperatures below 0 °C is not recommended for horticultural products (or others susceptible to freezing damage)</li> <li>• Sub-cooling to -2 °C can be well tolerated by some dairy products (e.g. milk, butter, cheddar cheese)</li> <li>• In CA storage, tolerance of commodities to temperatures above the recommended storage temperature needs to be investigated experimentally. No temperature tolerance guidelines have been fully established for CA storage.</li> </ul>

# Appendix 2. Examples of patented technical inventions for adaptation and mitigation

## Glasshouse —energy management

Publication	Similarity	Title
<a href="#">US07343341</a>	16%	Systems and methods for trading emission reductions
<a href="#">US07440871</a>	14%	Method and system for tracking and reporting emissions
<a href="#">US27260405A1</a>	14%	METHOD AND SYSTEM FOR TRACKING AND REPORTING EMISSIONS
<a href="#">US29018884A1</a>	14%	METHOD AND SYSTEM FOR TRACKING AND REPORTING EMISSIONS
<a href="#">WO2008103512A1</a>	14%	APPARATUS AND METHOD FOR COLLECTING AN ATMOSPHERIC GAS
<a href="#">US06904336</a>	13%	System and method for residential emissions trading
<a href="#">US07133750</a>	13%	System and method for residential emissions trading
<a href="#">US07415418</a>	13%	Method and apparatus for generating standardized environmental benefit credits
<a href="#">US29070040A1</a>	12%	Sustainability Systems and Methods Directed to Food Compositions
<a href="#">WO2009033020A2</a>	12%	SUSTAINABILITY SYSTEMS AND METHODS DIRECTED TO FOOD COMPOSITIONS
<a href="#">WO2008112893A1</a>	12%	METHOD TO IMPROVE THE EFFICIENCY OF REMOVAL OF LIQUID WATER FROM SOLID BULK FUEL MATERIALS
<a href="#">US07457758</a>	12%	Method and apparatus for generating standardized carbon emission reduction credits
<a href="#">US07451839</a>	12%	System and method for powering a vehicle using radio frequency generators
<a href="#">WO2008100659A2</a>	12%	RELIABLE CARBON-NEUTRAL POWER GENERATION SYSTEM
<a href="#">WO2008100659A3</a>	12%	RELIABLE CARBON-NEUTRAL POWER GENERATION SYSTEM
<a href="#">US06890497</a>	12%	Method for extracting and sequestering carbon dioxide
<a href="#">US07208007</a>	12%	System and method utilizing guided fluorescence for high intensity applications
<a href="#">US05300226</a>	11%	Waste handling method
<a href="#">EP00969713A1</a>	11%	INTEGRATED SYSTEM FOR ENERGY SUPPLY AND ENERGY USE IN GREENHOUSE HORTICULTURE
<a href="#">WO2008099252A1</a>	11%	CONVERSION OF CO2 CAPTURED FROM COMBUSTION SYSTEMS OR OTHER INDUSTRIAL PROCESSES INTO METHANE THROUGH ANAEROBIC DIGESTION COMBINED WITH BIOMASSES
<a href="#">US07282189</a>	11%	Production of hydrogen and removal and sequestration of carbon dioxide from coal-fired furnaces and boilers
<a href="#">US07426489</a>	11%	Method and system for banking and exchanging emission reduction credits
<a href="#">US04077158</a>	11%	Agricultural greenhousing reconciling intensified urban methods
<a href="#">US06620689</a>	11%	Method and apparatus for generating pollution free electrical energy from hydrocarbons
<a href="#">US06056919</a>	11%	Method of sequestering carbon dioxide
<a href="#">US05439054</a>	10%	Method for treating a mixture of gaseous fluids within a solid carbonaceous subterranean formation
<a href="#">US05566756</a>	10%	Method for recovering methane from a solid carbonaceous subterranean formation
<a href="#">US06668677</a>	10%	Combined fuel cell and fuel combustion power generation systems
<a href="#">JP28043314A2</a>	10%	METHOD FOR INCREASING YIELD OF PLANT AS ENERGY RESOURCE
<a href="#">WO00193972A1</a>	10%	APPARATUS FOR DISTILLING WATER USING SOLAR ENERGY AND METHOD FOR USE THEREOF
<a href="#">US06855241</a>	10%	Process and apparatus for smelting aluminum
<a href="#">WO09838849A1</a>	10%	INTEGRATED SYSTEM FOR ENERGY SUPPLY AND ENERGY USE IN GREENHOUSE HORTICULTURE
<a href="#">US29014170A1</a>	10%	SYSTEMS FOR EXTRACTING FLUIDS FROM THE EARTH'S SUBSURFACE AND FOR GENERATING ELECTRICITY WITHOUT GREENHOUSE GAS EMISSIONS
<a href="#">CN01872989A</a>	10%	Method for heating firedamp gas of solar energy
<a href="#">US07396972</a>	10%	Methanol feed for producing olefin streams
<a href="#">US29127861A1</a>	10%	Fluid-dynamic renewable energy harvesting system
<a href="#">US07528272</a>	10%	Biodiesel process
<a href="#">WO2007026187A1</a>	10%	ENERGY SAVER

