2xEP Doubling Australia's Energy Productivity

The Next Wave – Innovation to Double Energy Productivity by 2030

Version 2, February 2017

AUTHORSHIP OF THIS REPORT

This report is published by the Australian Alliance for Energy Productivity (A2EP). A2EP is an independent, not-for profit coalition of business, government and environmental leaders promoting a more energy productive economy.

The 2xEP program is an industry-led project to double energy productivity in Australia by 2030, supported by A2EP. 2xEP is guided by a Steering Committee of business leaders. An innovation working group, reporting to the committee (comprising 50 representatives of industry associations, researchers, companies and government agencies), provided significant input to the Next Wave. A2EP thanks members of the working group for their contributions.

The views expressed in this report are those of A2EP and do not necessarily represent the position of all individual working group members.

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In particular, the Board and staff of A2EP gratefully acknowledge the amazing contribution made by Alan Pears.

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Note: acknowledgement of this support does not indicate that these departments endorse the views expressed in this report.

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Note: Currently establishing Victorian presence at RMIT

Executive summary

NOTE: the executive summary consists of two documents that are published separately as stand-alone summaries of the two value chains explored in the Next Wave project. These documents can be found on the 2xEP website at http://www.2xep.org.au/innovation-next-wave.html

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1. Background on energy productivity

Energy productivity (EP) refers to the value created from using a unit of energy. The 2xEP target (doubling energy productivity by 2030 from a 2010 base) can be achieved either by doubling the value created from using the existing amount of energy, or halving energy use without increasing GDP – or more likely some intermediate position of achieving greater value with less energy use. It is important to understand that energy productivity innovation also has these two aspects as this project is looking at innovations that facilitate both improved value adding as well as reducing energy use, and ideally both benefits.

Productivity improvement is a key determinant of Australia's economic growth. For nearly two decades, economic productivity in many sectors of the Australian economy has been flat or declining. Until 2011, the deterioration in Australia's economic productivity had been masked to a great extent by high commodity prices. Australia needs to rapidly and substantially lift its performance on key productivity metrics across all economic sectors to maintain global competitiveness and national income growth. Focusing only on labour and capital productivity improvements is not sufficient. For example, in order to counter the effects of an ageing population and falling terms of trade, growth in labour productivity would need to increase to 2.7%/annum – almost double the rate of the past decade – just to *maintain* historical levels of growth in per capita income[1] . The productivity focus needs to be broadened to deliberately target the optimisation of other production inputs, such as energy, where potential productivity gains are not fully exploited at present.

Australia's national energy productivity, as measured by the ratio of real GDP to primary energy consumption, has improved at an average rate of 1.6 percent per year from 2000-01 to 2012-13[2]. Australian gains in energy productivity have been smaller than the increases in energy productivity made in many other developed economies[3] (Department of Industry, Innovation and Science, 2016), and other countries are accelerating their efforts in this area, while experiencing lower energy price increases. This spells increasing competitiveness challenges unless we rapidly and urgently address energy productivity.

Recognising the importance of energy productivity to the Australian economy, in December 2015 COAG, the Council of Australian Governments, established a target for improving energy productivity and a National Energy Productivity Plan. Initiatives to improve energy productivity will also be central to meeting Australia's international commitments to reduce carbon emissions.

The Australian Alliance for Energy Productivity - A2EP, (which recently changed its name from the Australian Alliance to Save Energy - A2SE), has been working for three years to progress an agenda for doubling Australia's energy productivity by 2030 from 2010 base. A2EP is developing roadmaps for doubling productivity in each end use sector of the Australian economy. Please see the http://www.2xEP.org.au website for more information on the sector roadmaps. These roadmaps

[1] Fraser, J. (2015, February). *Australia's Policy Challenges*. Address by Secretary of the Treasury to the Committee for Economic Development of Australia. Sydney

[2] Department of Industry and Science. (2015) *Energy White Paper 2015*. Canberra: Author. Retrieved from http://ewp.industry.gov.au/sites/prod.ewp/files/EnergyWhitePaper.pdf

[3] Department of Industry, Innovation and Science. (2016) *Industry Monitor 2016*. Canberra: Author. Retrieved from http://www.industry.gov.au/Office-of-the-Chief-Economist/Publications/IndustryMonitor/download/Industry-Monitor-May-2016.pdf

focus on what can be done with existing best practice commercial technology and how existing barriers to progress can be overcome.

The work done on the 2xEP sectoral roadmaps has identified likely gaps between the expected improvements in energy productivity and the 2xEP target by 2030. There is every expectation that these will be more than met through new technology development and deployment. So this work on the innovation roadmap is critical to provide clarity regarding the key new technology opportunities for energy productivity improvement by 2030.

To complement the sector roadmaps, A2EP launched a 'Next Wave' project to explore the opportunity to make further major improvements in energy productivity through the deployment of innovative technologies and business models in these energy end use sectors by 2030. Note that 'innovation' as covered by this report includes existing commercial technologies with less than 10% market penetration in Australia and energy solutions that are close to commercial, with prospects for growth.

Technology cost trends and market penetration

This Phase 1 report focuses on a scan of literature, preliminary analysis of relevant data, analysis of the fundamental energy requirements of processes and systems, and identification and discussion around emerging options that could contribute to a doubling of energy productivity by 2030.

The extent to which a given technology or business model may contribute within this timeframe will depend greatly on how, over time, its performance improves, its economics evolve relative to competing options, the level of support received, and a number of other factors that influence its potential market penetration within a competitive environment. These issues will be explored in the next stage of this work, subject to funding. Nevertheless, it is useful to provide some preliminary discussion of these issues here.

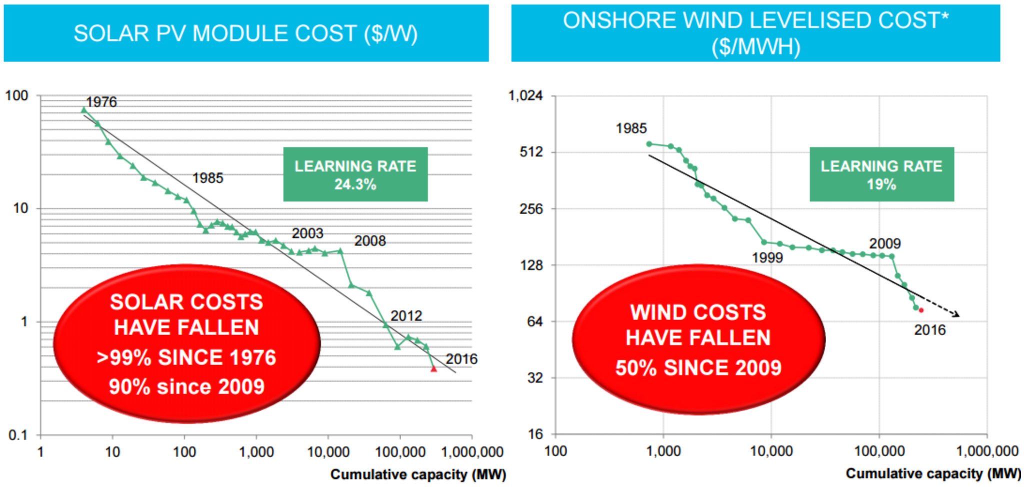
Technology cost trends

Cost is not the only factor influencing the rate of adoption of an innovation. But if we focus on this initially, we see that, for manufactured technologies, costs can decline over time for many reasons. One factor is the scale of production - a rule of thumb is that, for each doubling of cumulative production, unit cost declines by around 20%. Another is improvement of the technology e.g. with electronic goods, the impact of Moore's law still sees a fall of 10-30% annually in electronic goods.

Some recent examples of this include photovoltaic (PV) cells, wind generation, battery storage and LED lighting. Figure 1 below, from Michael Liebreich of Bloomberg New Energy Finance[4], shows the cost trends for PV (25% decline per doubling) and wind (19% decline per doubling) over several decades.

[4] http://www.theage.com.au/environment/climate-change/seven-energy-charts-that-will-cheer-and-frighten-about-australia-and-the-world-20161206-gt53fq.html

Figure 1.: PV and wind cost trends



Note: Prices are in real (2015) USD. 'Current price' is $0.4/W

Note: Pricing data has been inflation corrected to 2014. We assume the debt ratio of 70%, cost of debt (bps to LIBOR) of 175, cost of equity of 8%. *Data is for Northern Europe.

In practice, many factors drive such trends, and different ones are relevant at different points in the process. For example, funding support and subsidies (e.g. PV rebates) can be important. Where niche markets exist for early technologies, limited sales at premium prices can underpin ongoing development and market growth. Often these markets place high value on certain features, e.g. technologies for space travel must minimise weight and be very reliable; buyers of laptop computers value efficient screens and computing technologies, light weight and long battery life; wealthy people or early adopters may associate ownership with high status (e.g. a Tesla car or the latest Apple phone); or companies may buy them as part of a strategy to position the firm as 'innovative' or 'forward-looking'. Early LED lamps were expensive, but their long life made them useful for some applications.

Other factors

Changing market conditions, such as a rapid increase in grid-sourced electricity prices or due to social responses to climate change, can not only make alternatives more cost-effective, but can provoke dissatisfaction, reduce perceptions of risk relating to competing solutions, or shift investment towards RDD&C of emerging alternatives, as researchers and financiers look for alternatives.

While initially there can be many barriers to adoption, over time, and as demand grows, supply chains evolve to deliver the new solutions more cheaply and creatively. New packages of services may be assembled, or benefits recognised and valued. Support infrastructure evolves, making it easier to adopt and maintain products. Synergies are captured as improvements in materials and sub-components follow their own cost reduction curves. Consumers and the supply chain perceive less risk and may focus more on positive attributes as they become familiar with them. Up-front costs are reduced as financiers offer packages so they can profit from loaning money. In production, initial tooling-up costs are recovered, so costs fall. Economies of scale are captured. Value engineering reduces costs.

Some products are more likely to succeed than others. A relatively small tooling-up cost for initial production, capacity to utilise existing supply chains or capacity for direct delivery, access to high value niche markets as stepping stones, visible attractive features and functions, etc. can all help.

This complexity makes it very difficult to predict the likely trend in cost and rate of market adoption of emerging energy productivity improvement solutions.

This initial scan and preliminary analysis is an attempt to identify a variety of technologies, business models and systems that look likely to capture significant market shares, and offer potential to make significant contributions to the doubling of Australia's energy productivity by 2030. We have proposed assessment criteria, and have reviewed our 'priority measures' against them. But, due to limited funds and resources, and lack of quality data, we have not attempted to rank or score our selections.

We have proposed possible next steps based on the work to date. In the next phase of this work, among other things, we will look at the factors for each key technology/business model that could influence cost trends and acceptance, as well as examining past trends in costs of energy solutions.

2. Purpose and importance of the Next Wave project

The Next Wave project, as originally mapped out, sought to understand and catalyse technology/business model innovation to drive a doubling or better of energy productivity by 2030 by:

1. Building an energy productivity innovation inventory. This activity is covered in this report, and was supported by three State governments and the Commonwealth government. This report includes a scan of the literature and research identifying relevant opportunities.
2. Modelling the evolution of the economics of game-changing energy productivity innovations as they evolve technically, capture economies of scale and their value proposition becomes attractive relative to the incumbent technologies and models. The aim of this work is to define the likely penetration and their expected impact on EP of the emerging models by 2030. It will also seek to identify how to accelerate Australian energy productivity innovation by addressing barriers and managing risks to their implementation, and by capitalising on opportunities in niche markets. A2EP plans to recommend policy initiatives and pilot activities to accelerate uptake of energy productive technology and business models in Australia to ensure achievement of 2xEP or better by 2030. This work is subject to securing funding.
3. Feasibility analysis and pilot implementation, including: definition of the implementation steps for new technology/business models; stakeholder engagement to define the feasibility of implementation and the steps to delivery; measurement in trials; further analysis to better define the potential energy productivity benefits from use of the technology; and pilots to test the validity of assumptions and prove the benefits, economics and practical issues of deployment.

The Next Wave project is focused on opportunities for emerging technologies and new business models to substantially improve energy productivity beyond the impact of current best practices that have been implemented in Australia. This may include measures that are commercial, but have very low market penetration at present (less than 10%), as well as developments that are close to commercialisation and seem to offer benefits sufficient to support their commercialisation and adoption by 2030. This report does not cover activities that may be considered part of incremental change; are already achieving significant increases in adoption (and are covered by sector roadmaps); or are likely to be pursued for reasons other than energy productivity improvement.

The Next Wave project is critical at this juncture:

- To address uncertainty in government about planning issues and risks involved with technological transformation. There is still poor understanding of the likely impact of these new technologies, including the commercial impact on government owned assets, such as electricity infrastructure, as well as on planning.
- As input to the Commonwealth's 2017 climate policy review, which will need to come to an understanding of technologies that could improve energy productivity and cut emissions to 2030, and how to accelerate the deployment of these technologies.
- As the Prime Minister's Innovation Statement speaks to economic opportunities from innovation, and it needs to include an understanding of the opportunities for energy

productivity innovation and funding requirements. The Prime Minister's 'Mission Innovation' commitment to doubling clean energy research and development investment will need to be supported by information on energy productivity innovation, as will the government's commitment to the expansion of ARENA's mandate to include energy efficiency/productivity, providing it receives funding support from the Commonwealth.

- This work will contribute to redressing the historical imbalance between funding of innovation activity on the demand side and the energy supply side. Globally demand side innovation has been poorly funded relative to supply side action, yet authorities like the International Energy Agency and ClimateWorks Australia have concluded that demand side energy productivity measures will have to do a lot of the 'heavy lifting' if global carbon emission reduction targets are to be met at least cost.
- The Paris accord outcome will unleash a wave of innovation in energy productivity/low carbon technologies at rate and scale never seen before. It is vital Australia captures its share of these opportunities.

3. Scope of the Next Wave project

The Next Wave project covers:

- Improved technologies and processes to perform tasks/deliver services needed by customers, with higher energy productivity. This includes accelerated transfer of existing international best practices not currently utilised in Australia.
- Systems optimisation, including supply chain optimisation.
- Big data and the "internet of things" - innovations in ICT to better measure, control/ automate and optimise energy use.
- Game changing combinations of new technologies (1-3 above) and new business models that deliver required end use services in a different way, with a step change improvement in energy productivity.

The focus is on technologies and business models that can have an impact by 2030, with an emphasis on commercialisation and technology transfer.

The following lie OUTSIDE the scope of this project:

- Utility energy supply is not covered (including grid integration and energy supply chain productivity). On-site renewables and other energy generation are in scope.
- Using current commercial technology and practices unless there is less than 10% penetration in the Australian market in this specific application, and a slow rate of market uptake.
- Technologies in early stages of research. There has to be a high likelihood of the technology making a major impact by 2030. The exception may be technologies with substantial opportunity for energy productivity improvement, which utilise Australian intellectual property and are applied in industries where Australia has a competitive advantage.

Our approach recognises the biggest energy productivity benefits are often to be gained where the application of energy delivers significant value added benefits as well as saving energy.

4. Methodology

4.1. Basic principles

The Next Wave project team reviewed a range of potential approaches to identify the key energy productivity opportunities in the economy: a sectoral approach, a review by process, and a technology driven approach. We ultimately decided that the most effective systematic approach would be to address energy productivity opportunities based on analysis of value chains.

A value chain is the series of activities involved in delivering useful products and services, through transforming major raw inputs, with economic value being added at each step. It is important that we look at the value chain starting from the service needed by the end user, as we need to remember that all the upstream activity is only there to deliver a useful end service. The value chain can be likened to a much-simplified Life Cycle Analysis focused on energy and economic factors.

Energy productivity benefits can be maximised by starting with an examination of the end service required, and working back through the chain to the sources of raw inputs. This approach can provide an overview of the energy and material flows throughout the process of delivery of the end service. This offers insights into ways to optimise these flows, as well as new business models that may fundamentally alter the way the end service is achieved and the relationships between the elements of the value chain.

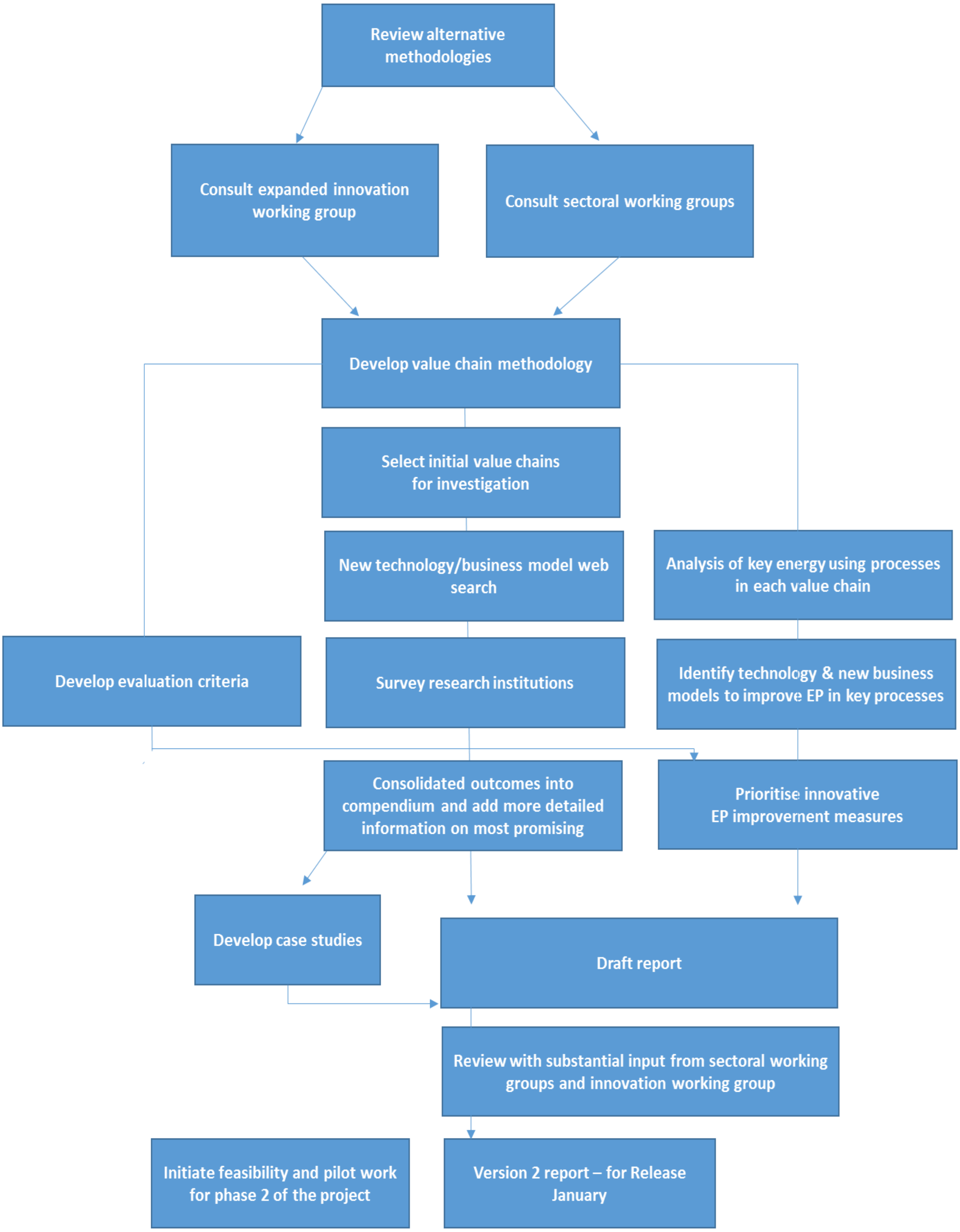
Steps in the Next Wave project methodology

1. Examine the overall value chain, starting from the user end:
    a. Determine which steps in the value chain have the greatest energy usage, losses and energy productivity opportunities.
    b. Examine opportunities to optimise the service delivery chain by integrating across the chain, focusing on common processes and end needs that touch on multiple steps of the chain e.g. in the food value chain these include preservation and extending shelf life; dewatering and drying; and utilisation of co-products and waste.
    c. Examine new business models that could disrupt the existing supply chain and deliver major energy productivity benefits.
2. Study in detail each of the large energy using blocks in the chain, and scan for innovative technologies. This includes process changes, energy saving technologies, and innovative investments designed to improve overall productivity through an energy focus.

Most innovation will be achieved by integrating combinations of technologies, e.g. ICT/sensors and smart controls with a reluctance motor/drive (or induction motor and VSD) driving a high efficiency pump or fan with low pressure drop filters, valves and pipes/ducts. Integration can also occur through combining low cost and reliable sensors and controls with cloud based computing, facilitating improved fault identification and preventive maintenance, monitoring and process optimisation. ICT also can facilitate optimisation along a supply chain and via the 'sharing economy'. Another example is integration of technologies such as on-site renewables, energy efficiency, demand management, batteries and thermal storage to capture synergies. There can be real innovation in these integrations even where each of the technology elements is well proven, and they can deliver major savings when optimally integrated. There is also a myriad of smaller step innovations in existing technologies that will make incremental savings over time. We do not explore these incremental improvements, but do note them.

The Next Wave project methodology is presented diagrammatically in the figure below.

Figure 2.: Next Wave project methodology



4.2. Value chains selected

The Next Wave project focuses on two value chains that are significant within the Australian economy. These include many activities that are also relevant to other sectors of the economy.

In this report, we use the term value chain in broad terms to include the supply chain and key elements of a lifecycle model. Our approach is not comprehensive, as that would be an enormous task. The approach is intended to focus attention on major areas of activity, and to support consideration of energy productivity measures that may cross sectoral boundaries, involve shifting activity from one sector or activity to another, integration of several EP measures, or other forms of innovation.

The two value chains considered in this report are:

- Food: Plate (or export) back to farm: core activities involved in food production, transport and processing.
- Shelter back to raw materials: this includes core activities involved in the production of materials to operation of buildings, with emphasis on the former and embodied energy.

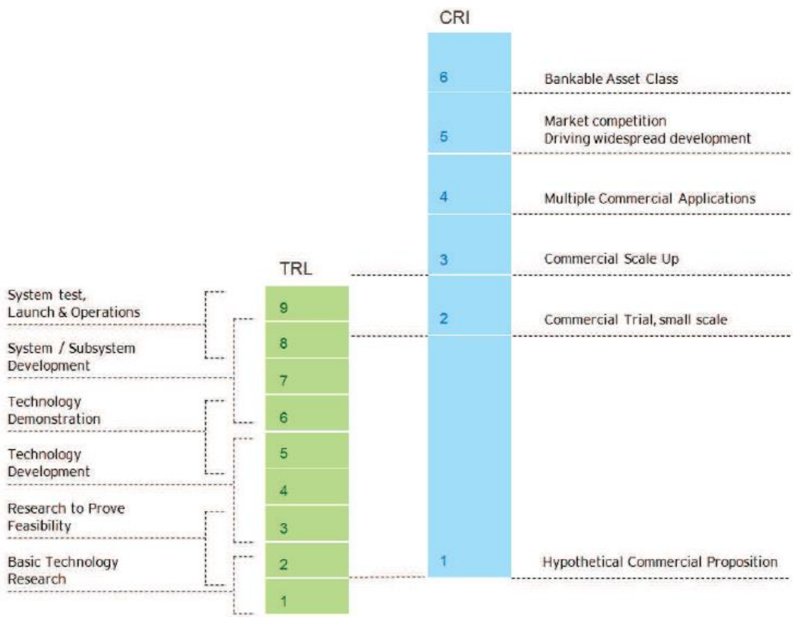
The team decided on these two value chains with input from working groups because:

- They are large energy consumers.
- They have a long term future in the Australian economy.
- They were areas of particular interest to stakeholders, with all state governments being particularly interested in the food value chain.
- It appeared that, while energy use in the built environment had received a lot of attention, the manufacture and impact of construction materials/business models in terms of both embodied energy and operating energy were not well addressed.
- The team expected that there would be potential major energy productivity opportunities in these chains.

4.3. Technology readiness level and commercial readiness index

The Next Wave project utilises the technology readiness level (TRL) and commercial readiness index (CRI) methodology employed by the Australian Renewable Energy Agency (ARENA) to assess innovations considered in this report. The TRL methodology is a globally recognised benchmarking tool to track the development of a technology. ARENA adopted the CRI to provide a rigorous structure to evaluate barriers to commercialisation. The TRL and CRI ranking systems are depicted in the diagram below. 2xEP have adapted these systems of measurement to evaluate Energy Productive technologies in case studies.

Figure 3.: Technology readiness level and commercial readiness index



US Department of Energy Technology Readiness Assessment Guide (DOE 413.3-4 10-12-09)

Extracted from Commonwealth of Australia (Australian Renewable Energy Agency) 2014

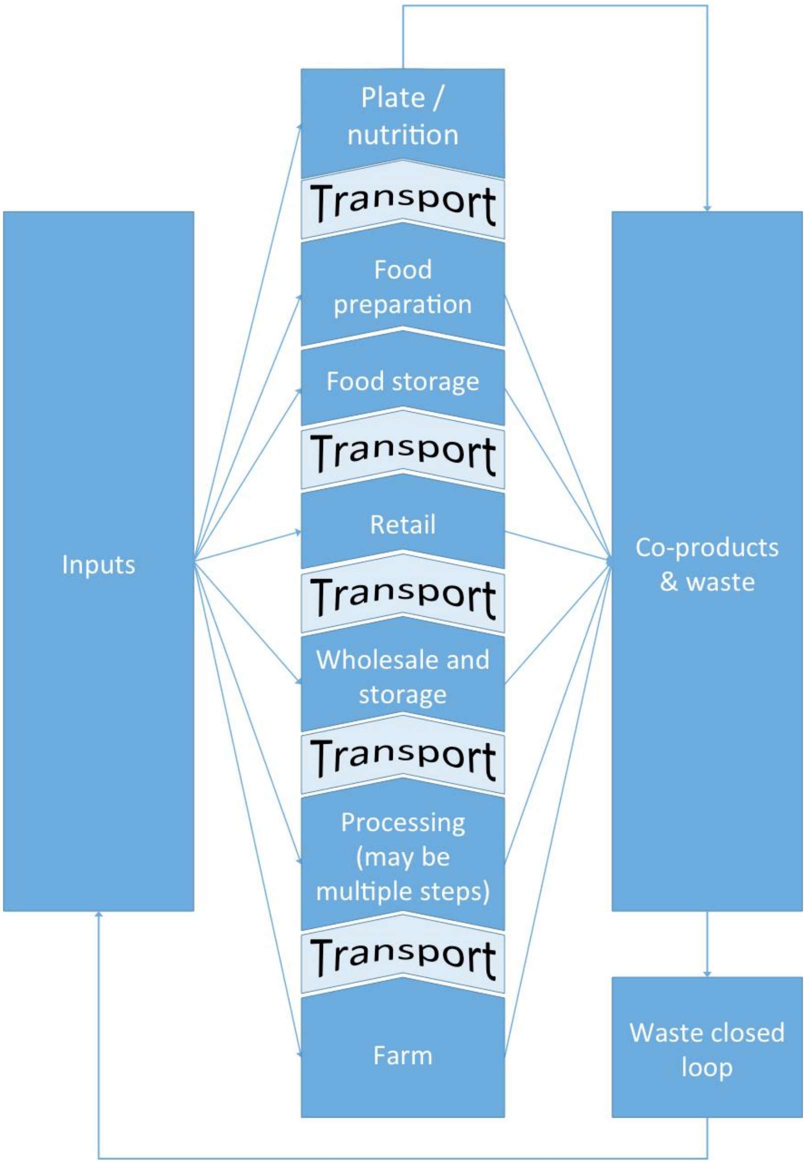
5. Overview of value chains

Two value chains, food and shelter are investigated in this Phase 1 report. The following sections detail material flows and energy use in these value chains. This analysis has highlighted key systems for energy productivity improvements within each value chain. A detailed discussion of these key systems, including case studies, is set out in section 6 of this report.

5.1. Food (plate-farm) value chain

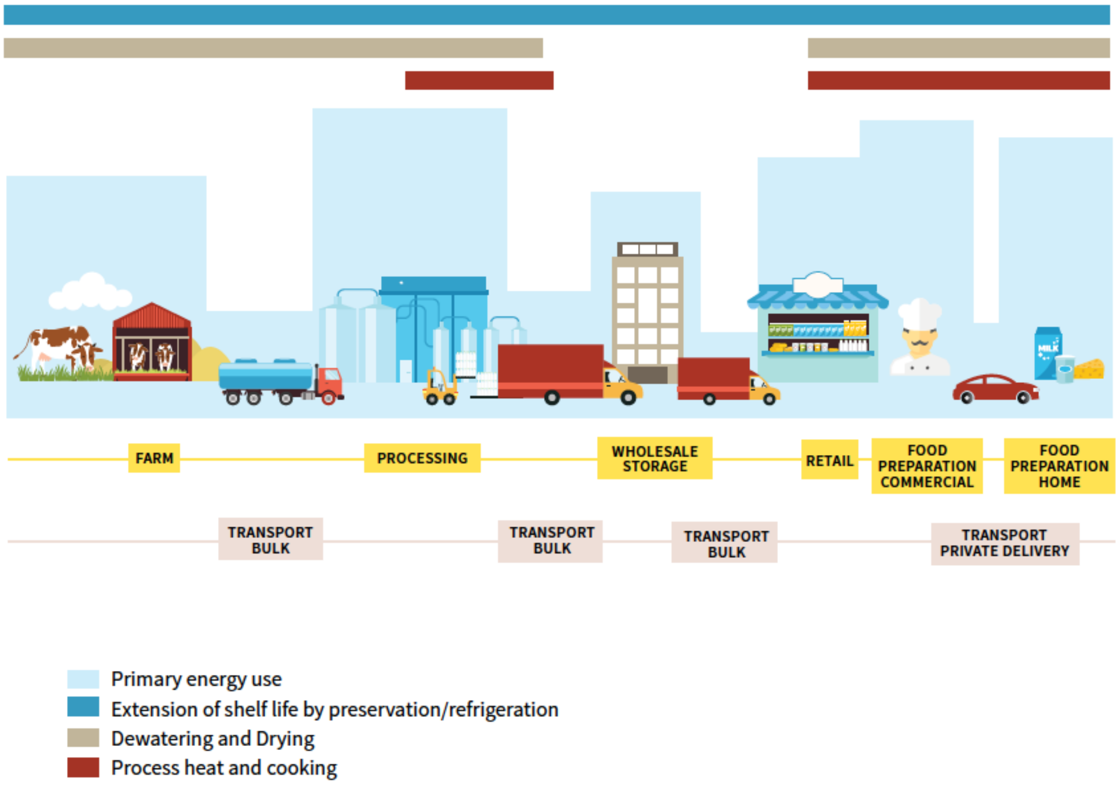
This value chain, shown in Figure 4, includes the major activities involved in the production and transformation of raw food into provision of edible food consumed by people.

Figure 4.: Food value chain



Inputs may include machinery, equipment, consumables, chemicals, maintenance services. Co-products and waste may include saleable organic materials, chemicals, products created during the core process of food production, or wastes that incur disposal costs and impacts – and which may be convertible into saleable product or service.

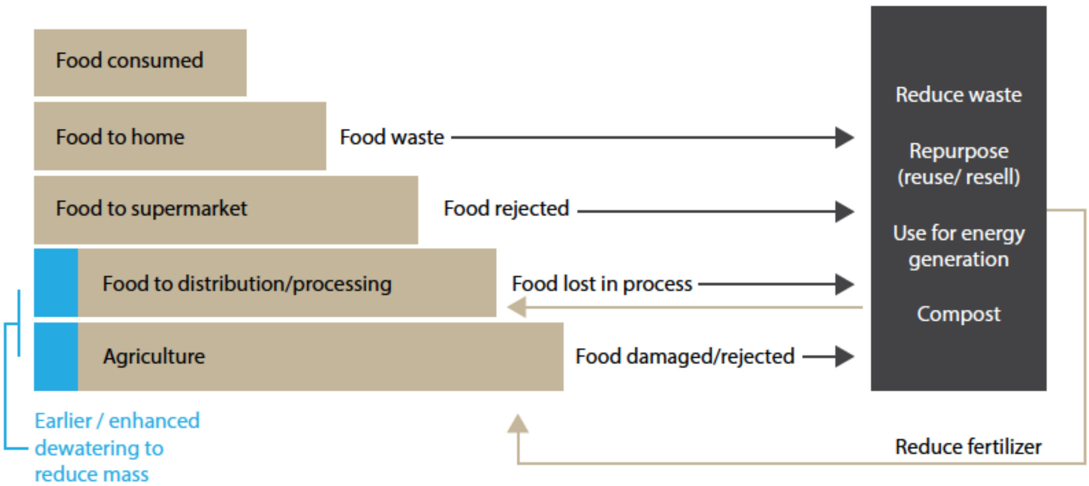
Figure 5.: Primary energy use in the food value chain



The figure above highlights primary energy use in the food value chain and key systems present along the chain. Primary energy is found to better correlate with carbon emissions and energy cost than final energy – the significance of using electricity (which involves inputs of three units of primary energy per unit of final energy) efficiently is emphasised.

The figure below depicts the waste cycle in the food chain, highlighting material flows: as raw materials move upstream greater quantities of waste are generated. The waste and co-products have the potential to be reduced, captured, reused and repurposed. Reducing waste saves energy and resources along the whole value chain.

Figure 6.: Waste cycle in the food value chain

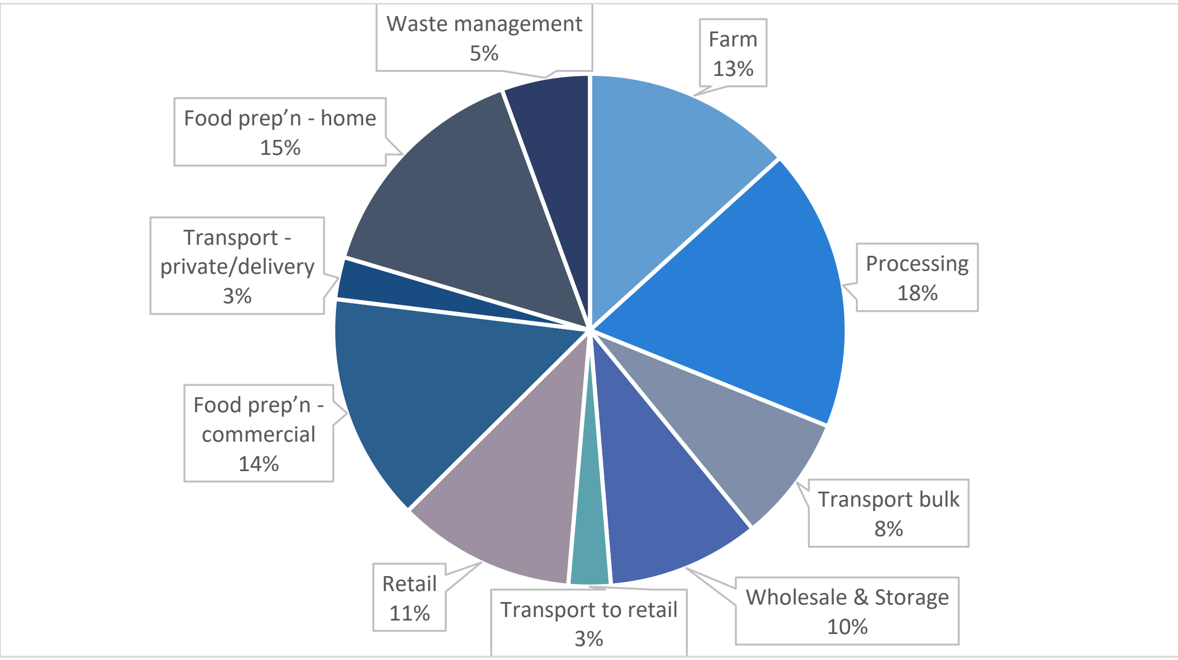


Some preliminary analysis was carried out to establish 'ball park' estimates of the amounts of energy consumed in the stages in this value chain. This assisted with identification of potentially significant aspects of the value on which our literature scan and engagement with specialists was based.

An analysis of studies from three countries that analyse energy use in the 'farm to plate' value chain led to indicative estimates of the contributions of each major sector and some activities to overall energy use. These estimates provide a basis for the pie chart in Figure 7.

Figure 7.: Indicative breakdown of primary energy use in food value chain.

Note that this reflects a total of approximately 1,000 PJ of primary energy ('raw' energy such as fossil fuels used to generate electricity). Using primary energy (the indicator chosen for energy productivity calculations), electricity-intensive activities and sectors, e.g. retail and commercial food preparation and storage, are much more significant than if final energy data (measured at the meter or pump), and totalling around 700 PJ for this value chain is used (e.g. data published by the Office of the Chief Economist). In broad terms, primary energy correlates better with both carbon emissions and energy cost than does final energy. Home and commercial food preparation includes refrigeration and cooking.



A brief review of this breakdown highlights the significance of some sectors and activities, as described in Table 1 below. This table also flags the kinds of activities this project focuses on, and other actions that are potentially important but are outside the scope of this project.

Table 1: Major contributors to energy use in food value chain

Examples of energy productivity improvement opportunities, and classification regarding project scope. Note a large proportion of the activities of some components of this value chain involve production for export. The household contribution is based on data for household cooking and refrigeration from the *Residential Energy Baseline Study: Australia*[5].

ACTIVITY	ENERGY USED (as proportion of chain)	EXAMPLES OF INNOVATIONS POTENTIALLY WITHIN SCOPE	BEYOND PROJECT SCOPE
Farming	Up to 15%, mostly diesel for vehicles/irrigation; some electricity (refrigeration, hot water, irrigation) & process heat (e.g. washing dairy equipment). Also through fertiliser manufacture (not included in VC).	Cut vehicle movement, e.g. using GIS data, drones, 'virtual paddocks' etc.; optimise irrigation; efficient equipment; process innovation; on-site RE and energy storage (See A2XEP Agricultural 2XEP overview[6])	Incremental improvements; broader structural change, e.g. changing crops (see A2XEP Ag roadmap)
Transport	Around 15%, but occurs at several points in value chain	Reduce amounts & distances transported; optimise vehicle efficiency (see Freight), reduce mass/volume of product	Incremental improvements: A2EP freight transport roadmap will address
Industrial processing and wholesale storage (excludes sugar industry bagasse)	Around 25-30%: various scales and locations; process heat, refrigeration, material handling	Major process innovations; e.g. heat pumps and refrigeration, high pressure processing, integrated management systems; on-site RE and energy storage	Incremental improvements: A2EP manufacturing roadmap will address
Retail, commercial food preparation (including supermarkets, restaurants, meal services etc.)	Around 25% and electricity-intensive: refrigeration, cooking, HVAC, lighting	Process innovation; high efficiency equipment; on-site RE and energy storage	Incremental improvements, e.g. improved management, behaviour change. See A2EP built environment roadmap
Household refrigeration, cooking and private transport	Around 15% of value chain total	Step changes in household appliance efficiency; on-site RE and energy storage	Incremental household energy efficiency – appliances, behaviour, diet change
Waste management	Around 5% - small in terms of direct energy use, but avoiding waste reduces amounts of food and associated packaging produced, processed, transported, as well as offering potential for use in a 'closed loop' economy	New technologies to reprocess, extract valuable elements of waste streams, produce energy	Waste minimisation throughout value chain, behaviour change, infrastructure provisions. Note reducing waste at point of consumption reduces the need for production upstream

[5] Energy Consult. (2015) *Residential Energy Baseline Study: Australia* Prepared for Department of Industry and Science on behalf of the trans-Tasman Equipment Energy Efficiency (E3) Program

[6] http://www.2xep.org.au/files/sectors/2xEP_Agriculture_Sector_Overview_150312.pdf

Common energy using processes that appear across the value chain include:

- Preservation – largely refrigeration (and other methods for extending product life), ensures health and product quality, while also allowing some activities to be shifted between stages in the value chain;
- Dewatering/drying and heating for preservation (e.g. pasteurisation, sterilisation);
- Cooking; and
- Wastes and co-products.

Transport and storage of food also occurs at multiple locations along the chain.

There is increasing potential to shift such activities to different points in the value chain. For example, a hot bread shop combines baking and retail, and changes the roles of wholesale and distribution of consumer products. The value chain approach also supports consideration of changes that influence upstream and/or downstream effects of changes. For example, reducing waste reduces the amount of food that must be produced, transported and processed upstream of the point where the waste reduction occurs, and partial dewatering of milk at the farm reduces transport energy (as well as refrigeration and storage costs at the farm and processing costs at the factory.

5.2. Shelter (building/raw materials) value chain

The justification for exploring potential to improve energy productivity along this value chain, not just operating energy, is:

- Many of the processes involved are energy-intensive. Also, improvements will benefit other sectors that also use the outputs of the associated industries (e.g. steel is used for many things other than buildings), and innovations in this sector's processes may be applied to other areas;
- Improving business competitiveness within this value chain will help them remain in Australia, and maintain the diversity and resilience of our economy;
- Some activities have significant environmental impacts, such as quarrying, mining, some forms of forestry, processes with industrial process greenhouse gas emissions, etc. Improving energy productivity can help to reduce those impacts;
- As we improve the energy efficiency of buildings and the equipment used in them, the importance of the energy use and impacts of the construction supply chain increase in relative terms: it could use up 30-66% of our global carbon budget by 2050; and
- Large numbers of people are employed in the construction industry, as well as other elements of this value chain, so improving energy productivity can help to maintain or expand employment in this sector.

The following section utilises the value chain methodology to prepare a value chain flow diagram, data on the contributions of the major elements in the chain to energy productivity and identification of potentially significant areas within and beyond the scope of this project.

Attempts to quantify each of the contributions of the elements in the shelter value chain were constrained by a number of factors including:

- The lack of detailed data on energy use in specific parts and for each end-use within the industrial and commercial sectors of the economy.
- Limited data on proportions of output from various industries used in construction activity.
- Difficulty in separating use of materials between building and infrastructure construction.
- Difficulty separating domestic use of materials given significant exports and imports of materials and products.

Overall, the elements of this value chain upstream of building operation are widely considered to be responsible for energy use of up to 20% of that from operating energy use within buildings. However, recent studies reported by ClimateWorks[7] in their ASBEC study (2016), Energy Consult (2015)[8] and Pitt&Sherry (2012)[9] point out that, on average, heating and cooling energy comprises only 40% of residential final energy and 43% of commercial sector final energy. So the gap between the main aspect of building energy use affected by this value chain and energy use upstream of operation is often much smaller than usually suggested, and the gap is closing as operating efficiency improves. However, in more extreme climates, and for thermally poor buildings, heating and/or cooling can still comprise a large proportion of lifecycle energy.

A lifecycle analysis of inputs to households by Sydney University's Institute for Sustainability Assessment for the Australian Conservation Foundation (*Consuming Australia – main findings* (2007) Australian Conservation Foundation, Melbourne, https://www.acfonline.org.au/sites/default/files/resource/res_Atlas_Main_Findings.pdf) estimated, based on input-output economic data, that annualised emissions from residential construction and renovation were 11.8%, compared with 20% for all household electricity and gas use: so upstream construction material emissions may exceed residential space conditioning emissions if indirect emissions associated with upstream inputs are included. The validity of this approach is one of many debates in the life cycle analysis community.

As buildings become more energy efficient, transition off gas to high efficiency electric technologies, and increasingly are powered by renewable energy, embodied energy and greenhouse gas emissions of building materials will become the main life cycle source of greenhouse gas emissions for this sector. This has been formally recognised as being important by Queensland, South Australia, Victorian, Tasmanian and ACT climate change and environment ministers in the 2016 Climate Change Roundtable communique statement[10] which committed to

> *"Supporting innovation in low carbon technologies and materials such as timber, and develop supply chains and business models that accelerate penetration of carbon reducing practices"*

Internationally there is great interest in how to both improve the energy productivity and reduce related greenhouse gas emissions in the production of building materials such as steel, cement,

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[7] *Low Carbon, High Performance: How buildings can make a major contribution to Australia's emissions and productivity goals* (2016) ClimateWorks for Australian Sustainable Built Environment Council (2016)

[8] Energy Consult. (2015*) Residential Energy Baseline Study: Australia* Prepared for Department of Industry and Science on behalf of the trans-Tasman Equipment Energy Efficiency (E3) Program August 2015

[9]Pitt & Sherry. (2012) *Baseline Energy Consumption and Greenhouse Gas Emissions In Commercial Buildings in Australia Part 1 - Report November 2012* Department of Climate Change and Energy Efficiency

[10] http://www.actsmart.act.gov.au/__data/assets/pdf_file/0005/981023/20160818-Climate-Action-Roundtable-Communique_FINAL.PDF

aluminium, bricks and glass. Steel and cement production alone contributed 9% and 7%, respectively, of greenhouse gas emissions in 2006 (Allwood et al., 2010[11]).

Importantly, if cities in developing countries are to meet the building needs of 3 billion more people by 2050 and lift their citizens out of poverty using steel, cement and aluminium, then the embodied carbon of its construction and manufacture will be 30-66% of the remaining global carbon budget to 2050 (Müller et al.(2013[12])). We simply cannot afford to continue to produce and use high emission materials if we are to limit global temperature increase to 2C or less.

Therefore there is substantial opportunity for businesses and nations that lead in developing and producing low embodied energy / high energy productivity building and construction materials.

[11] Allwood, J., Cullen, J. and Milford, R. (2010). *Options for Achieving a 50% Cut in Industrial Carbon Emissions by 2050*. Environmental Science & Technology, 44(6), pp.1888-1894.