Publication	Similarity	Title
<a href="#">WO04020922A1</a>	20%	DEVICE FOR DRYING PRODUCTS SUCH AS IN PARTICULAR PURIFYING STATION SLUDGE
<a href="#">US25241174A1</a>	20%	Device for drying products such as in particular purifying station sludge
<a href="#">WO04020921A1</a>	19%	INSTALLATION FOR DRYING WASTE, IN PARTICULAR WASTEWATER PURIFYING SLUDGE
<a href="#">US25246919A1</a>	18%	Installation for drying waste, in particular wastewater purifying sludge
<a href="#">US07240440</a>	14%	Installation for drying waste, in particular wastewater purifying sludge
<a href="#">US04069593</a>	14%	Solar curing and drying structure and method of utilizing solar energy associated with available solar radiation in curing and drying various materials
<a href="#">MX05004781A</a>	14%	LIGHT TRANSFORMING MATERIAL COMPRISING AS ADDITIVE A BARIUM AND MAGNESIUM SILICATE.
<a href="#">WO04044090A1</a>	14%	LIGHT TRANSFORMING MATERIAL COMPRISING AS ADDITIVE A BARIUM AND MAGNESIUM SILICATE
<a href="#">WO09104228A1</a>	14%	PROCESS FOR THE PRODUCTION OF FRESH WATER USING WATER CONTAINING IMPURITIES AND INSTALLATION FOR ITS IMPLEMENTATION
<a href="#">US26168905A1</a>	13%	Light-converting material comprising a barium magnesium silicate as additive
<a href="#">US04184479</a>	13%	Greenhouse with stored solar energy capability
<a href="#">US04109395</a>	13%	Greenhouse, drying, storing nursery system
<a href="#">WO2008098265A1</a>	13%	COVER FOR GREENHOUSES, AND GREENHOUSE HAVING SUCH A COVER
<a href="#">US04184477</a>	13%	Solar heating and storage
<a href="#">US07181865</a>	12%	Device for drying products such as in particular purifying station sludge
<a href="#">US05316626</a>	12%	Process and apparatus for the production of fresh water using solar energy
<a href="#">US04018213</a>	12%	Solar heating structure
<a href="#">US04170261</a>	12%	Heat storage device
<a href="#">US04173212</a>	12%	Self-contained solar greenhouse
<a href="#">EP01808067A1</a>	12%	System for energy management in a greenhouse
<a href="#">MX05002342A</a>	11%	DEVICE FOR DRYING PRODUCTS SUCH AS IN PARTICULAR PURIFYING STATION SLUDGE.
<a href="#">US07536834</a>	11%	Light-converting material comprising a barium magnesium silicate as additive
<a href="#">WO09732466A1</a>	11%	GREENHOUSE
<a href="#">US27062105A1</a>	11%	Suntrap self-regulating solar greenhouse
<a href="#">US04383891</a>	11%	Device for desalting brackish water, and a conditioning method and device relating to said desalting device
<a href="#">WO05119014A1</a>	11%	REMOTE-HEATING PLANT FOR URBAN, CIVIL, INDUSTRIAL AND AGRICULTURAL APPLICATIONS
<a href="#">US27044494A1</a>	10%	Super Energy Saver Heat Pump with Dynamic Hybrid Phase Change Material
<a href="#">US04195441</a>	10%	Solar greenhouse
<a href="#">NL01033213C1</a>	10%	Greenhouse energy management system includes series of mirrors activated by sensors to intercept sun radiation being captured and stored as electricity by organic ranking module (ORC)

## Photovoltaics/solar energy for agricultural purposes

Publication	Similarity	Title
<a href="#">CN21203335Y</a>	31%	Series-parallel connection type solar multifunctional garden stuff drying apparatus
<a href="#">CN21014892Y</a>	31%	Greenhouse type agricultural product solar drying facilities
<a href="#">CN02911533Y</a>	29%	Forced ventilating solar supplying unit utilizing light heat, photovoltage and wind electricity
<a href="#">CN11144683A</a>	29%	Solar energy hot air current heated dried material produced by power-free style
<a href="#">CN02308852Y</a>	28%	Full glass vacuum tubes solar energy collector
<a href="#">CN21011158Y</a>	27%	Heat collecting type raisin making and airing house
<a href="#">CN02266111Y</a>	27%	solar dryer
<a href="#">CN02340931Y</a>	26%	Temperature difference energy device and pneumatic power apparatus thereof
<a href="#">CN11086423A</a>	26%	Additional energy drying device of solar energy drying apparatus
<a href="#">CN02760944Y</a>	26%	Solar ventilating device
<a href="#">CN21032773Y</a>	26%	Edible mushroom cultivation chamber
<a href="#">CN21051810Y</a>	25%	High performance day-light greenhouse
<a href="#">CN01776336A</a>	25%	Two-way ventilating humidity-regulating drying method and clevice

Publication	Similarity	Title
<a href="#">CN02482792Y</a>	31%	Multi-functional green house covered with plastic film
<a href="#">CN02689675Y</a>	29%	Multi function flower pot
<a href="#">CN02616055Y</a>	29%	Solar insect expelling device
<a href="#">RU02253211C1</a>	28%	BIOENERGETIC APPARATUS
<a href="#">CN11410317A</a>	27%	Ruralarea energy supply system
<a href="#">RU02284967C1</a>	27%	BIOENERGETIC INSTALLATION
<a href="#">CN01631823A</a>	26%	Controllable box type complete equipment for anaerobic fermentation and methane liquid treatment
<a href="#">CN11144581A</a>	26%	Lumination device for fruit cover bag production of solar energy photovoltaic generation system
<a href="#">CN11381118A</a>	25%	Irrigation installation by sea water desalination
<a href="#">CN11416615A</a>	23%	Pest trapper
<a href="#">CN11353620A</a>	22%	Solar greenhouse methane tank and methane production method thereof

Publication	Similarity	Title
<a href="#">CN20983802Y</a>	34%	Solar-energy photocatalyst biology plate for adhering insect
<a href="#">CN21131238Y</a>	33%	Solar energy photo-catalytic biologic sticky board
<a href="#">CN02826969Y</a>	27%	Solar energy greenhouse
<a href="#">CN21166505Y</a>	26%	Non-metal flat plate core heat collection type solar energy drying device
<a href="#">CN02489275Y</a>	25%	Salar heat-collecting, heat-storage, energy-storage plate
<a href="#">CN02777981Y</a>	25%	Self-powered photoelectricity-induced grasshopper trapping machine
<a href="#">CN21174920Y</a>	24%	Sunlight heating type cowhouse
<a href="#">CN02280881Y</a>	24%	Solar boiler
<a href="#">US07168207</a>	23%	Potato drip irrigation system and method
<a href="#">US07565767</a>	23%	Potato drip irrigation system
<a href="#">CN02223460Y</a>	23%	Solar energy water heating device
<a href="#">CN11291125A</a>	23%	Light, wind, electricity and hot gas multifunctional environment friendly electricity generator