[12] Ibid

Figure 8.: The shelter value chain

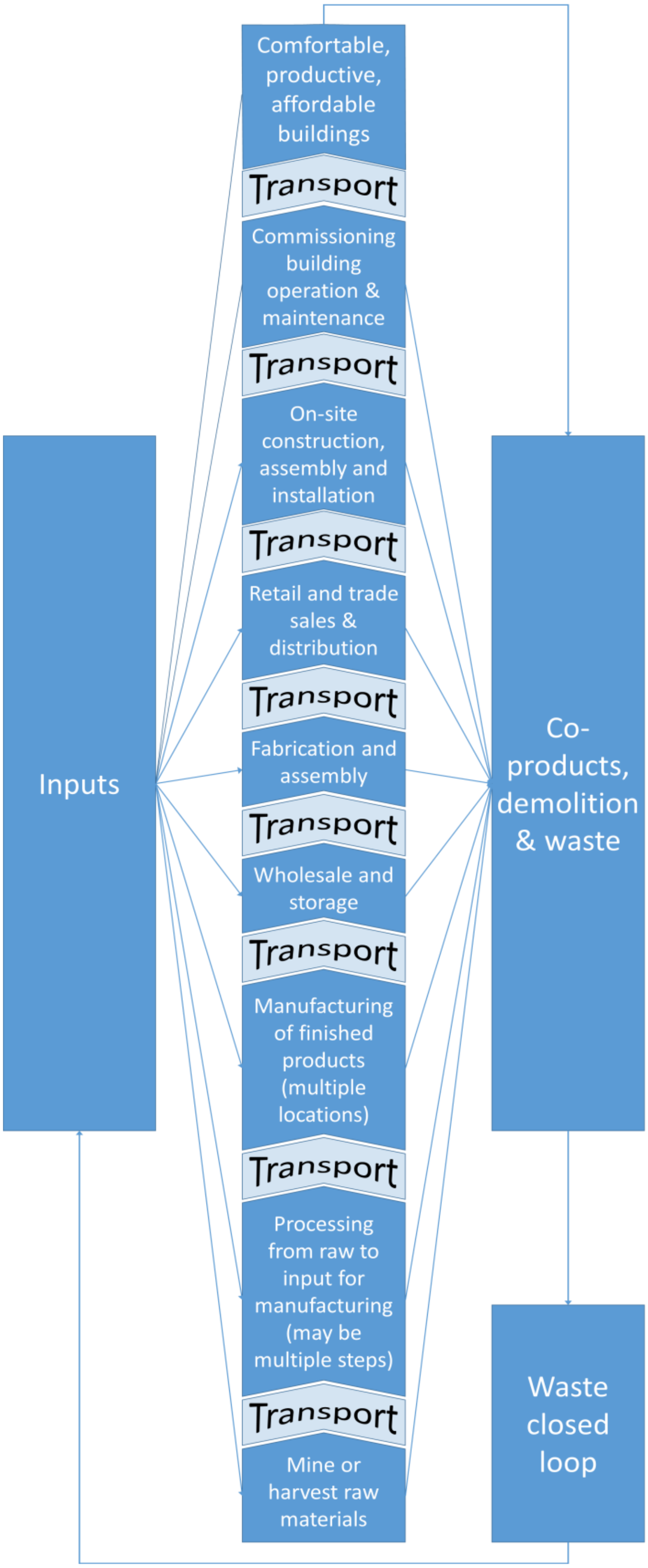
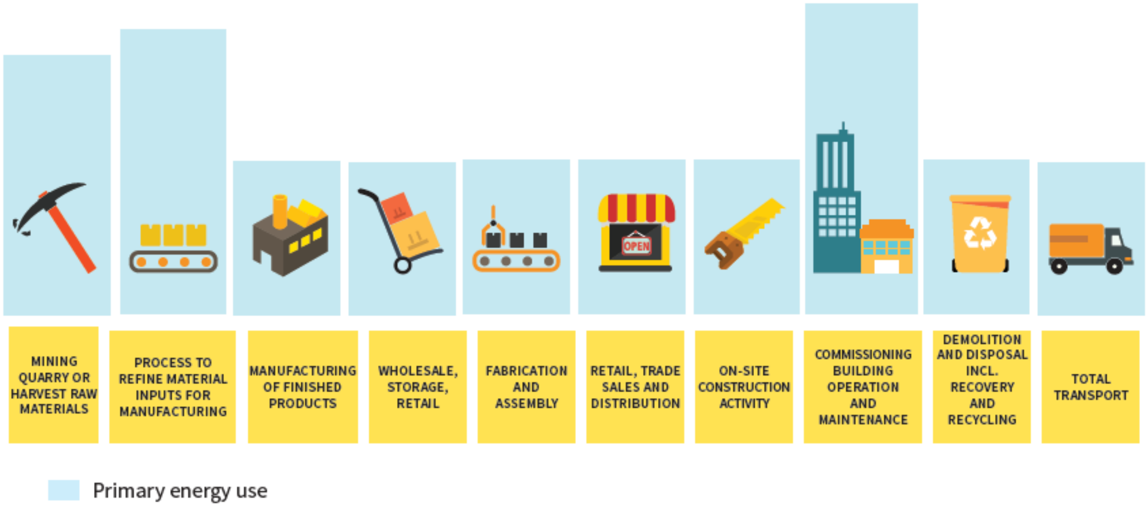
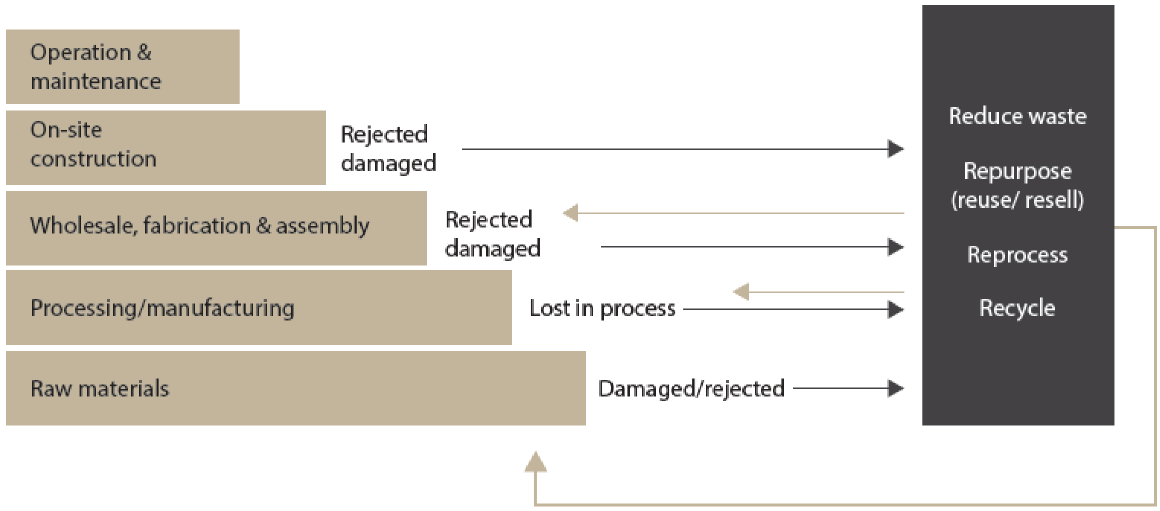


Figure 9.: Primary energy use in the shelter value chain



The figure above highlights the use of primary energy in the shelter value chain and key systems present along the chain. Primary energy is found to better correlate with carbon emissions and energy cost than final energy - the significance of using electricity (which involves input of three units of primary energy per unit of final energy) efficiently is emphasised.

Figure 10.: Waste cycle in the shelter value chain



The figure above depicts the waste cycle in the shelter value chain, highlighting material flows: as raw materials move upstream greater quantities of waste are generated. The waste and co-products have the potential to be reduced, captures, reused and repurposed. Reducing waste saves energy and resources along the whole value chain.

Overall, there is a strong case for this project to explore energy productivity improvement potential in this whole value chain, not just operating energy. This is not intended to provide an argument for ignoring building operating energy: new buildings 'lock-in' energy consumption and impacts for many decades, and the performance of the building envelope is an important influence on health, amenity and productivity, as well as influencing the level of investment in energy supply infrastructure. Further, large numbers of existing inefficient buildings and extreme climates mean large amounts of energy will be used for building operation unless we improve building operating energy efficiency. So, ongoing performance of buildings is a critically important issue.

Inputs to this value chain may include additional materials, consumables, services and use of premises. Shelter may be provided for households, businesses and their activities, animals, materials, products and/or recreational activities.

Broad features of energy use in this value chain, based on the review of limited available data:

- Primary energy use in this value chain upstream of building operation is likely to be over 400 Petajoules (PJ), responsible for at least 40 million tonnes of $CO_{2\ equivalent}$ annually from energy use, almost 10% of Australian energy-related emissions and over 7% of total emissions. Transport is likely to represent at least 20% of the total. The emissions of the manufacturing industries involved in production of these materials are much higher, but a good deal of their output is used for other activities, including infrastructure construction. So, the broader energy productivity implications of change in the sector would be much larger.
- Operational energy use of buildings comprises 773 PJ of final energy, of which 59% is electricity (so electricity is around 80% of building operation primary energy)[13] and 125 Mt CO_{2equiv}, 23% of total Australian greenhouse gas emissions[14]. Of this, space conditioning is likely to be over a third (lower than its share of final energy due to the significant roles of gas and wood, which have much lower emission intensity than electricity), and associated refrigerant leakage (from refrigeration and HVAC) amounts to 10% (i.e. 2% of total Australian emissions)[15].
- For stationary energy use upstream of building operation in this value chain, total final energy use is likely to be over 400PJ. Process heat and electricity dominate, with the industries contributing to this value chain responsible for over half of Australian industrial heat use[16].
- Steel (much of which, in the building construction area, would be recycled steel from electric arc furnaces) dominates upstream 'embodied' energy impacts, followed by cement products (which also emit process CO_2 emissions during cement manufacture) and bricks.[17]. Timber and aluminium are significant contributors.
- Building fit-outs and renovations are likely to be responsible for up to a quarter of energy use associated with building construction in the value chain. This reflects their higher frequency

[13] Office of the Chief Economist (2016) Table A

[14] ClimateWorks report for ASBEC (2016)

[15] See discussion later in this report

[16] ITP (2015) *Renewable Energy Options for Australian Industrial Gas Users* ARENA

[17] Based on RMIT et al (2006)

and use of energy-intensive products. Further, the implications for building operating energy use are very significant, because of the energy use of equipment specified and installed.

- Use of construction materials for infrastructure (not considered in this value chain) is likely to be greater than for buildings, so it may be responsible for more than an additional 40 Mt CO_{2e} and 100 PJ annually beyond building construction. So waste in the supply chain, as well as end of life recovery and recycling, offers important opportunities to reduce energy use throughout the value chain
- The construction sector uses around 100 million tonnes of raw material, from which around 25 million tonnes of useful products and materials are produced.

Table 2, below, includes a preliminary indication of the scale of energy use in each element of the value chain, as well as examples of measures that may improve energy productivity. The table includes examples of energy productivity improvement opportunities, and classification regarding project scope. Note that values for energy use are indicative only. Even though some of the technologies included as innovations exist, adoption has been limited and partial, and integrated solutions will offer additional large savings.

Table 2: Major contributors to final energy use in shelter value chain

ACTIVITY	SCALE OF ENERGY USE (excl building operating energy: upstream activity only)	EXAMPLES OF INNOVATIONS WITHIN SCOPE	BEYOND PROJECT SCOPE
Mine, quarry or harvest raw materials	Around 25% of total value chain energy (excluding building operation), approx. 100 PJ. Mostly diesel for off-road vehicles, power generation, crushing and grinding	Minimise energy use for moving material, e.g. replace trucks with mine-floor processing, conveyors; downstream measures cut usage; shifts to other materials with large reduction of impacts	Optimise operations; minimise material use in value chain; use recovered/recycled materials; shift to other materials
Process to refined material inputs to mfg.	35-40% of total energy. Some processes electricity intensive, some require very high temperature heat	In downstream value chain adopt emerging products, materials, systems, e.g. factory mfg of buildings; engineered timber or tensile structures; step changes in process efficiency	Optimise operations, high strength alloys, help designers to optimise material use
Mfg. of finished products	Less than 5% of total energy, but some electricity-intensive; often high value adding	Advanced mfg. techniques, technologies, e.g. 3-D printing, design to minimise materials and utilise low impact ones; step improvements in design for energy efficiency	Optimise operations; replace old, inefficient equipment, improved product design
Wholesale, Storage, Retail	Less than 5% of total energy, but some electricity-intensive; often high value adding	Online shopping; local 3-D printing	Optimise operations and equipment within buildings, smart storage systems, improved logistics
Fabrication & assembly	Less than 5% of total energy, but some electricity-intensive; often high	Factory construction of modules, buildings; improved product	As above

ACTIVITY	SCALE OF ENERGY USE (excl building operating energy: upstream activity only)	EXAMPLES OF INNOVATIONS WITHIN SCOPE	BEYOND PROJECT SCOPE
	value adding	design	
Retail and 'Tradie' sales & distribution	Less than 5% of total energy but electricity intensive and influence impacts of trade customers	Stock and promote products with best energy efficiency, provide feedback to designers	As above, and customer advisory services, skill up and motivate tradespeople
On-site construction activity	Less than 5% of total energy – most for large buildings and infrastructure projects	Efficient equipment, scheduling, factory modular construction; advanced materials and systems	As above; project management
Commission-ing, building operation & maintenance	773 PJ (2012-13) of final energy, with electricity 59% (3/4 of commercial final energy and half of residential, and around 80% of primary energy). Approx. 125 Mt CO2e p.a. New buildings much more efficient than stock (but could be better, especially in summer)	High performance building envelopes, appliances and equipment; smart packages that combine monitoring, analysis, feedback, smart control; improved design; on-site renewable energy and storage	As above; training; accountability; budgeting and finance; dwelling size, climate and micro-climate, occupant behaviour, ongoing appliance and equipment efficiency improvement
Demolition & disposal (incl. recovery & recycling)	Small energy cost, but improvement avoids substantial energy use by reducing demand for upstream supply chain	Material reprocessing technologies	Design for disassembly, material selection, optimal structural design
Transport	Unknown share of transport emissions allocated to commercial 26.7 Mt and residential 45.6 (NGGI by economic sector); raw and bulk materials large (100 Mt mass of raw materials, 25 Mt finished product materials) but transport impact not yet quantified. Scale varies across and within sectors: bulk, medium (e.g. containerised), light freight. LCV, tradie travel inefficient, add to congestion and costs.	Minimise need for amount of and movement of materials, goods and people, e.g. factory building construction (also reduces 'tradie travel'), in-situ processing and conveyors replace off-road trucks; online shopping with optimised delivery; electric delivery vehicles	Minimise need for transport, e.g.: Locate elements of system close to each other, switch modes Optimise vehicle selection, management and use, packing and loading Optimise operations; improved logistics, e.g. back-loading; vehicle efficiency, mode shifts
Waste management	Low energy use, dominated by transport and reprocessing	Small scale local recycling technologies with 3-D printing and other local production; separation and reprocessing of materials to maximise value	Build recycling and reprocessing infrastructure, motivate community and business

Demand for the outputs of this value chain is driven by several factors, including:

- Floor area choices (e.g. houses getting larger), and planning impacts on building height, development density and extent of excavation involved, which influence the amount of materials and types required for construction and infrastructure. Virtual solutions can transform energy use. For example, on-line shopping is likely to reduce retail floor area required, while optimised delivery services can use less fuel than private vehicles.

- Adaptability and durability of buildings and materials also influence the level of construction activity.
- Urban development trends influence the distance materials must be transported, amount of infrastructure per square metre of buildings, and types of infrastructure provided e.g. roads or rail transport.
- Choices about types of materials are influenced by cultural and institutional factors, technological evolution (e.g. engineered timber may challenge concrete and steel construction but require retraining of designers and on-site staff), availability of design tools, Standards and specifications, skills, cost and time involved in accessing materials or virtual alternatives, reliability of quality outcomes, etc.

Therefore, there are many opportunities for emerging energy productivity solutions to cross-sectoral boundaries, and replace or transform existing activities and processes.

6. Key systems for improved energy productivity

This section contains detailed discussion of common systems across each chain offering the opportunities for improved energy productivity.

6.1. Food value chain

To maintain a reliable food supply, food must be stored, or transported from farms to people via a supply chain, so maintaining food in good condition between source and time and place of consumption is a fundamental requirement.

Many food products degrade over time, so they become less palatable, and may become dangerous to eat. Over history, humans have used a variety of techniques to extend the shelf life (that is the period over which the food is edible and safe to eat). There are many options to achieve this outcome (see https://en.wikipedia.org/wiki/Food_preservation for a comprehensive list of food preservation techniques).

Options to preserve food include a range of mechanisms, such as:

- Creating a hostile environment for micro-organisms, by heating, cooling, changing pH or exposure to extreme pressure or radiation to kill or slow growth;
- Isolating food from exposure to micro-organisms (often after the above treatment).

Most food preservation options involve an initial energy consuming process over a relatively short time. However, refrigeration and some 'modified atmosphere' solutions involve ongoing energy use to maintain the conditions necessary to maintain food quality and safety.

This project focuses on emerging technologies that offer potential to improve energy productivity by a substantial margin, so our focus is on improving or replacing:

- Methods that require long periods of energy use, such as refrigeration (both cooling and freezing);
- Methods that are energy-intensive, usually because large quantities of water are evaporated, as the latent heat of evaporation of water is large (around 2.3 MJ/litre).

Energy productivity improvements include:

- Improved ongoing process efficiency (such as high efficiency refrigeration);
- Alternatives that replace the need for ongoing energy use (such as sterile packaging and use of advanced films and inert gases in containers);
- Alternatives for 'once off' actions that either use less energy or utilise electricity, potentially sourced from renewable energy;
- Measures that increase the sale value of products and/or reduce wastage, or shift a process from one sector to another where the need for preservation energy use is reduced and/or greater value can be captured (e.g. micro-breweries, which may not need to pasteurise beer because it is drunk soon after production); and
- Energy impacts of packaging, in its manufacture, impact on preservation, and at end of life.

In this report, our focus for cross-sectoral energy productivity improvement options in the food value chain is on:

- 6.1.1 Extension of shelf life by preservation/refrigeration;
- 6.1.2 Dewatering and drying;
- 6.1.3 Process heat and cooking; and,
- 6.1.4 Food waste and co-products.

6.1.1. Extension of shelf life by preservation/refrigeration

Name of technology or measure: REFRIGERATION

Area(s) of potential application and context

Services provided: maintain consumer health (avoid pathogens etc.); extend shelf life; element of food processing (e.g. freezing); storage before, after food preparation; enhance product value.

In the food value chain, refrigeration is a major energy consumer, and likely accounts for 25-30% of total primary energy in the value chain. It can be a major contributor to energy consumption at each stage of the value chain, including in transport.

Refrigerant energy and emission issues

Refrigerant leakage

Refrigeration leakage directly impacts on energy productivity in a number of ways:

- Many replacement refrigerants operate more efficiently than traditional products. For example, hydrocarbon refrigerant, now widely used in household refrigerators and small freezers, reduces energy consumption by 4-11%[18] compared with traditional refrigerants; ammonia's weighted average efficiency was estimated at 12% better than HFC134a, and even more efficient at part load[19]
- The Australian government has committed to a phase-out of HCFCs and HFCs[20]. There will be accelerated investment in new refrigeration and air conditioning equipment due to this transition. It is economically preferable if replacement equipment is also designed for maximum efficiency. For example, a recent consultation paper published by the government's appliance efficiency committee found that savings of 25% could be achieved by 2035 for commercial refrigeration equipment at a benefit-cost ratio of 7.8 to 1: that is for each dollar invested in efficiency improvement a return of $7.80 would be gained[21]. Clearly even larger savings would still be cost-effective. So this opportunity to combine removal of high impact refrigerants and improved equipment efficiency must not be missed.

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[18] P.9 and p.16 *Natural Refrigerants case studies* AIRAH (2007)

[19] http://www.achrnews.com/articles/89851-chiller-comparisons-ammonia-vs-r-134a

[20] http://www.environment.gov.au/protection/ozone/legislation/opsggm-review/hfc-phase-down-faqs

[21] *Consultation Regulation Impact Statement – Refrigerated display and storage cabinets* Energy Efficiency and Conservation Authority on behalf of the Equipment Energy Efficiency Program (2016)

- If the refrigerant charge is partly lost, which is common in larger units and transport equipment, efficiency can decline by 30% or more[22], so measures that reduce leakage have significant energy efficiency benefits.

In addition to adverse impacts on energy efficiency and productivity, leakage of HFC and HCFC refrigerants, especially from large commercial and industrial refrigeration systems and trucks, comprises up to 10% of greenhouse gas emissions from the value chain total of around 100 Mt CO_{2e}. Government estimates of leakage of HFCs alone from refrigeration equipment for 2014 are 6.75 Mt CO_{2e}, of which 0.75 Mt is from trucks and mobile refrigeration equipment. Emissions are increasing at about 7% annually. The Australian Refrigeration Association (2013)[23] suggests this may be based on conservative assumptions related to factors such as leakage rates and end of life emissions.

A significant but declining proportion of existing refrigeration equipment uses HCFCs, which are not included in the greenhouse inventory: annual leakage of HCFCs seems to be around 1.3 to 2 Mt CO_{2e}. This emission calculation is based on the 100 year warming impact (GWP), the usual Kyoto criterion. However, there is increasing focus on the short term impacts of warming because of the increasing urgency to act on climate: a common HFC, 134a, has a 20 year GWP 2.7 times its 100 year GWP, as it breaks down over time.

Progress on use of zero or low climate impact refrigerants

The transition to zero (or very low) emission refrigerants has begun, but has a long way to go. Hydrocarbon refrigerants now dominate domestic appliances and are increasing market share in small commercial applications. CO_2 is emerging as a major option across a wide range of products. Domestic heat pump hot water services using CO2 refrigerant, when combined with rooftop PV or grid-sourced renewable electricity, are now out-performing solar systems, and are cheaper and simpler to install. CO2 is also challenging ammonia and HFCs in large systems. According to industry expert Michael Bellstedt of Minus 40 P/L (Nov 2016),

> "Full CO2 systems are far more compact than HFC and NH3 systems and hence very large capacity units can be factory built in low cost regions and shipped in standard container sizes. We are finding full CO2 systems can be less than 1/2 the cost of ammonia systems as a result. Efficiencies are higher on an annualized basis than HFCs, but lower than ammonia. However, by adding a solar PV system you can get a total system costing less than an ammonia system, using nett less power and less plant room space with lighter pipework and without a highly toxic refrigerant. All of these benefits add up to a convincing business case.
>
> "Full CO2 systems have advanced with leaps and bounds with the advent of parallel compression and more recently liquid and vapour ejectors. Evaporatively precooled gas coolers are now common. Manufacturers have cracked oil return challenges and a much wider range of high pressure compressors is now on the market."

Refrigerant manufacturers are also developing a variety of new refrigerants in response to environmental pressures.

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[22] One source quoted on p.43 found up to 36% loss of efficiency when half of charge was lost *Refrigerant Emissions in Australia: sources, causes and remedies* Expert Group (2010) for Australian Government Environment Dept.

[23] Notes on *Cold Hard Facts 2* Australian Refrigeration Association (2013).

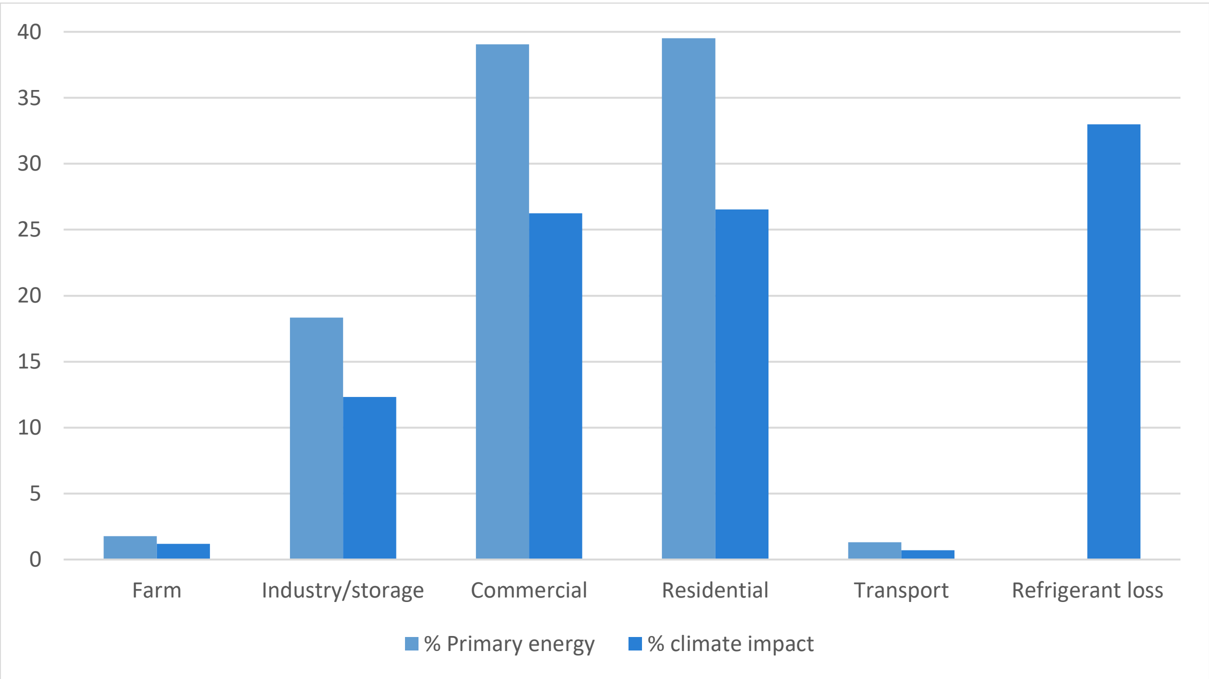
Integration of thermal and/or electricity storage with advanced refrigeration/HVAC systems and on-site renewable electricity offers even greater potential for energy productivity improvement. The site manager can optimise operation of chillers and on-site generation, imports from and exports to the grid, minimise capacity (and cost) of equipment and improve reliability. One early pilot by UNISA and Glaciem in South Australia, using phase change materials (PCMs) for storage, has demonstrated the practicality and economics of such approaches.

A number of innovative refrigeration technologies are also emerging. A useful overview of emerging refrigeration options can be found at Tassou et al (2011)[24]. Options such as cascading of compressors, dynamic optimisation of condensing and evaporation temperatures, and real-time benchmarking of performance are also driving efficiencies, wider applications and improvements in economics, as discussed later.

A preliminary assessment of the contributions of refrigeration in the elements of the value chain is presented in Figure 11 below. Data for non-residential energy is from 2008, from E3 report *In From the Cold*, residential data for 2014 from EnergyConsult *2015 Residential Baseline Study*, transport energy from *Cold Hard Facts 2* (2013) by Expert Group for SEWPC, HFC refrigerant data from *2014 NGGI*, with A2EP's estimate for refrigerants other than HFCs (1.3 to 2 MtCO2e/year) being a crude value based on data from Refrigerant Emissions in Australia (2010) by Expert Group. Data were cross-referenced against Australian Refrigeration Association (2013).

Figure 11.: Approximate primary energy and climate impact for refrigeration

Total primary energy approximately 255PJ and total climate impact approximately 30.3 Mt CO2 equivalent. Percentages by sector in farm to plate value chain. This does not include indirect energy impacts on HVAC, defrosting, etc. (see text).



[24] S.A. Tassou, J.S. Lewis, Y.T. Ge, A. Hadawey, I. Chaer. *A Review of Emerging Technologies for Food Refrigeration Applications*. Applied Thermal Engineering, Elsevier, 2009, 30 (4), pp.263. <10.1016/j.applthermaleng.2009.09.001>. <hal-00593332>

What it is and how it works

Services that refrigeration delivers:

- Reduces temperature rapidly, potentially including freezing.
- Maintains suitable temperature for health, safety, extension of shelf life, product quality and aesthetics.

It should also be noted that refrigeration also leads to indirect energy use. First, where a refrigerator operates in a heated space it contributes useful heat. In a cooled space, it increases the cooling load. However, this can actually improve overall cooling efficiency due to its 'cascading' effect, as the efficiency of the refrigerator is improved by operating at a smaller temperature difference, which tends to offset the higher consumption of the HVAC system (see below). Second, in many cases food is defrosted by using electricity or heat. If frozen food is cooked, the cooking time is extended significantly. These effects have not been considered here, but the latter effect is effectively incorporated into cooking energy, which is considered separately.

Energy productivity fundamentals for refrigeration

Most refrigeration utilises electric motor-driven compressors, refrigerant, a condenser (where heat is dumped) and an evaporator (where heat is extracted from the immediate surroundings i.e. the cooling occurs). Other refrigeration processes are used, such as absorption and adsorption cooling that use heat to drive the processes, and thermo-electric devices, which typically deliver only small amounts of cooling using electricity as a direct input. However, motor-driven compressors dominate refrigeration, and offer very large energy saving potential beyond both present stock and mainstream commercially available equipment.

The key principles regarding energy efficiency improvement of refrigeration are:

- The bigger the temperature differential across which mechanical refrigeration operates, the less efficient it is. Very roughly for every extra degree Celsius of temperature difference between condenser and evaporator, efficiency declines by 2-4%. Options to reduce the temperature differential include:
    - Increasing evaporator temperature to the highest level at which the appropriate cold temperature can be supplied. Variable valves and sensors can optimise these factors in real time.
    - Techniques that reduce condenser operating temperature (e.g. cooling towers, misting sprays, bodies of water or ground heat sinks, cooler environments e.g. shading or location on heat reflective roofs) can significantly improve efficiency, although some can have significant parasitic energy losses from pumps, fans etc and may incur chemical or other costs.).
    - More efficient (typically larger surface area) heat exchangers and/or higher flow rates of air or liquid improve overall system efficiency. Modern fan, pump, motor and airflow/pipe flow design can often improve heat transfer efficiency by more than the extra energy consumed, increasing overall system efficiency.
    - 'Cascaded' or 'multi-stage' refrigeration systems, where two or more compressors are in series, with cooling output of one providing a lower condenser temperature for the following compressor can deliver large efficiency improvements because the

temperature difference across each compressor is much reduced, though this comes at a higher capital cost.

  - Minimise the amount of heat released into the cooled space and the amount of heat to be removed from the product and its packaging/materials handling equipment by minimising input temperatures and total mass (heat capacity). Lights, inefficient fans, inefficient defrosting, thermal bridging, air leakage and inadequate insulation can all add heat.

- Where cooling loads vary, some types of compressors (e.g. inverter controlled units) can vary their speed or refrigeration output, and their efficiency can improve because heat exchanger efficiency improves at lower loads. Multiple compressors in parallel can be managed to optimise efficiency.
- Storage of 'cold' can allow refrigeration equipment to be operated (more efficiently) in cooler ambient conditions or at lower peak loads, at times when cheap (or on-site generated) energy is available. Heat gain to storage vessels and pipes, or higher operating temperature differentials (to chill storage to a lower temperature) can offset savings, so careful system design and control is needed.
- Useful heat can be recovered from refrigeration equipment for other activities (e.g. space heating, hot water or process heating). This may improve or reduce overall system efficiency, depending on the value of the recovered heat and/or any change in operating temperature differential of the refrigeration system.
- Ensuring waste heat from refrigeration is not dumped where it may add to energy consumption of other systems can improve their efficiency. But care is needed: operating a refrigerator in a cooler environment that must be kept cool for other reasons may actually reduce overall energy consumption, as the two coolers are effectively operating in 'cascade' mode.

How can it contribute to energy productivity outcomes?

Rapid technology development and cost reduction in cooling equipment (applying the principles outlined above), insulation (e.g. higher R value per unit thickness, improved glazed doors), energy recovery and energy storage, and smart design, monitoring and control, mean that very large, cost-effective efficiency improvements can be achieved in many applications: 50 to 80% savings are often achievable.

The major opportunities for energy productivity improvement in refrigeration, beyond the refrigeration equipment itself, related to 'farm to plate' are:

- Reduce the amount of material to be cooled. For example, partial dewatering of milk at the farm using micro-filtration reduces the volume that must be chilled, and reduces downstream transport and processing energy requirements. Containers holding product being cooled should have minimum thermal mass (heat capacity) if they move between different temperatures.
- Reduce reliance on cooling to maintain food quality. E.g. vacuum packaging can be an alternative to freezing and reduces cold storage requirements throughout the value chain.

- Pre-cool using ambient cooling, residual coolth from product leaving a process, or evaporative cooling.
- Reduce heat gains through storage cabinets/containers, pipe walls, doors and openings, open refrigerated cabinets and other system elements where temperature differentials exist. Options include improved insulation materials, avoiding thermal bridges through improved design and use of thermal imaging, optimisation of location of refrigeration equipment, reduction of air movement and control of outdoor or ambient air ingress and local humidity, etc. Smart monitoring, management and controls support these options.
- Optimise defrosting energy, for example by limiting entry of water vapour to refrigeration equipment or removing water vapour by other, less energy-intensive, methods, and by optimising defrosting process efficiency. To condense a litre of water vapour uses 2.3 MJ of thermal energy, and to freeze it uses 0.335 MJ – if theoretical efficiency is achieved. Then more energy must be used to remelt the ice during defrosting.
- Manage inventories to limit the volume of refrigerated storage required – although this can be offset by higher transport costs or adverse impacts on customer service (e.g. through reduced choice).
- Lower cost, smaller sensors and improved controls mean that temperatures and storage conditions can be optimised and monitored along the 'cold chain' to ensure health, optimise product value and identify equipment failures.
- Smart monitoring, particularly for commercial units with fan-powered condensers, can identify deviations from expected performance to alert users to the need to clean heat exchangers or fix other emerging problems. Fixing refrigerant leaks, fouled heat exchangers or other faults could improve efficiency by up to 47% based on US research.
- While new household refrigerators have improved efficiency by over 60% (and commercial refrigerators have also improved) over the past 30 years, average existing stock is well below efficiency of best new units, while 5-18% of household refrigerators are considered to be 'faulty'. 'Smart' real time monitoring and benchmarking software could identify units whose performance is deteriorating. Best practice appliances available in Europe offer significantly better efficiency (around 30%) than those available in Australia (see www.topten.eu). There is potential to further improve efficiencies through a range of technology developments, as discussed earlier.

Energy Productivity Implications:

- Rapid temperature reduction of product can require large plant capacity (but achieve poor average utilisation) and high peak electricity demand, especially if freezing is involved, as it involves extraction of latent heat of fusion of water (around 335 kJ/kilogram of water frozen), while freezing inappropriately may impact on aesthetics or physical/flavour characteristics of the food. Thermal and electricity storage systems can reduce required plant capacity while complementing on-site power generation and allowing overall demand management to optimise energy costs and overall efficiency. For example, 'over-cooling' cold stored stock can provide 'cold' for pre-cooling incoming product.
- Maintaining food at a suitable temperature throughout the supply chain is a major factor in optimising sale price and minimising product losses (and this has a major potential impact on

the top line of energy productivity). High efficiency refrigeration that can maintain optimal conditions potentially increases sales revenue. Effective monitoring and precise management of conditions can avoid waste and enhance sale value. Food storage involves potentially long periods of steady-state maintenance of required conditions in a variety of containers or cold-rooms, which may be insulated to varying standards, or open to the environment (e.g. display units in shops).

- Energy efficiency and capital cost can be affected by many factors, including cooling/chilling equipment design, installation, management and maintenance, refrigerant selection and management, as well as distribution infrastructure insulation, fans, motors, pipe length and size, sensors and controls.
- Leaking refrigerants are major contributors to ozone depletion (although this is declining) and climate change, as well as impacting on energy efficiency, as discussed earlier. Many commercial, industrial and vehicle systems have significant refrigerant losses: smart monitoring systems can identify leaks early. Different refrigerants (and appropriate amounts and operating parameters) can influence refrigeration energy efficiency, cooling capacity and OH&S requirements. Mandated and voluntary transitions away from ozone depleting and high Global Warming Potential refrigerants can create a need to replace or upgrade refrigeration plant or reduce cooling loads, leading to opportunities for efficiency improvement and reduced refrigerant costs.

Barriers/opportunities to rate and scale of adoption

Note that research into this issue is in the scope of the next planned stage of this project, so the comments below are preliminary observations.

- Limited appliance-level real-time monitoring and benchmarking means faults and inefficient operation of systems are difficult to detect.
- Split incentives apply within the commercial sector, where drink and food manufacturers provide refrigeration units but shop owners pay the running costs. There is a significant second-hand market that has no information on energy performance.
- Many agricultural and smaller food and beverage processors have limited in-house expertise regarding refrigeration, while many contractors have trade backgrounds and lack training in high efficiency practices.
- Much of the equipment manufactured for commercial and small industrial refrigeration is manufactured by SMEs that have limited RD&D capacity, and there is variable effort across sectors. Some, such as the dairy industry, are active, and could be used as models for other sectors.
- The E3 Committee recently issued a consultation Regulatory Impact Statement on commercial refrigeration equipment. While its recommendations for mandatory energy performance standards are weak, there is in fact potential to broaden the range of measures and significantly enhance standards cost-effectively[25].

[25] See RMIT submission at http://energyrating.gov.au/consultation/consultation-ris-refrigerated-display-and-storage-cabinets

Key organisations involved

- The E3 committee is responsible for national programs to improve energy efficiency of refrigeration equipment, motors, fans and other equipment related to refrigeration. It has extensive contacts throughout the industry.
- AIRAH and ARA, and other associations, including specialist groups like the Winery Engineering Association (http://www.wea.org.au/).
  - Food Innovation Australia Ltd (*https://**fial**.com.au/*)
- Plumbing trainers and regulators could develop new training units for industrial and commercial equipment.
- CSIRO network of researchers involved in food processing technology development.

Table 3: Refrigeration Overview

Note Energy Productivity can be increased by improving energy efficiency, reducing activity costs, increasing sale value of product, reducing energy price paid/on-site generation.

(NOTE: VC=Value Chain). Estimates of the scale of energy use are preliminary only.

ACTIVITY	SCALE OF ENERGY USE, saving potential	EXAMPLES OF INNOVATIONS WITHIN SCOPE	BEYOND PROJECT SCOPE
Household refrigeration	~10% VC primary energy Saving potential 60% c/f stock	Step changes in household appliance efficiency: cascaded compressors/advanced thermo-electric, aerogel and evacuated panel insulation, real-time fault diagnosis/alerts	Incremental household energy efficiency – appliances, behaviour, diet change, identify and remove inefficient stock
Transport refrigeration	~1% of VC primary energy, but occurs at several points in value chain. Saving potential 60+%	Reduce distances/time; shift to electric compressors (EV, energy recovery, plug-in to grid during stops); water misting of condensers (1.5 litres/hour= 1kWthermal); upgrade insulation – aerogel/ vacuum panel/ high performance foams, minimise thermal bridging; integration of all; cold chain mgt.	Incremental improvements: A2EP freight transport roadmap
Industrial refrigeration	<5% of total primary energy for VC. Saving potential 50+% (Refrigerant leakage maybe 2% of emissions from VC)	Chilling/freezing: alternative preservation methods; pre-cooling (ambient, waste 'coolth'); energy storage (thermal and/or electrical), demand mgt. and on-site RE reduce peak loads and capital costs, may improve efficiencies; cascaded chillers; lower condenser temp (misters, water body, ground source, etc.); high efficiency fans/motors (and aero system design) and pumps (and hydraulic system design) Storage: improve thermal performance of cold rooms etc.: advanced insulation, minimise thermal bridging, air locks; chiller eff – see 'chilling' above. Refrigerants: cut leakage and shift to low GWP refrigerants	Incremental improvements: A2EP manufacturing roadmap
wholesale storage refrigeration	<5% of total primary energy for VC. Saving potential 50+% (Refrigerant leakage maybe 2% of emissions from VC)	See 'industrial' and 'retail'	A2SE built environment Roadmap
Retail, commercial refrigeration	~10% of total primary energy for VC. Saving potential 50+% (Refrigerant leakage maybe 4% of emissions from VC)	Process innovation, high efficiency equipment, cut losses from open refrigerators and glass-door refrigerators, cut refrigerant losses, online shopping, efficient fan systems	Incremental improvements, e.g. improved management, behaviour change

ACTIVITY	SCALE OF ENERGY USE, saving potential	EXAMPLES OF INNOVATIONS WITHIN SCOPE	BEYOND PROJECT SCOPE
Farming refrigeration	~1% primary energy in VC. Saving potential 50+% (Refrigerant leakage maybe 1% of emissions from VC)	On-site partial dewatering; efficient equipment; ambient pre-cooling; process innovation (e.g. use thermal storage and on-site RE); utilise waste heat from refrigeration	Incremental improvements; broader structural change, e.g. changing crops, A2EP agriculture roadmap
Waste management	Small in terms of direct energy use, but avoiding waste reduces amounts of food produced, processed, transported – and hence refrigerated	New technologies to cut waste, reprocess, extract valuable elements of waste streams,	Waste minimisation throughout value chain, behaviour change, material recovery infrastructure provision. Note that diverting waste at point of consumption to consumption reduces the need for production upstream
TOTAL refrigeration	25-30% of primary energy in VC (Total refrigerant leakage around 10% of emissions from VC – total VC emissions around 100 Mt)	~10% of total refrigeration in VC is residential appliances. High share of value chain energy use is because refrigeration is widely used, energy intensive (as practised) mostly uses electricity, which consumes 3 units of primary energy per unit of final energy	

Optimisation of the 'Cold Chain'

There are opportunities for improved refrigeration not only in each unit operation, but also along the chain. A particular technologically-facilitated opportunity is to use IOT, ICT and cloud computing to track and optimise product temperatures across the chain. The current arrangement is that at every step of the chain operators set refrigeration temperatures in the refrigerated spaces (not the actual product) and overcool to ensure product safety with a very large margin for error.

The new energy productive concept is having low cost temperature sensors and transmitters on batches of food, with a cloud computing application continuously monitoring product temperatures. This would allow for increased evaporator temperatures throughout the chain (saving energy), and at the same time improving quality and reliability/safety, driving large EP benefits.

Case study A – Utilisation of radio-frequency identification (RFID) and digital temperature recorders

Cold supply chain optimisation

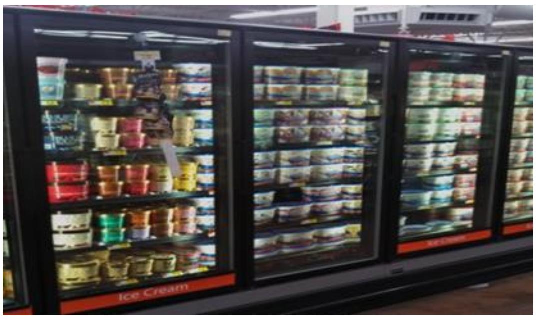
Key organisation(s): Walmart

Innovation: In its pursuit of lower consumer prices Walmart investigated the use of RFID technology and digital temperature recorders in its cold supply chain inventory tracking system. The state-of-the-art technology and network design allows Walmart to accurately forecast demand, track and predict inventory levels, create high efficiency transportation routes, monitor and manage the effects of various temperature conditions on perishable produce.

The aim of the combined RFID and digital temperature recorder tracking is to decrease shrinkage due to food spoilage and to have faster response to equipment failure. This design allows the user to access both the traceability and sensor information.

Benefits: This technology has enabled Walmart to optimise its supply chain, reduce waste and increased product availability for consumers, through efficient inventory management e.g. selling produce that may be spoiling sooner first. Reduced shrinkage due to reduced loss of water content means higher sales revenue, as most product is sold by weight. Energy savings by helping to identify faulty equipment before it wastes a lot of energy and leads to loss of saleable food, and sub-optimal operation of refrigeration equipment.

Combined use of RFID and digital temperature recorders also offer a broader array of advantages compared with traditional barcodes. They store more data, provide real-time information, and can be scanned from a distance and without a clear line of sight.



EP potential: RFID and digital temperature recorder solutions, like those used by Walmart have the potential to greatly improve EP across the manufacturing supply chain, by matching supply and demand needs of businesses.

Status: Walmart has used RFID tags for decades and in recent years have begun using digital temperature recorders to further optimise its supply chain. RFID combined with temperature monitoring has been adapted by a variety of businesses in recent years to reduce waste, increase efficiency of shipments to decrease dependence on transport and respond to consumer demand for fresher produce. Technology is currently estimated a TRL 7 and CRI 3.

Barriers: For RFID and digital temperature recorders to be used efficiently, the total supply chain must be on board. Although Walmart encourages its suppliers to use digital temperature recorders in the cold supply chain, the company has not enforced a mandatory policy. This is because of the relatively high cost, difficulty of establishing a return on investment, reliability and accuracy. All these components have the potential for improvement with further cold chain application.

Digital Temperature Recorder Information

http://www.freshplaza.com/article/114875/Wal-Mart-approves-digital-temperature-recorder

http://www.iifiir.org/userfiles/file/publications/notes/notefood_04_en.pdf

Walmart

Packaging

Packaging is a mixed blessing from an energy productivity perspective. On one hand, it can play a key role in extending product shelf life, protecting it during transport and presenting it to buyers in an attractive way. All these features add value and/or reduce energy waste by avoiding the energy cost of producing unsaleable product. Modified atmosphere packaging involves replacing oxygen with an inert gas or, for fruit and vegetables, designing the packaging film to allow in controlled amounts of oxygen.

But packaging requires significant energy and resource consumption. For example, in one Australian study, manufacture of a glass wine bottle generated around 0.6 kg CO_{2e}, 20% of the total cradle to consumer greenhouse gas emissions in wine production, and equivalent to driving a car about 3 kilometres. A 15 gram aluminium tray incurs a primary energy 'cost' of around 3 MJ, equivalent to enough electricity to run an electric oven for up to 15 minutes. And if using an aluminium tray leads consumers to reheat the food in a conventional oven instead of a microwave oven, energy use is much higher.

So, it is important to minimise energy and resource use of packaging, and where it is necessary, maximise recovery and recycling at end of life. This topic is not dealt with in more detail in this project as it is out of scope. [RMIT has done work on the life cycle benefits of packaging - http://mams.rmit.edu.au/ie9rn2ifqca.pdf]

The recommendations of the RMIT (Verghese et al, 2015) study include:

1) Distribution packaging that provides better protection and shelf life for fresh produce as it moves from the farm to the processor, wholesaler or retailer. This may require the development of tailored solutions for individual products.
2) Distribution packaging that supports recovery of surplus and unsaleable fresh produce from farms and redirects it to food rescue organisations. The packaging itself also needs to be recoverable to minimise overall environmental impacts.
3) Adoption of new packaging materials and technologies, such as modified atmosphere packaging and oxygen scavengers, to extend the shelf life of foods.
4) Education of manufacturers, retailers and consumers about the meaning of use-by and best-before date marks on primary packaging to ensure that these are used appropriately. Confusion about date marking results in food being thrown away when it is still safe to eat.
5) Product and packaging development to cater for changing consumption patterns and smaller households. Single and smaller serve products will reduce waste by meeting the needs of single and two person households.
6) Collaboration between manufacturers and retailers to improve the industry's understanding of food waste in the supply chain. Greater attention to be given to where and why this occurs, tracking over time, will reduce the costs and environmental impacts of waste.
7) More synchronised supply chains that use intelligent packaging and data sharing to reduce excess or out-of-date stock.
8) Increased use of retail ready packaging to reduce double handling and damage and improve stock turnover, while ensuring that it is designed for effective product protection and recoverability (reuse or recycling) at end of life.

Consideration of the interaction between packaging and cooking energy use also seems potentially significant, as discussed below in Process heat and cooking.

6.1.2. Dewatering and drying

Name of technology or measure: DEWATERING AND DRYING

Area(s) of potential application and context

Services provided: Dewatering and drying is a major energy consumer, and plays a critical role in production of dry food products. It can be a major contributor to energy consumption at each stage of the value chain. It is often combined with cooking, but can be separated from the cooking process, which is addressed later.

What it is and how it works

Specific services dewatering and drying delivers are:

- Reduction of water content, as food is cooked and quality is stabilised, or for producing more concentrated product;
- As a means of preserving food through production of dried products such as powdered milk, dried fruit, etc.;
- As part of a food production process, such as malting, where grain is soaked, sprouted, then dried.

Energy productivity fundamentals for dewatering

Most dewatering and drying is achieved through heating, to evaporate water. Evaporating water uses large amounts of energy. To evaporate one litre (1 kg) of water requires about 2.3 MJ (0.64 kilowatt-hours) of heat energy, while raising the temperature of water by one degree consumes only 0.0042MJ of heating. So, heating water from 20C to the boiling point requires 0.34 MJ, then boiling it requires another 2.3 MJ. In practice, actual efficiencies are often poor, so much more energy may be consumed.

In many cases, this heat is provided by burning fossil fuels in systems with overall efficiencies of 50% or less. With gas prices increasing, this places an increasing cost burden on food processors. At a gas price of $10/Gigajoule and efficiency of 50%, the cost of removing a litre of water by evaporation is over 5 cents. Two key approaches to improving energy productivity apply technologies that avoid evaporation, or recover heat from water vapour (and upgrade it above boiling point so it can be re-used to evaporate more water).

Drying product that has cell membranes (e.g. grain, woody material), or is thick can be difficult, as the membranes can block or slow transfer of water or water vapour or the rate of movement of the water and water vapour through the material may lead to variations in dryness within the product. Options such as microwave heating that penetrate the food can increase rate of drying and potentially improve productivity and/or overall drying efficiency in such situations.

Drying product to a low water concentration can be difficult in some conditions, such as humid, hot weather, where the capacity of drying air to absorb additional water vapour may be limited. Where direct gas heating is used, the additional water vapour added to the drying air as a product of combustion can also reduce the drying effectiveness. Under conditions such as these, other options such as closed loop drying using a heat pump, either as a replacement, or for a final drying phase, can improve energy efficiency and productivity, while improving consistency and quality of product.

The key principles regarding energy efficiency improvement of evaporation processes are:

- Removing water using free ambient energy or by methods that avoid heating can be far more energy efficient than evaporation using heat. Options include forced evaporation using an efficient fan system and ambient temperature; microfiltration; centrifuging (high speed rotation); and crushing.
- Methods of evaporating water using less energy include:
    - Microwave heating where water must be removed from within a shell or cell membrane, which acts as a barrier to reduce conventional heat and water vapour flow, because the heat is generated within the item to be dried.
    - Reuse of heat recovered from the exhaust water vapour and product stream. Much of this potential 'waste' heat is in the form of latent heat in the water vapour in exhaust air. Condensing the water vapour releases this heat, but this delivers heat at below 100C that may be useful if there is a large demand for lower grade heat elsewhere in a site, but otherwise would be lost. If the recovered heat is to be used to replace a large proportion of the process heat, it must be 'upgraded' to a temperature high enough to again drive evaporation of the water from the incoming product. This can be done using new technology such as high temperature industrial heat pumps or vapour recompression, or by depressurising the main evaporation process so that it occurs at a lower temperature (just as the boiling point of water is lowered at high altitudes where air pressure is lower).
- Heat should be provided at the lowest temperature sufficient to perform the task, and heat losses from the system providing the heat (often a boiler and steam distribution system) should be minimised.
- Combinations of technologies can be used in series, and (at least partial) dewatering can be done before cooking, and even before transport from the farm.
- There is potential in some cases to shift from traditional batch operation to continuous processes, so that heat recovery and product consistency can be improved.

How can it contribute to energy productivity outcomes?

Increasing costs of gas and electricity are making traditional dewatering and drying more expensive. New technology can provide an effective response. Developments in renewable energy and heat pump technologies are providing alternative sources of energy (often at lower temperatures than fossil energy sources, but still hot enough to drive the processes). Improved energy efficiency solutions are reducing the amount of energy required, and making advanced technologies more affordable. For example, mechanical vapour recompression is now able to reduce drying energy requirements by up to two-thirds. Prototype industrial heat pumps in Japan can produce steam from 60C input heat at a Coefficient of Performance of 3 (i.e. 3 units of heat per unit of electricity input)[26].

Development of modular technologies also means they can be applied close to the point of use, reducing heat distribution and standby losses and costs, including lower maintenance and staffing costs, and allowing optimal operation to match demand. This is critical in manufacturing sites where unwieldy steam systems with poor condensate return may waste half the total energy supplied. One

[26] International Energy Agency Heat Pump Program *ANNEX35 Application of Industrial Heat Pump, TASK 3 Apparatus technology, 1. Overview of industrial heat pump technology in Japan* (2013)

of the key EP improvement opportunities is to use new technologies to allow companies to remove their entire steam or hot water reticulation systems.

New modular technologies can also be deployed at different points in the value chain, so they can capture additional savings. For example, partial dewatering of milk using membrane technology to double the concentration of milk at the farm can deliver multiple benefits including:

- Reducing refrigeration costs at the farm, as well as reducing peak refrigeration capacity required and storage capacity, and hence capital costs.
- Providing water at the farm for stock or other purposes.
- Reducing the volume of milk to be transported, increasing transport productivity and saving fuel.
- Reducing drying and processing energy and capacity requirements at the processing plant. (where necessary, extra water can be added back downstream in the value chain (similar to 'post-mix' soft drinks produced in hotels and bars).

In some cases, improved dewatering processes can deliver more saleable product. For example, improved extraction of juice from grapes increases wine production while also capturing more flavour.

The major opportunities for energy productivity improvement in dewatering and drying related to 'farm to plate' are:

- Reduce energy required in these processes
- In some cases, reduce capital costs of equipment and/or peak energy demand
- Improve quality and consistency of product
- Conduct these processes earlier in the value chain, reducing the amount of material to be transported and processed.

Energy Productivity Implications:

- Shift energy requirements from fossil fuels (largely gas) to smaller amounts of electricity, which can be supplied from renewable sources.
- Reduce the temperature and/or amount of heat required from renewable heat sources, thereby reducing size and capital cost, or allow low grade waste heat to be better utilised.
- Allow food processing plants to be established in areas where low cost natural gas is not available, so that more rural regions may value add locally, creating local employment and reducing bulk transport requirements.
- Improve product quality and consistency of output.

Barriers to and opportunities that may increase rate and scale of adoption

- Adoption of new techniques involves cultural change, retraining and potential dislocation, as well as a need for demonstrations and commercialisation and manufacture of equipment.
- Existing processing plants may be less profitable or be phased out and investment required in new plant

- Many agricultural and smaller food and beverage processors have limited in-house expertise regarding these technologies, while many contractors have trade backgrounds and lack training in high efficiency practices.
- These technologies are already used in some sectors, so the technical expertise from these sectors could be applied in other sectors, creating business opportunities.
- RD&D expertise exists that could be used to adapt these technologies for other applications.

Key organisations involved

- CSIRO network of researchers
- Dairy researchers

Table 4: Dewatering and Drying Overview

Note energy productivity can be increased by improving energy efficiency, reducing activity costs, increasing sale value of product, reducing energy price paid/on-site generation

ACTIVITY	SCALE OF ENERGY USE, saving potential	EXAMPLES OF INNOVATIONS WITHIN SCOPE	BEYOND PROJECT SCOPE
Household food preparation	~4% of value chain total primary energy Saving potential ~60% c/f stock	See 'cooking', as dewatering is a major (and energy intensive) component of household cooking	Incremental household energy efficiency – appliances, behaviour, diet change, identify and remove inefficient stock
Wholesale storage	small		
Retail, commercial	Sector is around 11% (retail) +14% (commercial food services) of VC primary energy	Commercial food preparation – see cooking	Incremental improvements, e.g. improved management, behaviour change
Industrial	~32% of sector primary energy is heat and electricity for dewatering and drying, 6% total primary energy for VC Saving potential 50+%?	Replace central steam systems with modular, depressurisation, centrifuges, micro-filtration etc.; replace gas with advanced electro-techs; improved waste heat recovery (including by using heat pumps)	Incremental improvements: A2EP manufacturing roadmap will address
Farming	Up to 0.5%,	efficient equipment; process innovation, application of modular dewatering technology	Incremental improvements; broader structural change, e.g. changing crops, integrating tourism

Case Study B – On-farm dewatering

Dewatering in the dairy industry

Key organisation(s): Yanakie Dairy Farm, Gippsland and Tetra Pak Pty Ltd

Innovation: A research project into the feasibility of removing 50% of water from cow milk on a dairy farm in Gippsland and identifying end uses for the water were carried out by Tetra Pak Pty Ltd. A demonstration unit was installed in 2011 and tests were carried out to determine the quality, quantity and options for water reuses.

A reverse osmosis system manufactured by Tetra Pak Dairy & Beverage was leased from New Zealand and retrofitted to suit the needs of the trial on the Gippsland Dairy Farm of Yanakie.

Resulting data showed it was feasible to economically extract water on a dairy farm from milk and to utilise the extracted water for beneficial uses such as milk machinery and yard cleaning, irrigation, pre-cooling and animal drinking water.

The project successfully extracted water from milk. The system was found to be capable of producing 400 l/hour of water. This water was found to be suitable for pre-cooling of milk as it leaves the cow. This water is already chilled as the milk entering the reverse osmosis system was coming from the vat that had milk stored at around 4C.

Benefits: Preliminary assessments have conveyed a payback period of one to two years for the system. It was shown that up to 50% of the milk volume can be extracted as water. The remaining concentrate can be transported to the milk factory requiring less transport capacity. The project identified the following benefits:

- Scope to utilise chilled water produced to save energy
- Transport to manufacturer savings
- Milk machinery cleanliness
    - Optimal chemical use
    - Milk quality
    - Equipment longevity
- Potential milk production improvement from feeding cows cleaner drinking water
- Reduced energy consumption at processing plant for drying.

EP potential: It was estimated that transport savings related to delivering milk to milk factory would be approximately $30 per kl. There are also benefits of feeding clean water to the cows for dinking and increased effective storage capacity for milk storage, as dewatering reduces volume. Process energy savings for drying at plant.

Status: Opportunities exist to further enhance the system to optimise the operation and to customise the system to suit the specific needs of the demonstration dairy farm. Technology is currently estimated at TRL 5, further development from the learnings of the feasibility study

Barriers: Potential barriers to uptake can be identified as:

- Lack of funding from Commonwealth and State Governments to further the research and development work.
- Upfront cost of initial investment, even with the one to two year payback period – the farming community may lack confidence in the technology.
- Not yet commercially available for dairy farmers.

Report information

All information and images for this case study has been extracted from the 2012 Cleawater Final Report 'On Farm Milk De-Watering System for Reuse' prepared by Glen MacMillan.

Available here in full - https://www.clearwater.asn.au/resource-library/smart-water-fund-projects/on-farm-milk-de-watering-system-for-reuse.php

6.1.3. Process heat and cooking

Services provided: Conversion of raw food into a variety of edible products of higher value often involves use of heat for:

- Removal of water (see DEWATERING)
- Sterilisation and pasteurisation
- To provide energy for chemical processes involved in cooking
- Other process heat such as during packaging and space heating

How big an issue?

A recent study for ARENA[27] investigated the use of heat in industry. It concluded that dairy, beverage & tobacco and other food manufacturing used 8.4% of gas sourced industrial heat identified in the study. The Office of the Chief Economist (Table A, 2015) suggests that the whole food and beverages sector uses about 80PJ of energy (as well as 90 PJ of biofuels mainly used by the sugar industry), of which 30% is from electricity. OCE suggests the sector uses 40 PJ of gas and 17 PJ of coal and oil, compared with the ARENA study's 35 PJ of heat. (This study does not look at the sugar industry in detail, so all energy data referred to excludes sugar processing).

Table 5: ARENA study of industrial heat requirements (PJ/year)

Note temperature of heat shown is delivered temperature, not necessarily that required for the process.

	<150C	150-250C	250-800C	800-1300C	TOTAL
Dairy products	3.6	3.6			7.2
Beverage & Tobacco	0.8	1.8	0.8		3.4
All other food manufacturing	9.0	10.6	4.5		24.1

A substantial proportion of the heat used in this sector is for dewatering, which is considered elsewhere. It seems likely that most industrial cooking and pasteurisation occurs in the 'all other food manufacturing' sector, so it may be in the range of 10-20 PJ final energy. The bulk of this energy is likely to be gas, but this is a judgement based on limited data.

Data on energy for cooking in the commercial sector is scarce. Brent Hawkins from Beyond Zero Emissions used data from their extensive buildings study to suggest commercial cooking is 19% of Australian commercial final energy use of around 310 PJ – around 60 PJ, much of which may be electricity, as commercial sector gas use is quite low (51 PJ, of which most is believed to be used for space heating and hot water). Few other studies even try to separate out commercial cooking as a separate activity. EMET and Solarch's 1999 baseline study of commercial energy use for the Environment Department estimated commercial sector cooking at around 10% of the sector's

[27] *Renewable Energy Options for Australian Industrial Gas Users* IT Power (2015) report for ARENA

greenhouse gas emissions: this puts EMET's estimate of primary energy for commercial cooking somewhere between 20 PJ (all electric) and 100PJ (if all gas – impossible because total commercial sector gas use is only 51PJ according to the Office of the Chief Economist's data). In the residential sector, the recent EnergyConsult Baseline study (2015) puts cooking at 19.1 PJ, with 10 PJ electric and 9.1 PJ gas and other fuels.

To summarise, we see cooking energy, pasteurisation and process heat including:

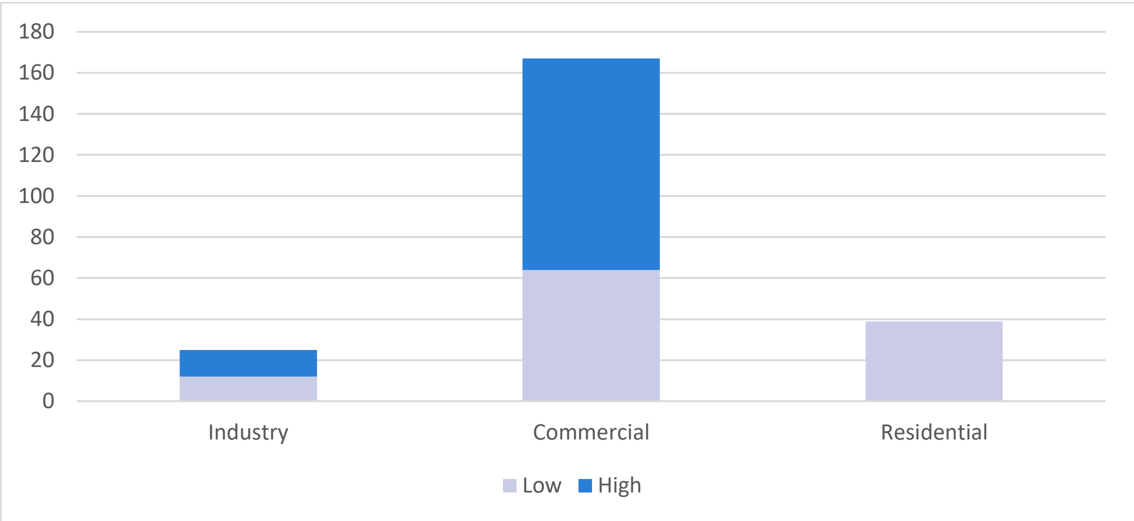
- Industrial 10-20PJ (maybe 12-25PJ primary energy), mostly gas
- Commercial 30-60PJ (65-165 PJ primary energy), assuming final energy of 10 PJ from gas, with the rest from electricity
- Residential 19.1 PJ, with 10 PJ of that from electricity - around 40 PJ primary energy.

Overall, this means cooking and other process heat is around 50-100 PJ of final energy, 120-230 PJ primary energy, around 11 to 18 million tonnes of CO_2 emissions and around 12 to 23% of primary energy use in this value chain. Up to 72% of cooking primary energy use seems to occur in the commercial sector. This may seem surprisingly high, but it includes a lot of display of hot food, and cooking in restaurants and many fast food venues is very inefficient, while many of these venues do not use gas. In contrast, many industrial sites use gas, capture economies of scale, and utilise at least some of their waste heat.

This analysis is summarised in Figure 12 below.

Figure 12.: Approximate breakdown of cooking and process heat other than dewatering/drying

High and low estimates of primary energy use in the food value chain (PJ/year primary energy)



Indirect energy impacts of cooking and process heat through increasing heating and cooling loads are also likely to be very significant, particularly in the commercial sector and, to some extent, the residential sector, as discussed below. For example, a typical residential exhaust fan removing 600 cubic meters per hour of air when the outdoor air is 10C colder or hotter than indoors is removing or adding 2 kilowatts of heat with the outdoor air it is drawing into the house. Since a gas cooktop is only around 35% efficient, 65% of the heat from the gas is released into the kitchen – almost twice as much heat as that delivering the cooking service. In contrast, an induction cooktop, at around 85% efficiency, is dumping less than 20% as much heat beyond what is being used to cook the food. And an exhaust fan may be run at a higher speed when cooking with gas, to remove the extra heat and fumes. Cooking practices are also very significant: cooking without a lid can use five times as much energy as with a lid. Cookware is very rarely insulated, while many ovens are poorly insulated, have significant thermal inertia, and release hot exhaust air into the kitchen.

There are opportunities to improve the energy productivity of heating and cooking processes at the commercial, industrial and residential stages of the supply chain.

Efficient Heat Transfer

Throughout industry, substantial effort has been put into improving the efficiency with which heat is transferred to product, and recovered from waste. The focus of this report is on significant emerging solutions, but it is useful to note that there is much scope to improve heat transfer by applying best practices (possibly from other industries) and incorporating incremental improvements. Some options that could potentially be used more widely include:

- Replace indirect heating with more direct options such as direct fired dryers, noting the potential for contamination from combustion gases and production of moisture in combustion: savings of up to 45% can be achieved
- Utilise multi-stage heat transfer systems, such as 'multiple effect' systems when using steam for heating. Such a system has a series of heat exchangers, each operating at lower pressure than its predecessor (with later stages even operating below atmospheric pressure). Effectively, vapour condenses in each stage, transferring heat to product at a specific temperature and at a high heat flow density. As it moves to the next stage, its pressure is reduced so it becomes a mix of vapour and liquid condensate. The condensate is drained and returned to be reheated while the vapour is used as a source of heat in the next stage of heat transfer as it condenses. This approach can maximise the utilisation of the input heat.
- Maximise heat transfer area: microgrooves, fins and other surface treatments can significantly increase heat transfer area within a given space
- Minimise fouling, as this increases resistance to heat flow: improved monitoring and new surface treatments can help optimise frequency of de-fouling
- Minimise boundary layer effects, again to minimise resistance to heat transfer: advances in fluid dynamics modelling are leading to new approaches such as jet impingement that can significantly enhance heat transfer

Commercial cooking

It seems that commercial sector cooking should be a major focus for energy productivity improvement in cooking. The main aspects of cooking activity that involve energy use include:

- Driving the chemical processes involved in cooking, that change flavour and structure, while sterilising
- Dewatering, often by boiling or 'simmering' (slow boiling)
- Heating food and cooking equipment from ambient temperature to cooking temperature – note that, in industrial processes some of this heat may be recovered and utilised, while this is rarely the case in household or commercial services. Burning of cooking fats and oils also consumes some energy, although this is likely to be minor

- Efficiency of cooking equipment, noting that the waste heat from inefficient cooking equipment is released into the immediate environment
- Re-heating or reconstituting of food previously prepared elsewhere or on-site and refrigerated, frozen or preserved in some other way (e.g. industrial drying of pasta). This can be very inefficient, as it can take a long time to heat the core of frozen food to a safe and edible temperature, and this may also involve heating up the materials of an oven from ambient temperature. The latent heat of frozen food varies from 0.2 to 0.3 megajoules per kilogram, which is multiplied by the inefficiencies of the cooking equipment.
- Other interactions with the immediate environment, such as condensation of steam from cooking, use of exhaust fans to remove odours and steam, and impacts on space heating and cooling energy due to heat released by cooking and removal of air from conditioned spaces by exhaust fans or other ventilation mechanisms.
- Sale of food in containers unsuited for reheating in a microwave oven can lead to extended use of a conventional oven, which uses far more energy. Attitudes are also significant: many people do not realise you can safely reheat food in open aluminium containers in a microwave oven - although you need to know the guidelines to keep it away from the walls of the oven to avoid sparking.
- Changes in transport energy requirements of different cooking solutions, such as switching between personal car use for food shopping, collection of take-away food, delivery of food or hot meals, etc.

So, the overall energy impact of cooking can be far greater than the energy actually used for cooking.

Industrial – Food and Beverage Process Heat

Pasteurisation is common in industrial processing to kill bacteria. When heat is used, the product is typically heated to above 65C for a specified period: the higher the temperature, the shorter the period required, but the greater the risk of changing flavours or textures. Where a liquid can be pasteurised in bulk, efficient counter-flow heat exchangers can be used to recover a high proportion of the heat. Pasteurising after packaging is more difficult, as the container acts as a barrier limiting heat transfer. In some breweries, pasteurisation of bottles of beer can achieve as low as 25% heat recovery. Heat for pasteurisation is often supplied via central steam systems, at temperatures far higher than are actually needed, with significant energy losses.

Emerging pasteurisation options replace heat with other mechanisms that kill or physically damage pathogens. This reduces or avoids the need for heat, but replaces heat with electricity, so the net impact on energy cost and loads on energy infrastructure must be considered. Alternative processes may offer value adding benefits, such as extended shelf life or maintenance of more attractive texture or taste. So, the overall outcome must be evaluated.

Technologies that avoid heating are emerging[28] and, in some cases, have been available for many years. They include:

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[28] Wang, L., *Energy efficiency technologies for sustainable food processing*, Energy Efficiency, 2014, Volume 7, pages 791-810. Retrieved from https://www.researchgate.net/publication/271917124_Energy_efficiency_technologies_for_sustainable_food_processing

- Microfiltration
- Microwaves
- Ultrasonics
- High pressures (2 new technology factories have just been commissioned in Australia for baby food and juice)
- Irradiation (electron beams, X-rays), which can be controversial
- Ultraviolet light (especially suitable for sterilising containers used with bulk sterilisation).

In some cases, it is possible to maintain sterile production conditions so that pasteurising is not needed when the product is to be consumed fairly soon, the cold chain can be well managed, or advanced packaging is used.

This project focuses on emerging technologies that offer potential to improve energy productivity by a substantial margin, so our focus is on improving or replacing:

- Processes associated with cooking, pasteurisation and processing that waste a high proportion of the total energy when existing technologies and methods are used.
- Indirect energy impacts associated with heating and reheating.
- Capture of non-energy benefits, such as extended shelf life or aesthetics.

Energy productivity fundamentals

Pasteurisation is used to extend shelf life and ensure food safety. If heat is used, in theory high efficiency heat recovery should provide almost all of the required heat, apart from start-up (which could be partly served by storage of heat from previous operation, solar energy or other low emission heat sources). Heat pumps can, in principle, very efficiently upgrade recovered heat to a temperature high enough to pasteurise using as little as a fifth of the electricity required by resistive heating, and can operate on renewable electricity. So, there is substantial scope to adapt existing pasteurisation systems to achieve very low emissions.

Historically, low gas prices relative to electricity, large centralised pieces of equipment, and large scale processing plants have worked in favour of using heat. And optimising use of heat can deliver very high efficiency. But gas prices are rising, and some emerging business models wish to locate away from the gas grid.

Alternative pasteurisation technologies offer other benefits such as longer shelf life, and maintenance of texture and taste. At the same time, declining costs of renewable electricity, energy storage, modular equipment and precise controls have improved the performance of alternatives. Some business trends have also favoured options. For example boutique breweries may even be able to avoid pasteurising through sterile processing and less need to achieve a long shelf life.

The proportion of total energy associated with cooking is not well documented, as the solutions chosen impact on the energy used for refrigeration, reheating (sometimes multiple times), space heating and cooling, transport, social activity and more.

Commercial restaurant, hotel restaurant, and household kitchen cooking activities The cooking activity is typically straightforward, as the objective is to heat food to an appropriate temperature for long enough to cook it. The process may involve frying, grilling or other techniques intended to produce the desired flavours and textures.

Energy productivity improvements include:

- Changing the amount of heating or cooking required, through reduction of waste of prepared food and uncooked food ingredients, change in diet, change in downstream cooking behaviours (e.g. bulk or communal cooking at home)
- Shifting cooking activity from one stage of the value chain to another, while recognising the potential impacts of indirect effects such as increased energy used for display of heated food and operation of restaurant facilities, transport associated with different cooking and eating patterns, reheating food, cooling hot food for storage, etc
- Improving efficiency of heating processes by equipment design and controls, fuel or technology switching, energy recovery
- Reducing the indirect energy impacts of heat and water vapour produced during cooking
- Business models that may increase the value added in the supply chain and capture value from potential co-products, co-services and wastes (both organic and inorganic)

In commercial and residential sectors, the varied nature of demand means that often small batches of food are cooked at low efficiency. Gas cookers may be only 35-40% efficient, while traditional electric cookers achieve around 60% efficiency. Induction cooktops can achieve over 80% end use efficiency. Small ovens are often very inefficient – under 15%. In the retail sector, large amounts of energy are used to keep food hot in display units that are often uninsulated and open to the air. The heat lost adds to local cooling loads. Major issues include:

- In residential and commercial sectors, user behaviour is a major factor (though this is outside the scope of this work). Failure to place lids on pots means evaporation rates may be high. Excessive boiling can increase cooking energy by around factor 5. In many commercial kitchens, gas burners and electric elements, chip fryers and other cooking equipment are left on, even when they are not delivering useful services, so that a chef can minimise time loss.
- Cookware, ovens, hot display units are often uninsulated or poorly insulated, with high air leakage so heat losses are high. Exhaust air may remove large amounts of heat from ovens. The thermal inertia of heavy pots, pans and other cooking containers can also contribute significant energy waste.
- Even in industrial bakeries and food production plants, heat recovery may be limited. Because of the 'batch' production, and losses in heat exchangers, any heat recovered may be at too low a temperature to be utilised for cooking.
- In many cooking facilities, ambient temperatures and radiant heat loads on staff may be high, leading to discomfort, lower productivity and high staff turnover.

Case Study C – Preshafood & CSIRO Food Innovation Centre: high pressure processing

Process heat/cooking alternative

Key organisation(s): Preshafood Ltd and CSIRO

Innovation: Preshafood manufactures premium fruit juices, seasonal fruit blends, smoothies and vegetable juices using high pressure processing (HPP). HPP is an emerging technology and uses very high pressures instead of heat processing to kill yeasts, moulds and bacteria. HPP extends shelf life without the use of preservatives and heating. Juices produced using HPP technology can be stored up to five times longer than other chilled juices.

Benefits: The HPP technology is not only applicable to juices but also across a range of product categories such as meat, poultry, seafood, fruit and vegetable products, meal solutions, dips and sauces. The technology has the potential to extend the shelf-life of cooled perishable products and provide improved safety, taste, texture, quality, fresh-like characteristics and nutritional value, without having to use chemical preservatives.

This technique used by Preshafood was developed by the CSIRO Food Innovation Centre. This research and development arm of CISRO works closely with the food manufacturing industry to develop innovative technological solutions to deliver value-add opportunities for industry in horticultural and grain produces, specialising in post-harvest technology, food technology, process engineering and advanced separations.

EP potential: HPP carries the potential to be used across the food manufacturing industry as highlighted above. HPP technology offers an alternative to traditional process heat technology and eliminates the need for added preservatives and improves the nutrient value of the manufactured product.

Status: The HHP technology is currently at a TRL of 9 (System has been tested, launched and operational) and CRI of 3 (commercial scale up). Thus, there is potential for multiple commercial applications and widespread market development in the near future.

Barriers: The largest foreseeable barrier for the uptake of HPP technology is the initial upfront capital investment needed and resistance from established manufacturing sector using traditional heat processing technologies.

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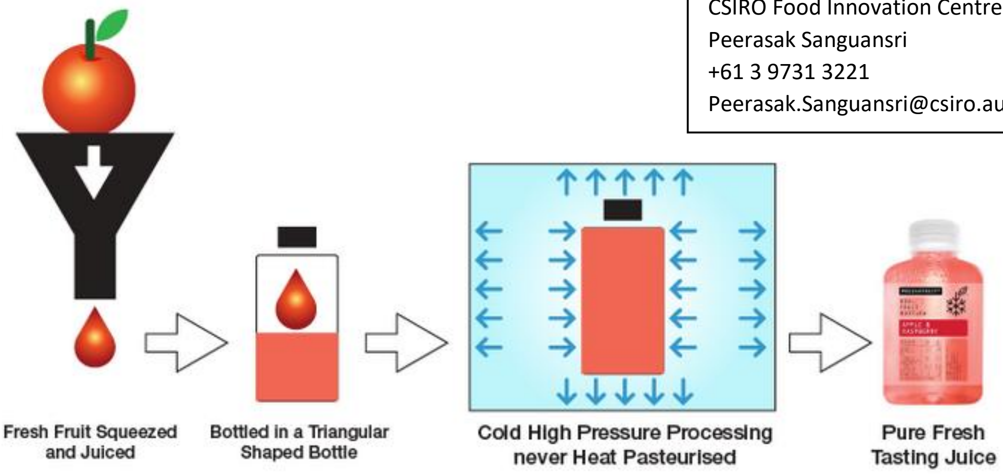


Image credit to http://www.preshafruit.com.au/process.html

Step changes in household cooking appliance efficiency could include: advanced insulated cookware with feedback to manage cooktop energy (or integrated heating element within insulation) to minimise 'over boiling' – for example, the efficooker[29]. Induction cooktops offer precision and up to 40% higher efficiency. Microwave ovens designed specifically to safely heat food in aluminium containers could replace conventional oven use. Extreme insulation of ovens is possible with aerogels, reflective insulation, etc to minimise wall thickness. Heat recovery can be incorporated into ovens to pre-heat inlet air. Examples of emerging cooking options include steam, 'air fry', pulsed electric fields (IXL Nutri-Pulse), bulk cooking (at home or service).

How can energy productivity outcomes be improved?

- Improved cookware design that incorporates insulation and limits boiling losses offers very large energy saving potential. For example, the prototype 'efficooker' which is insulated and has a heating element inside the layer of insulation halved cooking energy requirements relative to conventional pots on cooktops.
- The thermal inertia of ovens, cooking containers and cookware is a significant factor in energy waste in cooking. For example, the energy required to heat up an electric oven would run a microwave oven for 15 to 20 minutes. One industrial bread baker found that the heat capacity of the baking pans and conveyors used was 15% of baking energy. Evaporation of water from bread during cooking is around 35% of baking energy: a heat pump could potentially recover much of this[30].
- Lightweight, better insulated ovens with quadruple pane low-emissivity glass doors and heat recovery to transfer heat from exhaust air to inlet air can improve efficiency. The best performing ovens save 50 to 70% relative to less efficient models. A challenge is that, for household purposes, there is limited space for insulation, so high performance lightweight insulation such as aerogel and/or multi-layer reflective surfaces may be needed to achieve high performance and allow oven capacity to be maximised within standard cabinet dimensions.
- Benchtop cooking appliances, including slow cookers and ovens are typically poorly (or not) insulated. Uninsulated stainless steel containers are widely used in hotels and catering services: development of methods of incorporating insulation between two layers of stainless steel, so that cleaning and washing could be done without damaging insulation or adding to task complexity could transform the efficiency of cookware.
- For cooking, induction cooktops offer significant energy savings, and can out-compete gas for responsiveness. In commercial kitchens, the fact that induction cookers stop heating when the pot is removed, but can heat up rapidly, means they can save a lot of energy relative to the common practice of leaving a gas burner or heating element on continuously.
- In commercial and retail cooking facilities, chip fryers achieve low efficiencies, often around 25%. If easily controlled lids were fitted and the vats insulated, very large energy savings would be achieved while occupational safety would be improved and fat/oil consumption

[29] http://orbit.dtu.dk/fedora/objects/orbit:65590/datastreams/file_5825457/content

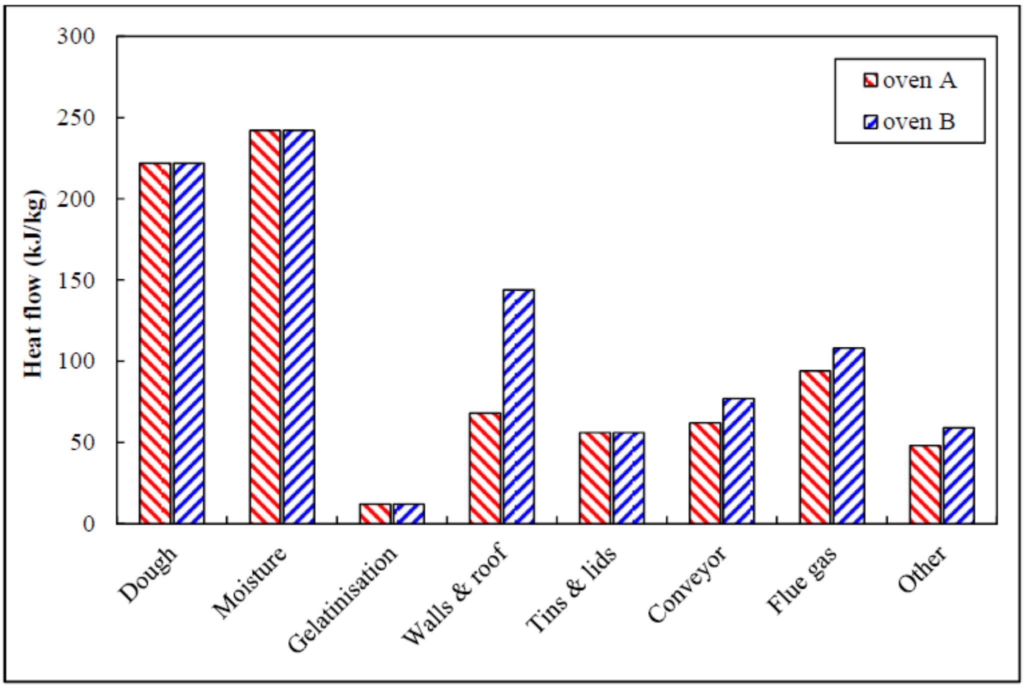
[30] Paton, J (2013) *Energy utilisation in commercial bread baking.* University of Leeds Mechanical Engineering

reduced. Fryers that use much less oil are also being developed: the challenge is to produce chips that taste 'right' and have the desired texture.

- In industrial facilities, high temperature, high performance heat pumps offer potential to upgrade waste heat to a temperature suitable for cooking, increasing the extent to which waste heat, including latent heat in water vapour, could be utilised (see IEA report).
- Thermal bridging between inner and outer liners of cooking equipment is a common means of heat loss. Careful design can avoid much of this energy waste.

Figure 13.: Energy used by industrial bread ovens

(Paton, J 2013 p. 115)[31]



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Barriers to and opportunities that may increase rate and scale of adoption

Note that research into this issue has not yet been funded, so the comments below are preliminary observations.

- The need for easy cleaning and limited space, combined with tradition, means that simple metal cookware dominates, despite its thermal inefficiency.
- To minimise labour costs, compact, quick response cooking solutions are a priority.
- The need to display food for sale, as well as the significance of aesthetics in presentation of food also distract attention away from energy efficiency.
- Energy losses associated with extraction of air from above cookers comprise an invisible energy waste that requires radical redesign and smart control systems.

Key organisations involved

[31] Paton, J (2013) *Energy utilisation in commercial bread baking.* University of Leeds Mechanical Engineering

- The E3 committee is responsible for national programs to improve energy efficiency of appliances and equipment, but it has paid little attention to cooking equipment.
- CSIRO has a network of food researchers who have relationships with the relevant industries.
- A significant proportion of commercial and industrial cooking equipment is locally made, because much of it is custom made, and it is bulky to transport. CSIRO and other research groups already have relationships with some key industries.

Case Study D – Ferguson Plarre Bakehouses energy efficiency program

Reducing energy use in a baked goods business

Key organisation: Ferguson Plarre Bakehouses

Innovation: Melbourne based Ferguson Plarre Bakehouses operates a central bakehouse with over 50 franchise shop fronts. They invested in a range of energy efficiency improvements including:

- Replacement of existing equipment with the most energy efficient ovens and cooking equipment sourced from Europe
- Co-locating ovens side by side in an insulated room to concentrate heat and use radiant heat from one oven to heat others
- Separating ovens from the rest of the bakery with insulation and air tight door, minimising heat loss to adjoining spaces
- Recovering heat from cooling baked products with exhaust fans to provide heat from the main production area in winter
- Pre-heating water entering hot water systems with energy recovered from equipment such as compressors in refrigerators
- Using solar hot water systems for the staff and office (the majority of the hot water used in the bakery is provided using a heat exchanger)
- Using a diesel hybrid truck to deliver baked goods from the central bakehouse to shop front, and reducing the number of trips by half, improving fuel efficiency by 25-30%

- Installing a fully programmable and automated energy efficient lighting system
- Offsetting emissions, including transport related emissions, through accredited offsetting schemes
- Using a fully integrated SCADA (supervisory control and data acquisition) energy and water monitoring system to enable 'real time' monitoring of water and energy consumption and greenhouse emissions. Displayed in high traffic corridor to encourage further staff behaviour change.

Benefits: A more than 60% reduction in energy consumption (62% reduction in electricity use and 76% reduction in gas use) was achieved through the energy efficiency program.

EP potential: The Ferguson Plarre Bakehouse energy efficiency program could be replicated in similar businesses.

Status:.Ferguson Plarre continue to seek ways to continue minimising environmental impacts across their operations and value chain. Technology is currently estimated at TRL 9 and CRI 3.

Barriers: .Up-front capital costs may be a barrier for other bakeries wishing to emulate the Ferguson Plarre energy efficiency program.

Information

To create this case study, information was gathered from the publication "FACTOR 5: Transforming the global economy through 8-% improvements in resource productivity" produced by The Natural Edge Project.

http://www.naturaledgeproject.net/Documents/Factor5-FoodandHospitalityOnlineSectorStudy.pdf

6.1.4. Food waste and co-products

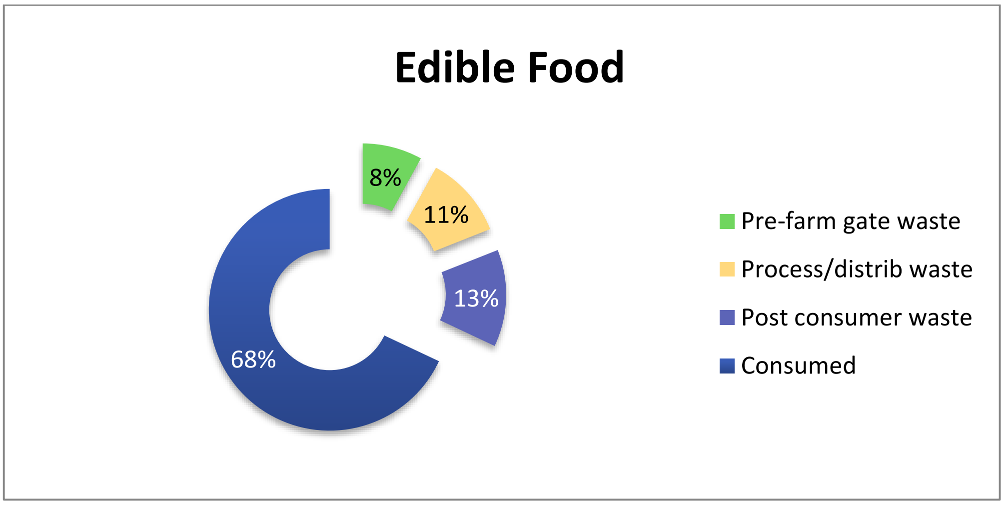
One of the key findings of this work is that you cannot optimise energy productivity without considering materials flows, and particularly food waste streams.

At each stage of the food chain, food is wasted, packaging is disposed of (or recycled) and costs are incurred to manage these wastes. In addition, in food manufacturing waste streams from processing, often with high BOD need to be addressed. In some cases, opportunities to produce co-products or by-products, such as energy, pharmaceuticals, and useful materials may be captured. Doing this can reduce waste management costs, generate revenue, or even create new business opportunities, as can be seen in Case Study E, CSIRO/Murray Goulburn.

Most Australian data is available for 'edible food' and associated wastes. It ignores most farm organic wastes, such as crop stubble and manure. An attempt to at least define a ballpark for on-farm waste for this project suggests that crop wastes alone, which may be burned, ploughed in or dealt with in other ways comprise about 60 million tonnes of material annually. This is about 10 times the amount of edible food available in Australia, and contains around 900 petajoules of 'raw energy'. If used to generate electricity at 25% efficiency, this would produce over 60,000 gigawatt-hours, over a quarter of present total Australian generation. It also contains valuable nutrients and other potentially valuable substances. It can also be used to produce biogas, liquid fuels, fertilisers, building materials, fabrics and other products[32]. Clearly we need to improve our understanding of the 'on-farm waste' resource.

As shown in Figure 14, around a third of edible food is wasted (graph based on data from the 2016 Foodprint Melbourne report[33]).

Figure 14.: Sources of food waste for Melbourne



[32] Lin, C. S. K., Pfaltzgraff, L. A., Herrero-Davila, L., Mubofu, E. B., Abderrahim, S., Clark, J. H.,& Thankappan, S. (2013). *Food waste as a valuable resource for the production of chemicals, materials and fuels. Current situation and global perspective*. Energy & Environmental Science, 6(2), 426-464

[33] Sheridan, J., Carey, R. and Candy, S. (2016) *Melbourne's Foodprint: What does it take to feed a city?* Victorian Eco-Innovation Lab, The University of Melbourne.

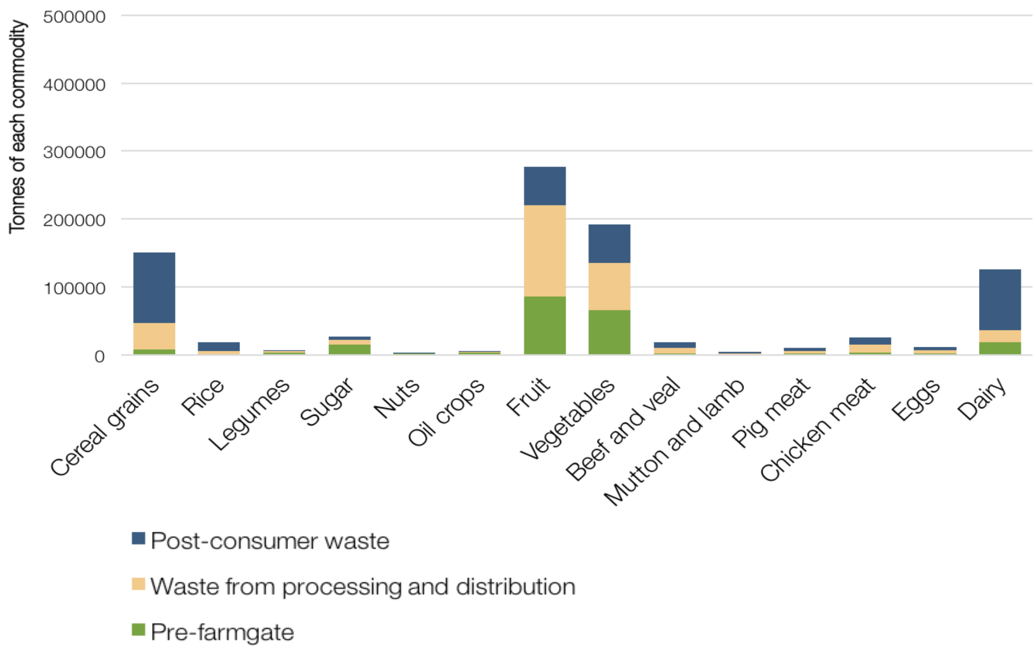
Farm and process/distribution waste are relatively concentrated, and more likely to be uncontaminated. So, they may be potential sources of co-products such as fibre, animal feed, energy and/or fertiliser. In some cases, product that has traditionally been sent to waste because of aesthetic issues is now being sold to consumers.

Post-consumer food waste is widely distributed and diverse in composition. Some community groups now capture some of this food to produce meals for the disadvantaged. Some local councils allow food wastes (excluding meat) to be included with green waste collections: it is usually composted, but could be used to generate biogas and fertiliser.

Figure 15 shows the breakdown of wastes for major food types (graph reproduced from the 2016 Foodprint Melbourne report[34]). This shows wastes are dominated by cereals, fruit, vegetables and dairy products, all of which can contribute to bio-energy production. There is potential to combine these wastes with urban green waste and sewage, to produce biogas. Appropriate combinations of different wastes can increase the productivity of the bacteria in biogas digesters. This has the added benefit of reducing production of high climate impact landfill gas.

There is also potential for urban vegetation to be more actively managed to produce more urban biomass, to support a higher level of biogas production. As conventional grid gas prices increase, and uncertainties over supply contracts emerge, reliable supplies of biogas (which can be cleaned up to 'pipeline gas' standard, or burned in modified gas equipment are likely to become more competitive**.**

Figure 15.: Analysis of types of food wasted for Melbourne.



Bio-energy, and the organic fertiliser it produces, are increasingly important co-products, as we move towards a low carbon economy and rural energy prices for both gas and electricity increase. Avoiding emission of climate-active methane (e.g. by producing energy) and refrigerants (which affects refrigeration efficiency) are also important dimensions of waste management, both of which can

[34] Sheridan, J., Carey, R. and Candy, S. (2016) *Melbourne's Foodprint: What does it take to feed a city?* Victorian Eco-Innovation Lab, The University of Melbourne.

offer energy productivity benefits. The sugar industry already utilises almost 90 petajoules of primary energy from bagasse (OCE Table F, 2016), which is used to provide process heat and electricity. There is potential for this industry to export much larger amounts of electricity to the grid by improving cogeneration efficiency and optimising utilisation of the bagasse.

At present, according to the Clean Energy Council's 2015 assessment, total Australian generation of bio-energy is around 3,200 gigawatt-hours, about 1.3% of total Australian electricity generation. But CEC estimate bio-electricity potential of up to 73,000 GWh, up to a third of Australia's present generation. Potential for biogas and heat production is also significant, but not well documented. ARENA has recently published a study of the potential to replace grid gas with renewable energy in industrial applications. Combining renewable energy with storage and high efficiency equipment can provide many benefits in rural and regional areas.

A number of factors may improve the economics of local or regional agricultural and agro-industrial energy production and efficiency in the future. Increasing natural gas prices and difficulties negotiating long term contracts make biogas and other on-site renewable energy options more competitive. Losses in electricity transmission lines to rural areas are often high. Local generation also reduces risks of power failures in fragile distribution networks or even transmission lines and can also decrease fire risk from powerlines. Business activity related to local energy generation and efficiency improvement keeps more money in the local economy and employs more people. And export of energy can even create an income stream for a community. In some hilly rural areas, especially where there are existing dams or even disused mines, there is potential for pumped hydro energy storage using relatively small dams. This can enhance local energy supply reliability. In many cases, local people own earth-moving equipment that can be used to build the additional dams required in quiet times of the year, to minimise construction costs.

As with modular energy production, high efficiency electric or renewable energy powered industrial process equipment and energy storage are becoming cheaper and working better, so there is increasing potential for cooperation between food processors and communities to establish and operate local energy grids, and shared energy storage capacity. The potential to shift more food processing closer to farms and rural communities is enhanced. These trends all support greater utilisation of on-farm 'wastes' for energy and for potential co-products, as well as local value adding. There may be opportunities to pool wastes for central processing in some rural hubs. The employment created, along with savings on energy costs, and even revenue from energy exports builds local economies and provides supplementary income for farmers and others whose incomes are variable. Integrated solutions can deliver multiple benefits for farmers. For example, oil mallee projects (see http://arena.gov.au/media/mallee-a-clean-solution/) deliver multiple outcomes including:

- Protecting crops and animals from wind
- Producing high value eucalyptus oil and activated carbon
- Providing fuel for local energy production
- Creating a carbon store, as the roots store a large amount of carbon and the crop is harvested by coppicing: this leaves the roots intact and new trees can grow from them very quickly.

Developments in engineered timber construction mean that wood waste can be processed into building materials, used to produce biofuels and electricity, and even blended with clay to produce near zero net carbon bricks (see case study).

Many food processing businesses incur large costs in treating organic wastes. Analysis of their constituents can identify potentially useful products (see CSIRO/Murray Goulburn Case Study E) that can avoid waste management costs and create new revenue streams.

Case Study E – Separation technology to reduce waste and increase efficiency

Utilisation of co-products and waste

Key organisations: Murray Goulburn Co-operative and CSIRO Food Innovation Centre

Innovation: Murray Goulburn, Australia's largest dairy company, worked with CSIRO's Food Innovation Centre to develop and commercialise continuous ion exchange processing technology (CSEP) to manufacture high value dairy protein ingredients such as whey protein isolates and the bioactive, lactoferrin. Prior to this the company was producing approximately 35,000 tonnes of cheese per year but were only using 10-15% of the residual whey, as mainly pig feed.

With the chromatographic system developed with the help of CSIRO, the company was able to treble its cheese production each year and commercialise protein ingredients from the by-product streams.

These ingredients are now used in valuable manufactured products such as the billion dollar sports foods, beverages and meal supplement markets in North America and in infant formula.

Benefits: The CSEP processed allows Murray Goulburn to turn an otherwise low value co-product/by-product and a waste stream into a valuable manufacturing product; reducing waste and cost, while increasing efficiency and revenue.

Image credit - https://csiropedia.csiro.au/dairy-products-for-improved-human-health/

Initial investment by Murray Goulburn into commercialising the manufacturing plant was over $10 million, and in 2006 products from the plant were worth $20 million in sale revenue.

EP potential: CSEP has the potential to be used across the food manufacturing industry to separate otherwise waste compounds in an efficient manner. CSEP technology offers alternative solutions to tradition modes of disposal and means to repurpose co-product into high value products.

Status: Currently the CSEP technology is not only used by Australia's largest dairy company but also by other companies and the beverage industry in Australia. Technology is estimated to be at CRI 5 (deployment stage).

Barriers: Cost of initial capital required to implement these processes and procure the required technology. Lack of knowledge by industry that such opportunities exist – particularly working alongside CSIRO Food Innovation Centre to develop unique solutions.

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Case Study F – Co-digestion to create biogas and meet onsite energy needs

Utilisation of co-products and waste

Key organisation(s): Glenelg Wastewater Treatment Plant

Innovation: The success of a number of research projects on co-digestion of industrial high strength organics to boost biogas production in anaerobic digesters driven by SA Water, led to the construction of the fully automated co-digestion plant at the Glenelg Wastewater Treatment Plant in 2012-13.

This plant is the first of its kind in Australia, and adding different waste streams results in a better balance of nutrients, leading to boosted biogas production. It also avoided overloading the sewer and secondary treatment systems with trade waste. The co-digestion plant consists of a trade waste unloading station, retrofitted with a filter to prevent any solids entering, and two 30kL storage tanks with recirculation pumps to mix the substrate in the tank.

The volumes of trade waste being delivered monthly to the plant are now consistently above 1000 kl, and represents on average 6% of the flow going into digesters. The amount of energy generated with biogas has remained above 65% since the co-digestion plant was commissioned, reaching up to 84% in October 2014.

Benefits: The amount of natural gas used by engines has decreased, representing great savings for the site. The engines are fuelled by either biogas or natural gas. Biogas is used primarily, but should biogas production not meet demand for the engines, their operation is supplemented by natural gas. In addition to benefit of heat and power produced at the plant, there is also the benefit of avoiding release of methane.

Image Credit - http://www.sustainabilitymatters.net.au/content/wastewater/article/sustainable-wastewater-treatment-thanks-to-codigestion-589900367

The co-digestion plant has been a successful addition to the Glenelg Wastewater Treatment Plant with 13.7ML of trade waste received, and an extra 1355 MWh of power been generated onsite since its commissioning to late 2014.

EP potential: The installation, operation and optimisation of the co-digestion plant at Glenelg gas lead to a reduction in imported power and natural gas use onsite. This has reduced the plant's carbon footprint by producing up to 84% of the power required onsite, without compromising the performance of the digesters.

Status: The co-digestion plant has been online for more than a year. Significant improvements to the power generation have occurred during this period, however SA Water Trade Waste Team continue to seek new customers in order to increase the output of the plant to full capacity and thus maximise gas production. Technology is a fully bankable asset and classified at CRI 6.

Barriers: It would be difficult for a wastewater treatment plant to source the initial upfront capital needed and would require government backing. Physical space constraints are another barrier and co-digestion is not typical considered core business for wastewater treatment plants.

Information

To create this case study, information was gathered from the publication "Anaerobic digestion and power generation: the success of the co-digestion plant at Glenelg Wastewater Treatment Plant" produced by AllWater and SA Water.

http://www.awa.asn.au/documents/061%20JDreyfus.pdf

6.2. Freight

Transport is the largest end-user of energy in the economy, consuming nearly 40% of all final energy. Freight transport is a significant component of transport energy use (~30%). It is also an integral component of both the Food and Shelter value chains.

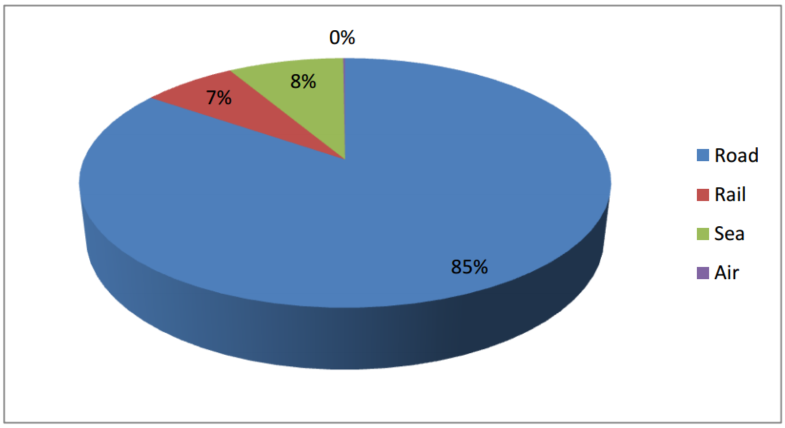
Area(s) of potential application and context

Services provided: Freight transport moves goods between various stages of the value chain. Table 1 suggests that freight transport accounts for only around 15% of total primary energy use in the food supply chain – because many other activities in this value chain involve use of electricity, which involves use of three units of fossil fuel energy per unit of electricity consumed. Transport fuel is significantly more expensive per unit of primary energy than electricity. In terms of costs, transport is likely to contribute around 5-6% of the retail price of most grocery items[35] significantly more than other energy inputs. However, transport costs can represent a much larger proportion of overall costs for organisations or activities lower down in the supply chain (e.g. diesel for equipment and transport is a major input cost for farming).

Across most freight classes, road transport is the dominant transport mode (for both food and other goods). In energy terms, around 84% of all energy used in freight transport goes to road vehicles. For the food supply chain specifically, Figure 16 shows that 85% of the food transport task is carried on road. It is worth mentioning that air freight plays a small (by weight/volume) but significant (by value) role in the international food value chain.

The concept of "food miles" was coined to highlight the significant distances that food travels in its journey to reach the dining plate.

Figure 16.: Mode share for transport of food (based on tonne-km travelled)*[36]*



Note: Food is defined as 'food (for human and animal consumption)' and does not include cereal grains or live animals. The data do not include road freight movements made by rigid and light commercial vehicles. Although tonnage by air is negligible, air does account for some high-value food movements.
Source: ABS 2002, Freight Movements, cat. 9220.0, Australian Bureau of Statistics, Canberra, data for year ended March 2001 (most recent survey).

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[35] ACCC 2008, *Report of the ACCC inquiry into the competitiveness of retail prices for standard groceries*, July 2008 https://www.accc.gov.au/system/files/Grocery%20inquiry%20report%20-%20July%202008.pdf

[36] Department of Agriculture, Fisheries and forestry 2012, *Resilience in the Australian food supply chain*, February 2012, Commonwealth of Australia http://www.agriculture.gov.au/SiteCollectionDocuments/ag-food/food/national-food-plan/submissions-received/resilience-food-supply.pdf

What it is and how it works

Freight transport connects the elements of the value chain. Without efficient and cost-effective freight transport, the various activities in the chain would need to be co-located or in close proximity to the location of final consumption (of food) or residence (in shelter). That's not to say that there would not be benefit of avoiding some transport tasks e.g. taking food from Mildura to Melbourne so it can be sold back to Mildura consumers as a packaged product from a supermarket.

Specific tasks freight delivers in the food value chain include:

- Transport of inputs to farms and food processors;
- Transport of farm produce to food processors;
- Transport of processed goods to storage facilities, wholesalers. retail outlets and consumers.

Specific tasks freight delivers in the raw materials chain include:

- Transport of inputs to mines, plantations, processors of raw inputs and manufacturers;
- Transport of manufactured goods to storage facilities, wholesalers and retail outlets;
- Transport of manufactured goods, materials, tools and construction equipment to site.

Energy Productivity Fundamentals

Energy use in freight transport is dominated by diesel, fuelling virtually all machines and equipment used in the supply chain – from crop harvesting equipment on the farm to delivery trucks bringing groceries to residential consumer homes, and all steps between. Under the definition of energy productivity, the main opportunities relate to:

- Avoiding the transport task or reducing it
- Shifting to lower-cost fuels and renewable energy sources;
- Reducing energy inputs, by using it more efficiently in both individual pieces of equipment and from a system perspective; and
- Generating more output value (more freight, higher-value freight) or reducing negative impacts.

How can it contribute to Energy Productivity outcomes?

The major opportunities for energy productivity improvements in freight are:

- Reducing trips: co-locating activities negates the need for transport steps in the supply chain. There are opportunities to reduce the number or distance of trips, eliminating entire branches of energy use that would otherwise be required for that trip) by better locating or co-locating various processing or storage activities[37].

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[37] "*Woolworths alone moves 20,000 tonnes of food around the country each day, but in some parts of Australia longer transport times are unavoidable. There is no distribution centre in the Northern Territory, so produce grown there has to be trucked interstate before it is sorted and then trucked back to be sold in Territory supermarkets. In the same way, produce grown in the fertile soil around Gatton is trucked 90 kilometres east to the Brisbane distribution centre, before it is trucked back to Gatton to be sold*".

http://www.abc.net.au/news/2010-03-19/unseasonal-desires-the-hidden-cost-of-fresh-produce/371016

- Shifting to less intensive transport modes: rail transport uses only a third to a half of the energy per unit of freight (tonne-km) as road transport. Rail is already used for transporting raw crops and for much of the food freight task to Western Australia, but rail share on the east coast is still low.
- More efficient vehicles: Australia's heavy vehicle fleet is already one of the most productive in the world due to extensive use of high productivity vehicles such as B-Double, road trains, and the performance-based standards scheme. However, the technical potential for better fuel efficiency through measures like engine/drivetrain improvements, aerodynamics, tyres and light-weighting, is in the range of 30-60%[38]. Of this, up to 30% is economically viable using currently-available technology.
- Improved company practices: includes a wide range of measures from driver training, maintenance and inspection, data monitoring, and improved payload factors (from right-sizing vehicles to payload consolidation). Properly trained drivers can improve fuel efficiency by an average of 10-20% alone. Note that over 85% of road transport fuel use is consumed by owner-operators, who often have poor access to the sorts of tools and training that are available to the large corporate logistics companies.
- Alternative fuels offer potential improvements, particularly electrification of urban delivery vehicles. Other fuels (such as natural gas) may save energy costs at times of higher diesel price.
- The final stages of food transport may involve a range of options, from light commercial vehicles, to private passenger vehicles, to bicycle delivery services. Light commercial vehicles are much less efficient than larger freight vehicles – but they provide a different service. Replacing use of privately owned passenger vehicles with light commercial vehicles for local deliveries (eg take-away food and supermarket shopping) can reduce net fuel use through optimisation of delivery routes and avoiding multiple car trips using cold engines (which use more fuel and are more polluting. Bicycle-based delivery services are also emerging. Some services deliver food from a number of food outlets, improving economic efficiency by avoiding the need for each shop to have its own dedicated food delivery capacity.

Innovations and technologies to accelerate energy productivity opportunities

- Autonomous vehicle technology will accelerate and integrate several of the opportunities above. Fleet "platooning" involves a number of trucks following each other very closely without the need for driver input, bringing together benefits from (computer controlled) eco-driving techniques, reduced aerodynamic drag, lower accident risks, and (eventually) elimination of driver costs to the business. The enabling technologies for platooning and other forms of autonomous driving are developing rapidly, and include both hardware (sensors, radar, cameras) and supporting systems like software and controls. The potential

[38] In September, a demonstration truck produced by Volvo under the US EPA SuperTruck program achieved a 70% improvement in fuel efficiency (and 88% improvement in freight productivity once additional payload is taken into account), compared with the 2009 baseline conventional truck. Other truck manufacturers participating in the program have also achieved similar, albeit slightly lower, savings. http://www.volvotrucks.us/about-volvo/news-and-events/high-tech-supertruck-exceeds-goals/

elimination of drivers from some tasks could significantly reduce fleet costs (of which labour is the largest), improve road safety, and liberate significant additional payload capacity as the truck cab would no longer be required.

- Other developments in intelligent transport systems (ITS) will allow vehicles to communicate both with each other and with infrastructure, improving road safety and reducing traffic congestion. This will also enable new road pricing models to better recover costs and to shift behaviour (for example, by using congestion charging).
- One of the simplest ICT opportunities is a driver advisory system to provide real-time feedback on the driver's performance, helping reduce fuel use via better driving techniques. A tailored training program in ecodriving is probably more effective and can commonly reduce fuel consumption by 10-20% (even more or less, depending on the driver); but the nature of the freight industry, consisting of many smaller resource-constrained operators, means that very few drivers outside the larger companies can attend training. A driver advisory system overcomes this barrier by providing feedback to the driver (in real time, or after a trip) based on actual data collected from the truck systems via a telemetry unit. It can be easily fitted to many older trucks already in the fleet (so doesn't rely on slow adoption at the rate of new vehicle sales – a big plus given the long asset life of most trucks, which can be >15-20 years). While GPS and telemetry systems are used widely already in the industry (and can access very granular, specific data on energy use by the truck), very few are used for this purpose at the moment. So, the innovation is adapting the technology to report on new performance parameters. Ultimately, driver advisory systems should become redundant as autonomous vehicles increasingly take over the driving task, but significant energy could be saved in the interim as the timing of autonomous freight vehicles is unclear, but some time off. Data gathered from driver advisory systems could also be used to inform smart driving software programs for the AVs.
- Battery technology is improving rapidly, for both lithium-ion and other battery chemistries. This is being seen in electric cars with longer driving range and/or significantly lower costs. The move to electric freight vehicles will be a more significant challenge and more significant for energy use (because commercial vehicles are more highly utilised), and will likely begin with smaller, urban-based delivery vehicles.
- Second and third generation biofuels – particularly diesel from algae, and biogas as a transport fuel source (in lieu of fossil gas in CNG/LNG).
- Micro-turbine drivetrains. Several companies are working on micro-turbine systems to power future trucks. This arrangement still uses an internal combustion engine (the turbine), but in a series-hybrid or range-extender arrangement to charge batteries, which then drive electric motors to drive the wheels. Much like Tesla in the passenger car sector, Nikola Trucks has thousands of forward orders for a new model micro turbine hybrid prime mover that doesn't yet exist. Wrightspeed is similarly developing a retro-fit system, which could transform the market quicker than relying on the slow diffusion of new truck sales into the market.
- Battery electric hybrid system for diesel locomotives, which save energy in the same way as their application to other vehicles.
- Digital freight matching or the application of ICT in better matching freight loads with freight carriers. A shorthand analogy for this opportunity is Uber for freight. The productivity benefit

from this technology is mostly derived from filling empty or partially loaded trucks (30% of all truck trips according to ABS), which means they operate more fuel efficiently (fewer litres per tonne-kilometre) as well as taking partially-loaded trucks off the road to reduce congestion. At a very basic level, digital freight matching might include freight auctions, where carriers bid on jobs they can fit into their available space and which suit their existing journey. However, it could also include independent fleet operators sharing or combining loads (1 full truck instead of 2 half-full trucks). Ultimately, even the line between passenger and freight transport could be blurred so that someone on their way to work or a meeting in the city could pick up a parcel along the route and drop it off along the way, all matched by size/time/origin/destination/price via a smartphone app or central booking system. This would increase productivity by reducing the number of separate trips different vehicles make, and reduce congestion immensely. It would also ensure right sizing of vehicles for their intended load.

- Given the high energy demands in maintaining the cold chain integrity in food transport, new technology for in-transit refrigeration (e.g. nitrogen based systems - or battery electric systems) could have a significant impact in future, once these technologies mature and as vehicles are increasingly electrified (see for example http://www.gcca.org/wp-content/uploads/2016/03/Europe16_Fox_ZeroEmissionColdandPowerTechnologies.pdf). Careful analysis of the lifecycle energy costs of options will be necessary to avoid energy waste upstream in the systems.

Barriers, levers and key organisations

- The structure of Australia's freight fleet involves a small number of very large fleets and a majority of very small fleets, with 75% of operators owning just one truck, and 99% of operators having less than 10 trucks. This results in a range of barriers including difficulty accessing capital for fleet investment, limited (human) resourcing to identify and evaluate opportunities for improvement, and vehicles often poorly matched to the task (leading to inefficiency).
- Downtime risks: service reliability and vehicle uptime are crucial ingredients for a successful small business in the freight sector. Many new technologies are unproven or suffer reliability problems, and are therefore seen as risky to business continuity.
- Price premiums for new truck technologies (e.g. micro turbine, battery-electric), over and above the already high capital costs for fleet assets can make financing more difficult.
- (Recent) low fuel prices – which undermine the business case for investing in energy efficiency via technology, fuels, or other high-cost or high-risk projects.
- Transport is a highly regulated industry sector. Regulatory reform is required before autonomous vehicles (and ICT more generally) can be introduced in Australia. The National Transport Commission has investigated some of the main areas for reform. The Driverless Vehicle Initiative, ARRB, i-Move CRC, and ITS Australia are working in various forums and with a range of suppliers/stakeholders to run trials, understand and demonstrate the technologies, and to identify future needs.
- Restrictions on vehicle load and dimensions can also constrain the adoption of new technologies because of payload penalties (e.g. heavy batteries resulting in lower payload

capacity from which to derive revenue) or infrastructure incompatibility (e.g. aero devices increasing maximum length or height). Road condition can also constrain the use of high productivity vehicles in rural areas where much of the food supply chain originates, due to concerns about road damage. The National Heavy Vehicle Regulator and road asset owners are jointly responsible for permits and exemptions controlling road access.

- Digital freight matching could reduce empty or partial running, but would only apply to one part of the freight task (that not covered by formal freight contracts for regular loads). However, this “general freight” is still the second biggest category of road freight by both weight (tonnes) and overall task (tonne-km), so is still a significant opportunity.
- Split incentives – the ability of some fleet operators to simply pass on fuel surcharges or all fuel costs to their customers reduces the incentive to invest in efficiency.
- The opportunity to deliver logistics and energy efficiency information services to the independent trucking industry via cloud computing to provide them with comparable tools to those available to the large corporate logistics companies and significantly improve their energy productivity.

6.3. Shelter value chain

Consumers want services such as shelter from the elements, security and safety, comfort, status, reliable performance and affordability. The options for delivering these services are changing rapidly, and businesses must adapt, as there is no inherent demand for traditional building materials. For example, on-line shopping changes the demand for high profile retail space, warehouse space and freight. New materials, construction techniques and business models reshape the skill requirements and demand for materials and skills. Improvement in energy productivity is based on technology development and new business models, facilitated by these innovations, that cut energy use per unit of service delivered, and increase value of outputs.

The value chain approach focuses on core services wanted by potential occupants of buildings. This opens up possibilities to deliver these end services quite differently than a continuation of current practices. So, while at the most incremental level one may look at ways of making an existing type of building material or product in ways that save energy or enhance perceived value, the bigger opportunities to increase EP often come from alternative materials delivered through different business models.

The price someone will pay for a material integrated into a useful product is far higher than the raw material cost, and most of the value added occurs in the light manufacturing and services sectors. So, replacing a high volume commodity production system with a low volume 'high value' solution targeting a consumer market can be more profitable. Further, shifting processes from commodity oriented centralised production to more distributed, higher value production can increase the potential for renewable energy and other emerging smart energy and material options. Custom car, caravan manufacture, and custom kitchens all provide examples of shifting processes between sectors.

The building services value chain, like the energy services value chain, has historical and cultural dimensions, powerful incumbent industries and conservative regulators. But consumers will switch to competing solutions if they offer sufficient perceived benefits. At the same time, powerful incumbent industries can use their market power and political influence to slow change: but when innovators finally break through, the rate of change can be rapid, with serious consequences for those slow to react.

Buildings last a long time, so their performance and adaptability determines whether they become community assets or liabilities over time. The creativity of innovators in developing options that can be retrofitted to existing buildings will be a key factor influencing our ability to meet climate targets, and to cope with a changing climate, as well as responding to rapid change in consumer preferences and externally driven technology change.

Efforts to improve energy productivity have implications that include:

- Activities that minimise material impacts through design techniques, selection and use of materials, and construction practices.
- Changes to technologies and practices in industries that supply inputs to construction and building operation, particularly steel, bricks and cement, which dominate the embodied energy of buildings, and products that support improved energy productivity in operation, such as insulation and glazing.

- Transformation of technologies that deliver comfort and other services to occupants of buildings.

Key energy/carbon productivity-related drivers include:

- Major property companies making sustainability commitments due to shareholder expectations and reputation/brand image.
- Home buyers responding to technologies such as rooftop solar, energy storage and energy efficiency solutions in response to increasing energy prices, concern about reliability of energy supply and lack of confidence in/anger about energy suppliers.
- Corporations voluntarily reducing emissions requiring action by their suppliers.
- Business opportunities driving companies like Lend Lease and others to invest in more sustainable building practices and materials manufacture.
- National Energy Productivity Plan measures to drive increased Energy Productivity and state government incentives for energy efficiency.
- Construction issues: some focusing more attention on Life Cycle Analysis, embodied energy, climate adaptation and emission reduction and other emerging issues.
- Projects like Barangaroo having development consents on sustainability/ circular economy.
- Council requirements (cities are increasingly drivers of carbon mitigation).
- Increasing government policy focus on the energy efficiency of mid-tier buildings, existing buildings.
- Increasing pressures to meet increasingly stringent climate goals.
- Increased access to finance and incentives, e.g. green bonds, Clean Energy Finance Corporation, Energy Upgrade Agreements, state energy savings schemes and the Emission Reduction Fund.

Key systems providing significant potential to improve energy productivity in the shelter value chain, discussed in further detail in the following subsections, are:

- 6.3.1 Lower energy intensity manufacturing of construction materials such as concrete, bricks, steel and toughened glass;
- 6.3.2 Reduction in use and substitutes for high embodied energy construction materials e.g. tensile structures, optimal computerised structural design, high strength concrete, geopolymers, cement extenders (blast furnace slag, fly ash) and magnesium-based cements;
- 6.3.3 Utilisation of waste and conversion into co-products
    - Recycled and reprocessed building materials. Note that this is not all positive: There is some concern amongst EPA’s that the use of composite materials is leading to the first reductions in recycling rates experienced in the last two decades.
    - Waste to energy;

- 6.3.4 Business system innovation e.g. prefabrication / factory manufactured housing, advanced design and construction management software, which offers opportunities to capture multiple benefits including:
    - Reduced interest costs and reduced impact on neighbours and traffic congestion through faster completion
    - Improved quality control, including avoid weather damage
    - Opportunity for standardisation and close tolerances – making multiple glazing much more cost effective, and buildings far easier to seal
    - Increased scope for optimal material use and efficient recycling
- 6.3.5 Novel construction materials and solutions e.g phase change materials (replace mass), aerogels and roof integrated photovoltaic and thermal systems; and,
- 6.3.6 Building commissioning and operation e.g use of software to identify issues, optimise performance

6.3.1. Lower energy intensity manufacturing of construction materials

Steel, cement and bricks dominate energy use for building materials, although glass, aluminium and other materials are significant. In this section, the two main materials are discussed.

Steel

Steel is widely used for many purposes. It is a major input to construction, where it is used in structures, for roofing, reinforcing and many other purposes. Its high energy intensity means it is a major contributor to energy in this value chain. For example, if new steel is used in a concrete slab floor for a house, its carbon impact can be similar to that of the cement.

A key factor influencing demand for steel is improvement in steel quality and strength. Substantial progress has been made in development of much lighter, higher strength steels, especially in the car industry, and this has begun to flow through to the building sector. Commercial buildings in many developed economies are currently built with up to twice the steel required by safety codes (Fischedick & Roy, 2014)[39]. Steel framing is another example where design innovation can maintain functionality with less material use. For example, some house framing that used to be 1.20 mm thick is only 0.6 mm thick today– a saving of 50%. BlueScope Steel's latest high strength roofing products that were once manufactured at 0.55 mm thick, are today made from high-strength Colorbond steel 0.42 mm thick – a reduction of 24%. So, less steel can deliver the same service as improved alloys are developed and production techniques applied. More sophisticated computerised design and real time monitoring of stresses and deflections in structures can also optimise the amount of steel required.

Demand for stainless steel is increasing (see http://www.worldstainless.org/statistics), as it is very durable, and replaces galvanised steel or avoids the need for regular painting of untreated steel exposed to the environment. Recycled steel is often an ingredient of stainless steel.

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[39] Fischedick, M. & Roy, J., 2014. *Mitigation of Climate Change*. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Newyork: Cambridge University Press.

Steel is produced either from recycled scrap, or from iron ore. Production from recycled steel involves much less energy than from virgin materials (300-500 kWh/t or 3-5.5 GJ/tonne of steel (primary energy) for EAF compared with 17-25 GJ/t), and does not require use of coking coal to remove the oxygen content from iron ore. Most recycled steel product is produced using Electric Arc Furnaces (EAFs), although scrap is also added to blast furnaces that produce 'new' steel. In future, EAFs could use renewable electricity to deliver low climate impact steel, and there is still room for efficiency improvement as the theoretical energy requirement is around 110 kWh/tonne of steel.

The percentage of recycled steel as a share of total global steel has risen over time to around 35%, of which 90% is from 'old steel' (Bureau of International Recycling, 2015) as increasing amounts of scrap steel have become available from building and infrastructure demolition and scrapping of old equipment. Steel consumption in Australia and New Zealand in 2011 was close to 7 million tonnes (http://steel.org.au/about-our-industry/steel-indicators/). In 2014, Australia exported 2.36 million tonnes of scrap steel.

Large amounts of scrap steel are not captured, for example when old ships are scuttled, and in mixed waste. There is scope to increase scrap for production of recycled steel through more effective recycling programs, new technologies to extract it from mixed waste (see UNSW Case Study I), and even by actively freeing up steel by replacing old infrastructure and equipment with new (more energy efficient), less steel intensive alternatives.

At the same time, the potential to use less steel for a given service (see below) is increasing. So, there seems to be significant potential to increase the share of services delivered by recycled steel through more active and effective recycling, and through improved utilisation through optimised structural design and metallurgy to produce higher strength steel. Traditionally recycled steel has been used for lower value applications, as virgin steel has dominated markets where consistent surface finishes and quality are required. However, EAF technology is continuously improving. From a 2006 RMIT study[40], it seems that the building sector uses a disproportionately high amount of recycled steel, presumably because reinforcing and structural steel do not have to meet criteria for more visible applications.

Modular electric arc and remelting technologies, combined with 3-D printing (if equipment can cope with the high temperature of melting steel) may allow more localised recycling of steel, which could open up new business models for recovery and reuse of steel at a regional level. Given that Australia now exports a large amount of scrap steel, this could allow Australia to add value to a low value product that is now exported, while reducing import costs.

Steel production from iron ore requires removal of the oxygen from the iron oxide ore, as well as addition of some carbon to convert iron to steel. 'Pig iron' is initially produced from ore, coke and limestone in a blast furnace, then the carbon content is reduced and contaminants removed in a basic oxygen furnace (BOF). Some scrap steel is also fed into the process. Substantial effort has gone into improving the energy efficiency and reducing waste heat losses[41] of iron and steel production, whether through BOF, EAF or DRI methods (see Figure 17 below).

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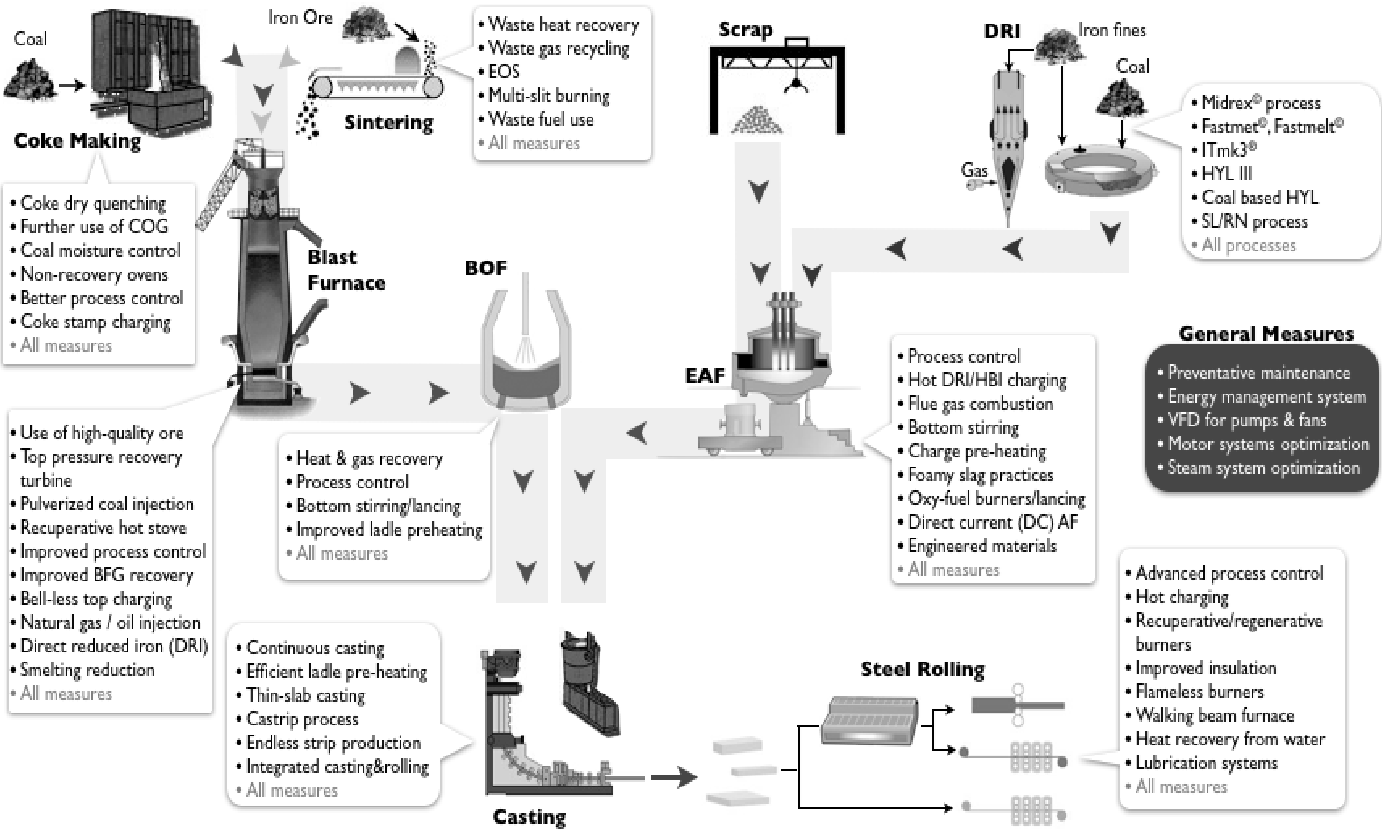
[40] Centre for Design, RMIT University et al (2006) *Scoping Study to Investigate Measures for Improving the Environmental Sustainability of Building Materials* Report for Department of Environment and Heritage, Canberra

[41] US DOE, 2004. *Waste Heat Reduction and Recovery for Improving Furnace Efficiency Productivity and Emissions Performance- A Best Practices Process Heating Technical Brief*., s.l.: United States - Department Of Energy.

Figure 17.: Energy efficiency and waste heat recovery opportunities in the steel making processes



(Source: (IIP, 2015))[42]

However, new processes are emerging that offer further energy efficiency improvement and reduction in carbon intensity[43]. Basically, steel production involves the removal of oxygen from iron oxide, addition of small amounts of carbon, the melting of metals (at very high temperature), and removal of contaminants.

Research in Australia and other countries is developing methods of using wood-sourced charcoal in modern steel production (see http://www.csiro.au/en/Research/MRF/Areas/Community-and-environment/Responsible-resource-development/Green-steelmaking). Research at UNSW has also led to utilisation of waste materials such as plastics and tyres to replace some of the coking coal used and improve process efficiency[44]. However, it should be noted that, where these materials would have remained inert in landfills, this activity is releasing the carbon dioxide 'stored' in those wastes, reducing the net climate benefit. In the future, plastics and other products are likely to be increasingly produced from renewable materials, so the climate benefits of this approach will increase.

[42] IIP, 2015. *Industrial efficiency technology database - Iron and Steel*. [Online] Available at: ietd.iipnetwork.org/content/iron-and-steel [Accessed 2 9 2015].

[43] Quader, M. A., Ahmed, S., Dawal, S. Z., & Nukman, Y. (2016). *Present needs, recent progress and future trends of energy-efficient Ultra-Low Carbon Dioxide (CO 2) Steelmaking* (ULCOS) program. Renewable and Sustainable Energy Reviews, 55, 537-549.

[44] Fontana, A., O'kane, P., O'Connell, D., Sahajwalla, V., & Zaharia, M. (2012). *Injection of recycled tyres in EAF steelmaking as a slag foaming agent.* Steel Times International, 36(6), 17

Researchers are also developing radically different steel production techniques[45]. There are many projects exploring such options. As Ahuja, in his ANU PhD thesis (2015)[46] notes:

> Some other breakthrough technologies with a potential to radically reduce the emissions from the steel industry are investigated through the ULCOS programme (ULCOS, 2015[47]) - A joint initiative of the European steel industry and the European Commission, the POSCO programme in Korea, the Course 50 research programmed in Japan and many others including the US DOE programs and Australian and USA steel industry programs.

Many of these low carbon emission options rely on development of carbon capture and storage, which still seems some distance away, but some offer **low carbon solutions without CCS**. These include:

- Molten Oxide Electrolysis: MIT researchers (Sadoway, 2014)[48]" are replacing use of carbon as the reducing agent with electricity. Iron oxide is fed into a bath of molten slag and an electric current run through it to separate the oxygen and iron. The researchers estimate a factor 5 reduction in emissions from the 1750 kg CO2e/tonne for benchmark blast furnace technology http://steeltrp.com/briefing07slides/09-trp9956_mit-07ibs.pdf If the electricity is from a renewable source, this is a near-zero emission option (see http://jes.ecsdl.org/content/162/1/E13.full). It also produces a potentially valuable co-product of pure oxygen. This approach seems similar to techniques being developed under the US government's ARPA-E program for production of titanium, aluminium and magnesium (https://arpa-e.energy.gov/?q=%5Csearchprojects/steel). A similar approach seems to have been applied by MIT researchers for antimony (https://www.australianmining.com.au/news/new-method-produce-metals-developed/) This approach is also suited to smaller scale production than traditional blast furnaces (https://www.technologyreview.com/s/515411/eco-friendly-steelmaking/)
- Hydrogen Flash Smelting This approach (https://www.iea.org/media/workshops/2013/hydrogenroadmap/Session1.3BiratETSEPSteelHydrogen.pdf) replaces coke with hydrogen as the reductant, and seems feasible. But it is dependent on reduction in cost of hydrogen, the reduction agent used instead of coke. However, recent developments in hydrogen production suggest cost reduction may now be more likely (https://www.newscientist.com/article/mg23230940-200-crack-methane-for-fossil-fuels-without-tears/).
- Electric Arc Furnaces processing recycled steel and using renewable electricity can also achieve near zero emissions, and is also the most energy efficient, typically using 300-550 kWh with potential to reduce this significantly with pre-heating of material, waste energy recovery, air-tight construction and other measures (http://ietd.iipnetwork.org/content/electric-arc-furnace)

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[45] US DOE, 2010. *Steel Industry Technology Roadmap*, s.l.: US-DOE.

[46] Eshan, A (2015) *Insights from the 1st and 2nd Industrial Revolutions and Recent Developments to help achieve the next Low Carbon Industrial Revolution*. ANU Masters thesis Supervisor Dr Michael Smith (ANU)

[47] ULCOS, 2013. *CCS for iron and steel production*, s.l.: Global CCS Institute .

[48] Sadoway, D. R., 2014. *A Technical Feasibility Study of Steelmaking by Molten Oxide Electrolysis*, s.l.: Cambridge, Massachusetts and Wang, D., Gmitter, A. J. & Sadoway, D. R., 2011. Production of Oxygen Gas and Liquid Metal by Electrochemical Decomposition of Molten Iron Oxide, s.l.: Journal of The Electrochemical Society

Remelting metals after recycling, using electric arc or induction furnaces, uses much less energy than producing virgin materials, a third or less, depending on the metal. However, it is still relatively energy-intensive, thus avoiding remelting when recycling offers significant energy savings. One study (http://www.lcmp.eng.cam.ac.uk/wp-content/uploads/WellMet2050-Conserving-our-metal-energy-Sept-2010-Web.pdf) estimates that 75% of steel and 50% of aluminium recovered could be used without remelting. A variety of strategies can be used, including trimming manufacturing offcuts to make smaller items; solid bonding; sorting post-consumer waste; design for disassembly, etc. A wide range of steel products can be reused – from construction components, to wind turbines, rail tracks, transport vehicle and ship parts. Many steel products are already remanufactured. This includes machine tools, electrical motors, automatic transmissions, office furniture, domestic appliances, car engines and wind turbines.

Some of the options discussed here offer potential for integration with other developments, including smaller scale production facilities that can be located close to demand (and sources of recycled material), 3-D printing and increased activity in more sophisticated sorting/recycling businesses.

Cement

Cement production is energy intensive, and also produces large amounts of CO_2 from the production process. Portland cement is typically blended with water, sand, aggregate or other materials to produce concrete, and often reinforced with steel to enhance its structural properties. The production of clinker from limestone is the major energy and carbon-intensive step in cement production, as calcium carbonate must be broken down, yielding calcium oxide and carbon dioxide. Heat energy is applied to drive this high temperature chemical process.

A key feature of cement is that, after blending with other constituents, it becomes concrete that can be processed into a slurry which, in turn, can be easily transported, formed and handled, then sets fairly quickly into a strong, durable and stable solid. These features mean that it is often used as convenient 'filler', not just for structural purposes. Further, tight time constraints in building projects means that changes that extend the time before the concrete cures are seen as problematic, as any delay increases construction costs. So, actions aimed at reducing energy use in cement production must address significant practical barriers.

In the following discussion, options for improving the efficiency of the present cement production process will be explored, as well as alternatives for producing cementitious material that could replace Portland cement with lower energy alternatives. Options to reduce the amount of cement and concrete consumed are discussed in a later section.

Table 6 below shows a breakdown of energy and CO_2 emissions from US cement and concrete production. The core processes consume 74% of total system final energy and generate 83% of total greenhouse gas emissions. So clearly they are important. However, there are substantial opportunities in other elements of the system, especially transport, blending/mixing/grinding and, of course at point of use.

Table 6: US cement and concrete production: annual energy breakdown and CO2 emissions

Annual energy use and CO_2 emissions associated with cement and concrete production				
	On-site Energy		CO_2 emissions	
	10^6 kJouls	%	10^6tonne	%
Raw materials - Quarrying and crushing				
Cement Materials	3,817	0.7%	0.36	0.3%
Concrete Materials	14,287	2.6%	1.28	1.2%
Cement manufacturing				
Raw Grinding	8,346	1.5%	1.50	1.4%
Kiln: fuels	410,464	74.0%	38.47	36.8%
Reactions			48.35	46.3%
Finish Milling	24,057	4.3%	4.32	4.1%
Concrete Production				
Blending, Mixing	31,444	5.7%	5.65	5.4%
Transportation	61,933	11.2%	4.53	4.3%
Total	554,409	100%	104.50	100%

Source: Energy and Emission Reduction Opportunities from the Cement Industry, US Department of Energy

From http://www.climatetechwiki.org/technology/energy-saving-cement

From Table 6, it can be seen that electricity comprises at least 11.5% of final energy for cement production. This is almost 30% of the total primary energy. Since electricity is more expensive than gas, there is clear value in focusing on reducing electricity consumption within cement production. Utilisation of waste heat to generate electricity will also become more attractive. And, as cost of renewable electricity declines, shifting the source of electricity will also become more attractive.

Table 7 below shows a breakdown of energy use within the core process of cement production. Note that plants Australia use the 'dry' process which is more efficient. Even so, it is only 37% efficient. The largest opportunities for savings appear to be reducing heat losses from the stack, recovering heat from flue gases and re-condensing water vapour. Given the high temperature of the process, there may be potential to generate both electricity and useful heat from exhaust gases. Stack insulation would increase the amount of energy available from the exhaust gases. These types of efficiency improvement strategies for existing Portland cement production processes are summarised below in Figure 18.

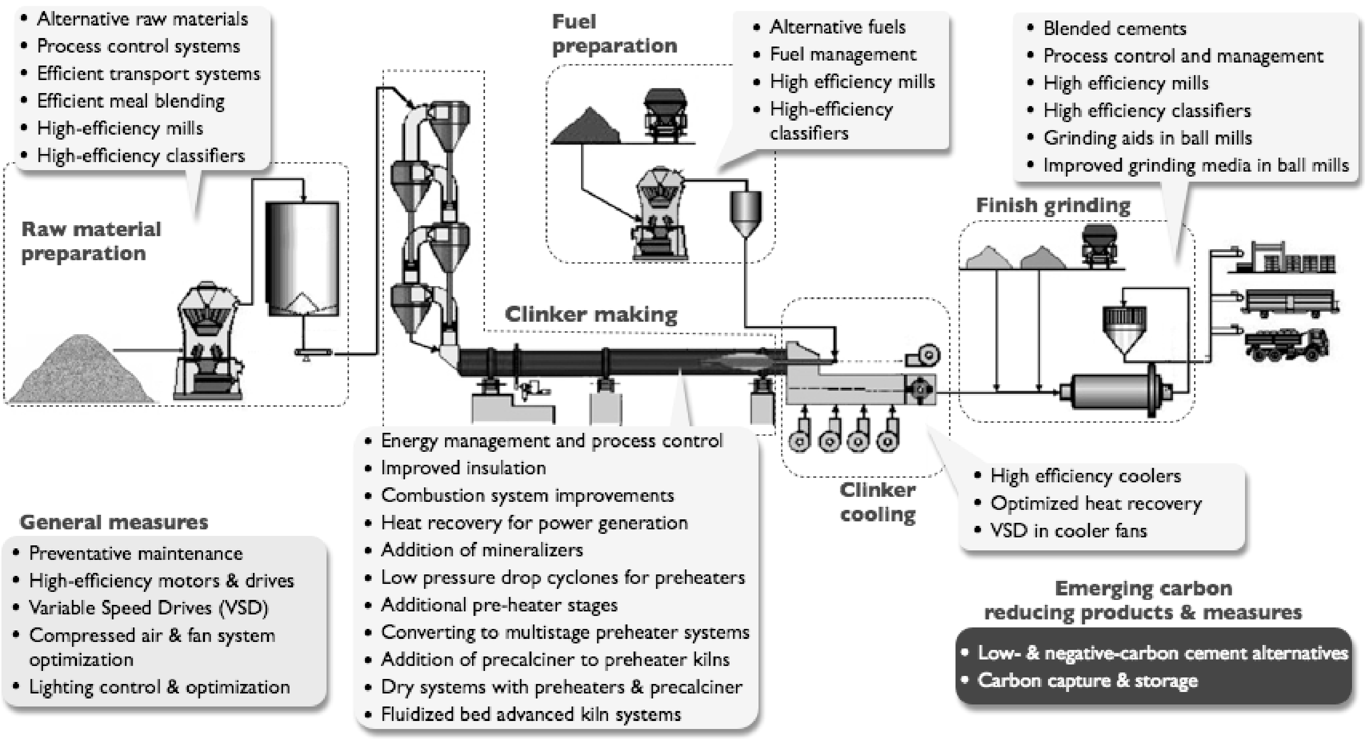
Table 7: Thermal energy balances within the core process of cement production

Thermal energy balances to produce clinker in process kilns						
	Wet Kiln		Dry Kiln		Preheater Kiln	
Energy Use Area	**Jouls/tonne**	**%**	**Jouls/tonne**	**%**	**Jouls/tonne**	**%**
Theoretical Requirement	1,782,950	30.5	1,825,150	36.6	1,761,850	49.6
Exit Gas Losses	752,215	12.9	1,382,150	27.7	496,905	13.8
Evaporation of Moisture	2,236,600	38.3	300,675	6.0	235,265	6.5
Dust in Exit Gas	11,288	0.2	12,976	0.3	1,287	0
Clinker Discharge	56,706	1.0	61190	1.2	65,832	1.8
Clinker Stack	189900	3.3	590,800	11.8	614,010	18.4
Kiln Shell	677,310	11.6	606,625	12.1	175,130	4.9
Calcination of Waste Dust	40,723	0.7	18,426	0.4	6,193	0
Unaccounted Losses	89,179	1.5	192,010	3.8	173,020	4.8
Total	5,840,480	100	4,989,939	100	3,529,492	100

Source: Perry

From http://www.climatetechwiki.org/technology/energy-saving-cement

Figure 18.: Energy efficiency and waste heat recovery opportunities in Portland cement making processes



(Source:(IIP, 2015))

However, there are thermodynamic limits on how much more efficient the Portland cement process can be improved. So researchers and companies have been developing new products to replace or supplement Portland cement with other cementitious materials. Several options have been identified and are at varying stages of development. An option to reduce process energy substantially is to switch from calcium carbonate to magnesium-based input materials. Magnesium compounds can be processed to an oxide at a much lower temperature. It is also claimed that they cure faster, are stronger, can be blended with cellulose (e.g. wood chips) and can re-absorb CO2 over their life (http://www.naturalbuildingblog.com/magnesium-cement-for-roofs-and-plaster/) so, even though they are more expensive, the extra cost can be offset. Traditional magnesium based cement (Sorel cement) is not very water resistant.

Tec-cements are made from kilned magnesite blended with Portland cement and other cementitious materials such as fly ash and slag (http://www.tececo.com.au/simple.tec-cement.php). A British start-up firm called Novacem has improved upon this approach by using magnesium silicates and carbonates, which have a reduced carbon impact (http://www.smithsonianmag.com/science-nature/building-a-better-world-with-green-cement-81138/?page=1).

Other firms, like Australian ZeoBond (see Case Study G) have used similar approaches, with blends of fly ash, blast furnace slag and geopolymers. Zeobond estimate an 80% reduction in the carbon footprint of their products.

Fly ash and blast furnace slag are cementitious materials already widely used by the existing cement industry as 'extenders' to reduce the content of Portland cement. A 20-40% blend is common, but blends of up to 60% cement extenders are available: a 60% blend halves the carbon impact relative to traditional cement (see for example Enviia (2015)). The challenge is to use a much higher percentage of these waste materials, or even replace Portland cement completely. Organisations like the Australasian (iron and steel) Slag Association promote the wider use of cement extenders.

Case Study G – Zeobond Group

Lower embodied energy construction materials – geopolymer cement

Key organisation: Zeobond Group

Innovation: Geopolymer cement technology[49] has been developed as an alternative to Portland cement, a highly energy and carbon intensive ingredient in concrete. Geopolymers are a type of inorganic polymer that can be formed at room temperature by using industrial waste as source materials to form a solid binder that looks and performs like Portland cement. The industrial waste products used in the Zeobond geopolymer cement are fly ash from coal fired power stations and blast furnace slag, the by- product of manufacturing steel.

Benefits: Recycling fly ash and blast furnace slag to manufacture geopolymer cement avoids disposal of these industrial wastes and the need to source alternative raw source materials, such as quarried limestone. The manufacturing process to produce geopolymer cement is significantly less energy intensive than Portland cement. The Portland cement manufacturing process requires heating to 1400 degrees Celsius.

Life cycle analysis comparing Zeobond geopolymer binder with conventional concrete binder found the geopolymer binder to have an 80% lower embodied energy and carbon footprint

Concrete produced using geopolymer cement is structurally equivalent to concrete using conventional cement, and is considerably more fire resistant.

EP potential: Geopolymer cement is a viable alternative to Portland cement, manufacture of which is one of the most energy intensive processes in the construction industry.

Status: Zeobond geopolymer cement has been used in a range of applications since 2006, including for VicRoads projects.

Currently estimated at CRI 4, geopolymer cement technology is not widely adopted and not required to meet building environmental standards. Tightening of building standards and changes to building specification schemes like NATSPEC may increase adoption rates.

Barriers: Lack of coverage in Australian standards. Lack of widespread understanding in the Australian building industry of the availability and performance of lower environmental impact alternatives to Portland cement.

Key Contact Information
www.zeobond.com

Image credit to http://www.zeobond.com

[49] Deventer, J. S. V., Provisa, J. L. & Duxson, P., 2012. *Technical and commercial progress in the adoption of geopolymer cement*. ELSEVIER, 29(3), pp. 89-104. For more information see Melbourne University Geopolymer Cement Research Group –geopolymer publications available from http://chemeng.unimelb.edu.au/geopolymer/publications.html

6.3.2. Reduction in use and substitutes for high embodied energy construction materials

Steel

Steel is very strong in tension. Tensile structures offer opportunity to dramatically reduce the amount of steel in a structure. Computerised design also facilitates optimisation of structural design. Use of smart stress sensors provides a way of monitoring actual performance of structures, so that problems can be identified before failure, and pre-emptive remedial action taken. Higher strength steel also means structures themselves will be lighter, so less support is needed. Lighter, stronger structural elements also allow bigger spans, freeing up more useful space within buildings[50].

Integrated steel mills already carry out basic metal shaping as the product cools. If 3-D printing or other techniques can be developed to cope with the high melting temperature of steel, molten steel direct from an electric arc furnace could be used to create structurally optimised steel solutions without needing to remelt metal.

There is also increasing potential to combine steel with other materials in structures. For example, some existing bridges are now reinforced with carbon fibre to increase load capacity.

Steel is also widely used for other building elements, such as roofs and walls. Thinner, stronger panels and composites of steel and foam insulation allow larger spans between supports. New coatings extend the life of panels and replace energy-intensive galvanising processes, while integration of PVs means steel provides a substrate for onsite renewable energy production.

'Cool roof' coatings are now available. These improve building energy efficiency by reflecting heat, and also improve roof-top air conditioner efficiency by lowering the air temperature above the roof, as solar radiation is now reflected instead of being absorbed, then raising air temperature above the roof. They also extend the life of an existing steel roof at lower cost than replacement.

Large amounts of steel are now used for reinforcing in concrete. But alternatives to concrete, as well as fibre-reinforced concrete, could reduce steel demand for this purpose.

The scope for replacement or reduced use of steel within the construction sector, as well as across the whole economy, is substantial. Engineered structural timber products sourced from sustainably produced timber are evolving rapidly, with proposals for timber high rise buildings of up to 33 storeys. The cost of carbon fibre, to strengthen composite materials and for aesthetic purposes is declining. Other fibres, including organic fibres from hemp, bamboo and other sources, are also being used in construction, fittings and products.

http://www.hempcrete.com.au/index.php?option=com_content&view=article&id=24&Itemid=25

Steel is used for many items of equipment and fittings, and much of this can be replaced by plastics or composite materials, or the requirement is simply being avoided through reduction in product size or virtualisation: for example, the need for a steel casing for a desktop computer has been avoided by integrating the computer into the monitor casing. Green fit out guidelines and consumer pressures are encouraging use of recovered and recycled materials, and lower impact products.

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[50] Kim, S.-H., Kim, H. & Kim, N. J., 2015. *Brittle intermetallic compound makes ultra strong low-density steel with large ductility*, s.l.: Graduate Institute of Ferrous Technology, POSTECH.

Energy efficient metal production processes, such as use of near ambient temperature ionic liquids for electrolytic production of metals including aluminium and magnesium, are reducing the cost and energy impacts of competing metals (see Markiewicz et al, 2008, Park et al, 2014 and the US ARPA-E program). These metals are more easily used with 3-D printers because of their lower melting temperatures, and are particularly attractive where light weight and high strength are valued. Lighter, stronger materials offer benefits such as reduced space occupied, e.g. allowing more useful floor area in a building. In low rise buildings, lightweight structural elements can avoid the need to hire cranes.

Cement

There are many ways to use less cement such as:

- Encouraging the use of nature strips and green urban spaces with shade trees and permeable pathways, which has been shown to be the most effective way to reduce the urban heat island effect. This can improve energy productivity by reducing urban building air-conditioning loads in summer helping to reduce peak electricity demand.
- Utilising water sensitive urban design that utilises natural hydrology rather than cement intensive trapezoidal stormwater drains.
- Utilising lightweight materials and insulation for foundations and flooring as an alternative to concrete slabs for residential homes.[51] Where thermal storage is important, phase change materials (PCMs) can provide this without adding significant mass.

The potential for Portland cement to be improved or replaced by low emission cementitious materials is substantial, and transition has already begun, as discussed earlier, and shown in the Zeobond case study. For instance, Boral Pty Ltd, have developed a new cement technology that can be used for all applications of cement without impacting on performance whilst cutting emissions by 40% (ENVISIA, 2015)[52].

We have not found any studies evaluating the extent of unnecessary use of concrete as ‘filler’, but it seems likely that development of tools, demonstrations and strategies could lead designers to question wasteful use of concrete and cement. Specifications are slowly changing to allow use of recycled concrete, blast furnace slag and fly as road base.

Ultra-high strength concrete is being developed. Strengths up to 300 Mpa, compared with typical strengths of 30 Mpa are being used to increase usable floor space in buildings, as well as to improve the practicability of taller buildings and reduce the weight of bridges and other infrastructure (http://www.cement.org/for-concrete-books-learning/concrete-technology/concrete-design-production/ultra-high-performance-concrete and http://www.cipremier.com/e107_files/downloads/Papers/100/32/100032023.pdf).

Within the building sector, innovation is providing alternatives to concrete in almost every area. Cross-laminated timber construction, structural insulated timber panels, insulated timber party walls in apartments, engineered timber and composite beams, plastics and prefabricated construction are among the innovations reducing demand for concrete.

[51] https://www.empowerconstruction.com.au/fast-efficient-and-feature-packed-alternative-to-concrete-slabs/

[52] http://www.boral.com.au/concrete/envisia-lower-carbon.asp

Case Study H – Lend Lease Forte apartment building

Lower embodied energy construction materials – cross-laminated timber

Key organisation(s): Lend Lease

Innovation: Ten-storey residential apartment building in Melbourne constructed using cross-laminated timber. Timber panels undergo a process whereby they are stacked at right angles, bonded together and then hydraulically pressed. This process results in a construction material that is a viable alternative to concrete and steel that can withstand the same pressure as prefabricated concrete.

Benefits: A life cycle analysis (LCA) performed by RMIT[53] compared the Forte building with a building of similar design built using a conventional reinforced concrete structure to a 6 star energy standard.

The LCA found the Forte building has a lower environmental impact on all assessed categories, except renewable energy demand, compared to the reference building.

The global warming potential of the building materials (cradle to gate) for the Forte building are 30% lower than the reference building[54], despite

the transport impacts of importing the panels from Germany, as they were not locally manufactured at that time.

EP potential: Cross-laminated timber has the potential to be deployed across the construction industry in residential and commercial applications.

Status: Cross-laminated timber is a relatively new building material in Australia, more widely used in Europe, with an estimated CRI 4.

Barriers: Lack of widespread understanding in the Australian building industry of ability to substitute cross laminated timber for traditional building materials such as reinforced concrete.

Key Contact Information
http://www.lendlease.com/projects/forte/

Image credit: www.victoriaharbour.com.au/live-here/forte-living

[53] http://www.fwpa.com.au/images/marketaccess/PRA282-1112_Life-Cycle_Assessment_of_a_cross_laminated_timber_building_0.pdf

[54] Lehmann, S. (2013). *Low carbon construction systems using prefabricated engineered solid wood panels for urban infill to significantly reduce greenhouse gas emissions*. Sustainable Cities and Society, 6, 57-67.

6.3.3. Utilisation of waste and conversion into co-products

Waste is produced at every step in this value chain. Management of these wastes incurs costs and consumes time. As alluded to in parts of the discussion above, there are significant opportunities to reuse, remanufacture or recycle steel, cement, aluminium, bricks, glazed windows, timber and furniture, from commercial and residential buildings when they are decommissioned or knocked down. It is possible in the design and construction of buildings to make it easier to re-use building materials. Green fit-out guidelines such as those used in the 60L Green Building in Melbourne, encourage reuse of second-hand materials and furniture[55].

Often, there is potential to convert a waste into a co-product. A waste from one sector may become a resource for another: the use of blast furnace slag from metal production in cements is one example. Another example is reusing crushed concrete to replace aggregate for road sub-base. Application of closed loop and industrial ecology principles helps to identify such opportunities.

Reducing waste and extending the lifetime of end use products reduces waste (and energy use) back through the whole supply chain. The design process also has far-reaching implications: a designer selects materials, influences the amount and type of waste at the point of manufacture, use and end of life, while also impacting on transport requirements.

Smart technologies offer potential to utilise waste in creative ways. New technologies can deliver high quality materials from waste (e.g. the UNSW case study), robotised systems to sort wastes more efficiently, and match availability of a waste (e.g. recovered structural beams in building waste) to potential customer demand.

One research project (Wellmet, discussed elsewhere in this report) has reached the conclusion that 75% of steel and 50% of aluminium recovered could be used without energy intensive remelting.

Note that the transition to composite materials e.g. as part of factory manufactured buildings needs to be done with a focus on the circular economy. It has been reported in NSW that the proportion of building materials recycled has fallen for the first time in 2 decades due to the increasing proportion of composite materials which are difficult to separate. This could be overcome by products which are designed to facilitate reuse and recycling, as well as improved sorting, recycling and material management technologies.

[55] https://www.acf.org.au/60l_green_building

Case Study I – Pilot metal recycling micro-factory under development at UNSW

'Mining' e-waste for valuable metals

Key organisation(s): UNSW Centre for Sustainable Materials Research and Technology

Innovation: Professor Veena Sahajwalla has developed a process to 'mine' e-waste stockpiles. A drone is programed to identify printed circuit boards, which contain many valuable elements, in waste stockpiles. The drone passes this information to an intelligent robot, which extracts the circuit board from the waste pile. The circuit boards are fed into a transportable micro-smelter that uses precisely controlled temperatures to produce copper and tin-based alloys and destroy toxins.

Benefits: This process is a low cost solution to transforming waste printed circuit boards into valuable alloys and simultaneously destroying toxins. The micro-smelters may be taken to waste sites, reducing costs, energy use and emissions associated with transporting waste to large industrial scale smelters.

EP potential: Large scale roll out of this process could result in economic recycling of metals, reducing the quantity of virgin materials mined and stockpiles of toxic e-waste in landfill. The metal alloys produced by the process are valuable and would generate a source of revenue.

Status: This technology is currently at the pilot stage of development and estimated to be at TRL 7.

Barriers: The project team is seeking to commercialise this innovative process with an industry partner.

Key Contact Information

http://www.smart.unsw.edu.au/projects

Image credit: http://www.smh.com.au/technology/sci-tech/unsw-develops-minifactory-that-can-turn-old-mobile-phones-into-gold-20160729-gqgr83.html

6.3.4. Business system innovation

Many business system innovations are cross-sectoral. They involve helping key actors to learn about innovations that they can incorporate into designs, specifications, and practices.

Updating of Standards, model specifications and regulations underpins widespread adoption of innovations. Products such as NATSPEC (see https://www.natspec.com.au/) are widely used by building designers with limited consideration of their implications for energy, either in operation or material and component production.

Training, education and promotion are fundamental. If a builder, tradesman or designer does not know a product exists, or doesn't know how to install it or integrate it into their design, it will not be adopted.

Innovative businesses conduct field research to better understand how their products and services are used or installed, and issues that block or slow adoption. They then adapt to overcome barriers and enhance the perceived value of their products and solutions e.g. Chameleon III lighting includes features that avoid the need for an electrician to change the battery, makes it easy to measure light levels and allow a smart phone app to adjust light output (see http://www.enlighten.com.au/); Zeobond accelerates curing time.

As new generic technologies become available and cheaper, businesses develop ways of utilising them to fill gaps or deliver useful services in different ways. For example, smart lighting controls originally 'piggy-backed' the development of sensors for security systems. Emerging applications of generic developments and infrastructure for the Internet of Things include stress sensors; HUX indoor environment monitoring devices; diagnostic software (Building IQ, EcoTracker, etc); Organic Lighting. Services such as Ecospecifier (http://www.ecospecifier.com.au/) demonstrate business models that link participants in supply chains to facilitate more environmentally sound solutions. By certifying claims, it builds confidence in use of emerging products.

CSR has also reframed its approach from selling building products to selling sustainability solutions (see http://www.csr.com.au/building-knowledge). It has diversified into glazing, ventilation and other products, and projects such as a high performance demonstration home in Sydney show how integrated solutions can work.

There is an increasing trend towards factory manufactured (pre-fabricated) housing which is designed for high operating efficiency. See the case study following.

Finally, governments are increasingly interested in how to encourage developers to build affordable housing. Governments can use local developer incentives and changes to planning laws to allow developers to build to higher energy productive building standards and more affordable housing in return for trade-offs such as not having to build basement car parks or having 1-2 extra stories in height. There are a range of complimentary business models to further encourage developers to build affordable housing.

Case Study J – Habitech Systems

Innovative business system – factory manufactured buildings

Key organisation(s): Habitech Systems, Victoria Australia

Innovation: Factory fabrication housing based on a system of interlocking wall and roof components as an alternative to on-site construction of housing.

Low embodied energy materials are employed including magnesium oxide cladding boards and plantation grown timber. The content of the cladding boards is 50% recycled timber.

Benefits: Production cost savings are realised through standardisation and mass production and minimisation of material and energy wastage when fabricating building components.

Modular system allows panel components to be delivered in a flat pack format to maximise transport efficiencies. Modular system also results in a faster build than traditional construction methods, reducing financing costs as the time gap between incurring costs and occupancy of the building is reduced.

As factories offer a safer working environment than construction sites, shifting fabrication of buildings from construction sites to factories reduces risks to worker safety. It also increases productivity, as trades can be better coordinated and the amount of driving between sites by trades people is reduced. Further weather interruptions and theft from sites is reduced.

Precision manufacturing results in airtight, highly insulated energy efficient buildings. High energy efficiency performance results in lower operating energy use and costs.

At the end of the buildings life, panels may be dis-assembled and reused. Faces of wall panels may be mulched.

EP potential: Factory manufactured buildings have the potential to be deployed across the construction industry in residential and commercial applications. see my earlier comments – maybe the prefab conference organisers can link us to people who have looked at the economics, scale of waste reduction.

Status: Prefabricating buildings in factories is a rapidly emerging business practice overseas, with considerably lower uptake in Australia currently. Technology estimated at CRI 4 (deployment stage).

Barriers: Low uptake of this innovative business practice in Australia is primarily due to cultural factors in the Australian construction industry, where traditional construction methods are entrenched.

Key Contact Information
www.habitechsystems.com.au

Image credit: www.habitechsystems.com.au

6.3.5. Novel construction materials and solutions

Materials that deliver the desired services but offer advantages over past practices can be transformative. For example, Phase Change Materials can offer the thermal storage functions of mass, but without occupying as much space, and while offering lightweight construction. Advanced insulation and avoidance of thermal bridges can improve thermal performance while occupying less space and, in the case of some aerogels, providing both insulation and daylight with much reduced weight and cost compared with glazing (eg see https://www.kalwall.com/).

Cool roof technologies have advanced in the last two decades and can reduce air-conditioning loads in warm to hot climates in two ways. First, they reduce heat flow into the building by reflecting radiant heat. This dramatically lowers the temperature of the roof, reducing the temperature difference driving heat into the building. Also the air above the roof is not heated by a hot roof. This means the input air to roof-mounted air conditioning equipment is much lower. Since air conditioner efficiency is improved by 2-4% for each degree reduction in temperature differential, this can significantly improve air conditioner efficiency. Cool roofs also reduce air-conditioning related peak electricity demand, cut infrastructure costs and reduce risks of blackouts in warm to hot climates. The University of Melbourne has undertaken a significant review of these technologies and their applications to date in Australia evidencing their value to warm to hot climate zones[56].

A new wave of innovation to embed solar PV and energy storage within the building envelop is occurring, where Australia is making a significant contribution often through partnerships with the Low Carbon Living CRC and ARENA. (See Case Study L)

Low cost sensors, combined with intelligent software, wireless internet, 'the cloud' and appropriate feedback solutions can help optimise building and equipment operation, identify emerging faults and even adapt operation to cope with changes in equipment performance.

Prefabricated or 'manufactured' buildings, modules and components are becoming more widely used in Australia. They have been common in many other countries, often pioneered by firms outside the building industry. For example, car manufacturers such as Hyundai in South Korea and Toyota in Japan are also major builders. This approach offers many benefits over traditional on-site construction, including improved worker productivity, tighter quality control, shorter project times (with noise and amenity benefits for neighbours), reduced impacts of extreme climates, and so on. It is easier to incorporate energy efficiency features, as well as to build tighter buildings, and 'tradie traffic' is reduced, with flow-on reductions in road congestion.

Virtual solutions can increase the efficiency of utilisation of floor area, or even allow activities to be conducted in multi-use spaces (e.g. home-offices or even in cafes, hot desks). They can shift the needs for space, for example on-line shopping reduces the need for retail space but may increase requirements for warehouse and packing areas, and increases the need for lockable storage in convenient locations.

MIT has innovated new multi-residential storey buildings with movable walls enabling better use of relatively small apartments[57]. The idea is that rooms in the apartment can be used for different

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56 Hes, D et al (2012) *Cool Roofs Report*. City of Melbourne at https://www.melbourne.vic.gov.au/SiteCollectionDocuments/cool-roofs-report.pdf

57 Larson, K – TED talk – *Brilliant Designs to Fit More People into Cities* at https://www.youtube.com/watch?v=4uuEQxmEum8 and https://www.youtube.com/watch?v=SM_hPk4rmMM

functions if the tenants are able to adjust the walls to adjust the size of the rooms in the apartment. Whilst energy is needed to move the walls, this is done on rollers so does not need much energy. Designing and building new multi-story apartments in the centre of cities or urban centres in ways that maximise the flexibility for use of space helps reduce per capita energy usage compared to the energy used by couples or families in large homes, whilst improving housing affordability, liveability and reducing per capita transport energy consumption.

Case Study K – Aerogel Australia

Innovative building solutions - insulation

Key organisation(s): Aerogel Australia

Innovation: Aerogel Australia is a leading insulation product range on the global market; Cryogel, Spaceloft and Pyrogel. Aerogel Super Insulation provides a solution based product to a broad spectrum of industries with insulation products spanning temperature ranges from -265C to +650C.

Cryogel and Pyrogel are designed for industry and commercial use, while Spaceloft is an ideal insulation solution for residential properties, with a life span of 50+ years and with only a 2% reduction in thermal performance thereafter.

Aerogel insulation uses 30-60% less material versus conventional alternatives such as polyisocyanurate and cellular glass. Less material produced results in less waste generated during production and from end-of-life disposal. The net environmental impact from the manufacturing and solid waste is approximately estimated to be to be less than 2%.

Benefits and EP Potential: Heating and cooling of commercial buildings is directly responsible for 11% of Australia's national greenhouse emissions. Air conditioning systems are one of the main causes of peak power demand requiring significant investment in electrical infrastructure, and are a primary driver of increased electricity prices.

Innovative insulation solutions such as that offered by Aerogel Australia will reduce reliance on air conditioning systems, thus reducing energy costs, greenhouse emissions, peak power demand and associated infrastructure costs, and HVAC capital costs. Also, the reduced thickness means a given insulation value can be achieved in a much smaller space, reducing problems of fitting insulated pipes into existing cavities or tight spaces and increasing usable floor area. The light weight reduces the need for structural components and installation costs.

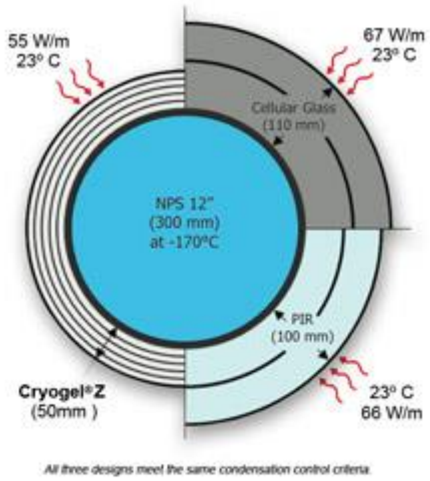
Status: Aerogel Australia is a world leader in insulation solutions, covering residential, commercial and industrial sectors. Aerogel insulation is also utilised by the aerospace and defence industries. The technology is estimated to be a bankable asset at CRI6.

Barriers: Upfront initial cost of the insulation – it may be difficult for individuals or businesses to understand the long-term benefits verses upfront costs. Low level of use means there is significant potential for cost reduction through economies of scale.

Key Contact Information

http://www.aerogel.com.au/

aerogelsaustralia B&C superinsulation



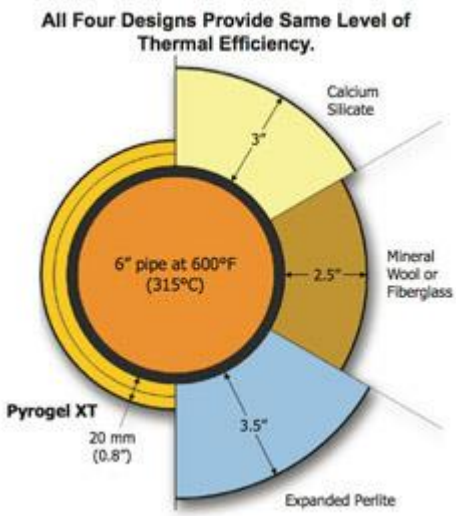


Image credits - http://www.aerogel.com.au/products-and-services/cryogel-z and http://www.aerogel.com.au/products-and-services/pyrogel

Case Study L – Roof integrated photovoltaic and thermal system (RIPV-T)

Building integrated energy generation

Key organisation(s): Tractile

Innovation: The RIPV-T integrates four key elements into one product: roof system, PV cells, solar thermal collectors and insulation. Through this combination, the system also achieves significantly increased electrical performance in hot conditions, due to the thermal energy generation cooling the PV cells. In this way, more energy is generated per unit surface area when compared to separate PV panels and solar thermal collectors side-by-side.

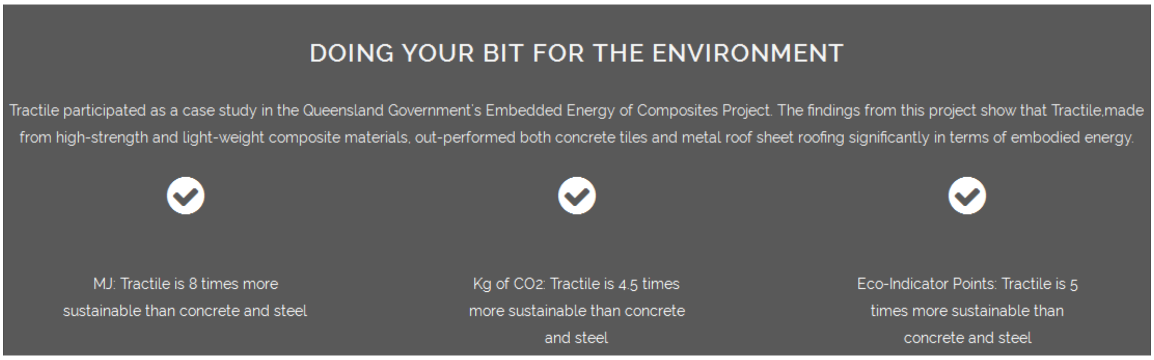
Benefits: The system has proven when installed significantly increased electrical performance due to the thermal energy generation retracting heat from the PV cells. The system also allows medium temperature water heating or cost effective water preheating and low to no maintenance required during the life of the system.

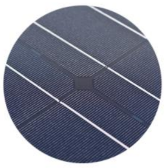
RIPV-T has a faster payback than traditional systems and a more aesthetically pleasing building integrated alternative to side-by-side water heating and PV models. It is also easier and less expensive to install compared to side-by-side modules.

EP potential: RIPV-T system has the potential to be utilised across commercial, industrial and the residential sectors. The solution has been created with the design of houses and commercial buildings in mind and seamlessly joins with metal roofing.

Status: Tractile has won numerous sustainability awards over the past years, including the 2013 Queensland Premier's Sustainability Award for Innovation in Sustainable Technologies. Currently estimated at a TRL 9 and CRI 2, the technology has been embraced at small scales.

Barriers: Although installation costs are lower compared to side-by-side models, the upfront cost of the system is still a potential barrier. There is also lack of installation skills and knowledge regarding the product.





All images sourced from http://tractile.com.au/

Key Contact Information

Tractile 1300 008 722

http://tractile.com.au/
Level 49, Governor Phillip Tower
1 Farrer Place
Sydney NSW 200

6.3.6. Building commissioning and operation

Building operation consumes almost 800 PJ of energy and emits 23% of Australia's total greenhouse gas emissions. Buildings last a long time, so poor design and performance of new buildings locks-in energy waste, poor comfort, unhealthy conditions and lower productivity.

In this report, it was decided that to focus more on construction materials and embodied energy rather than building operation, because A2EP's built environment roadmap addresses many issues relevant to building energy performance, and other groups such as ClimateWorks, ASBEC and the National Energy Productivity Plan, as well as international reports such as the IPCC[58], have done extensive analysis and policy development in relation to building operational performance.

For example, ClimateWorks, in their 2016 report for ASBEC[59], concluded that effective energy productivity action on building energy performance could deliver:

- More than half of Australia's 2030 energy productivity target
- A quarter of Australia's 2030 national carbon emission reduction target
- A net benefit of around $20 billion by 2030
- A net zero emission buildings sector by 2050

And that 5 years delay in implementing the energy productivity measures would have a $24 billion cost impact over the lives of the buildings constructed in that time.

Nevertheless, we would like to make some basic comments on building operating efficiency and EP improvement opportunities through innovation.

Our existing stock of buildings and their equipment is inefficient, particularly outside A grade office buildings. Equipment replacement, building renovation and fit-outs provide important opportunities to cost-effectively invest in improving energy performance and capturing other benefits. At present, there is very limited policy emphasis on ensuring these opportunities are captured. For example, apart from Minimum Energy Performance Standards for smaller air conditioning systems, there are no efficiency requirements for replacement HVAC (heating, ventilation and cooling) systems in large buildings as well as refrigeration equipment.

An emerging opportunity in buildings, related to both HVAC and refrigeration equipment (see farm to plate value chain) is the planned phase-out of HFCs and other refrigerants that impact on climate. In many cases, HVAC equipment will need to be modified or replaced, so action to improve efficiency could be cost-effectively combined with this phase-out. This also provides an incentive to upgrade building energy performance, as well as HVAC and refrigeration equipment. This can allow HVAC and refrigeration system capacity to be reduced, cutting the capital cost and space required by new equipment.

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[58] Lucon O., D. Ürge-Vorsatz, A. Zain Ahmed, H. Akbari, P. Bertoldi, L. F. Cabeza, N. Eyre, A. Gadgil, L. D. D. Harvey, Y. Jiang, E. Liphoto, S. Mirasgedis, S. Murakami, J. Parikh, C. Pyke, and M. V. Vilariño, 2014: *Buildings*. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

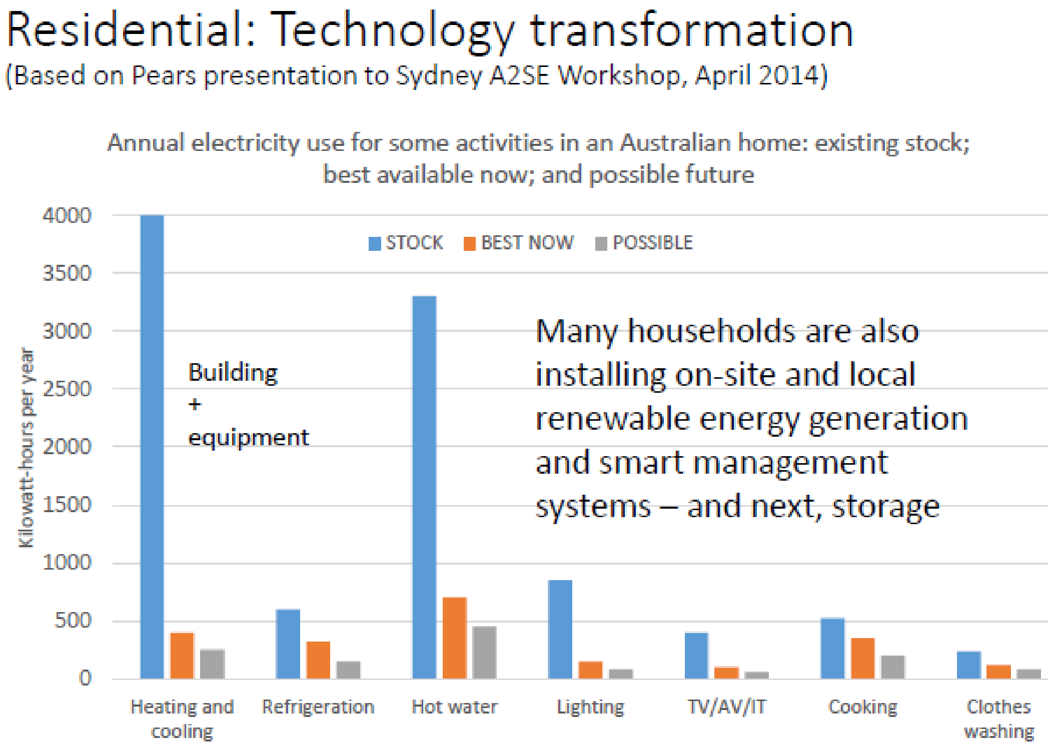
[59] ClimateWorks Australia (2016) *Low Carbon High Performance*. ASBEC at http://www.asbec.asn.au/wordpress//wp-content/uploads/2016/05/160509-ASBEC-Low-Carbon-High-Performance-Full-Report.pdf

The Commercial Building Disclosure program, initiated in 2010 is delivering ongoing incremental improvement in base building energy efficiency for offices, based on NABERS rating data. Expansion of the scheme to office spaces over 1,000 square metres (reduced from a 2,000 sqm threshold) is making a difference, but we need to apply this approach much more widely.

In the commercial building sector, the potential for large, cost-effective energy productivity improvements is clear. A combination of best practice energy efficiency, improved energy monitoring, dynamic benchmarking, analysis and feedback, renewable energy (not necessarily all on-site) and energy storage seems capable of achieving zero net energy use. Particular attention should be paid to refrigeration and cooking energy use. Advanced insulation and glazing systems offer potential for step changes in building performance. HVAC efficiency improvements, based on the heat pump technology potential discussed in the farm to plate value chain, as well as broader HVAC system improvements, is also critically important. Recognition of the multiple benefits energy productivity measures will bring, particularly improved staff productivity, health and comfort, and reduced investment in energy supply infrastructure should allow this outcome to be achieved with net benefit, as demonstrated by the ClimateWorks ASBEC report.

In the residential sector, too, the potential for zero net energy performance is achievable at low cost or even net saving, with additional benefits such as improved health and amenity, and reduced peak energy demand. A focus on rental properties and apartment buildings is important for equity and health reasons. Figure 19 below shows the enormous potential for energy productivity measures to reduce energy consumption, depicting saving potential through adoption of best existing technologies and technologies likely to emerge within the next 5 years. When combined with smart management, energy storage and renewable energy, energy efficiency can certainly deliver net zero energy and carbon emissions in buildings.

Figure 19.: Household energy saving potential[60]



The big issues for building operational energy are the implementation of effective policies for new buildings and complementary measures to upgrade existing buildings and drive ongoing innovation. To optimise cost-effectiveness, policies should take advantage of factors such as the HFC phase-out, equipment replacement cycles, fit-outs and renovations, and the need to provide improved social housing.

This does not mean there is no need to drive innovation in building and equipment energy productivity.

Much can be done to improve the economics and effectiveness of insulation, glazing, air tightness and shading of buildings. Potential developments in heat pump technologies can deliver big savings in heating, cooling, hot water, refrigeration and clothes drying. There is scope for very large savings in cooking energy, lighting and entertainment/ICT, and smart energy monitoring and management can inform and empower occupants and building managers. We must also be careful that the Internet of Things and high speed broadband do not unnecessarily increase energy consumption, including standby power usage.

Where to for building energy productivity?

Key areas for improvement in energy performance in buildings include:

- The thermal performance of the building envelope in both summer and winter, and under a range of environmental conditions, at multiple levels, from the micro-environments around people to the whole building and even precincts

60 https://www.eiseverywhere.com/file_uploads/1bfa00dafec436dd0e20c361d7b0a5fa_Pears_Alan.pdf

- Systems that actively maintain comfort for occupants, including air quality. These can vary from 'whole of building' to personal level
- Equipment that uses energy to provide the services required by occupants and business activities, but not related to maintaining comfort, and the complex interactions between that equipment and heating and cooling
- Smart ways of utilising available renewable energy, storing energy and managing energy to manage costs, optimise service delivery and limit demands on external energy supply infrastructure or even assist grids to cope with unusual circumstances. Advances and cost reductions in monitoring, measurement, collection of external data, analysis, diagnosis, prediction and management provide many exciting opportunities to optimise management, identify faults, response to circumstances in real time, and 'plan ahead' to prepare the building for future conditions
- Ways of enhancing amenity, health and productivity of occupants

There are complex interactions between the local environment, building energy use, the building envelope, design and operation of equipment and occupancy of buildings. Few practitioners understand the significance of these, or the range of potential responses. Some examples include:

- A supermarket, where upgrading to high efficiency lighting led to higher energy use, due to complex and unexpected effects on heating
- Increased heating and cooling costs due to exhaust fans increasing inflow of outdoor air
- Buildings with significant solar gains or internal heat generation using more cooling energy when thermal insulation is improved
- Painting a roof white can improve HVAC efficiency by reducing the temperature of inlet air to roof-mounted air conditioners and air inlets. Where an existing roof is deteriorating, this treatment can be considered to be maintenance under taxation rules.
- Because HVAC works hardest in extreme weather conditions, design to reduce peak HVAC demand can be cost-effective, especially under more cost-reflective time of use pricing, and through reducing capital costs of HVAC and energy supply infrastructure, even if it does not save energy

We are still in the early days of understanding these complexities, and addressing them in design and operation of buildings and equipment. Many issues also must be addressed in development of effective policies.

As in other areas, a clear focus on the services to be delivered is fundamental to large efficiency improvements. For example, in many commercial buildings, poorly insulated ring main pipes deliver hot water from central gas boilers (often oversized) to kitchenettes, toilet basins etc. For toilet basins, tempered water at close to 20-25C may be satisfactory, and could be provided for very water-efficient taps by in-line heaters, or even a small buffer tank that simply absorbs ambient heat from the conditioned space. Most kitchenettes have 'boiling water units' (and often very inefficient water chillers too). Options such as the Microheat instant electric HW units can be used to deliver different temperature heat to a 'boiling water tap' and the sink taps, avoiding the very large energy losses of the ring mains and also avoiding the cost of a separate boiling water unit. Typically, hot water usage in a kitchenette is small. The combined boiling water/chilled water' units have very poor efficiency because the hot and cold tanks are packaged together with limited insulation separating them! Where showers are provided, very water efficient showers can use very little hot water, which can be provided by an instant Microheat unit or small resistive storage tank or, in future, a thermo-electric device. Central Hot Water systems in apartment buildings are also typically very inefficient.

There seems to be substantial scope to develop tools to evaluate the actual energy use of a wide range of systems in buildings, and to compare them to 'ideal' dynamic benchmarks, so that waste can be identified and managed.

The following list provides examples of the kinds of developments that could transform energy use in buildings of all types.

Provision of comfort:

- Personal and micro-environment comfort, e.g.
    - Thermo-regulatory clothing
    - work station comfort management using radiant surfaces, micro-heat pumps, advanced thermo-electric heating and cooling and small high efficiency fans
    - management of radiant heat loads from windows
- Improved efficiency and zoning of HVAC, e.g.:
    - Cascaded heat pumps
    - Ways of minimising the temperature differential across which heat pumps work, such as heat reflective coatings to reduce inlet air temperature to chillers, evaporative pre-coolers, utilisation of exhaust air heat/coolth
    - Minimising or avoiding reheat
    - Optimisation of environmental conditions, e.g. through using technologies such as HuxConnect (https://huxconnect.com/) with more flexible HVAC systems
    - Low air movement space conditioning such as chilled beams, radiant panels, and underfloor air supply
    - More sophisticated management and maintenance of economy cycles.
- Improved building envelope thermal performance, e.g.:
    - Use of high performance insulation, smart glazing and window coatings, avoidance of thermal bridges and air leaks, effective management of doors, energy recovery ventilation
    - Adjustable shading, management of glare and radiant energy flows
- Lighting management and efficiency, e.g. LED lamps, OLEDs, advanced sensors and smart management systems
- Overall energy management, such as rapid and user-friendly building energy modelling tools, virtual building audits, real time modelling and benchmarking, predictive management systems

Extensive development is occurring with regard to energy use of ITC equipment such as data centres, computers, and copiers. E.g. high efficiency independent data centres are replacing space-consuming and inefficient on-site facilities.

Previous sections of this report discuss potential for improving efficiency of refrigeration, cooking and some other equipment. Other studies have identified large savings potential in appliances and equipment used in buildings, as shown in Figure 19. Much of this potential is already available, but has low market share. Tools and services that assist building managers, occupants and owners to make optimal decisions are also needed to drive adoption.

The building envelope is the barrier between indoor and outdoor environments.

As mentioned earlier, the combination of the building envelope and internal heat loads is important and complex. For example, if solar gain and internal heat load are not carefully managed, insulating the building can increase annual energy consumption, although it will still help to cut peak loads in extreme weather. Modelling energy use with time of use tariffs that are cost-reflective for energy supply infrastructure is also important if the benefit of better envelope performance is to be recognised and energy productivity improved.

HVAC technologies in many existing buildings are also extremely inefficient. For example, HVAC systems that use fixed speed fans and dampers to control air flows use more fan energy as flow rate declines, as the damper increases flow resistance. Control systems often lead to heating and cooling 'fighting'. As noted building energy expert Paul Bannister has said, many commercial buildings are operating in chronic failure mode.

7. Assessment framework

Phase 1 of the Next Wave project aims to identify technologies and business models that may significantly impact energy productivity by 2030. An international scan of innovations with the potential to improve energy productivity was performed. The scan was followed by prioritisation of the innovations using a systematic approach based on a set of criteria developed for this purpose.

We do not claim that our project was totally comprehensive or the assessment is based entirely on sound data. Our capacity to provide a comprehensive assessment was constrained by limited data (as well as budget) and any attempt to 'predict' the future is fraught with uncertainties. However we hope this report provides a step in a useful direction.

There are many measures that may deliver large benefits in a niche area of energy use (e.g. pasteurisation and sterilisation) that did not make it into our highest priority list. That does not mean they are unimportant, especially for specific industries. Our analysis and literature scans have identified many opportunities, and we have tried to address as many as possible them in the body of the report, and list them at the end of this section. But our focus was necessarily limited to measures that offer large improvements in energy productivity by 2030 within the value chains considered.

Prioritisation of measures

The assessment framework consists of primary and secondary assessment criteria. The first two primary assessment criteria reflect the nature of energy productivity: improvement in value (or economic benefit) per unit of energy consumed. So, using energy more efficiently or capturing greater economic benefit from energy consumed, or a combination, improves energy productivity. We recognise that some benefits are difficult to quantify, may be difficult for specific actors to capture, or may occur within different timeframes. These issues need to be addressed, but are beyond the scope of this initial assessment.

Energy productivity exists within a global context and improvements in Australia's energy productivity contribute to the competitiveness of the Australian economy. So the third primary criterion considers interactions with the global economy and employment implications within Australia: this reflects the linkage of energy productivity to overall productivity, and productivity of labour and capital. The final primary criterion reflects the impact of the innovations assessed on carbon mitigation.

The secondary criteria explore the practical issues involved in implementing the measures. The focus clearly must be on technologies that are ready for commercial deployment, or will be within a few years, if they are to have a major impact by 2030. Many of the business model changes that make the priority list actually use existing commercial technologies, and the innovation is in the combination and deployment of these technologies in novel ways to gain energy productivity benefits.

7.1. Primary assessment criteria

Primary criterion 1: Energy savings delivered

In this project, one focus is on measures likely to save a significant amount of energy, both in terms of total energy and percentage savings in an activity or sector where large amounts of energy are consumed. It should be noted that the energy criterion is measured in terms of primary energy. So some electricity intensive activities become more significant using primary energy, as about three units of primary energy are used per unit of electricity supplied.

Primary criterion 2: Enhanced value created

This criterion focuses on the potential to enhance value of output of a process or industry by using energy more effectively (while energy consumption will either increase more slowly, stay the same, or even decrease in absolute terms). This is often the key to major EP improvements as the total value from EP projects is often a large multiple of the value of energy savings. The International Energy Agency[61] and others have increasingly recognised that apart from energy savings there were other 'multiple benefits' of energy efficiency improvement projects, and found these additional benefits could be worth as much as 2.5 times the value of the energy saved. But energy productivity includes all potential value added, including improved labour and other factor productivity, improved safety, reduced health costs, product quality and value, reduced energy supply infrastructure costs, improved reliability/resilience, reduced resources/water, reduced cost of effluent disposal, and improved access to export markets. Some of these outcomes are not easily quantified, but that does not make them less real, and highlights the need for development of more comprehensive approaches to valuing them. The multiplier of total value to energy savings is often much greater than 2.5.

Primary criterion 3: Export/employment opportunity

This criterion addresses more strategic opportunities. It focuses more on Australia's potential to build a strong '21st century' economy that engages with the global economy. We need to consciously work to leverage our innovation and created advantages to maximise global returns, while also competing effectively with imported goods and services, which transfer funds away from local economic activity. A balanced mix of employment with regard to skills, locations and growth rates can contribute to a diverse, equitable and resilient society.

Primary criterion 4: Reduction in climate impact

Fossil fuels are responsible for three-quarters of Australian emissions, and energy productivity measures are the most cost effective way to reduce carbon emission, so failure to capture the maximum energy productivity contribution to emission reduction means that, to achieve a given target, we will have to spend more money paying for more costly emission reductions.

[61] International Energy Agency (2014) *Capturing the Multiple Benefits of Energy Efficiency* Paris

7.2. Secondary assessment criteria

Secondary criterion 1: Readiness and potential market impact

The path across the 'valley of death' from a good idea to a strong market share is long and rocky. Technical, institutional, regulatory and supply chain changes/support are often needed. Given that this project is focused on measures that may have significant impact by 2030, this criterion is critical. In our case studies, we have attempted to allocate TRL (Technology Readiness Levels) and CRIs (Commercial Readiness Indices) to provide some insight into the extent to which the technology has progresses along the path towards widespread commercial adoption.

While technical development and commercialisation are important elements of commercial success, other issues must also be addressed. Even when commercialised, products must attract customers, compete with established businesses, build supply chains, and so on. In this criterion, we begin to look at how likely a measure is to achieve significant market impact by 2030.

Secondary criterion 2: Economics/trend

For many energy productivity measures, economies of scale, 'learning effects' and technological leaps play vital roles in increasing adoption. Typically, each doubling of cumulative production of a product leads to about a 20% reduction in production costs, though electronic innovations (like LEDs and PV) have followed 'Moore's Law', with much more rapid exponential capital cost reduction, while some innovations that involve more mature technologies or are not well suited to mass production may improve more slowly. These trends mean rates of adoption can accelerate more rapidly than predicted where there is a strong learning cost curve, especially where a product or service can grow new markets instead of relying on end-of-life replacement cycles of existing product stock.

Where a product or service can compete within niche markets at high prices in its early production, it can build revenue streams, improve performance and gain experience in the real world. It can then expand into additional markets progressively. For example, laptops and smart phones have provided premium niche markets to support development of energy-efficient, high quality screens. So a product that can only compete against major incumbent suppliers in large markets where it is difficult to differentiate your product faces a much tougher path towards market success.

Potential financiers are interested in limiting risk and gaining a return within a reasonable time. So measures that need large amounts of capital early, and/or take a long time to develop a revenue stream are less attractive. In the marketplace, many potential buyers are influenced by up-front costs and access to finance. Creation of mechanisms to reduce initial capital cost or to reduce risks for early adopters (e.g. through grant funding of demonstration projects), and ideally also provide access to finance can be significant influences on success. Capacity to drive down prices and fund effective marketing strategies also helps to reduce prices also reduce the upfront price barrier and may also build supply chain capacity.

Secondary criterion 3: risk, barriers, support and infrastructure

This criterion considers a range of factors that may impact on the rate of adoption (success in growing market share or rate of replication), ranging from failure to achieve technological performance targets, gaining access to finance/funding for RD&D, tooling up, field trials and commercialisation, and the extent to which it can utilise existing infrastructure and supply chains or needs new infrastructure to operate. A big concern for early adopters is the availability and competence of local suppliers to implement, support and maintain the technology.

An efficient and informed supply chain that is trusted by consumers is important as a way of reducing perceived risk, especially where poor reliability or lack of support services could undermine major revenue streams from production, or create a crisis if an essential service fails.

8. Priority measures and their assessment against criteria

Listed below are technological and business model innovations found by the 2xEP Next Wave project to have the greatest potential to improve energy productivity in the two value chains considered. This list has been structured such that some over-arching technology developments that have a broad range of impacts on energy productivity opportunities in the value chains are firstly considered. The list then hones in on specific potential innovations that could transform energy productivity in the two value chains of focus.

The priority measures were selected using a systematic methodology, as described in section 7, as the measures and related technologies most likely to have a significant impact on energy productivity by 2030. Table 8 and the following sections explore the performance of the priority measures against our evaluation criteria, but do not attempt to 'score' them or rank them. This has been done with limited data and is an inexact science, but we are confident that the innovations identified, while not being extensive or complete, are worth pursuing in the next stages of work. The priority measures listed below are not ranked in any particular order.

Over-arching innovations

- 8.1 Optimise service delivery technologies with Internet of Things (IoT), communications and cloud computing applications
- 8.2 Integrate clean energy (ICE): energy productivity (including electrification and demand management), renewable energy, storage, and 'smart' systems

Food value chain

- 8.3 Electrification of food processing
  - 8.3.1 Deploy heat pump heating and (latent) heat recovery, mechanical vapour recompression combined with renewable energy (electricity and thermal)
  - 8.3.2 Utilise dewatering as early as possible in the value chain, removing water mechanically to reduce thermal loads and cut mass/volume for transport and further processing
- 8.4 Transition to high efficiency commercial cooking and food display systems
- 8.5 Step change in refrigeration energy use
  - 8.5.1 Transition to high efficiency, low carbon refrigeration
  - 8.5.2 Optimise refrigeration use across the cold chain

Shelter value chain

- 8.6 Prefabricated construction with engineered timber and other low impact materials
- 8.7 Increase recovery of high value materials from building material waste
- 8.8 Utilise new technologies and business models to accelerate improvement of building energy performance
- 8.9 Promote optimal structural design and incorporate emerging materials and systems into structures

8.10 Transition further to low emission steel production

8.11 Implement a cement emissions reduction strategy

High potential innovations may be individual technology or business model innovations or clusters of innovations, which together drive a significant shift in energy productivity.

The table below contains a summary of the priority measures evaluated against the assessment criteria and the following sections contain a detailed evaluation of each of the priority measures.

Table 8: Summary of priority measures evaluated against assessment criteria

Note more detailed discussion of measures and their performance against criteria follows this table

MEASURE	PRIMARY CRITERIA				SECONDARY CRITERIA		
	Energy savings	**Enhanced value added**	**Export/ employment opportunity**	**Reduction in climate impact**	**Readiness and potential market impact**	**Economics/ trend**	**Risk, barriers, support and infrastructure**
	Include primary energy both within and beyond VC	*Broad economic and 'perceived' value*	*Competitiveness, net impact on employment*	*National and global impact from all gases*	*How close to practical, commercial adoption*	*Potential and time to improve economics*	*Potential blocks and key support factors for success*
Over-arching innovations							
8.1 Optimise service delivery technologies with Internet of Things (IoT), communications and cloud computing applications	Very broad and large energy savings in all sectors. Some risk of energy waste	Allows tailoring of solutions to consumer demand, sophisticated optimisation. Improved maintenance, lower risk of loss of production and plant capital costs. Can complement renewable energy and storage	Global tech and business solutions, so very competitive space – but big benefits from success in global markets. Many niche opportunities for SMEs and start-ups	Very large potential to cut ghgs overall. But can be applied to activities that increase ghgs, 'accidental' energy waste	Wide spread of readiness, rapid evolution; some good examples	'Virtualisation' and optimisation can drive very rapid and large cost reductions and value enhancement. Costs of sensors, hardware falling rapidly, capability expanding	Critical that all elements of the service delivery system are monitored, controllable and use efficient techs. In early stages, high costs, lack of consumer and supply chain understanding
8.2 Integrate clean energy (ICE): energy productivity	This has to be done well to minimise energy	Effective integration optimises	Within the energy sector, clean energy solutions increase	Efficient, smart, clean energy is fundamental to a	While there is a long way to go, many aspects are	Unexpectedly rapid cost reductions and performance	Powerful incumbent industries, sunk capital in existing

(including electrification and demand management), renewable energy, storage, and 'smart' systems	losses/waste and maximise benefits. Part of the primary energy saving is due to the anomaly in how accounting is done for renewable electricity as primary energy	performance, environmental benefit, reliability, empowerment of energy service consumers. But energy is a small component of total service costs, so need to emphasise broad value adding of the service, not just energy	employment Supports innovation, improves competitiveness and underpins broad economic development Niche market opportunities	low carbon economy as emissions from energy dominate Australian and global emissions	already cost-effective, but not being optimally adopted. The large amount of sunk capital in both energy supply and energy using technologies slows change	improvements are occurring. Creative integration is amplifying benefits and improving perceptions of value. Increasing visibility of climate change is focusing attention	infrastructure, captive policy makers and regulators, lack of understanding of emerging solutions, lack of industry capability and capacity, limited RDD&C resources, limited training available
Food value chain							
8.3.1 Deploy heat pump heating and (latent) heat recovery, mechanical vapour recompression combined with renewable energy (electricity and thermal)	Moderate value of total savings but major cost for some industries. Firms face big increases in gas and electricity prices which are significant input costs	Key element of shift to integrated EE, RE and storage, supports industrial development beyond gas grid. May underpin survival given gas price increases	Potential exports in niche markets, IP Aust has extensive HVAC&R industry which can build capacity	When replacing resistive electric heat, big reduction When replacing gas, reduction depends on overall system efficiency improvement and COP, gh intensity of electricity: range from small to very large ghg reduction	Wide range of product available internationally and large scope to expand market share High temperature units (steam) still prototype/ emerging commercial	Costs falling, cost of gas increasing, need for large ghg reduction accelerating Economies of scale and learning potentially very large due to global scale Fits with trend toward modular equipment	Demonstrate performance and applications Capital cost and change in design philosophy Need to develop and demonstrate 'modular factory' packages for non-gas regions agro-industrial processing
8.3.2 Utilise dewatering as early as possible in the value chain, removing water mechanically to	Direct energy savings by reducing energy-intensive evaporation of	Reduce costs associated with volume, including equipment cap cost, labour,	Lower supply chain costs.	Maybe 1-5 Mt pa avoided emissions at negative cost	Many technologies commercial in other industries, or low penetration Preferable to	Past low gas prices and culture of centralised heat supply	Poor data on how much energy is used Lack of sub-metering and benchmarking to

reduce thermal loads and cut mass/volume for transport and further processing	water or evaporating it more efficiently. Indirect savings through reduced transport energy Energy data limited, and overlap with cooking, heat pumps and process heat.	operation of refrigeration, transport, storage, central processing plant Value of additional clean water for use where dewatering occurs			integrate with high process efficiency, heat pumps local RE, etc		identify waste
8.4 Transition to high efficiency commercial cooking and food display systems	Direct and indirect energy costs uncertain but between $1.5-4 billion annually – around half could be saved	Improved OH&S and food safety, reduced peak electricity demand, lower operating costs, new business opportunities	Some potential for new business models and exports	Up to 20 Mt pa cost-effective emission reduction	Neglected area, so significant opportunities	Significant uncertainty and limited economies of scale unless exports	Establishment of FIAL a positive, but cultural barriers and low priority for efficiency unless quality and aesthetic objectives met
8.5.1 Transition to high efficiency, low carbon refrigeration	Substantial energy saving potential, including summer peak demand reduction. Some avoided food waste. Natural refrigerants improve efficiency.	Substantial cost-effective energy saving potential- $200 mill+ pa savings. Smarter, better insulated appliances help manage peak demand and reduce food loss. Combining efficiency improvement with	Some potential for niche market manufacture, export of IP	Up to 20 Mt pa emission reduction from energy, up to 10 Mt from refrigerant losses. Negative carbon cost savings are very attractive.	Best products from overseas much more efficient than ours. Smart diagnostics simple to do but not yet implemented	Already very cost-effective but economies of scale for best products, and for emerging insulation and compressor techs can be captured	Mixed situation: weak MEPS, lack of focus on commercial refrigeration, split incentives etc. Concerns about safety of some natural refrigerants, but can be addressed

		HFC phase-out optimises investment					
8.5.2 Optimise refrigeration use across the cold chain	Savings result from direct energy and avoided food production due to reduced food waste. Refrigeration is over 4% of Aust primary energy and food production is much larger.	Retail value of food no longer wasted may be 1-2% of total household expenditure. Improved management may lead to wider range of food available in rural and regional areas, reduced health risks. Reduced waste management costs	Longer life and improved quality increase potential for exports and higher prices. May reduce local employment but increase export employment	Reductions in emissions/unit of edible food across a range of ghgs from agriculture, industry, commerce and homes due to reduced food waste and energy savings – maybe 1% of Aust ghgs	Elements exist, but cost of sensors, integration and evidence of reliability and scale of food savings needed	Economies of scale would rapidly improve economics through investment	See 'readiness'. If industry is confident of benefits and economics OK, industry is capable of adopting quickly. But industry is (rightly) risk averse with regard to health
Shelter value chain							

8.6 Prefabricated construction with engineered timber and other low impact materials	Energy savings mostly indirect, through reduced tradie travel and material transport, better waste mgt, integration with high operating efficiency building products, lower embodied energy materials	Quality, minimise time on site (cuts cost of capital, impacts on neighbours, weather disruption, theft etc) Reduced 'tradie travel' and road congestion improves staff productivity Suits Design for Manufacture and Assembly	Significant potential productivity improvement improves competitiveness Application of DIMA opens opportunity for decentralised manufacture of elements Engineered timber products can use timber from faster rotation plantations, coppicing	From energy savings, enhanced material management and use of low embodied energy and sustainably sourced materials	Already well-established overseas. Some application locally	Rapid progress feasible by applying overseas experience	Requires capital, supply chains, demand to support growth and capture economies of scale
Increase recovery of high value materials from building material waste	Recycling materials (especially metals) instead of producing virgin material can save 50-95% of energy and metal production is very energy intensive	Challenge is to match or exceed virgin product quality or capture niche markets (eg stainless steel, high value metals)	Recycling typically employs many more people in distributed locations than virgin metal production. Supports local (aust) production to replace imports	Reduces energy use of emission intensive processes	Already established in some areas RDD&C needed for large scale and more cost-effective applications	Depends on charges for landfill, achievement of quality standards, integration into supply chains	Need to improve processes, develop new ones, meet industry standards or revise standards
Utilise new technologies and business models to accelerate improvement of building energy	Energy use in building operation is the largest component in this value chain. Zero net energy buildings have	Energy-efficient buildings are usually more comfortable and healthier, staff are more productive Energy	Design, construction and management of high performance buildings is a global growth sector in which Australian firms are already active and	Building operation is responsible for about a quarter of Australian emissions and up to 40% in some countries	Australia's leaders are world-class and our very varied climates support skill, product and service development	Economics and product performance are improving, while energy prices are increasing. Recognition of	Deep cultural barriers due to focus on 'sticker price' instead of annual cost of loan repayments, energy and value of

performance	been demonstrated in most climates, so saving potential is very large	infrastructure costs and dependence on reliable infrastructure can be reduced Business reputation of owner and occupants can be enhanced, as well as asset value and rental returns	well regarded Higher standards of workmanship and greater system complexity may increase employment Increasing refurbishment will also add jobs	Construction can lock-in or avoid emissions for decades Increasing temperatures and weather extremes create a need for better buildings	relevant to many countries Present share of high performance buildings is small and faces market barriers	value of broader benefits is increasing established rating schemes help build market shares	broader benefits Poor quality of workmanship and lack of training
Promote optimal structural design and incorporate emerging materials and systems into structures	Reduction in materials, use of low impact materials cuts embodied energy, software allows improved energy efficiency to be built-in	Many cost reductions during construction Potential to improve energy performance, aesthetics, larger spans, increased usable floor area	New market niches Synergies with other technology developments International services business opportunities	Construction materials are a large part of global carbon budget, land clearing	Many existing examples: improving materials and software cuts cost, time and widens scope for application	Economies of scale, training needed	Cultural barriers, perceived risk, training New solutions must be integrated with site operations, time-frames Standards, software tools must be developed

Transition further to low emission steel production	EAF recycling uses much less energy than producing new steel. New processes may reduce energy requirements, and can also utilise zero carbon energy sources and reductants	Smaller size plants may reduce risk and financing costs Increasing pressure from customers for low emission product Solar/electric steel production suited to Pilbara iron ore; improved EAF for east coast cities recycling	Add value and jobs to existing iron ore exports; more steel recycling adds services jobs	Coking coal and fuel make steel production emission intensive, so higher efficiency and shift to renewable electricity cut emissions	Improved EAFs are commercial Non-carbon reductant processes still research/pilot Techniques for recovery of waste metals (eg UNSW) may provide input and do some processing	Smaller, modular plants involve smaller amounts of capital, economies through multiple production, can be integrated with renewable energy development. Increasing prices of grid electricity, coal (with future C price)	Large amount of existing steel production capacity globally, strong competition on price
8.11 Implement a cement emissions reduction strategy	Concrete and the steel used to reinforce it dominate energy and carbon emissions embodied in building construction. Energy savings of 50% or more are already achievable.	Reduce mass of structures, free up more floor area, speed up construction	Reduce cement imports	Global cement production is 5% of total emissions, and large emission reductions are feasible.	Some options already commercial, others at varying stages of development	Present economics vary from savings to higher costs. RD&D, production scale, climate policy are improving competitiveness	Major cultural and institutional change needed to shift approach to design and construction

Over-arching innovations

8.1. Optimise service delivery technologies with Internet of Things (IoT), communications and cloud computing applications

Description

Our focus has been the application of the concepts and technologies of IoT to specific situations. This involves the integrated development of systems including conversion of data to information, then into action, which requires flexible and 'smart' controls (e.g. variable speed motors, compressors that work efficiently at part load), and in some cases, organisational capacity to respond.

For example, dramatic improvements in fan or pump system performance can be achieved by installing a combination of sensors to monitor loads/environmental conditions and access/send relevant data to/from 'the cloud', variable speed drives on (high efficiency) motors, improved fan or pump design, reduced flow resistance in pipes or ducts, and a smart management system to manage response to changing conditions. This combination can cut energy use by up to 90% and deliver additional benefits, such as reduced noise, lower maintenance, lower risk of failure, improved quality of output due to more accurate and rapid control, and faster response from remotely located maintenance contractors.

Examples of this approach with large energy productivity potential identified in our scans and analysis include:

- Food cold chain management: this involves fitting sensors to perishable food to ensure it remains at an appropriate temperature as it travels from farm to plate. Even short periods outside the optimum temperature range can create health risks or affect food quality, while this information can also be used to benchmark energy consumption, to allow faulty equipment to be detected and management optimised, thereby saving energy.

- Application of real time monitoring, benchmarking and diagnostics to buildings, appliances and equipment across all sectors: capacity to compare actual energy use with predicted performance under actual operating conditions is a powerful tool to identify faults and support optimal management of equipment. Since the farm to plate value chain involves extensive refrigeration, process heat and materials management, this approach has broad application. For example, development of a plug-in smart monitoring/diagnostic unit to check operation of existing plug-in refrigeration equipment would provide a powerful tool to identify energy waste.

Savings are both direct, through reductions in process energy use, and indirect, for example by reducing food waste, energy is saved in upstream processes.

Primary criterion 1: Energy savings delivered

The EP benefits achievable from this approach are very large, and include:

- Higher operating efficiency when equipment runs close to optimum instead of part-load

- Early identification of faults leading to energy waste, such as failing bearings, loss of refrigerant, failed controls, and worn components. This leads to increased plant reliability.
- Optimisation of operation by providing feedback for effective maintenance (e.g. maintaining clean filters and heat exchangers), operating parameters, and training of operators.
- There is some risk of increasing energy waste through poorly managed or designed systems with high standby energy use or algorithms that drive inefficient operation.

Primary criterion 2: Enhanced value created

These systems provide more accurate and responsive control. If equipment is not performing optimally, it is likely to affect product quality and consistency, leading to higher rejection rates or product losses (e.g. spoiled food) and lower labour and capital productivity.

Non-optimal equipment performance and lack of monitoring can lead to other costs such as:

- Oversizing equipment and infrastructure to provide a 'safety margin', adding to capital costs, space occupied and installation costs
- Reduced plant reliability/increased disruption to production
- Higher noise and heat in the workplace, as well as potential OH&S risks

Primary criterion 3: Export/employment opportunity

Improved productivity and quality, and lower production costs make an Australian business more internationally competitive. Export of intellectual property, products and services associated with practical application of IoT to industrial processes, buildings, appliance and equipment design, software development and specialised components, training all provide export and employment opportunities.

Primary criterion 4: Reduction in climate impact

Practical IoT offers very large reduction potential for climate impacts. Not only can it save a lot of energy and resources, but much of the energy saved is electricity, which has a high climate impact. The large improvements in energy efficiency also make the cost of adding renewable energy and energy storage more affordable, as smaller capacity is needed, and smart systems can optimise utilisation of these low carbon energy sources.

Secondary criterion 1: Readiness and potential market impact

We have examples of successful application of these approaches in vehicles, some appliances (eg Siddons 'Bolt-on' heat pump hot water service), some industrial processes and building management. However, many applications are partial and crude, and much of the potential benefit is not yet captured. The benefits are large, and the basic technologies and tools are available.

Secondary criterion 2: Economics/trend

Especially in the early stages of development, new technologies and systems cost more. More time is required to identify suitable products, systems, suppliers and installers, to program and fine tune operation, and to confirm practical benefits in the field without risking loss of production or consumer complaints. Application of practical IoT to existing facilities may also require significant skill, design, construction and installation of custom equipment. However, declining costs of sensors and increasingly flexible software can allow standardised product operation to be adapted to real world circumstances in a wider range of applications. Costs decline over time, while supply chains upskill to deliver new solutions, where they demonstrate their business value.

Secondary criterion 3: Risks, barriers, support infrastructure

Much Australian industrial and commercial equipment is old and poorly maintained, and much of it is imported. Maintenance practices are often far from optimal, and many maintenance contracts focus on rapid response to failures rather than preventive maintenance, smart system design and capture of its spin-off benefits. While 'hackathons' and other approaches are bringing together the combinations of skills, potential clients and technologies, our approach is still piecemeal. Lack of active measurement and analysis of energy flows through equipment and systems during the R&D, design, and installation phases leads to many lost opportunities.

An example of the potential is a recent experience of an industrial design firm, who purchased a 3-D printer. Their electricity costs quadrupled. After analysis, they found that the equipment had very high standby power use, as it kept many components hot. But switching the unit off meant software had to be rebooted every time it was used, wasting time. The solution was a simple separate power supply for the computerised controls. Improved insulation and other measures seems likely to offer further savings. Issues like this should not arise if energy was properly evaluated during development and design, and users received effective feedback on energy performance.

The solutions are often fairly simple. The challenge is for those involved in the value chain to be educated and informed so the focus on energy aspects, and for customers to raise expectations.

8.2. Integrate clean energy (ICE): energy productivity (including electrification and demand management), renewable energy, storage, and 'smart' systems

Description

A range of new technologies, software and business models can now be integrated to minimise electricity use and costs at specific times, maximise utilisation of renewable energy, and even generate additional revenue through export to the electricity grid or other customers (e.g. electric vehicles). The potential benefits are very large both for consumers and the electricity grid.

Elements of ICE include:

- Improved energy efficiency, which often reduces the peak demand as well as total consumption, especially if activities that contribute disproportionately to peak demand are targeted.
- Demand management, which shifts consumption to times when energy is cheaper or low emission energy is available, cuts peak demand to reduce pressure on constrained supply infrastructure, and/or adapts to equipment failures.
- On-site or local energy generation or conversion (e.g. solar PV, fuel cells, biomass combustion, cogeneration), which can supplement or replace imported energy, and/or export energy and reduce transmission and distribution energy losses and costs.
- Energy storage, which may include thermal or prepared feedstock storage, batteries or other fuels (eg biofuel, hydrogen). Storage can capture excess energy or cheap imported energy,

then make it available when alternatives are expensive, supply fails, or to assist the grid in coping at times of extreme load.

- Smart energy management and control systems which can monitor environmental conditions, equipment performance, demand, and energy prices to optimise performance of on-site energy systems and their interactions with energy supply systems. 'Learning' and predictive systems can look ahead to prepare storage and other equipment to minimise future energy costs or usage relative to predicted availability and activity. Management systems also can interact with dynamic energy pricing markets.

We are focused on where these technologies and management systems are utilised on-site, or in home, and even built-into individual appliances (including laptop computers, back-up for phone answering machines, and potentially micro-storage in electric cookers, dishwashers, thermal storage in refrigerators and hot water tanks).

Primary criterion 1: Energy savings delivered

Energy savings from integration occur in a number of ways, including:

- Reduction of embodied energy in energy supply infrastructure through reduced peak demand and optimisation of utilisation of equipment.
- Diagnostic analysis that can identify faults or unusually high energy use and alert users or managers.
- Where on-site or local generation replaces grid power, transmission and distribution energy losses can be reduced: this can be a very large saving in rural and regional areas, and at times of peak demand, as line losses increase with the square of demand. In Queensland, ERGON is implementing energy storage projects on its rural SWER (single wire earth return) powerlines[62].
- Shifting of energy using activity to times when conditions support higher efficiency, e.g. running a heat pump hot water service at a warmer time of day improves efficiency by around 3% per degree warmer. Running cooling equipment overnight instead of during hot afternoons can also save energy, although the energy losses associated with storage must be taken into account.

Care must be taken in design and operation, as cycling losses associated with shifting demand and storage, standby losses (thermal and electrical) and non-optimal operation can waste a lot of energy.

Primary criterion 2: Enhanced value created

There is enormous scope to optimise energy use and costs, reduce equipment size/capacity, enhance reliability, optimise deployment of maintenance staff, and maximise profits from interaction with the energy grids. Emerging energy storage and management systems for rooftop PV reflect this potential, as does the emergence of trading mechanisms such as Reposit (http://www.repositpower.com/).

[62] See *S&C's Energy Storage Solution: a case study* pp.21-22 Solar & Storage Summer 2016, Aust Solar Council and Energy Storage Council

These approaches also offer potential to improve power quality, smoothing voltage and power surges to protect equipment from damage and extend its life, and assisting grid stabilisation. Being able to avoid supply interruptions allows production to be maintained and can avoid equipment 'tripping out' because of short interruptions. This avoids loss of partially manufactured product (e.g. partly cooked food), start-up and shut down losses and time, and loss of production. These benefits can be particularly significant in rural and regional areas, and where grid capacity is constrained or unreliable.

Integration with smart diagnostic systems means maintenance costs and response times can be reduced, and major failures avoided by preventive action. Staff can be better utilised, as fewer people are needed to be on standby to respond to crises, and maintenance and other activities can be better planned. Staff morale can also be improved, as business activity suffers from less disruption.

Primary criterion 3: Exports/employment potential

The potential for integration and optimisation offers significant productivity benefits by avoiding loss of production and improving productivity of staff and equipment. As with measure 8.1, there are many niche opportunities, so small start-ups and SMEs can find opportunities.

Primary criterion 4: Reduction in climate impact

Smart integration offers the potential to reduce climate impacts by supporting improvement in energy and resource efficiency, expansion of renewable energy and ongoing replacement of physical products, movement and activity by 'virtual' and smarter solutions. It will also assist in climate adaptation.

Secondary criterion 1: Readiness and potential market impact

We are seeing early movers installing on-site generation, improving efficiency and adding storage. But the synergies are nowhere near being fully captured, because present technologies and software are still crude. At the same time, use of market power by incumbent energy supply companies means energy prices are often distorted and it can be difficult for others to capture benefits. Inflexible equipment in both the energy supply (e.g. limits on exports to grids) and energy use sectors (e.g. fixed speed motors) limit the scope for smart management at present, but these problems can be overcome through equipment upgrades/replacements and innovative policy.

Large numbers of businesses from a variety of backgrounds, and big and small, are investing in this area, because they see its potential.

Secondary criterion 2: Economics/trend

Costs for all elements of integrated systems have been high, but are falling rapidly. Given past experience costs will continue to fall for some time, while sophistication and performance will continue to improve. The capacity for software and business models to be upgraded without needing extensive physical change (e.g. Tesla's EV software upgrades) means learning and development can be rapid, as roll-out is not constrained by limitations of physical equipment, once it achieves an adequate level of flexibility. Increasingly, smart integration will involve low capital costs, and will enhance the utilisation of existing investments.

Secondary criterion 3: Risks, barriers, support infrastructure

The market power of incumbent energy supply industries, and the slow rate of response by regulators and policy makers are key risks to the rate of progress. It will also be very important to ensure that communication protocols and access regimes are open and compatible. As with measure 8.1, existing inflexible equipment must be modified or replaced so that its operation can be varied to suit circumstances.

Provision of adequate numbers of suitably skilled people, and retraining of people in businesses, industry and households to operate the systems is also an important prerequisite for change. The first business pilots of this integrated approach are being planned and implemented now, and suppliers of equipment and services are in the early stages of developing local knowhow.

Food value chain

8.3. Electrification of food processing

This measure relates to the replacement of thermal processing, boiler/steam/hot water systems with electric technologies:

- Heat pump heating and (latent) heat recovery, mechanical vapour recompression combined with renewable energy (electricity and thermal).
- Mechanical dewatering versus drying; dewatering earlier in process to reduce cooling/transport of water.
- Innovative sterilisation or heating e.g. microwave/high pressure processes.

8.3.1. Deploy heat pump heating and (latent) heat recovery, mechanical vapour recompression combined with renewable energy (electricity and thermal)

Description

The amount of energy used for process heat in this supply chain is poorly documented. Not only do we not have high quality end use data, but most available data focuses on the temperature at which heat is supplied (section 5), rather than the temperature actually required for each process. So the fundamental energy requirements are not well understood.

Large amounts of process heat are used throughout the farm to plate value chain, as well as across our whole economy. Much of this is lost as waste heat, at temperatures too low to be useful. Heat pumps offer potential to increase the temperature of low grade heat to temperatures at which it can be productively used. Cascaded heat pumps (multiple heat pumps operating in series), emerging refrigerants, improved materials and mass production are driving ongoing rapid change that supports wider use of heat pumps over a wider range of temperatures, even for steam production.

There is increasing global interest in development of heat pumps, as pressure to decarbonise energy increases and gas prices rise.

Primary criterion 1: Energy savings delivered

In this value chain, 35 to 57 PJ of heat are consumed within industry, of which up to 80% is at temperatures attainable with emerging heat pump technologies (see section 6.1.3). This heat is used for activities such as dewatering, drying, packaging, cooking and pasteurisation. Of this, 12 to 25 PJ may be for the last two activities. (This ignores the 90PJ of bioenergy used in the sugar industry, much of it burned in cogeneration equipment).

Heat pumps and related technologies (e.g. mechanical vapour recompression) offer potential to recover and utilise up to two-thirds of waste heat. They can also be used with thermal renewable energy systems: lower temperature solar systems are cheaper and more efficient than high temperature technologies, and heat pumps can upgrade the heat they produce to more useful temperatures at high efficiency using renewable electricity.

Heat pumps can recover the energy in exhaust water vapour by condensing it: as discussed earlier, very large amounts of energy are lost in the latent heat of water vapour.

Primary criterion 2: Enhanced value created

Heat pumps offer potential to provide process heat efficiently, using electricity (potentially from renewable sources) instead of fossil fuels such as gas. Developments in heat pump technologies can flow through to, and benefit from, improvements in refrigeration and cooling, as the technologies are similar.

Heat pumps can be modular, and can be located where heat is needed (or waste heat is available), potentially replacing central boilers and steam distribution systems that are often extremely inefficient and expensive to buy, install and maintain. Heat pumps can also be used to recover (and upgrade) heat from water vapour in exhaust air streams (e.g. from milk dryers) that could otherwise be lost. The condensed water may also be a useful replacement for purchased water.

Using electric heat pumps to displace gas also creates potential to develop food processing industries in areas where gas is not available, or is too expensive. It also increases the potential for small modular processing plants, which could be located on farms. There is also potential to capture synergies between renewable energy and/or energy storage projects in rural areas and heat pumps. For example, a heat pump can upgrade heat to be stored for overnight use, and can improve overall efficiency and reduce cost of renewable electricity utilisation. It can also run on electricity from local generation (including a back-up generator), the grid, or storage.

Primary criterion 3: Export/employment opportunity

Australia has one manufacturer of high efficiency medium-to-large heat pump technologies – Smart Powerpax (http://www.powerpax.com.au/home). This firm has global links with other manufacturers. Airchange (www.airchange.com.au) produces a range of heat pump energy recovery and dehumidification systems and other equipment which could be applied to a range of roles in industry. There may be scope to work with these firms or others to develop locally sourced heat pump solutions for local and export applications.

Development of heat pump solutions could utilise the existing capacity in Australia's HVAC and refrigeration industries for design, fabrication of components, installation and maintenance.

Primary criterion 4: Reduction in climate impact

While most process heat is produced by burning natural gas with relatively low emissions for a fossil fuel, the need to achieve near carbon neutrality within decades means gas will not ultimately deliver the abatement required. Bioenergy offers a useful option, but it faces issues including land use conflicts, incidental emissions, reliance on fertilisers, process inefficiencies and where utilising externally sourced biomass, also supply chain issues. Heat pump solutions offer the potential for new low carbon, distributed agro-industrial business models that offer benefits beyond emission reduction.

Secondary criterion 1: Readiness and potential market impact

Heat pumps are widely used across all sectors. Mechanical Vapour Recompression is used in some industries, such as dairy processing. However, development of high temperature heat pumps for steam production is still in its early stages. The International Energy Agency's Heat Pump Centre and other groups around the world are working in this area, and there is potential for Australia to participate in international development.

The potential impact of heat pumps depends upon identification of suitable opportunities, ongoing development, and costs relative to benefits (see below).

Secondary criterion 2: Economics/trend

In the past, heat pumps have involved relatively high capital investment. Economies of scale and improved materials have seen costs for household units fall over the past two decades, while efficiencies have improved significantly. However, large, specialised heat pumps are still in the early commercialisation phase, so they are still expensive. Cascaded heat pumps are more expensive, as they are effectively two heat pumps connected in series.

The International Energy Agency Heat Pump Centre only approved establishment of an industrial heat pump annex in 2016, although work has been carried out under the IEA Industrial Energy-related Systems and Technologies Annex 13 and IEA Heat Pump Programme Annex 35.
There are signs that industrial heat pumps and vapour recompression, including those producing steam, may already be attractive in some circumstances. The IEA Annex 35 final report part 2 documents many case studies, some of which achieved simple payback periods of 2 years or less, with energy cost savings of 30 to 70%.

Key potential applications for process heat include cases without access to low cost heat sources, for dehumidification, and where modular applications can improve efficiency and avoid high costs associated with central sources of heat.

Secondary criterion 3: Risks, barriers, support infrastructure

The challenge for Australia is to engage with international and local groups who have experience in application of heat pump solutions to process heating, so we do not 'reinvent the wheel'. Research and demonstrations will be needed to develop practical models for application, and to build client confidence in the approach. In principle, Australia's HVAC and refrigeration industry should have the expertise to utilise heat pumps for process heating, and some sectors, such as dairy processing, already have practical experience.

8.3.2. Utilise dewatering as early as possible in the value chain, removing water mechanically to reduce thermal loads and cut mass/volume for transport and further processing

Description

Most of the removal of water from food products is currently achieved by evaporation. A large amount of energy is required to transform liquid water to water vapour. Given the inefficiencies in heat exchangers, it is not usually possible to capture and utilise this heat at a temperature high enough to evaporate more water, so heat recovery efficiency is typically fairly low. Heat pumps, discussed elsewhere, can be used to raise the temperature of the waste heat to a more useful level. But there are other far more energy efficient options that can dewater food products at or near ambient temperature using very little energy, and some of these can significantly add value through product quality and other benefits.

Key options are:

- Micro-filtration
- Centrifuge

- Depressurisation (which lowers the boiling point, but still evaporates the water)
- Ambient drying
- Microwave

The alternatives explored in this study replace heat with electricity to run pumps, motors or alternative drying methods such as microwave, which combines some physical removal of water with more precisely targeted heating.

These approaches may be used in combination with heat pumps or simple heat recovery, or separately. Some options may only support partial dewatering, particularly in situations where some cooking is required as part of the overall process.

Primary criterion 1: Energy savings delivered

Physical dewatering uses much less energy than evaporating water. In the limited time for this project, we have not identified industrial examples of the energy savings. However, they seem potentially very large. For example, evaporation requires around 2,300 kilojoules of energy per litre, as well as the energy required to heat up the food (and water) from ambient temperature, although some of this energy could be recovered. In comparison, desalination, which uses microfiltration to separate salts from water, uses 45 to 60 kilojoules. Centrifuging requires only a small amount of energy to spin the centrifuge to high speed.

So the potential energy savings are very large as a percentage, and given the large scale of dewatering that occurs in this value chain.

If a product is to be dried before sale (e.g. powdered milk), or can be reconstituted at point of use (e.g. fruit juice or soft drinks), partial dewatering close to the point of production reduces transport energy and cost by reducing the mass and volume transported. And where the initial dewatering process is more energy efficient than the final process, there may be significant energy savings in the final processing plant, as well as reductions in size and capital cost of processing equipment and storage. This report includes a case example of dewatering of milk to double its concentration (best done warm from the cows) at the farm – halving the volume (and mass) of milk to be stored, refrigerated, transported and ultimately dried (to produce concentrated/powdered milk).

Primary criterion 2: Enhanced value created

As outlined above, reducing water content as early as possible in the value chain reduces transport costs, as well as reducing the size, capital cost and some operating costs of the main processing plant. It also makes water available at the point of processing and reduces waste volumes at the main plant. In the example of the dairy farm dewatering, a pilot test in Victorian found that the application paid back in two years, and this is without counting further downstream benefits captured by the manufacturers.

Primary criterion 3: Export/employment opportunity

The main factor here is an improvement in competitiveness, due to reduced costs. Where product is transported overseas there may be significant savings in transport costs. This approach could provide a source of competitive advantage for milk powder manufacturing for example.

Primary criterion 4: Reduction in climate impact

Many food products are 60% or higher water content and, as explained, the amount of energy used to evaporate water is high: around 2.3 megajoules (0.64 kilowatt-hours) of heat energy is required to evaporate one litre of water.

Secondary criterion 1: Readiness and potential market impact

The dewatering techniques are used in different parts of the food industry, and commercial technologies seem to be available. The issues are the adaptation of technologies to specific products; testing of process suitability; optimisation of processes; demonstrations; and actions to support and encourage adoption.

Most of the dewatering technologies themselves have been around for years but not used for these applications. The innovation e.g. in the milk industry is in the application and ultimately also the logistics to help this to happen on a widespread basis.

Secondary criterion 2: Economics/trend

Purchase and installation cost of equipment, and integration into existing practices and processes are potential barriers. Support for adaptation to each product's processing and business model, and demonstration projects are necessary to reduce perceptions of risk. A key factor will be to demonstrate that taste, texture and other critically important consumer criteria can be met. The economics will also vary from product to product, so individualised financial analysis will also be important in gaining acceptance.

Secondary criterion 3: Risks, barriers, support infrastructure

If dewatering is shifted to a different sector e.g. from agro-industrial plant to farm, it will be important to design equipment for operation by less skilled staff, and at different volumes. Training will be required, as well as ongoing technical support. For some industries, a portable plant may be useful, so it can be moved around to maximise utilisation for seasonal crops. Most of these dewatering technologies have good support infrastructure behind them.

Impacts of shifting to high efficiency electric technologies on electricity supply systems

In the farm to plate value chain, we have identified a number of options that involve use of high efficiency electric technologies, including heat pumps, induction heating, micro-filtration, etc. This raises a number of questions about how that electricity might be supplied, and the extent of impacts on electricity supply infrastructure, such as generation and powerlines. Where modular electric industrial processing or other activities are established in areas away from the gas grid, the extent to which electricity supply infrastructure may need to be expanded or reinforced must be considered.

It is beyond the scope of this report to analyse these issues in detail, but some relevant points can be made.

First, such changes would occur within a context of disruptive change in energy solutions that are happening anyway. Distributed electricity generation, energy storage and smart energy management systems are becoming cheaper and working better at an astounding pace. So changes identified in this report could be integrated with other changes. Indeed, integration of electric industrial processing with other changes could help to justify investments in local generation and storage by increasing scale. Modular, efficient electric technologies may allow communities that do not have access to gas or other industrial fuels to drive local economic development and reverse loss of population.

Second, in this report we have emphasised that many energy services are delivered very inefficiently at present, often at temperatures far higher than are actually needed. So much less electricity may be needed than expected. Smart energy management and energy storage can also allow pressures on infrastructure to be managed. Introduction of limited back-up generation using liquid fuel could improve electricity supply reliability for a business and local community, avoiding need to upgrade networks and facilitating local activity after extreme events or during high fire risk periods. Further, there is potential within communities and local businesses to improve electricity efficiency, to offset additional consumption by new facilities.

Third, with the emergence of modular equipment, the process equipment (and associated on-site energy supply and storage) may be fairly small, and could even be portable, so it can be shifted around to where it is needed at different times.

Fourth, east coast gas prices are increasing significantly, due to a tripling of gas demand caused by the opening of three large Liquefied Natural Gas export facilities in Queensland.

Also, where high efficiency options replace inefficient electrical processes (eg refrigeration), loads on energy supply infrastructure will be reduced, and demand profiles potentially improved through installation of more flexible equipment and energy storage.

Overall, an integrated approach within a site, or involving a site and its local community, should be used to explore options to minimise the adverse impacts and capture the benefits of energy productivity improvement, while incorporating local renewable energy, energy storage and smart energy management.

Some examples of possible solutions illustrate the possibilities:

- A dairy farmer could more than offset the electricity use of dewatering milk by switching from resistive heating to an advanced heat pump hot water service and improving the efficiency of the refrigeration system using options outlined earlier in this report. Most available heat pump HWS systems are designed to heat to 60-65C but, if higher temperatures are required, they can be provided by a range of options including a cascaded heat pump, solar pre-heating of water, or resistive electric 'topping up' of output from a heat pump, or optimisation of existing best practice CO2 refrigerant heat pump design with possibly slightly lower Coefficient of Performance.
- An industrial process using 20 megawatts (thermal) of steam from a gas boiler could first of all analyse the actual temperatures and amounts of heat required, as well as assessing the overall system efficiency of use of its gas use, the amount supplementary electricity use associated with the operation of the steam system, and the costs associated with operation and maintenance of the steam system. Replacement of the boiler (assumed overall system efficiency 50%, using 144 GJ/hour of gas and some electricity for pumps and fans) with point of use heat pump(s) to recover and upgrade waste heat with a Coefficient of Performance of 3 (as demonstrated in the IEA paper referred to in this report) would mean that les than 7 MW of electricity would be required. At a gas price of $8/GJ and a notional electricity price of $100/MWh (possibly using on-site renewable generation and off peak grid power), the energy cost of the alternative would be 25-30% lower than the $1150/hour gas cost, while

maintenance and operating costs should also be reduced. Thermal and electricity storage could be integrated so that excess electricity could be exported. Capital costs would have to be evaluated, but the trend towards modular process equipment and economies of scale mean economics are likely to trend towards solutions such as these.

8.4. Transition to high efficiency commercial cooking and food display systems

Description

Cooking activity and display of hot food, especially in the commercial sector, is a large energy consumer (especially in primary energy terms), although the exact energy usage is not well documented (see section 5 and Figure 5). This activity is very diverse, ranging from large volume production by catering businesses and in hotels, function centres and meal delivery services, to small batch cooking in restaurants. It includes 'micro-factories', otherwise known as hot bread shops and fast food shops. Display of hot food in hotels and retail is also a large user of energy. However, we have quite limited data on energy use of specific activities.

We know that the energy efficiency of present commercial cooking and food display practices is typically very low. But this is a complex area, where factors such as speed of delivery, visual presentation and taste, and easy cleaning/sterilisation of equipment are very important, and the cost of the energy is a small component of overall input costs.

Savings are both direct, through reductions in energy use, and indirect, for example by reducing HVAC energy waste caused by release of cooking heat into buildings and exhaust fans drawing outdoor air into conditioned spaces. There can also be savings of more relevance to many of these businesses through using energy technologies which allow the food to be prepared faster and cleaning to be done easier and offer better control over food quality.

Primary criterion 1: Energy savings delivered

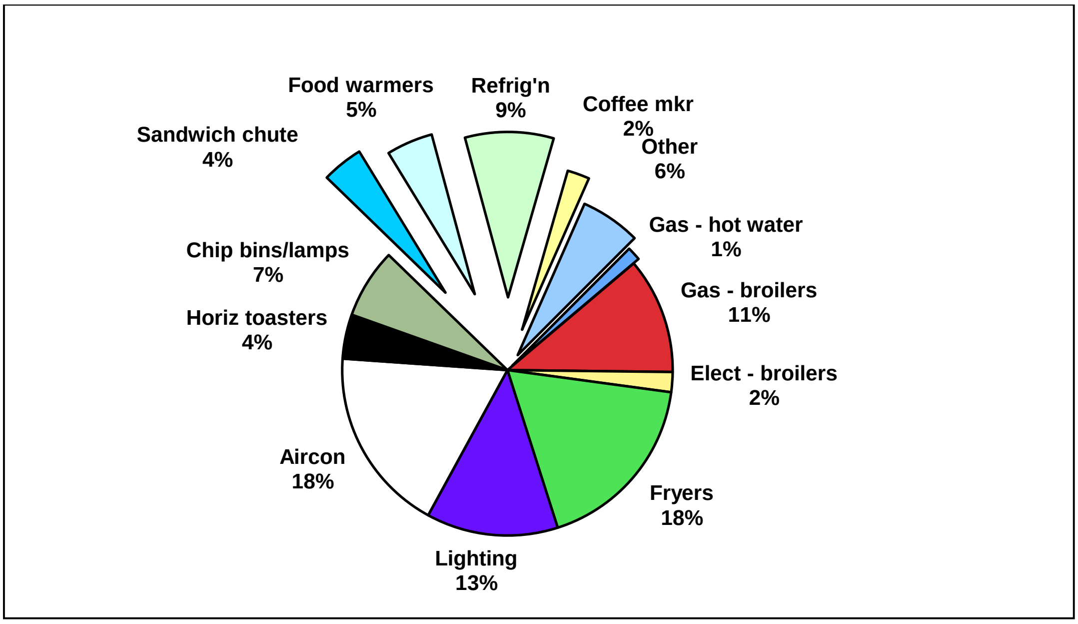
Commercial cooking is responsible for 70 to 160 PJ of primary energy annually (see section 5.1). It has significant indirect energy implications as well, due to release of heat into conditioned spaces and use of exhaust fans. These indirect energy impacts may be comparable with the direct impacts. Overall energy costs may exceed $1-2 billion annually.

The efficiency of cooking energy use in the commercial sector can only be described as appallingly bad, due to inefficient equipment and practices that are not focused on efficiency.

Where meals are likely to be reheated, energy costs of defrosting and the method of reheating can be very significant at point of consumption. For example, if the consumer incorrectly believes that aluminium foil containers cannot be safely heated in a microwave oven, they may reheat their food in a much less energy-efficient conventional oven. Heating or cooking frozen food in an oven dramatically extends cooking time and increases energy use.

A systematic approach to energy efficiency improvement, involving lightweight insulated cookware and cooking appliances, efficient cooking processes and smart management of pollutant extraction could deliver more than 50% energy savings. The diagram below shows an indicative split of energy in food preparation in one fast food restaurant as an example of the variety of cooking equipment used.

Figure 20.: Analysis of energy use in a fast food restaurant



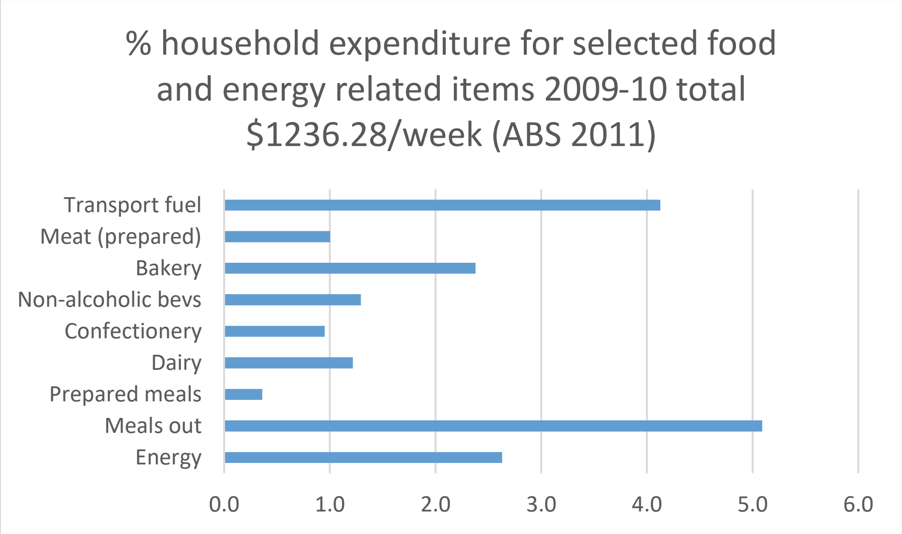
Primary criterion 2: Enhanced value created

The focus of cooking is on delivering attractive, pleasant tasting (and sometimes healthy) nutrition in a way that is profitable. But there are many OH&S issues in this area that could be reduced through a greater focus on energy productivity and efficiency. Many kitchens and processing plants are uncomfortably hot, with dangerously hot surfaces, hot cooking oil, flames and other risks. Noise levels can be high, often due to exhaust fans. Fires in kitchen exhaust flues are not uncommon, and can be catastrophic: smart monitoring systems could reduce the risk. These factors all indicate energy waste, and can affect insurance premiums, staff turnover and, where they are exposed to these factors, customer satisfaction.

Food may be served at unsatisfactory temperatures that may also create health risks for consumers.

Many of the benefits of improved energy productivity in this area are not recognised, seemingly because the people affected cannot imagine alternative approaches that would avoid the problems they face while maintaining or improving quality of service. Nor do customers realise how much they are spending on some energy intensive cooking related services, as shown below, which shows how a number of food-related activities are responsible for over 12% of household expenditure – more than four times expenditure on household energy and three times household transport fuel.

Figure 21.: Percentage household expenditure for selected food and energy



Cooking and food presentation involve significant risks, costs, and productivity issues. There is substantial scope for benefits, including:

- Reduced peak demand for cooking and HVAC, reducing investment in energy supply infrastructure and HVAC capacity
- Reducing heat in kitchens improves worker comfort, and can reduce noise by allowing exhaust fans to run more quietly at lower speeds
- Some food display equipment is an OH&S hazard, due to the risk of burns, to both staff and customers, from hot cooking oils and hot metal surfaces. These risks can be reduced by energy productivity measures
- Hot food displays may fail to maintain food at safe temperatures to avoid risk of food poisoning: this risk could be reduced by innovation
- At times of low customer demand, high standby energy losses from cooking and display equipment can eat into profits. More responsive equipment and design for lower standby and start-up losses can support improved service and product quality, while saving energy
- Better working conditions can reduce staff turnover and training costs, while a more pleasant, quieter environment with safer food management practices in a shop may attract more customers, increasing net profits
- Enhanced asset value, as sale price of a business is directly linked to net profits

Primary criterion 3: Export/employment opportunity

Commercial sector cooking is a very significant and energy intensive part of the economy. It occurs in a sector where the overall value added is also high and measurement of energy use is poor, so its significance is rarely recognised. For example, a very energy intensive hot bread shop may see energy as only a few percent of its overall input costs. Yet cooking seems to be costing over $2 billion annually in direct energy costs, and much more when its indirect energy costs and other impacts are considered.

Retailing and preparation of hot food involve many small businesses. Improved energy productivity in this area offers potential to improve the financial viability and profits of these firms.

High efficiency cooking equipment also opens up scope for new business models, for example portable renewable energy and storage technologies are more likely to be able to work at community events and remote sites without noisy generators.

Australia has a significant network of small businesses that construct commercial cooking and food presentation equipment in competition with importers. Improved technology can help to maintain competitiveness. Export of intellectual property, products and services associated appliance and equipment design and training all provide potential local and export opportunities.

Primary criterion 4: Reduction in climate impact

The potential emission savings from 50% energy savings seem to be from 10 to 20 Mt CO2e annually when direct and indirect savings are considered. This is comparable with the total emission reductions from Australia's present appliance efficiency program. Given the other potential benefits action in this area could deliver, it seems like a key opportunity.

Secondary criterion 1: Readiness and potential market impact

This sector has had surprisingly little attention, with only one US research centre (Food Service Technology Centre, San Francisco www.fishnick.com) identified in our scans. CSIRO does have some researchers and links to manufacturers of food processing equipment. There seems to be limited RD&D focused on this area from an energy productivity perspective. The recent establishment of FIAL (Food Innovation Australia Ltd) may provide an important opportunity to drive innovation in this area.

While there is limited data available, it would not be difficult to collect sufficient data to clarify the present circumstances and the extent of energy waste. Analytical techniques, technologies and materials are available to deliver large savings. There is a need to analyse and document the economic value of the broad impacts of cooking on business costs, households and health.

Induction cooking is emerging as a potentially significant cooking technology that can outperform gas while utilising renewable electricity. Other innovative technologies are also emerging, such as pulsed electric field cookers and 'air fryers'. High performance insulation such as aerogels, advanced smart fan technologies, lightweight materials for cooking equipment, and other developments mean potential for transformation exists. But it is at an early stage, and limited capability exists at all stages of the development and commercialisation process.

Secondary criterion 2: Economics/trend

Given the energy intensity of cooking operations, particularly in the commercial and residential sectors, the potential for very large energy savings is clear. Some measures are likely to be very cost-effective, while the cost-effectiveness of others is uncertain at present. Change may depend on development of new materials such as stainless steel/insulation sandwich sheet material for equipment construction, and techniques to minimise thermal bridging within cooking equipment and cookware.

Commercial cooking equipment is typically expensive. But incorporation of effective insulation and high efficiency design features may increase costs if it has to be achieved while maintaining ease of cleaning and durability. There are examples of double layer cylindrical stainless steel containers with a vacuum between them (e.g. https://www.thermalcookware.com/main.php?mod=dynamic&id=22), and bain maries with double skin casings or insulation sandwiched between sheets of stainless steel, but there is scope for substantial improvement in thermal efficiency, and for much wider use. Any impacts on productivity must be demonstrated to be positive from a customer service and productivity perspective, so consultation, market research, trials and demonstrations would be critically important.

Secondary criterion 3: Risks, barriers, support infrastructure

The time pressures, focus on food aesthetics and deeply entrenched practices in cooking combine with a lack of recognition of the costs and impacts of present practices to create significant barriers to change. However, new analysis and demonstration projects may lead to rapid shifts in awareness, because the benefits may be visible and surprisingly attractive.

There seems to be some RD&D support capacity in CSIRO and now FIAL. Many of the potential improvements could be captured by generalist researchers in universities or research consultancies, if they had access to stable ongoing funding, so they could build capability. However, they would need to work closely with business owners, chefs, supply chain and cooking/catering educators, as wasteful standard practices are entrenched, and the main focus of business operators is on other costs and customer perceptions of taste and quality of cooked food. So creative solutions that appeal to practitioners and business owners will be important.

8.5. Step change in refrigeration energy use

This measure relates to:

- The transition to optimally-sized, high efficiency, low global warming potential refrigeration; and,
- Optimisation of refrigeration use across the cold chain.

8.5.1. Transition to high efficiency, low carbon refrigeration

Description

Refrigeration is extensively used throughout the farm to plate value chain. Our analysis showed it is a large consumer of primary energy. A diverse range of equipment is used, and much of it is inefficient and leaks high climate impact refrigerants, particularly outside the larger scale manufacturing sector. Emerging technologies offer potential for very large percentage and total energy savings.

The recent international agreement to phase out HFC refrigerants as well as HCFCs under the Montreal Protocol provides a 'once in a lifetime' opportunity to integrate major energy efficiency upgrades with the transition away from these refrigerants. This would maximise cost-effectiveness. Government has an opportunity to intervene in the market to make high energy efficiency options compelling for businesses investing in new plant. The main opportunity here is in the transport and storage and commercial sectors and small scale manufacturing. Larger scale industry largely uses ammonia which is a natural refrigerant although, as noted earlier, carbon dioxide refrigerant systems may begin to replace ammonia.

Primary criterion 1: Energy savings delivered

Refrigeration in the farm to plate value chain uses 25-30% of the primary energy in the value chain, around 250 PJ and 33 Mt CO2e (see Figure 4). Energy consumption is dominated by commercial and residential sectors, followed by industry. Natural refrigerants offer efficiency improvements over traditional ones. Refrigerant leakage tends to occur most in larger systems and transport. Leakage not only creates climate impacts, but also reduces equipment efficiency and cooling capacity (see section 5).

In the residential and commercial sectors, large energy savings depend on identification and removal from the stock of faulty, old and inefficient appliances. A faulty old refrigerator can use more than five times as much electricity as a modern unit. Analysis of smart meter data and conventional meter data in moderate weather can identify opportunities. The most efficient residential products on global markets are nearly twice as efficient as the best on our market (based on adjusted data from www.topten.eu), and our weak Mandatory Energy Performance Standards allow poor performers to dominate the market.

Most new residential appliances already use low climate impact hydrocarbon refrigerants, which also improve efficiency. De-gassing refrigerators during disposal offers potential to recover HFCs (and CFCs from pre-1994 products).

Commercial sector refrigeration should be a major focus for energy saving. A wide range of products are used, and large, cost-effective savings potential exists across all types. For example, the most efficient hotel room mini-fridges save 80% compared with worst on market (www.topten.eu).

Primary criterion 2: Enhanced value created

Electricity to run refrigeration equipment in the farm to plate value chain costs up to $5 billion annually, of which at least half could be cost-effectively saved. This offers significant potential to improve business competitiveness.

The cost of replacing refrigerant that has leaked from equipment is significant, due to labour, refrigerant cost, food spoilage, higher energy consumption and disruption of business activity. Combining upgrades away from HFCs and HCFCs with improved efficiency and smart monitoring minimises capital costs of conversion and maximises future savings by reducing future refrigerant leakage and energy waste.

Since low income households often own old refrigerators, measures to identify and replace faulty units would have equity benefits, and could reduce subsidies paid by governments on energy bills.

Faulty refrigerators may still seem to keep food cold, but may increase risk of food spoilage by failing to maintain stable and appropriate storage temperatures, with potential health and financial impacts. Major failures can lead to significant loss of food and disruption to business activity. Smart diagnostic systems could avoid such problems.

Primary criterion 3: Broad economic potential: exports/employment opportunity

The refrigeration (and HVAC) industry is a major employer, and a significant industry. It involves repair and maintenance, design, fabrication, installation and associated business services. A large proportion of equipment is imported but, especially in the commercial and industrial sectors, there is a significant need for tailored solutions, which can be more easily managed locally. The HFC phase-out will require a significant retraining effort, and also provides an opportunity to upskill energy efficiency knowledge and skills.

With regard to employment, improved real time diagnostics would reduce demand for urgent repairs after critical failures, but may increase emphasis on improved scheduled maintenance, preventive replacement and repair. A focus on improved system design would potentially improve competitiveness of locally manufactured equipment and offer potential for export of design services, training and certification systems, and IP.

Primary criterion 4: Reduction in climate impact

As noted earlier, the combination of fossil fuel waste and refrigerant leakage makes refrigeration a major source of emissions. An effective strategy could deliver cost-effective emission reductions of over 10 Mt CO2e annually, comparable with Australia’s present appliance efficiency program.

Secondary criterion 1: Readiness and potential market impact

As noted earlier, the refrigeration industry and its customers face significant change due to the HFC phase-out, so there is potential to integrate energy productivity improvement with this process. Some cultural change will be needed, but there are multiple drivers for this, including ongoing increases in energy prices.

Stronger focus on real time monitoring and diagnostics can build on growing capability and capacity in energy assessment and environmental rating schemes.

There is significant variation in energy efficiency of existing products, so removal of inefficient products from the market, and identification and replacement of inefficient products in the existing stock offer potential savings. There is very large potential for further improvement: RD&D,

commercialisation and training will be needed. However, a number of government agencies are active, and interest among financiers is evolving.

Secondary criterion 2: Economics/trend

The combination of energy savings and business benefits already offers large cost savings: a recent consultation paper by Australia's E3 Committee found that stronger action on commercial refrigeration activity could deliver a benefit-cost ratio of 7.8 to 1 in Australia, from energy benefits alone[63]. Given the large technological potential for further improvement, this suggests there is potential to achieve even larger benefits while maintaining cost-effectiveness, as well as a need to overcome communication failures and market distortions in the relevant industries.

Economies of scale can be captured by integrating energy productivity with other activities, such as the HFC phase-out and 'smarter' appliances, industrial systems and buildings.

Secondary criterion 3: Risks, barriers, support infrastructure

Existing attitudes, practices and expectations are barriers to capture of the energy productivity potential. Significant applied RD&D, training and education of customers will be necessary. There is a significant uninformed second-hand market in refrigerated cabinets, and this provides an opportunity to identify and remove inefficient existing product from service.

8.5.2. Optimise refrigeration use across the cold chain

Description

It is essential to maintain food at appropriate environmental conditions to maintain quality, minimise health risks, and avoid unnecessary spoilage through its supply chain. A single failure at any point can negate the efforts elsewhere in the supply chain. For many food products, stable and appropriate temperatures are fundamental, so the food supply system relies heavily on refrigeration and appropriate handling to maintain food quality and safety. As discussed elsewhere in this report, refrigeration is energy intensive, and also involves extensive use of refrigerants, many of which have climate impacts and some of which lead to depletion of the ozone layer.

There is a trend towards more accurate monitoring of temperatures in cold chains, to improve quality and energy costs. The next big step is to attach low cost temperature sensors and transmitters to food items/batches, so that the actual temperature condition of the food can be monitored in real time and communicated to a cloud computing application, instead of tracking room temperatures and refrigerating for the worse combination of conditions. Real-time tracking and communication will ensure that emerging problems can be detected before food quality or safety is adversely affected.

Primary criterion 1: Energy savings delivered

As noted in the main report, the direct energy saving potential in the cold supply chain seems to be $1-2 billion annually from reductions in refrigeration requirements. It may be possible to save more by setting refrigeration temperatures higher if there is greater confidence that the whole supply

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[63] Energy Efficiency and Conservation Authority on behalf of the Equipment Energy Efficiency Program (2016) *Consultation Regulation Impact Statement – Refrigerated display and storage cabinets*

chain will perform reliably. In the commercial sector, further savings potential may be gained from reduced impact on HVAC energy. Reducing food loss also delivers energy savings throughout the upstream supply chain, as less food must be produced to deliver a given amount of food on plates. These energy savings may be comparable in size with the direct energy savings in refrigeration, but it is difficult to define them, as a significant proportion of upstream food production energy is linked to exports.

Primary criterion 2: Enhanced value created

The major financial benefit from improved cold chain management is reduction in costs and health impacts of reduced food spoilage and waste. Where food quality is improved, it may attract higher prices. A more reliable cold chain may also allow refrigerated food to be sold in a wider range of markets. Shelf life of food may also be extended at point of sale, reducing waste and financial losses for products where demand is variable. Consumers may also benefit from buying food with a longer life in their home refrigerators, so they may waste less food and be able to shop less often. To put this in context, Australian households in 2009-10 spent around $30 billion on perishable food[64], of which up to a third was wasted (see section 5). Improved monitoring and management should also help to reduce refrigerant leakage.

Primary criterion 3: Exports/employment opportunity

The key issue here is that importers of food want increasingly rigorous ways of tracking product quality, and this integrates right into that desire. If Australia becomes a leader in refrigeration chain optimisation, there is an export market for these services.

Primary criterion 4: Reduction in climate impact

The climate impact of this measure extends beyond tens of millions of tonnes of annual emissions avoided through direct and indirect energy savings in the upstream supply chain, to reduction in methane emissions from avoided decay of organic wastes, energy savings from emission reductions in fertilizer manufacturing, and reductions in refrigerant losses.

Secondary criterion 1: Readiness and potential market impact

Development of monitoring systems is progressing, but is still fairly basic and limited in scale.

Secondary criterion 2: Economics/trend

At present, sensor cost is still relatively high, and smart, cloud-based systems that provide feedback on operating performance of refrigeration equipment as well as food condition are just emerging. RDD&C is needed to improve systems, then demonstrate the multiple benefits.

Secondary criterion 3: Risks, barriers, support infrastructure

The major barriers are likely to be the cost of communications bandwidth, the coordination and cooperation required amongst stakeholders, the logistics of recovering/disposing of sensor/transmitters, and food safety regulations.

Other potential barriers include high initial setup costs, need for technology development, the work involved in setting up the technology, retraining and developing response strategies to feedback provided from the system. There may also be cost issues regarding the charging for use of

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[64] Australian Bureau of Statistics 2011) *6535.0 Household Expenditure Survey, Detailed Expenditure Items 2009-10* Canberra

communication networks. In principle, this approach reduces risk of losses and adds value to food at point of retail, but strong evidence that it does reduce, not increase, risk of adverse impacts on food quality is needed to overcome concerns within the cold chain sector.

Shelter Value Chain

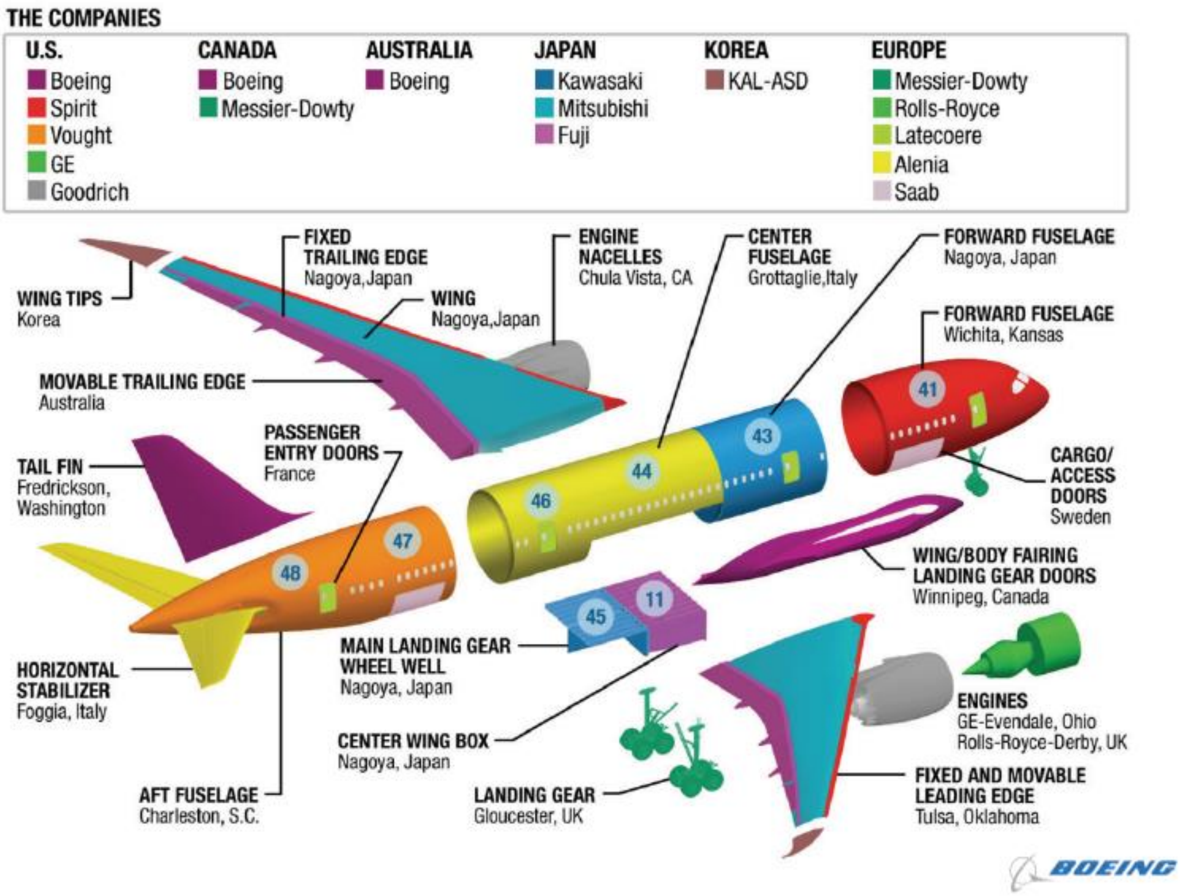
8.6. Prefabricated construction with engineered timber and other low impact materials

Description

Shifting fabrication and construction activity from open sites to manufacturing facilities offers many advantages, as discussed below. This can be done for sub-modules or whole buildings. Work can be carried out at a single site, or distributed across many sites using innovative fabrication techniques including 3-D printing, and utilising advanced software solutions and techniques such as Design for Manufacture and Assembly (DIMA – see for example http://www.engineeringexchange.com/profiles/blogs/11-principles-and-guidelines-in-design-for-manufacturing-and) to ensure elements fit together. Emerging materials such as Cross Laminated Timber and composites can be efficiently utilised in this approach.

Figure 22.: Example of DIMA including distributed manufacturing

(From Harris A (undated presentation) *Lessons from an Intrapreneur: Engineering the Future, Transforming Today*



Primary criterion 1: Energy savings delivered

On-site building construction involves extensive daily travel by many people, including trades, professionals, inspectors and delivery trucks. It also requires heavy machinery to be moved. This travel is not well documented, but anecdotal information, e.g. from traffic reports on radio on industry Rostered Days Off, suggest it is a significant contributor to congestion and higher fuel use at peak periods across the transport system. Minimising waste and maximising efficiency of material utilisation can be challenging on individual sites, so embodied energy in materials may be non-optimal.

While these savings can be significant, their financial value relative to other benefits is small.

More precise construction in a factory environment means buildings can be better insulated and more air tight, so the final building will operate more efficiently. Renewable energy components such as Building Integrated PV can be more easily incorporated.

Primary criterion 2: Enhanced value created

Manufactured construction offers many financial and other benefits:

- Travel time can be reduced, and this reduces road congestion while improving labour productivity and reducing exposure to risk on roads.
- Because all trades are accessible throughout each project, small tasks or correction of errors can be easily carried out without impacting on the construction schedule
- Theft from sites can be reduced, so security costs can also be cut.
- Weather damage to materials and incomplete construction and lost time due to extreme weather can be reduced
- Material usage can be optimised, as scraps from one project can be used for other purposes on other projects
- Waste management can be optimised. Not only can optimal material usage avoid waste, but large amounts of clean and easily sorted waste are produced at one site
- Reduction of overall project duration can reduce the amount and length of time finance is required
- Quality control can be better managed, and inspection costs minimised.

Primary criterion 3: Exports/employment opportunity

In some ways, a shift to manufactured building in Australia is just catching up with most of the rest of the world. It should be more economically efficient, but may reduce employment in the building industry unless it spurs higher levels of construction activity. It could be argued that replacing or upgrading pre-2003 homes (built before national building energy regulations) will deliver very large operating energy savings and comfort/health benefits, as well as supporting higher density development which reduces transport energy use and costs associated with a car-based society.

Primary criterion 4: Reduction in climate impact

A shift towards manufactured building and building elements offers significant potential to reduce the amount of energy embodied in buildings, as outlined earlier. It also helps to reduce uncontrolled air leakage, a major source of energy waste and discomfort. Prefabricated components such as SIPs incorporate high levels of insulation that also contribute to structural strength. Timber structures have less thermal bridging than concrete and steel. So these approaches offer potential to achieve higher levels of operating energy performance more cost-effectively and consistently. The extent of the savings captured will depend upon public awareness of the importance of high energy efficiency, and the stringency of building energy regulations, as well as the culture of the building industry. But the potential is large, as air tightness and insulation effectiveness are key elements of energy efficient design.

Secondary criterion 1: Readiness and potential market impact

A trend towards manufactured buildings has already begun. Prefabricated components such as trusses and concrete wall panels are now used. Modular bathrooms and apartments (eg the Little Hero building in Melbourne (http://www.architectureanddesign.com.au/news/nine-storey-melbourne-apartment-goes-up-in-just-fi)) and houses are now available. An annual 'Prefab' conference is run by PrefabAus (http://www.prefabaus.org.au/). In Victoria, prefab railway stations have been built as part of the government's railway crossing removal program (see, for example http://levelcrossings.vic.gov.au/crossings/north-mckinnon-centre).

Use of materials suited to prefabrication or rapid construction is increasing. This includes cross-laminated timber (CLT) construction, tilt concrete panels and Structural Insulated Panels (see http://www.build.com.au/structural-insulated-panels-sips).

Secondary criterion 2: Economics/trend

Prefabrication and other approaches that reduce construction time are beginning to move from niche markets towards the mainstream. Niche markets have included homes in rural areas, where it is difficult to find skilled labour, and projects with constraints on site access or tight timeframes. Given the widespread use of these approaches around the world it seems that their economics are fundamentally attractive when fully implemented.

Secondary criterion 3: Risks, barriers, support infrastructure

These approaches require initial capital investment in production facilities, design capability, training and installation equipment. The decentralised, contractor-based model widely used across the building industry, with many small building firms and independent tradespeople, is a potential barrier to mainstream adoption. But trends towards construction of medium and high density housing, increasing recognition of benefits of shorter on-site construction periods, especially at infill sites, declining costs and improving design software are all supporting change.

8.7. Increase recovery of high value materials from building material waste

Description

Australia has large resources of metals and other potentially valuable materials in landfills, existing building and infrastructure stock, and in waste streams. There is substantial scope to replace production of new materials from virgin ores with these resources. Resource recovery and reprocessing typically requires less energy, particularly for metals, than production of new materials. It can also reduce or avoid process CO_2 emissions (e.g. from steel and cement production). Emerging processes are more suited to use of renewable energy than fossil fuels.

Primary criterion 1: Energy savings delivered

Discussion earlier in this report demonstrated the large energy savings potential of reuse, recycling and reprocessing steel, and of using waste materials such as blast furnace slag in cementitious materials. Steel and cement are the biggest contributors to embodied energy in buildings, but other metals such as aluminium and copper are also significant.

The Wellmet report (http://www.uselessgroup.org/publications/reports/wellmet-2050-prolonging-our-metal-life), discussed earlier, proposes many options for productive reuse of materials in ways that avoid the energy cost of reprocessing.

The energy embodied in materials of buildings is a significant and, as operating efficiency improves, an increasing proportion of lifecycle energy use and carbon emissions.

Primary criterion 2: Enhanced value created

Reuse of waste materials reduces costs and environmental impacts of disposal, while creating employment in small businesses and the recycling industry. High value uses of recycled materials instead of ‘down-cycling’ or disposing of them offers potential for additional revenue streams.

There is potential to link new business models to manufactured construction and changes in the waste management industry.

Primary criterion 3: Export/employment opportunity

At present, Australia exports millions of tonnes of scrap steel and other metals, as well as other ‘recyclable’ materials. We buy this material back built-into high value goods. More effective utilisation within Australia offers net economic and employment benefits through value adding and integration of processing of waste materials into product supply chains, fabrication and construction.

Australia imports large amounts of steel, cement and other building materials and products, often produced with energy from coal. New technologies that improve the international competitiveness of local production and support decentralised industry also offer economic, social and environmental benefits.

Primary criterion 4: Reduction in climate impact

Data on the reduction of climate impact from improved utilisation of building waste is difficult to find. One study quoted by SITA some years ago put the emissions at over 30 Mt pa. The ISA study for ACF (2007) suggested embodied emissions in construction and renovation was 11.8% of Australian emissions, but this includes indirect inputs to the sector.

If we are aiming for a net zero emission global economy, then action by Australia to replace building material imports produced using fossil fuels with low emission local alternatives produced using renewable energy offers global climate benefits, as well as potential economic value for Australia.

Secondary criterion 1: Readiness and potential market impact

Developments such as robotised sorting and material handling, electronic tagging (being developed for cold chain monitoring) and computerised product and building design[65] offer increasing potential to match ‘waste’ materials to potential uses. Australia already has extensive recycling and recovery

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[65] Pullen, S., Chiveralls, K., Zillante, G., Palmer, J., Wilson, L., & Zuo, J. (2012). *Minimising the impact of resource consumption in the design and construction of buildings*. Griffith University

infrastructure, but lacks investment in the more capital-intensive phases that convert these materials into higher value product.

Research on extraction of high value materials from wastes is occurring in several research institutions (see UNSW case study). Australia's extensive experience in developing methods for processing of low grade ores with multiple components in mining contributes to this work.

Secondary criterion 2: Economics/trend

Environmental agencies are progressively increasing financial incentives to divert materials from landfills, but there is debate and uncertainty about the size of future disposal fees. These fees play a significant role in defining the returns from waste recovery and reprocessing.

Some businesses such as Visy and Simsmetal are large global players in recycling, and there are expert consultants and academics working in relevant areas. Government organisations such as Sustainability Victoria focus on resource efficiency. So there is expertise available to drive innovation.

Secondary criterion 3: Risks, barriers, support infrastructure

Barriers include competition from overseas processors of recycled materials, low shipping costs, significant investment costs associated with conversion of recycled materials into useful products, and need for funding of research and development limit progress.

Uncertainties and levels of fees for landfill, and lack of alternative financial support, limit industry confidence and undermine investment.

Potential to build on experience in minerals processing, and potential to 'piggy-back' on developments in advanced materials handling, sorting and manufactured construction could support investment and development of this sector.

8.8. Utilise new technologies and business models to accelerate improvement of building energy performance

Description

Developments across a range of areas are transforming the potential to improve building energy performance beyond levels achievable with present approaches and incremental improvement. Zero net energy (and net energy producing) buildings have now been demonstrated in most climates. These include advances in materials, technologies and 'smart' management. They involve focusing on the fundamental services provided by buildings: comfort, health, protection from extreme weather, security, resilience, durability and adaptability. With climate change now well under way, an increasing focus on summer performance and performance in extreme weather is needed.

Key aspects include:

- Large reductions in heat flow into buildings in hot weather: this requires major change in glazing and its management with adjustable shading and heat flow control, advanced insulation (including elimination of thermal bridges), management of fresh air supply and ventilation
- Radical ways of providing comfort, including personal micro-systems (clothing and accurate targeting of cooling and heating), zoning, predictive HVAC equipment with thermal storage
- Improved amenity, health and productivity through creative provision of daylight, fresh air, aesthetics, and management of glare
- Improved management of issues such as condensation, mould and air quality.

As discussed earlier in this report, many products and systems are emerging that can deliver these outcomes.

We must also focus more on transformation of existing building stock into beyond zero emission assets, instead of liabilities. This will require a reframing of perceptions of buildings from short term, narrow, private assets to long-lived community assets. Without this shift, we will not allocate the financial capital needed for transformation through recladding buildings and upgrading and shading of existing glazing.

Primary criterion 1: Energy savings delivered

New buildings now typically use less than half as much energy as existing buildings, due to technical advances and building energy regulation. But this improvement has focused on winter thermal performance and equipment efficiency. Many new buildings perform worse in summer than older buildings: but at least there is plenty of renewable energy available in summer to manage this problem. However, we need both thermally efficient buildings as well as efficient, renewable energy driven equipment, to achieve resilience and to minimise overall capital and operating costs and investment in energy supply infrastructure.

Around the world, net zero operating energy, and beyond zero emission buildings are being constructed in small numbers. The challenge is to make this the norm in Australia.

Primary criterion 2: Enhanced value created

Many studies have now shown that the benefits from improved productivity, health and amenity driven by improved building efficiency deliver far larger benefits than the savings on energy costs alone. These benefits, as well as reputational factors and potential for lower maintenance costs, drive higher asset value and rental returns.

Heating and cooling of buildings is a major driver of peak energy demand and hence capital costs of energy supply infrastructure. The size and cost of HVAC systems, energy storage and renewable energy systems, and hence the space they occupy, is also influenced by building and equipment efficiency.

Primary criterion 3: Export/employment opportunity

Development, design and manufacture of high performance materials, their integration into building products and systems, and related tools and techniques will potentially capture large global markets as developing countries seek to improve quality of life of their populations. Increasingly severe extreme events will increase demand in niche markets such as emergency housing, portable buildings, techniques for reinforcing and upgrading thermal performance of existing structures, and lower cost construction techniques.

At the same time, increasing globalisation will apply pressure for Australia to shift towards more prefabricated and manufactured building techniques. If we don't respond, they will be imported.

The building industry is a major employer, but employment in construction of new housing may decline as more efficient techniques spread. However, this decline could be offset by a stronger focus on upgrading performance of existing buildings and equipment, a need for higher standards of workmanship, and increasing complexity of buildings.

Primary criterion 4: Reduction in climate impact

Building operation is responsible for 23% of Australian greenhouse gas emissions (ClimateWorks Australia for ASBEC, 2016). Further, the long lives of our buildings and the associated large amounts of embodied emissions create 'lock-in' of higher emissions than necessary into the future. A typical building constructed today will still exist well beyond 2050, when we will need to be net carbon neutral. Buildings will require upgrading or improved design to withstand higher temperatures and more extreme weather events. The buildings we are constructing will be liabilities, not assets, in such a world.

Secondary criterion 1: Readiness and potential market impact

The potential impact of high performance buildings is broad and large: but we are slow movers compared with global leaders. However, our leaders are world class, and widely respected.

Australia has the elements of an advanced buildings strategy, with a growing 'prefab' industry, some world leading HVAC and ventilation equipment manufacturers, and some researchers in building performance. However, significant research facilities have been shut down over the past few decades. We do not include enough training in building performance modelling and building physics in relevant education and training programs. Many tradespeople are reluctant to embrace emerging solutions.

Secondary criterion 2: Economics

As in other sectors, early movers face higher costs and struggle to find reliable supply chains and practitioners capable of delivering the desired outcomes. So there is substantial scope for cost reduction through economies of scale and 'learning by doing'. In reality, the costs of design and construction for improved performance can often be offset by effective integration, or reductions in other costs such as HVAC equipment and energy supply infrastructure. At worst, reducing the size of new homes by a few square metres would offset the costs. Local/on-site renewable energy and storage technology costs are falling, and are already cost-effective or close to being cash flow positive if funded by extending mortgages. Effective energy and environmental rating schemes are building recognition of, and confidence in, the value of broader benefits.

Secondary criterion 3: Risks, barriers, support infrastructure

Australia is weak in RDD&C for advanced building and related equipment. There are deep cultural barriers within our building sector, including its policy and regulatory culture, slowing change. Consumers are uninformed, misled and confused. We are short of training and certification for high quality tradespeople and professionals. Our short-term focus undermines investment in long-lived assets. The situation is challenging.

8.9. Promote optimal structural design and incorporate emerging materials and systems into structures

Description

Many structures in Australia involve wasteful use of materials. For example, tensile steel structures use far less material than traditional steel girders and beams. Composite materials can be lighter, stronger and thermally superior (eg see http://www.makmax.com.au/tensotherm/68). Engineered timber structures can use plantation timber sourced from early growth, and can be lighter and stronger. Inflatable elements can also be incorporated into structures to reduce weight. Aerogels and other advanced insulation products can reduce weight and space occupied by insulation and deliver daylight efficiently.

Rapid developments in design software, improvements in materials, and flexible manufacturing enhance the potential of these approaches. Structural design software developments from the car industry offer potential for adaption to stationary structures.

However, an active strategy to develop new materials, applications of options, provide demonstrations, train professionals and trades, and adapt standards and codes is needed.

Primary criterion 1: Energy savings delivered

Application of optimal structural design can dramatically reduce the amount of material required, and hence the energy embodied in the structures. Often a multiplier effect means the reduced weight of the structure can reduce the amount of material required for footings and the structure itself. In some cases, these approaches also save operating energy by reducing thermal bridging, reducing thermal inertia, and facilitating use of higher insulation value materials.

Primary criterion 2: Enhanced value created

Optimal design can reduce construction time and need for use of cranes, trucks and other heavy equipment. Improved thermal performance can enhance comfort and health, and improve productivity. Optimal use of materials can provide opportunities for more aesthetic design and larger spans, reducing loss of floor area to structures and providing more flexible spaces.

Cost reduction of production of new materials is part of a virtuous cycle of innovation, whereby designers take advantage of their properties, increase adoption, which leads to further cost reduction and wider application.

Primary criterion 3: Export/employment opportunity

Optimal design creates new markets for emerging materials and systems, creating synergies. For example, 3-D printed structures provide exciting opportunities. If Australia develops expertise and businesses that can deliver low carbon structures that are thermally efficient, there are global markets for them.

Primary criterion 4: Reduction in climate impact

Production of materials for structures is a significant contributor to Australian and global carbon emissions and, in some cases, land clearing emissions. If developing countries are to improve welfare and grow their economies in a low carbon future, they will need low carbon structures, as attempts to apply existing developed world approaches would make it very difficult to meet our global carbon budget, as discussed earlier in this report.

Secondary criterion 1: Readiness and potential market impact

There are many examples of optimal structures produced over many decades, the analytical techniques exist, and both existing and emerging materials can be used.

Secondary criterion 2: Economics/Trend

Historically it has often been cheaper to use standardised structural elements and construction techniques to minimise labour, design and production costs. However, the balance is shifting towards optimisation of material use with computerised design, built-in stress sensors, new manufacturing and assembly methods, etc.

Secondary criterion 3: Risks, barriers, support infrastructure

Energy cost for material production and building operation has traditionally been a minor factor in construction costs. Designers are conservative, as structural failures can cost reputations and increase professional insurance premiums for them. They are also under pressure to deliver quickly. Demonstrations, appropriate standards, codes and specifications, improved software tools, training and consumer education are needed to facilitate change. Financial support for time to pursue innovative design and development of design tools is also necessary.

8.10. Transition further to low emission steel production

Description

Steel is the largest contributor to building (and infrastructure) embodied energy. The reduction of iron oxide to pig iron uses coking coal, so the process generates CO2 as well as using fossil fuel as an energy input. An increasing proportion of global steel production utilises scrap steel processed in Electric Arc Furnaces. In principle, these avoid the need for oxide reduction, and can use renewable electricity.

Emerging processes show potential to produce steel from iron ore without using carbon-based reduction sources, or by using carbon from renewable biomass, as well as using renewable energy. These technologies may offer potential to produce steel from iron ore near Australia's iron ore resources, using the bountiful solar energy there.

Primary criterion 1: Energy savings delivered

Electric Arc Furnaces processing scrap steel use much less energy than traditional steel making methods, and can use renewable electricity. In principle there is also substantial scope to improve EAF efficiency, as it is only 20-35% efficient at present.

The potential for emerging steel production processes to save energy depends on the efficiency of the process design: minimising heat loss and heat recovery are critical to efficiency. Insulating equipment that handles molten steel is challenging, although developments in the aerospace industry are producing new high temperature products, such as silicon oxycarbide (SiOC) aerogel material, suitable for use as thermal insulation at temperatures approaching 1,200 °C (http://www.techbriefs.com/component/content/article/ntb/tech-briefs/materials/6570).

Primary criterion 2: Enhanced value created

A shift towards more use of EAFs supports smaller, less capital intensive plants that can be located near sources of scrap steel. Increased utilisation of scrap steel reduces waste disposal costs and supports growth in the employment intensive recycling sector. In future, scrap steel may be able to be processed directly into feedstock for 3-D printing.

Emerging virgin steel production technologies discussed in the main report may also be more suited to smaller modular plants and use of solar energy, and could complement our existing iron ore mining in sunny regions.

Primary criterion 3: Export/employment opportunity

Emerging steel production processes that use renewable electricity or renewably produced hydrogen could improve the economics of steel production in sunny regions near Australian iron ore deposits.

Integration of steel reprocessing into advanced methods of recovery of high value materials from wastes (see earlier priority measure) could capture synergies and be more suited to small plants. The high profile of Australian firms in the global steel industry offers potential for innovation here to expand globally .

Primary criterion 4: Reduction in climate impact

While steel production in Australia is a modest (although emission intensive) industry, due to its decline in scale, application of technologies and solutions developed in Australia could have global markets, while renewable energy sourced steel production using emerging process technologies near our iron ore industry could add value to its production.

Secondary criterion 1: Readiness and potential market impact

Improvement of efficiency of EAFs is practical. But significant capital costs would be involved in upgrading or replacing present plant. However, increasing electricity prices may assist in such a shift. The non-carbon new steel production techniques, apart from use of bio-charcoal to replace coking coal, seem to still be at laboratory or pilot stage, so significant development is needed to achieve large scale production. However, the modular nature of these technologies reduces risk and means economies through scale of modular production rather than larger units could support rapid rollout.

Secondary criterion 2: Economics/trend

The global steel industry is very competitive, and there is significant excess production capacity using high fossil fuel intensity plant. A shift to low or zero emission steel production will require either a breakthrough cost reduction in new technologies, emergence of distributed processing technologies, a high carbon price and/or government intervention in markets.

However, Australia has strong RD&D capacity, an ageing and relatively uncompetitive steel production capacity (despite impressive efforts to upgrade) operating in a global commodity industry. So there is scope for change.

Secondary criterion 3: Risks, barriers, support infrastructure

Growth in Australian low emission steel production will rest upon upgrading of existing EAFs, or major changes such as successful technologies to extract high value materials from waste, or electrolytic steel production that could be located near our iron ore production and in the steel recycling supply chain.

8.11. Implement a cement emissions reduction strategy

Description

After steel, energy use and carbon emissions from cement are the biggest contributor to the raw materials to shelter value chain, apart from building operation. Around half of total emissions from traditional cement production are from the chemistry of the process, as carbon dioxide is produced in the reduction of calcium carbonate to calcium oxide. Concrete is also a poor thermal insulator, so its use for building elements, and thermal bridging around the edges of slabs and via structural design of balconies and other penetrations of thermal insulation increases operational energy use of buildings. However, the thermal inertia its mass provides can help to reduce energy use.

Steel is often incorporated in concrete for reinforcement, and to take tensile loads. This can involve as much embodied energy and emissions as production of the cement in the concrete.

For many structures, the high mass of concrete and steel can drive more use of concrete and steel to support the heavy structure itself.

Australia now imports some cement from countries that use coal for cement production, increasing its carbon intensity relative to Australian production.

Primary criterion 1: Energy savings delivered

Cement production is relatively energy intensive, and involves high temperature processes, as well as significant electricity use for grinding and handling. Production of solar heat at a temperature suitable for calcium-based cement production is very challenging. So use of cements from lower process temperature materials, replacement of cement, optimisation of its use and reduction of thermal bridging effects all offer significant energy saving potential throughout the value chain.

Primary criterion 2: Enhanced value created

The whole cement supply chain involves movement of large quantities of heavy materials and use of heavy machinery, which is costly, logistically difficult and can add to traffic congestion.

Use of alternative structural materials, and ultra-high strength concrete can increase usable floor area, by reducing the mass of the structure to be supported and the area it occupies, particularly in high rise buildings. There is also potential to reduce construction duration and hence costs.

There is increasing use of waste materials in concrete, and as fuel for cement production. This reduces waste disposal problems for other sectors.

Primary criterion 3: Export/employment opportunity

Reducing Portland cement consumption may reduce imports of cement, improving the balance of trade.

Primary criterion 4: Reduction in climate impact

According to the cement industry, cement production is responsible for about 5% of global energy and industrial carbon emissions[66]. About half of this is from energy, and the rest from process CO2 emissions. So reduction in consumption of cement or replacement with extenders or alternative materials is a major climate issue.

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[66] See http://www.cement.org.au/SustainabilityNew/ClimateChange/CementEmissions.aspx

As noted earlier, the cement production process involves very high temperatures which are not easily achieved by solar thermal technologies, so alternatives that involve lower temperature processes, such as magnesium-based cements, increase the potential for replacement of fossil fuels by renewables.

Secondary criterion 1: readiness and potential market impact

Less energy intensive cementitious materials have been used for thousands of years, and in countries with limited access to Portland cement. Over the past few decades, extensive research, much of it in Australia, has led to development of a range of alternatives and 'extenders' that can be mixed with or replace conventional cement.

Other materials and structural design techniques have increased potential to replace traditional cement and steel construction with alternatives, ranging from fibre reinforced concretes to cross laminated timber construction and other composite materials.

Some challenges relate to modifying the handling and curing characteristics of cement replacements and extenders to fit into construction schedules and practices, or to develop alternative approaches.

Secondary criterion 2: Economics/trend

See *Promote Optimal Design* measure

Secondary criterion 3: Risks, barriers, support infrastructure

The widespread use of cement is entrenched in the construction sector. Change will be required throughout the construction sector, from standards and codes, to design tools and training. Ongoing development of alternatives so they can be cost-effectively integrated into construction practices will also be essential. Demonstration projects will be needed.

Significant opportunities beyond our 'top' scorers

As discussed earlier, our scans and analysis identified a number of energy productivity opportunities that could be very significant within specific sectors of the economy, but did not contribute enough energy productivity improvement at the national level to qualify for our list of top measures. However, we think it is important to note these, as they may play very important roles within specific sectors, such as agriculture.

In agriculture:

- Reduce energy use in production of fertilisers and fertiliser use. Fertiliser production uses far more energy than direct on-farm energy consumption, and there seem to be a number of options to address it, including use of ionic liquids. Measures that reduce emissions of nitrous oxide from farms will contribute significant additional emission abatement, as this is a very climate-active gas.
- Virtual paddocks. The use of ear tags and tracking of animals to manage their movements offers significant potential to reduce fuel, time and risk involved in herding animals, and also supports optimal utilisation of on-farm food supply.
- Precision farming involves use of satellite, weather and other data and modelling to guide planting, water and fertiliser management, stock management and other farming activities.

In industry:

- Optimised anaerobic co-digestion of wastes from multiple sources for biogas production: different biomass sources have differing proportions of nutrients required by bacteria. Blending source materials (e.g. sewage, industrial wastes, biomass, municipal wastes) can increase biogas output.
- Extension of shelf life of food through advanced packaging, sterile production, emerging processes such as High Pressure Processing, use of heat pumps to upgrade waste heat from pasteurization. This offers large potential resource and energy savings throughout the farm to plate value chain while enhancing sale value, potentially providing greater diversity of fresh food in remote areas
- Development of model agro-industrial processing plants for regional towns off the natural grid using heat pumps, EE, RE (including optimised energy from waste such as co-digestion from multiple biomass sources), energy storage, etc. This integrates a number of measures but specifically targets regional economic development and employment and RE beyond the gas grid and for those facing increasing gas prices.

9. Conclusions and recommendations

9.1. Conclusions

The key conclusions from this first phase of the Next Wave project are as follows:

- The value chain analysis process applied in this project is a valuable methodology for defining energy and resource productivity opportunities and can provide an excellent overview of the flows and interactions of energy and materials. It is important to look at energy and material flows together (and associated carbon emissions). Only an integrated approach will deliver optimal outcomes. This methodology can be applied equally well to other value chains.
- Doubling energy productivity is an achievable objective in the value chains reviewed. Innovation provides the scope to fill the gap from what can be done from existing best commercial practices, provided business and governments take a proactive approach to accelerate change to gain the energy productivity benefits that are on offer.
- The best opportunities to significantly improve EP have the following characteristics
    - They are not incremental improvements – instead they apply new business models and often operate across sector boundaries.
    - They generally involve innovative and integrated applications of multiple technologies, which provide far greater benefits that the individual technologies alone. The interplay between technologies amplifies and enhances the benefits.
    - They often involve both energy and materials savings e.g. dewatering and waste reduction decrease mass to be transported and processed.
- There are some windows of opportunity that must be exploited in a timely manner. For example, the HFC phase out will drive increased turnover of refrigeration plant in the next 10 years. We must ensure that it is properly sized, smart and efficient. New buildings have very long lives, so failure to incorporate high efficiency and adaptability 'locks-in' longer term higher emissions and costs, and a need for more investment in energy supply infrastructure that could be avoided.
- Innovation opportunities that will lead to significant job creation in Australia will generally be around targeted technical innovations combined with delivery of integration services, which can be exported. For example:
    - Expertise in using IOT and cloud computing for optimising cold chains, and for optimising freight energy performance and logistics.
    - Integration of energy efficiency with renewables and storage, using Internet of Things to link them together.
    - Building on international research into fundamental processes and new materials in new ways. Apply principles, design and adapt technologies and new business models into novel applications and solutions to deliver EP benefits through products and services.

9.2. Key recommendations

The following recommendations have emerged as a result of the process undertaken to evaluate the two values chains, farm to plate and raw materials to shelter. These recommendations will feed into later phases of work of the Next Wave project.

9.2.1. Food value chain recommendations

Accelerate introduction of technologies and business models to improve energy productivity in the food value chain:

1. Optimise the cold chain: conduct feasibility studies and pilots utilising smart monitoring and diagnostic sensors and controls to track product temperatures across the chain. Benefits would include reduced energy use and improved product quality related to avoidance of overcooling and identification of equipment faults in real time. (Priority Measure 8.5.2).
2. Government and industry cooperation to ensure replacement of refrigeration plant, accelerated by phase out of HFCs and HCFCs, to drive a step change in energy performance. Also, promote use of high efficiency refrigeration (including cascade compressors) and high performance insulation in the commercial sector and homes. (Priority Measure 8.5.1)
3. Promote technology transfer and deployment of electric technology in food processing to replace low efficiency thermal systems for dewatering, drying and cooking. Utilise forced evaporation, membranes, centrifuging, microwave heating and high pressure processing; recover and upgrade waste heat using heat pumps or mechanical vapour recompression. (Priority Measures 8.3.1 and 8.3.2)
4. Promote technology development and transfer of high efficiency cooking and hot food displays in commercial and residential sectors. (Priority Measure 8.4)
5. Pilot model agro-industrial processing in regional towns off the natural gas grid using high efficiency electric technologies and renewable energy such as biogas produced from waste. (Priority Measures 8.1, 8.2, 8.3.1, and 8.5.1)
6. Promote development and adoption of integrated clean energy (ICE) solutions including energy productivity (+ electrification), energy storage, on-site renewable generation, smart demand management, monitoring and diagnostics. (Priority Measure 8.2)
7. Join the International Energy Agency Heat Pump Centre to best exploit heat pump applications. (Priority Measure 8.3.1)
8. Integrate energy productivity programs with materials efficiency and waste reduction programs. Target food waste throughout the food chain, including measures to produce new products from by-products, and/or utilise waste to produce on-site and regional energy
9. Develop better data to support value chain analysis and implementation of energy productivity improvements (Priority Measure 8.1). The current, very poor data quality on energy and mass flows and lack of appropriate benchmarks hampers quantification of costs and benefits. Lack of information on the theoretical energy and temperature requirements of processes makes it difficult to estimate the maximum potential for savings. Develop tools, guidelines, resources for identifying, analysing energy and material flows through value chains, and benchmarking against

theoretical optima. Run a project to convert this data into practical information and action outcomes, including case studies, independent monitoring and verification services free for potentially viable projects, model methodologies and business case templates, demonstration projects, and training.

9.2.2. Shelter value chain recommendations

1. Commission further research, including economic analysis, into:
    - Low energy methods of producing and utilising traditional building materials such as steel, cement and bricks (Priority Measures 8.10 and 8.11);
    - Development and use of alternative, less energy intensive building materials as substitutes for traditional, energy intensive building materials (Priority Measures 8.6, 8.8 and 8.9); and,
    - Opportunities to increase rates of recovery, reuse and recycling of building materials. (Priority Measure 8.7)
2. Establish design hubs and support networks to encourage:
    - Integration of energy/resource productivity into new products, materials, systems and business models, based on a circular economy approach. (Priority Measure 8.7)
    - Factory manufactured houses and commercial buildings, using prefabrication and Design for Manufacture and Assembly (DIMA) linked to distributed manufacturing of sub-modules and components using emerging techniques such as 3-D printing and materials such as cross-laminated timber to capture multiple benefits. (Priority Measures 8.6 and 8.8)
    - Optimal structural design integrating low energy/light materials into designs, fabrication and construction practices, e.g. tensile structures, blow-up structures, pre-fab construction, phase change materials (replace mass), aerogels, smart shading systems, ultra-low conductivity insulation materials, heat rejecting coatings and films. (Priority Measure 8.9)
    - Improved design, specification and construction for smart, efficient, comfortable buildings with a low embodied energy, carbon footprint and zero net energy use in increasingly extreme climates. (Priority Measure 8.9)
3. Rewrite model specifications (e.g. NATSPEC), standards, government specifications to drive low carbon, low material content, high efficiency options as priority choices. (Priority Measures 8.6, 8.7, 8.8, 8.9, 8.10 and 8.11)
4. Develop techniques for extraction and upgrading of high value building materials from landfills and waste, including ways of avoiding need to remelt metals and production of energy from waste. (Priority Measure 8.7)
5. Identify and implement effective mechanisms to ensure new and composite materials introduced into building construction are designed for reuse/recycling at end of life. (Priority Measure 8.7)

10. Next steps

This report marks the end of the initial scan and prioritization phase relating to two value chains.

- We recommend to proceed apace with further stages of this project. There are enough value creation opportunities identified by this project that demonstrate it is important to press ahead now to deliver some of the benefits. We will be seeking funding from States and ARENA in particular, and resources from the Commonwealth to press on with the work program outlined in this report.

The next stages of this project (subject to funding) are as follows (but in no particular order):

- Analysis of the priority technologies and business models to define:
    - Economics of implementation and how this is expected to change over time with technology development and volume of application. (See Section 1 for a discussion of trends in technology costs and market penetration.)
    - Barriers to implementation.
    - Potential measures that could be enacted to accelerate technology transfer and improve EP impacts.
- Feasibility analysis and pilot implementation, including:
    - Define the implementation steps for the new technology/business models.
    - Stakeholder engagement to define the feasibility of implementation and the steps to delivery.
    - Measurement in trials, and further analysis to better define the potential EP benefits from use of the technology.
    - Pilots to test the validity of assumptions and prove the benefits, economics and define practical issues with deployment in practices.
- Repeat this project for a number of other key value chains starting with Connectivity (passenger transport, including minimizing the need for it by considering access to the services now provided by transport).

Appendices

Appendix A: 2xEP Steering committee and working group members

2XEP Steering Committee

Kenneth Baldwin, Director, Energy Change Institute, Australian National University
Graham Bryant, Deputy Chair, Energy Users Association of Australia
Tony Cooper, Chief Executive Officer, Energetics
Bo Christensen, Manager Sustainability, Linfox
David Eyre, General Manager, Research & Development, NSW Farmers
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Tom Quinn, Future Business Council
Paul Baker, ClimateWorks Australia
Wei Sue, ClimateWorks Australia
Tom Yankos, ClimateWorks Australia
Peter Stasinopoulos, RMIT University
Alan Broadfoot, University of Newcastle
Deo Prasad, Uni NSW, Low Carbon Living CRC
Dominic Zaal, ARENA
Danny De Schutter, ARENA
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Luke Menzel, Energy Efficiency Council
Brian Morris, Schneider Electric
Azheem Haseeb, Siemens
Roderick Glass, Systems Agriculture
Chris Dunstan, Institute for Sustainable Futures, UTS
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Chris McLean, Energetics
Evan Beaver, Tesla Motors Australia
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Chris Greig, University of Queensland
Gordon Weiss, Energetics
Angus Crossan, Food Innovation Australia
Tennant Reed, Ai Group
James Gerraty, Telstra

Appendix B: Analysis of potential case studies

Please find attached an excel file containing a database of innovative technologies and business models (click paper clip icon in tool bar to left of screen).

Appendix C: Compendium of research and case studies

C.1 Food

REFERENCE	CONTACT
***Farm* - Alternatives to energy intensive nitrogen fertilisers**	
Zhang, W. F., Dou, Z. X., He, P., Ju, X. T., Powlson, D., Chadwick, D., ... & Chen, X. P. (2013). New technologies reduce greenhouse gas emissions from nitrogenous fertilizer in China. *Proceedings of the National Academy of Sciences*, *110*(21), 8375-8380. Retrieved from http://www.pnas.org/content/110/21/8375.full	zhangfs@cau.edu.cn Key Laboratory of Plant–Soil Interactions, Ministry of Education, and Center for Resources, Environment, and Food Security, China Agricultural University, China
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Farm – Irrigation	
Mushtaq, S., Maraseni, T. N., Reardon-Smith, K., Bundschuh, J., & Jackson, T. (2015). Inte.g.rated assessment of water–energy–GHG emissions tradeoffs in an irrigated lucerne production system in eastern Australia. *Journal of Cleaner Production*, *103*, 491-498.	**Shahbaz.Mushtaq@usq.edu.au** International Centre for Applied Climate Sciences, University of Southern Queensland, Australia
Tarjuelo, J. M., Rodriguez-Diaz, J. A., Abadía, R., Camacho, E., Rocamora, C., & Moreno, M. A. (2015). Efficient water and energy use in irrigation modernization: Lessons from Spanish case studies. *Agricultural Water Management*, *162*, 67-77.	**Jose.Tarjuelo@uclm.es** Re.g.ional Centre of Water Research (CREA), University of Castilla-La Mancha, Campus Universitario, Spain
Farm – General	
Kirke.g.aard, J.A., Conyers, M.K., Hunt, J.R., Kirkby, C.A., Watt, M., Rebetzke, G.J., Sense and nonsense in conservation agriculture: Principles, pragmatism and productivity in Australian mixed farming systems, Agriculture, Ecosystems & Environment, Volume 187, 1 April 2014, Pages 133-145 Conservation agriculture principles include (1) diverse rotations (2) reduced (or no-) till systems and (3) the maintenance of surface cover.	**john.kirke.g.aard@csiro.au** CSIRO Sustainable Agriculture Flagship, CSIRO Plant Industry, Canberra, Australia

REFERENCE	CONTACT
Mike Smith: Holistic grazing practices which restore natural capital to grazing farms have been shown to increase carrying capacity and stock rates, reduce farming input costs, improve the health and value of farm assets and thereby increase farm productivity/energy productivity in grazing systems in the majority of the literature since 1996. Earl and Jones, 1996[i], McCosker, T. 2000[ii]; McArthur 1998[iii]; Gatenby 1999[iv]; Joyce 2000[v]; Sparke 2000[vi], Ampt & Doombos, 2011[vii] Walsh, D. 2009[viii], Teague et al, 2011[ix], Sanjari et al, 2008.[x] Implementation of time controlled grazing in central Queensland, Australia led to almost a halving of farm input costs of production and a significant increase in return on assets managed[xi]. The *Soils for Life* initiative in Australia also features actual grazing farms (http://www.soilsforlife.org.au/case-studies.html) evidencing that holistic grazing practices have often doubled productivity. The restoration of the natural capital of the farm also increases the value of the asset increasing capital productivity. It is also important to note the farming sector can also improve productivity by diversifying to gain additional revenue for land sector businesses (i.e. farms, forest projects), through for instance, carbon farming and selling energy to the grid from wind farms, in ways that do not compromise agricultural production, and help to insulate farmers from loss of revenue due to extreme drought. [i] Earl, J. M., and Jones, C. E. (1996). The need for a new approach to grazing management – is cell grazing the answer? The Rangeland Journal 18, 327–350. doi:10.1071/RJ9960327 [ii] McCosker, T. (2002) Cell Grazing the First 10 Years. Tropical Grasslands. Volume 34, 207-218 http://tropicalgrasslands.asn.au/Tropical%20Grasslands%20Journal%20archive/PDFs/Vol_34_2000/Vol_34_03-04_00_pp207_218.pdf [iii] McArthur, S. (1998). Practical evidence supports cell grazing benefits. Australian Farm Journal – Beef, September, 8–9 [iv] Gatenby, A. (1999). Rangeland management: sustainable agriculture requires sustainable profit. In: 'Outlook 99. Proceedings of the National Agriculture and Resource Outlook Conference. Vol. 2, Agriculture'. Canberra, ACT. pp. 165–172. (Australian Bureau of Agricultural and Resource Economics: Canberra.) [v] Joyce, S. (2000). Change the management and what happens – a producer's perspective. Tropical Grasslands 34, 223–229 [vi] Sparke, R. (2000). Cell grazing – a producer's perspective. *Tropical Grasslands* 34, 219–222 [vii] Communities in Landscapes project .Benchmark Study of Innovators. Final Report November 2011. By Peter Ampt & Sarah Doornbos [viii] D. Walsh. 2009. A maximum sustainable stocking rate system in central Australia: Woodgreen Station, NT. DKCRC Working Paper 54, The Central Australian Grazing Strate.g.ies project Working Paper Series. Desert Knowledge CRC, Alice Springs. [ix] Teague, W. R., Dowhower, S. L., Baker, S. A., Haile, N., DeLaune, P. B., and Conover, D. M. (2011). Grazing management impacts on ve.g.etation, soil biota and soil chemical, physical and hydrological properties in tall grass prairie. Agriculture, Ecosystems & Environment 141, 310–322. doi:10.1016/j.agee.2011.03.009 [x] Sanjari, G., Ghadiri, H., Ciesiolka,C. and Yu, B. (2008) 'Comparing the effects of continuous and time-controlled grazing systems on soil characteristics in Southeast Queensland', Australian Journal of Soil Research, vol 46, pp348-358 [xi] McCosker, T. (2002) Cell Grazing the First 10 Years. Tropical Grasslands. Volume 34, 207-218 http://tropicalgrasslands.asn.au/Tropical%20Grasslands%20Journal%20archive/PDFs/Vol_34_2000/Vol_34_03-04_00_pp207_218.pdf	

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Terrasson, G., Llaria, A., Marra, A., & Voaden, S. (2016, July). Accelerometer based solution for precision livestock farming: geolocation enhancement and animal activity identification. In *IOP Conference Series: Materials Science and Engineering* (Vol. 138, No. 1, p. 012004). IOP Publishing. Discussion of solutions to technical challenges, energy consumption and suitability of communication protocols, of animal geolocation systems.	Guillaume Terrasson g.terrasson@estia.fr Ecole Supérieure des Technologies Industrielles Avancées, France
Precision Agriculture Laboratory http://sydney.edu.au/agriculture/pal/	precision.agriculture@sydney.edu.au Precision Agriculture Laboratory, University of Sydney, Australia
Example: Use of drones (unmanned airborne vehicles) for precision agriculture	http://www.droneag.com.au/
Processing – Optimise process management e.g. sensors, analysis, feedback to operators and designers	

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Nano-enabled sensor technology applications in food processing (source: ObservatoryNano Agrifood, Briefing No 28, March 2012)	Guillaume P. Gruère **g.gruere@cgiar.org** International Food Policy Research Institute Washington DC, USA
Centre for Technology Infusion, RFID Track, Trace and Find. http://www.latrobe.edu.au/technology-infusion/innovation/food-safety-and-supply-chain/rfid-track-trace-and-find Collaborative research project to utilize super high frequency Radio Frquency Identification (RFID) technology to track perishable consumer goods in transit.	a.desai@latrobe.edu.au Centre for Technology Infusion, Technology Enterprise Centre, La Trobe University, Australia
Veltman, R.H.; Verschoor, J.A.; Ruijsch van Dugteren, J.H., "Dynamic control system (DCS) for apples (Malus domestica Borkh. cv 'Elstar'): optimal quality through storage based on product response"; Postharvest Biology and Technology, 27(1), pp 79–86, 2003	**j.a.verschoor@ato.wag-ur.nl** Agro-technological Research Institute, Wageningen University, The Netherlands
Omar, A.F.; Matjafri, M.Z., "Specialized Optical Fiber Sensor for Nondestructive Intrinsic Quality Measurement of Averrhoa Carambola", Photonic Sensors, 3(3), 272–282, 2013	Ahmad Fairuz Omar **thinker_academy@yahoo.com** School of Physics Universiti Sains Malaysia, Malaysia
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Processing - Packaging to enhance shelf life and reduce waste	
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Thoden van Velzen, E.U.; Linnemann, A.R., "Modified atmosphere packaging of fresh meats – sudden partial adaptation caused an increase in sustainability of Dutch supply chains of fresh meats", Packaging Technology and Science, 21, 37-46, 2008	**ulphard.thodenvanvelzen@wur.nl** Wageningen UR Agrotechnology & Food Sciences Group, Wageningen University, The Netherlands
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Institute for Frontier Materials https://www.deakin.edu.au/research/ifm Plasma research facility focusing on the potential uses of cool plasma in packaging	**ifm-enquiries@deakin.edu.au** Institute for Frontier Materials, Deakin University, Australia
Institute for Sustainability and Innovation https://www.vu.edu.au/institute-for-sustainability-and-innovation-isi Sustainable and environmentally sound packaging technologies focused on: food security and safety; waste reduction; protection; post-harvest technologies; biode.g.radable and antimicrobial materials.	**vincent.rouillard@vu.edu.au** Engineered Packaging & Distribution Research Group, Institute for Sustainability and Innovation, Victoria University, Australia
Green Blue (2006) Sustainable packaging coalition, "Design guidelines for sustainable packaging" Green Blue, Charlottesville NC, December 2006	**spcinfo@greenblue.org**
Example: LiquiformTM blow molding and filling manufacturing technology which uses consumable, pressurized liquid instead of compressed air to form plastic containers	https://www.amcor.com/businesses/rigid_plastics/liquiform-home
Processing – High efficiency processing technologies such as membrane filtration, improved ways of driving chemical change e.g. high pressure cooking, microwave, UV, nano and micro processing, avoiding need for heat, efficient heating and dewatering.	
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Wang, L., Energy efficiency technologies for sustainable food processing, Energy Efficiency, 2014, Volume 7, pages 791-810. Retrieved from https://www.researchgate.net/publication/271917124_Energy_efficiency_technologies_for_sustainable_food_processing	Lijun Wang lwang@ncat.edu Biological engineering program, Department of Natural Resources and Environmental Design, North Carolina Agricultural and Technical State University
Goh, L. J., Othman, M. Y., Mat, S., Ruslan, H., & Sopian, K. (2011). Review of heat pump systems for drying application. *Renewable and Sustainable Energy Reviews*, *15*(9), 4788-4796.	Solar Energy Research Institute, University Kebangsaan Malaysia
Schutyser, M.A.J., Van der Goot, A.J., "The potential of dry fractionation processes for sustainable plant protein production", Trends in Food Science and Technology, 22(4), 154-164, 2011	maarten.schutyser@wur.nl Food Process Engineering Group, Wageningen University, The Netherlands

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CSIRO, Dairy: creating new opportunities for industry, 2015. Retrieved from http://www.csiro.au/en/Do-business/Partner-with-our-Business-Units/Do-business-Agriculture/Food-innovation-centre/Our-expertise/Dairy Innovation including: using novel technologies such as high pressure processing, pulsed electric field, ultrasound, ultraviolet and short-time heat processing; adding value to dairy by-products, waste streams and oversupply.	**Roderick.Williams@csiro.au** CSIRO Food Innovation Centre, Weeribee Australia
CSIRO, Horticulture and grains: value-added opportunities for industry, 2015. Retrieved from http://www.csiro.au/en/Do-business/Partner-with-our-Business-Units/Do-business-Agriculture/Food-innovation-centre/Our-expertise/Horticulture Innovate technologies including: modified atmosphere packaging to improve shelf life; high pressure processing, pulsed electric field, ultrasound, ultraviolet and short-time heat processing; advanced drying and microwave technologies.	Dr Mala Gamage **Thambaramala.Gamage@csiro.au**
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Technical University of Munich, Processing milk - how concentrates help save energy. Retrieved from https://www.tum.de/en/about-tum/news/press-releases/short/article/31876/ Reduction in amount of energy required to concentrate milk by approximately 20 per cent using separation instead of evaporation.	Prof. De. Ulrich Kulozik **ulrich.kulozik@tum.de** TUM Chair of Food Process Engineering adn Dairy Technology, Technical University of Munich, Germany
Example of milk concentrating process	http://www.dow.com/en-us/water-and-process-solutions/markets/food-and-beverage/dairy
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NASA, 3D printing: food in space, 2013. Retrieved from http://www.nasa.gov/directorates/spacetech/home/feature_3d_food.html#.V7P_444dZ9Q 3D food printing also being researched by Dutch company TNO https://www.tno.nl/en/focus-area/healthy-living/food-nutrition/food-innovations/3d-printing-makes-food-unique/	**davidirvin@systemsandmaterials.com** Systems and Materials Research Consultancy, USA
Department of Chemical Engineering, Monash University http://www.eng.monash.edu.au/chemical/research/expertise.html Research includes: spray drying and other drying technologies; large scale food processing; evaporation processes; heat exchanging; improved processes to avoid fouling and spoilage.	**Dong.Chen@monash.edu** Biotechnology and Food Engineering, Department of Chemical Engineering, Monash University, Australia
Centre for Advanced Processing and Packaging Studies, North Carolina State University USA www.cals.ncsu.edu/food_science/capps.html	**ken_swartzel@ncsu.edu** Centre for Advanced Processing and Packaging Studies, North Carolina State University, USA
Microwave Process Engineering Research Group, University of Nottingham https://www.nottingham.ac.uk/research/groups/microwave-process-engineering/index.aspx	**chris.dodds@nottingham.ac.uk** **MPE@nottingham.ac.uk** Microwave Process Engineering Research Group, University of Nottingham, UK
http://www4.shu.ac.uk/research/food-engineering/work-with-us/research	**business@shu.ac.uk** Centre of Excellence for Food Engineering, Sheffield Hallam University, UK
Commercial food preparation	
Food Service Technology Centre - end user technologies etc in food service industry – cooking, refrign etc in retail sector.	http://www.fishnick.com/
EU website that lists the best performing appliance across all sectors - for example, the best bar fridge for hotel rooms uses 0.11 kWh/day, while typical bar fridges use 0.85 kWh/day.	http://www.topten.au/

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Domestic food preparation - Innovation in technologies for domestic food applications	
US Department of Energy, Research and Development Roadmap for next-generation appliances, 2012. Retrieved from http://energy.gov/sites/prod/files/2014/07/f17/next_generation_appliances_roadmap.pdf	US Department of Energy Office of Energy Efficiency and Renewable Energy Building Technologies Office http://www.eere.energy.gov/buildings
Example: Nutri-Pulse, IXL Netherlands Innovation	**hroelofs@innovation-xl.com** http://www.innovation-xl.com
Across farm to plate value chain - General	
Institute for Supply Chain and Logistics https://www.vu.edu.au/institute-for-supply-chain-and-logistics-iscl/ Research into: food supply chain; cold/refrigerated supply chain; supply chain inte.g.ration, collaboration, risk management, network design and sustainability; warehousing and inventory control; scheduling; queuing; forecasting and simulation; demand management; port operations; supply chain analysis and optimisation; interaction and coordination across the supply chain; Enterprise Resource Planning; e-commerce; transport, handling and container equipment; Radio Frequency Identification (RFID)	**supplychain.information@vu.edu.au** Institute for Supply Chain and Logistics, Victoria University, Australia
Across farm to plate value chain - Digitisation/data analytics	
Hajkowicz, S., Eady, S. (2015). Chapter 6 Transformative Technologies in Rural Industry Futures: Me.g.atrends impacting Australian agriculture over the coming twenty years. pp74 - 87 Rural Industries Research & Development Corporation. Retrieved from https://rirdc.infoservices.com.au/items/15-065 Internet of Things examples: tracking and assessing the health of animals; GIS positioning used to enable automation, including by use of robots, of field operations such as spraying, planting and harvesting; automation of irrigation systems based on soil moisture probes, pumps and flow meters; real-time tracking of quantity and quality of product under production; embedding live information with into products so consumers, retailers, logistics companies and farmers can enter or extract data using RFID and smart software.	Stefan.hajkowicz@csiro.au Sandra.Eady@csiro.au CSIRO Agricultural Productivity Flagship (Armidale), Australia

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Examples of digitisation aiding energy productivity in the farm to plate value chain: ● Retail e.g e-commerce systems. ● Transport and logistics e.g. optimised vehicle movements. ● Manufacturing e.g. data analytics applied to automation and resource management to make more efficient use of plant facilities, raw materials and energy. ● Agriculture and food production e.g. use of weather simulations on weather, soil, seed, fertiliser, crop specifications etc, can be used to optimise yields and resources use; asset management systems for farm equipment, livestock and crops; improve collaboration between farmers and suppliers.	http://www.eco-business.com/news/how-to-digitise-six-major-industries-and-save-us33-trillion/?utm_medium=email&utm_campaign=Aug%2024%20newsletter&utm_content=Aug%2024%20newsletter+Version+B+CID_a05171cb74c090eeba6ce76a52a38388&utm_source=Campaign%20Monitor
Cisco Innovations Centres - purpose is to help organisations improve business outcomes by inte.g.rating, creating, testing and validating digital technology solutions. For example, exploring ways to improve network connectivity in re.g.ional areas through low range radio solutions to allow farmers to better access cloud based services.	http://www.cisco.com/web/ANZ/innovationcenter/australia/index.html
Across farm to plate value chain - Utilisation of waste and by-products for food (humans and animals), fertilizer, energy, pharmaceuticals, and heat/coolth	
Lin, C. S. K., Pfaltzgraff, L. A., Herrero-Davila, L., Mubofu, E. B., Abderrahim, S., Clark, J. H., ... & Thankappan, S. (2013). Food waste as a valuable resource for the production of chemicals, materials and fuels. Current situation and global perspective. *Energy & Environmental Science*, *6*(2), 426-464.	**james.clark@york.ac.uk** Green Chemistry Centre of Excellence, The University of York, UK
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Fava, F., G. Zanaroli, L. Vannini, E. Guerzoni, A. Bordoni, D. Viaggi, J. Robertson, K. Waldron, C. Bald, A. Esturo, C. Talens, I. Tueros, M. Cebrián, A. Sebők, T. Kuti, J. Broeze, M. Macias, H.-G. Brendle, “New advances in the inte.g.rated management of food processing by-products in Europe: sustainable exploitation of fruit and cereal processing by-products with the production of new food products (NAMASTE EU)”, New Biotechnology, in press (2013).	**fabio.fava@unibo.it** University of Bologna, Italy
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Bridle, T., Pilot testing pyrolysis systems and review of solid waste use on boilers, Meat & Livestock Australia, 2011. Retrieved from http://www.mla.com.au/research-and-development/search-rd-reports/final-report-details/Environment-Off-Farm/Energy-consumption-and-generation/1564 Download: A.ENV.0111	**trevorbridle@bigpond.com** Bridle Consulting, Australia
Example: biogas plant inte.g.rated into largest abattoir in Austria. 10,000 tons of slaughterhouse waste per annum are used to produced 3.6 million KWh of electricity and 3.6 million kWh of heat per year, significantly reducing energy and disposal costs of the abattoir.	http://www.green-foods.eu/best-practice/rudolf-grosfurtner/
Sturm B., Butcher, M. Wang, Y., Huang, Y., Roskilly, T. The feasibility of the sustainable energy supply from bio wastes for a small scale brewery - A case study, 2012 Applied Thermal Engineering Volume 39 June 2012 pages 45-52	**BarbaraSturm@daad-alumni.de** Sustainable Energy and Power Research Group, Newcastle Institute for Research on Sustainability, Newcastle University, UK
Issariyakul T. and Dalai A.K., Biodiesel from ve.g.etable oils, Renewable and Sustainable Energy Reviews , Vol. 31, issue C, pages 446-471, 2014	**ajay.dalai@usask.ca** Catalysis and Chemical Reaction Engineering Laboratories, Department of Chemical and Biological Engineering, University of Saskatchewan Canada
Hopwood, L. Farm-scale anaerobic digestion plant efficiency. National Non-Food Crops Centre, 2011. Retrieved from http://www.nnfcc.co.uk/tools/farm-scale-anaerobic-digestion-plant-efficiency-nnfcc-11-015	Lucy Hopwood **l.hopwood@nnfcc.co.uk** National Non-Food Crops Centre, UK
Example: CLEAN Cowra The project plans to use inputs from: ● Sludge from water treatment plant ● Green waste from the tip ● Industry by-products such as sugary water from food factory ● Waste from abattoir ● Soiled straw from piggery ● Horticultural by-products such as beetroot tops and corn trash. The project will use two processes: anaerobic digestion and thermal recovery through either pyrolysis or torrefication (the breakdown of organic material at high temperature). At full capacity, the Cowra biomass project will produce 60% of the town’s energy needs.	http://www.embark.com.au/display/public/Groups/CLEAN+Cowra+NSW

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Example: Woodlawn Eco Precinct ● *Woodlawn Bioreactor (BioEnergy)* accepts approximately 20% of Sydney's putrescible waste. The bioreactor facility recovers energy from what would otherwise be waste material to produce green electricity. ● *Aquaculture & Horticulture* utilising the waste heat produced from the energy generation process for fish farming, incorporating hydroponics in the filtrations system to remove excess nutrients. ● *Woodlawn Mechanical and Biological Treatment (MBT) Facility* designed to extract the organic content from the mixed waste stream to produce compost for onsite mine rehabilitation. ● *Agriculture* incorporating a working farm that applies nutrient and grazing rotation to improve meat and wool productivity while reducing impacts on the soil. ● *Windfarm* (operated by Infigen Energy) is a 50MW Windfarm in an area with significant year round wind generation.	http://www.veolia.com.au/sustainable-solutions/community-development/woodlawn-bioreactor
Example: South Australia Water's Glenelg wastewater treatment plant, commissioned in 2013, is Australia's first co-digestion facility. The addition of food byproducts such as milk, cheese, beer, wine and soft drink has increased power generation from 55% to 75% of the plant's power requirement.	http://www.awa.asn.au/documents/061%20JDreyfus.pdf
Example: Yarra Valley Water is currently constructing an anaerobic digestion waste-to-energy facility north of Melbourne. It will process 100 cubic metres of waste each day to produce biogas. The waste will be delivered by trucks from local commercial waste producers, such as markets and food manufacturing.	http://www.yvw.com.au/Home/Aboutus/Ourprojects/Currentprojects/WastetoEnergyfacility/index.htm
Example: anaerobic digester and generators to provide power and heat for Darling Downs Fresh E.g.gs by converting chicken manure from approximately 390,000 hens and other organic waste.	https://www.cleanenergyfinancecorp.com.au/media/63281/20130731-cefc-pdf-factsheet-darlingdownsfreshe.g.gs_lr.pdf
Example: Biomass boiler, using grape waste that would otherwise become landfill, generating over 60% of electricity needs on site	http://www.australiantartaric.com.au/NATURAL-PROCESS/Environment.aspx
Example: Spanish ve.g.etable processing factory using waste ve.g.etable to generate self-consumed electricity. Digestates will be used for the production of fertilisers.	http://www.green-foods.eu/best-practice/kernel-export/
Example: centralised biogas plant in Calais to reduce amount of household organic waste going into landfill. Gas produced feeds to electricity generators of 940 kW and 500kW power respectivity. Electricity produced is sold into the grid.	http://www.green-foods.eu/best-practice/sevadec/
Example: methane digestion system that captures gas from pig manure to generate electricity. Hot water is also heater from the generator. (see also Polish example of biogas from pig farm waste: http://www.green-foods.eu/best-practice/biogal/)	http://blantyrefarms.com.au/quality-sustainability

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Covered high-rate anaerobic lagoon example: biogas extracted from wastewater streams to replace natural gas consumed at abattoir	http://www.cstwastewater.com/oakey-beefs-spectacular-green-energy-orb-opens-the-way-to-environmentally-outstanding-and-profitable-performance/
Food waste example	http://www.ifr.ac.uk/waste/Reports/Provalor.pdf
Animal fats and proteins example	http://www.tenkate.nl/index.php/en/
Across farm to plate value chain - Onsite energy/heat technologies	
Walmsley, T. G., Walmsley, M. R., Neale, J. R., & Atkins, M. J. (2015). Pinch Analysis of an Industrial Milk Evaporator with Vapour Recompression Technologies. Energy. Up to 67% saving from optimal vapour recompression (heat pump)	Timothy Walmsley **timgw@waikato.ac.nz** Energy Research Centre, School of Engineering, University of Waikato, New Zealand
Law, R., Harvey, A., Reay, D., Opportunities for low-grade heat recovery in the UK food processing industry, Applied Thermal Engineering 05/2013; 53(2), pp. 188–196, 2012	**richard.law1@ncl.ac.uk** School of Chemical Engineering and Advanced Materials, Newcastle University UK
Sokhna Seck G., Guerassimoff G. and Maïzi N., Heat recovery with heat pumps in non-energy intensive industry: A detailed bottom-up model analysis in the French food and drink industry, Applied Energy, vol. 111, pp. 489-504, 2013	**gilles.guerassimoff@mines-paristech.fr** Centre of Applied Mathematics, Mines ParisTech, France
Ricardo-AEA. Projections of CHP capacity and use to 2030. Report for the Department of Energy and Climate Change (UK), 2013. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/191543/Projections_of_CHP_capacity___use_to_2030_2204.pdf	**Mahmoud.Abu-Ebid@ricardo-aea.com** Ricardo-AEA
McPhail, N. ,Rossington, D., The use of abattoir waste heat for absorption refrigeration, Meat & Livestock Australia, 2010. Retrieved from http://www.mla.com.au/research-and-development/search-rd-reports/final-report-details/Environment-Off-Farm/Energy-consumption-and-generation/1564 Download: A.ENV.0094	**Neil.McPhail@csiro.au** CSIRO Food and Nutrition Sciences, Australia
Colley, T., Economic and technical potential for cogeneration in industry. Meat & Livestock Australia, 2010. Retrieved from http://www.mla.com.au/research-and-development/search-rd-reports/final-report-details/Environment-Off-Farm/Energy-consumption-and-generation/1564 Download: A.ENV.0102	Tracey Colley Colley Consulting Pty Ltd, Australia

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Decarbonisation of heat in industry: A review of the research evidence, Report for DECC (UK), prepared by Ricardo-AEA and Imperial Colle.g.e, July 2013 Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/230949/D13_951813__Ricardo_AEA_Industrial_Decarbonisation_Literature_Review_201___.pdf	**heather.haydock@ricardo-aea.com** Ricardo-AEA Ltd UK
Waste heat recovery - information platform for heat pump use in industry with good case studies	http://www.industrialheatpumps.nl/en/
Information heat pump use in commercial and industrial settings, including waste heat recovery and inte.g.ration with renewables.	http://www.ee-ip.org/articles/detail/?article=28
Example: 75,000 litre external tank used to store waste heat in dairy. Heat exchangers increase the efficiency of process water. Used for heating and cooling milk.	http://www.green-foods.eu/best-practice/berglandmilch-feldkirchen/
Example: waste heat recovery in large Austrian baked goods factories to optimise cooling processes.	http://www.green-foods.eu/best-practice/rudolf-olz/
Example: waste heat recovered from freezer stored in hot water storage.	http://www.green-foods.eu/best-practice/bichlback/
Example: evacuated solar thermal collector that can achieve temperatures of 200°C for industrial applications	http://www.greenlandsystems.com/Projects_2.html
Example: on site solar PV and solar thermal preheater hot water system to provide process heat for bottling operations offset electricity and gas consumption at winery.	http://reneweconomy.com.au/2013/de-bortoli-to-launch-oz-wine-industrys-largest-solar-system-49988
Example: on site solar thermal low temperature (40-50C) process heat for washing and cleaning needs at Spanish cured ham factory.	http://www.green-foods.eu/best-practice/cured-ham-montesano-spain/
Example: Mashing process in Austrian brewery altered such that hot water used instead of steam, allowing better inte.g.ration of renewables i.e. solar thermal hot water system.	http://www.green-foods.eu/best-practice/solarbrew-goss-austria/
Example: renewable powered irrigation plants for agriculture and municipal water supply for councils. Developing a renewable powered system to optimize water and energy management using digital connectivity. Focused on Northern Australia, especially tropical re.g.ions.	Catalyst Power - Innovative Renewable Energy Precinct (iREP) Brendan Young Brendan@catalystpower.com.au http://catalystpower.com.au/
Across farm to plate value chain - Refrigeration, freezing, cooling	

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Tassou S.A., Lewis J.S., Ge Y.T., Hadawey A. and Chaer I., A review of emerging technologies for food refrigeration applications, School of Engineering and Design, Brunel University, 2009	**Savvas.tassou@brunel.ac.uk** School of Engineering and Design, Brunel University, UK
Evans J.A., Hammond E.C., Gigiel A.J., Fostera A.M., Reinholdt L., Fikiin K. and Zilio C., Assessment of methods to reduce the energy consumption of food cold stores, Applied Thermal Engineering, 62 pp. 697- 705, 2013	**j.a.evans@lsbu.ac.uk** Faculty of Engineering, Science and the Built Environment, London South Bank University, UK
LANL, Multi-stage cascaded stirling refrigerator. Retrieved from http://www.lanl.gov/projects/feynman-center/_assets/pdf/multi-stage-cascaded-stirling-refridgerator.pdf	Marcus A. Lucero **marcus@lanl.gov** Los Alamos National Laboratory, USA
Evans, J., Food chilling and freezing technologies: potential for energy saving, Food Refrigeration and Process Engineering Research Centre, University of Bristol	**frperc-bris@bristol.ac.uk** Food Refrigeration and Process Engineering Research Centre, University of Bristol, UK
Lebreton, H., Commercial to industrial refrigeration upgrade, feasibility and implementation study Ryan Meat Company, Meat & Livestock Australia, 2015. Retrieved from http://www.mla.com.au/research-and-development/search-rd-reports/final-report-details/Environment-Off-Farm/Energy-consumption-and-generation/1564 Download: P.PIP.0386	Helene Lebreton Minus40 Pty Ltd, Australia http://www.minus40.com.au/
Brooks, K., Fuel cell based auxiliary power unit for refrigerated trucks, 2014. Retrieved from https://www.hydrogen.energy.gov/pdfs/review14/mt014_brooks_2014_o.pdf	Kriston Brooks **kriston.brooks@pnnl.gov** Pacific Northwest National Laboratory
Refrigerated container transport example: the Quest II methodology for energy control in refrigerated storage and transport	Dr.ir.LJS (Leo) Lukasses email via http://www.wageningenur.nl/en/show/Energy-use-of-refrigerated-containers-further-reduced.htm Food Biobased Research, Fresh Food & Chain, Wageningen University, The Netherlands
Example: Thermal Energy Storage System combined with solar PV for cold storage facilities and supermarkets. Benefits include energy load shifting and reduced risk of interrupted grid supply.	http://www.pv-magazine.com/news/details/beitrag/australian-cold-storage-facilities-and-supermarkets-can-reduce-electricity-peak-demand-up-to-90-using-thermal-energy-storage_100025960/#axzz4IwA3DbRI
Example: Liquid nitrogen refrigerated transport system	http://dearman.co.uk/dearman-technologies/transport-refrigeration-system/

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Change in business practices such as shift to distributed processing e.g. at farm or local plants; inte.g.ration of several elements of value chain e.g. hot bread shop	
Gorle, P., Clive, A. (2013). Positive impact of industrial robots on employment. Retrieved from http://www.ifr.org/uploads/media/Update_Study_Robot_creates_Jobs_2013.pdf Automation/robotics can lead to increased productivity and enable manufacturing to remain in high wage economies. Critical areas for increased robotic deployment: ● robots carry out work in areas that would be unsafe for humans ● robots carry out work that would not be economically viable in a high wage economy ● robots carry out work that would be impossible for humans. See pp 52-54 for discussion of robots in food and drink sector	**peter.gorle@metra-martech.com** Metra Martech Limited
Study into export of high value, premium food products to Asia. E.g. analysis of exporting packaged beef to China was undertaken.	https://www.usq.edu.au/research/research-at-usq/institutes-centres/acsbd/our-projects/agricultural-value-chains/exporting-to-china
Other organisations with interest in energy-related innovation	
The Energy Efficiency Exchange	www.eex.gov.au
Food and Drink Federation (UK)	**members.enquiries@fdf.org.uk** http://www.fdf.org.uk/growth-through-innovation.aspx
National Centre for Engineering in Agriculture, University of Southern Queensland	http://www.usq.edu.au/research/research-at-usq/institutes-centres/ncea/our-projects
Carbon Trust (UK)	Industrial Energy Efficiency Accelerator guides: https://www.carbontrust.com/resources/reports/technology/industrial-energy-efficiency/
Green Foods - European organisation to encourage energy efficiency and management in the food and beverage industry. Website includes many best practice examples.	http://www.green-foods.eu/best-practice/
Institute for Industrial Productivity WRAP – Waste and Resources Action Programme (UK) – works with governments, businesses and communities to deliver practical solutions to improve resource efficiency	http://www.iipnetwork.org/ http://www.wrap.org.uk/sites/files/wrap/Food_Futures_%20report_0.pdf
AD (UK) – information portal on anaerobic digestion	http://www.biogas-info.co.uk/wp-content/uploads/2015/06/research.pdf

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Shipping Efficiency	http://www.shippingefficiency.org/
Walmart - RFID and digital temperature recorder technology to monitor cold supply chain	http://www.rfidjournal.com/articles/view?2860/2 https://cargodatacorp.com/product/wal-mart-approved-temperature-recorders/
Aerogel - insulation solutions	http://www.aerogel.com.au/

C.2 Freight

REFERENCE	CONTACT
Road freight	
Sternberg, H., Prockl, G., & Holmström, J. (2014). The efficiency potential of ICT in haulier operations. *Computers in Industry*, *65*(8), 1161-1168.	henrik.sternberg@plog.lth.se Lund University, Faculty of Engineering, Packaging Logistics, Sweden
US Department of Energy is funding $80 million of projects under the SuperTruck II program to research, develop, and demonstrate technologies to improve heavy-truck freight efficiency by more than 100 percent, relative to a manufacturer's best-in-class 2009 truck, with an emphasis on technology cost-effectiveness and performance. The recipients of the funding for plug-in electric powertrain technologies for medium and heavy-duty vehicles include: ● Robert Bosch LLC (Farmington Hills, MI) will receive $5 million to develop and demonstrate a medium-duty plug in hybrid vehicle powertrain that reduces fuel consumption by 50 percent. ● Cummins Corporate Research and Technology (Columbus, IN) will receive $4.5 million to develop and demonstrate a Class 6 plug in hybrid delivery truck that reduces fuel consumption by 50 percent. ● McLaren Performance Technologies (Livonia, MI) will receive $2.6 million to develop a Class 6 delivery truck with a scalable, innovative, lightweight, low-cost, and commercially-viable plug-in electric drive system that improves fuel economy by 100 percent. http://energy.gov/technologytransitions/articles/doe-announces-80-million-funding-increase-supertruck-efficiency	US DOE Energy Efficiency and Renewable Energy Funding Opportunity Exchange https://eere-exchange.energy.gov/default.aspx - FoaId0aa8732c-3c61-4040-aa2b-cd4fba6797d0 Robert Bosch LLC, Farmington Hill, Michigan Tel.: +1 248 553 9000 Cummins Tel.: +1 812 377 5000 http://investor.cummins.com/phoenix.zhtml?c=112916&p=irol-newsArticle&ID=2155214 McLaren Engineering, Michigan, US
Example: Retrofit hybrid technology for trucks. This has potential to transform the market quicker than sales of new hybrid trucks, because new sales represent only a small % of the entire vehicle population.	http://www.wrightspeed.com/
Example of an electric truck	https://nikolamotor.com/one
Rail	
Australian Centre for Rail Innovation http://www.industry.gov.au/industry/IndustryInitiatives/AustralianIndustryParticipation/SupplierAdvocates/Pages/Library%20Card/OnTrackTo2040-Roadmap.aspx http://www.slideshare.net/informaoz/matthew-doolan	Bruce Griffith – Rail Supplier Advocate, Australian Government **railadvocate@industry.gov.au** anuedge@anu.edu.au matthew.doolan@anu.edu.au

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Shipping	
Rehmatulla, N., Smith, T., Barriers to energy efficiency in shipping: A triangulated approach to investigate the principal agent problem, Energy Policy, Volume 84, September 2015, Pages 44-57	Nishatabbas Rehmatulla **n.rehmatulla@ucl.ac.uk** University Colle.g.e London Energy Institute, UK
Royal Academy of Engineering, Future ship powering options, exploring alternative methods of ship propulsion, 2013. Retrieved from http://www.raeng.org.uk/publications/reports/future-ship-powering-options	alan.walker@raeng.org.uk Head of Policy and member of working group, Royal Academy of Engineering, UK
Green Ship of the Future projects: http://www.greenship.org/projekter/ 3D Printing in the maritime industry - OSK ShipTech A/S Re.g.ional ECOfeeder - Odense Maritime Technology	**info@greenship.org** Anders Ørgård-Hansen **ahn@osk-shiptech.com** Thomas Eefsen, **thee@odensemaritime.dk**
Aviation	
Committee on Climate Change, Chapter 4 Improvement in fleet fuel efficiency through technology innovation, Meeting the UK aviation target – options for reducing emissions to 2050, 2009. Retrieved from https://www.theccc.org.uk/archive/aws2/Aviation%20Report%2009/21667B%20CCC%20Aviation%20AW%20COMP%20v8.pdf	Committee on Climate Change, UK www.theccc.org.uk

C.3 Shelter

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***Lower embodied energy substitutes for traditional construction materials* - Engineered timbers to replace steel**	
Bylund, D. (2014). Hybridised Australian cross laminated timber (ACLT) and oriented strand board (OSB) wall panels-a case study. In *World Conference on Timber Engineering 2014* (pp. 1-6).	David.Bylund@utas.edu.au School of Architecture, University of Tasmania, Australia
Lehmann, S. (2013). Low carbon construction systems using prefabricated engineered solid wood panels for urban infill to significantly reduce greenhouse gas emissions. *Sustainable Cities and Society*, *6*, 57-67.	Steffen.Lehmann@unisa.edu.au sd+b Research Centre, University of South Australia, Australia
Durlinger, B., Crossin, E., & Wong, J. (2013). Life cycle assessment of a cross laminated timber building. *Market Access*. The cross laminated timber building, Forte, had a lower environmental impact on all assessed cate.g.ories, except renewable energy demand (mainly related to embodied renewable energy in the cross laminated timber) than the reference (conventional construction) building.	enda.crossin@rmit.edu.au Centre for Design, RMIT University, Australia
Key Australian example of engineered timber: Lend Lease Forte Building, Melbourne	**http://www.forteliving.com.au/**
Carre, A. (2011). A comparative life cycle assessment of alternative constructions of a typical Australian house design. *Forest and Wood Products Australia, Project number PNA*, 147-0809. Study found that timber based constructions tend to have lower global warming, resources use and embodies energy outcomes than alternatives (p.62)	andrew.carre@rmit.edu.au Centre for Design, RMIT University, Australia
Crews, K. et al., 2010. Innovative engineered timber building systems for non-residential applications, utilising timber concrete composite flooring capable of spanning up to 8 to 10m, Sydney: Forest and Wood Products Australia.	http://www.fwpa.com.au/images/marketaccess/PNA012-0708_Research_Report_Engineered_Timber.pdf
Example: development of a timber system for quickly erected prefabricated high-rise construction	http://www.arup.com/projects/lifecycle_tower http://www.arup.com/timber_offices
Case study: use of timber rather than steel as the primary roof support in an international airport terminal led to a 32% reduction in the roof's embodied energy	http://www.arup.com/projects/raleigh_durham_airport
Lower embodied energy substitutes for traditional construction materials - Other	

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Cabeza, L. F., Barreneche, C., Miró, L., Morera, J. M., Bartolí, E., & Fernández, A. I. (2013). Low carbon and low embodied energy materials in buildings: A review. *Renewable and Sustainable Energy Reviews*, *23*, 536-542.	Luisa F. Cabeza **lcabeza@diei.udl.cat** GREA Innovació Concurrent, Universitat de Lleida, Edifici CREA, Spain
Iddon, C. R., & Firth, S. K. (2013). Embodied and operational energy for new-build housing: a case study of construction methods in the UK. *Energy and Buildings*, *67*, 479-488.	Steven K. Firth **s.k.firth@lboro.ac.uk** Building Energy Research Group School of Civil and Building Engineering, Loughborough University, UK
Memon, S. A. (2014). Phase change materials inte.g.rated in building walls: A state of the art review. *Renewable and sustainable energy reviews*, *31*, 870-906.	Shazim Ali Memon **shazimalimemon@gmail.com** Department of Civil and Architectural Engineering, City University of Hong Kong, Hong Kong
McLaren, W. (2015). The state of phase change materials in Australian building design, Architecture and design.	http://www.architectureanddesign.com.au/features/features-articles/the-state-of-phase-change-materials-in-australian
Example: aerogel insulation. Uses 30-60% less material than conventional insulation products.	www.aerogel.com.au
Example: translucent aerogel. Combination of high insulation (50mm is about R2.7, more than double traditional bulk insulation) and low glare daylighting with very low weight means structural components can be much reduced for facades. May be incorporated into tensile roofing structures.	http://www.cabotcorp.com/solutions/applications/construction/daylighting
Case study: Dedmon Athletic Center - translucent aerogel incorporated into roofing structure.	http://www.cabotcorp.com/solutions/applications/construction/tensile-roofing/project-gallery
Example: biocomposite facade panels for building construction with up to 50% lower embodied energy compared to conventional construction materials at no increase in cost. Biocomposites are composed of natural fibres such as flax, hemp and jute and natural resins made from the byproducts of corn, sugarcane and other agricultural crop processing.	http://www.arup.com/projects/biobuild_facade_system
Example: phase change material produced from rapidly renewable non-consumable plant extract. Rule of thumb: half an inch of this material is equivalent in thermal mass to approximately 12 inches of concrete when included in the walls of a structure.	http://www.phasechange.com/
Example: concrete free foundations using screw pile footing system manufactured in Melbourne. Lower environmental impact and cost to conventional concrete foundations.	http://www.surefootfootings.com.au/

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Case study: 8 Chifley Square, Sydney 40% reduction in embodied energy due to high recycled content cement and aggregate and high recycled content steel with offsite fabrication minimising waste. Design also includes features to enhance energy productivity during operational phase such as: trigen plant reusing waste heat; blackwater treatment plant treating sewage for reuse in cooling towers controlling a chilled beam ceiling system; and highly efficient lighting.	https://design100.com/SYD14/entry_details.asp?ID=12991
Sharma, B et al (2015) Engineered bamboo for structural applications. Construction and Building Materials. Volume 81, 15 April 2015, Pages 66–73 http://www.sciencedirect.com/science/article/pii/S0950061815001117 Researchers at MIT are looking to engineered bamboo to form a more structurally sound material which is CO2 free. Working with professionals from England and Canada, they have been working towards a new method of strengthening bamboo mostly by slicing stalk into smaller pieces and bonding it with wood composites ultimately forming a stronger more sturdier block of construction material.	Bhavna Sharma **bs521@cam.ac.uk** Department of Architecture, University of Cambridge, Cambridge, UK
Sabto, M. (2010) Australian Bamboo takes a Stand. CSIRO ECOS Fast growing demand in Asia for bamboo construction products creates opportunities for Australian farmers and local bamboo processing to create a local industry in Australia to export to Asia. Researchers have been funded in Australia to investigate this opportunity.	http://ecosmagazine.com/paper/EC156p22.htm
Hebel, D. (2014). Bamboo could turn the world's construction trade on its head. The Conversation. Extraction and combination of bamboo fibre with other materials to create a composite as an alternative to steel and timber.	https://theconversation.com/bamboo-could-turn-the-worlds-construction-trade-on-its-head-29685
Lower energy intensity manufacturing - cement	
UK Government (2015) – Cement Decarbonisation and Energy Efficiency Roadmap	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/416674/Cement_Report.pdf
US EPA – Cement Energy Savings Guide	https://www.energystar.gov/sites/default/files/buildings/tools/ENERGY%20STAR%20Guide%20for%20the%20Cement%20Industry%2028_08_2013%20Final.pdf
IEA – Cement Technology Roadmap	https://www.iea.org/publications/freepublications/publication/Cement.pdf
Berndt, M. L., Sanjayan, J., Foster, S., & Castel, A. (2013). Pathways for overcoming barriers to implementation of low CO2 concrete. CRC for low carbon living. Retrieved from http://researchbank.swin.edu.au/vital/access/manager/Repository/swin:37984 Analysis of and recommendations to overcome barriers to uptake of geopolymer concrete alternative to conventional concrete based on Portland cement.	Marita L. Berndt mberndt@swin.edu.au Centre for Sustainable Infrastructure, Faculty of Engineering and Industrial Sciences, Swinburne University of Technology, Australia

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Schneider, M., Romer, M., Tschudin, M., & Bolio, H. (2011). Sustainable cement production—present and future. *Cement and Concrete Research*, *41*(7), 642-650. Alternative fuel use and clinker substitution are key priorities in improving the sustainability of cement production.	M. Schneiger **sch@vdz-online.de** VDZ, Germany
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Osowiecki, W. (2015). Carbon ne.g.ative cement: turning a climate liability into an asset. Berkeley Energy & Resources Collaborative.	http://berc.berkeley.edu/carbon-ne.g.ative-cement-turning-climate-liability-asset/
Mathews, J. (2012). Eco-cement, the cheapest carbon sequestration on the planet. The Conversation. Cements using alternative materials that can be produced at much lower temperature and absorb CO2 as they set.	https://theconversation.com/eco-cement-the-cheapest-carbon-sequestration-on-the-planet-10978
Example: Fluidised bed advanced cement kiln system - demonstration stage technology to produce clinker using less energy than traditional rotary kilns.	http://ietd.iipnetwork.org/content/fluidized-bed-advanced-cement-kiln-system
Example: carbon dioxide mixed with lime to create a cement-like construction material using 3D printers	http://phys.org/news/2016-03-carbon-dioxide-sustainable-concrete.html
Important Commercial Innovation Case Studies	
Envisia, 2015. Breakthrough Technology In Concrete Mix Design, S.L