## Cogeneration/trigeneration in farms

Publication	Similarity	Title
<a href="#">JP21321740A2</a>	53%	DRYING METHOD AND DRYING SYSTEM FOR FOOD WASTE
<a href="#">JP22326071A2</a>	53%	METHOD OF AND SYSTEM FOR RECYCLING CIRCULATING RESOURCE SUCH AS WASTE FOOD
<a href="#">JP29034569A2</a>	51%	FOOD WASTE, AND SYSTEM FOR RECOVERING ENERGY FROM SLUDGE
<a href="#">JP25210953A2</a>	49%	COGENERATION SYSTEM IN FISH FARMING EQUIPMENT
<a href="#">JP27020524A2</a>	46%	ENERGY SUPPLY SYSTEM FOR PLANT CULTIVATION GREEN HOUSE
<a href="#">US04622757</a>	45%	Cogeneration microwave food dryer

## Biofuel from vegetable biomass

<a href="#">WO2007089645A2</a>	BIODIESEL FUEL ADDITIVE	2007-08-09	2007-01-26	7:
<a href="#">US20060201056A1</a>	Biodiesel fuel additive	2006-09-14	2006-01-27	7:
<a href="#">US20050255345A1</a>	Biofuel cell	2005-11-17	2003-06-30	7:
<a href="#">WO04004036A2</a>	BIOFUEL CELL	2004-01-08	2003-06-30	7:
<a href="#">US20090081746A1</a>	BIOFUEL PRODUCTION BY RECOMBINANT MICROORGANISMS	2009-03-26	2008-02-08	7:
<a href="#">WO2008098227A2</a>	BIOFUEL PRODUCTION BY RECOMBINANT MICROORGANISMS	2008-08-14	2008-02-08	7:
<a href="#">WO2009035551A1</a>	BIOLOGICAL OILS AND PRODUCTION AND USES THEREOF	2009-03-19	2008-09-08	80
<a href="#">US20090064567A1</a>	Biological oils and production and uses Thereof	2009-03-12	2008-09-08	80
<a href="#">WO2009073557A2</a>	BIOLOGICAL SYSTEMS FOR PRODUCTION OF COMMERCIALY VALUABLE COMPOUNDS	2009-06-11	2008-11-26	7:
<a href="#">EP1728771A2</a>	Biomass - derived grinding aids	2006-12-06	2006-06-02	7:
<a href="#">US20070275446A1</a>	Biomass conversion performance using igneous phyllosilicate minerals with high emission of far-infrared light	2007-11-29	2006-05-23	80
<a href="#">US7135332</a>	Biomass heating system	2006-11-14	2002-07-08	7:
<a href="#">US20030024686A1</a>	Biomass heating system	2003-02-06	2002-07-08	7:
<a href="#">WO03006400A1</a>	BIOMASS HEATING SYSTEM	2003-01-23	2002-07-08	7:
<a href="#">US20070261996A1</a>	Biomass Thermal Oiling	2007-11-15	2005-08-05	7:
<a href="#">US20080028675A1</a>	Biomass treatment of organic waste materials in fuel production processes to increase energy efficiency	2008-02-07	2007-07-25	80
<a href="#">US7481940</a>	Biomass treatment of organic waste or water waste	2009-01-27	2006-08-18	7:
<a href="#">WO2008021558A2</a>	BIOMASS TREATMENT OF ORGANIC WASTE OR WATER WASTE	2008-02-21	2007-08-20	7:
<a href="#">US20080023397A1</a>	Biomass treatment of organic waste or water waste	2008-01-31	2006-08-18	7:
<a href="#">WO06132762A2</a>	BIOMASS-DERIVED GRINDING AIDS	2006-12-14	2006-05-15	7:
<a href="#">US20060272554A1</a>	Biomass-derived grinding aids	2006-12-07	2006-05-15	7:
<a href="#">US7226539</a>	Bionest reactor for the application of anaerobic wastewater treatment and bioenergy recovery	2007-06-05	2004-06-01	7:
<a href="#">WO05026052A2</a>	BIONEST REACTOR FOR THE APPLICATION OF ANAEROBIC WASTEWATER TREATMENT AND BIOENERGY RECOVERY	2005-03-24	2004-06-01	7:
<a href="#">US20050011829A1</a>	Bionest reactor for the application of anaerobic wastewater treatment and bioenergy recovery	2005-01-20	2004-06-01	7: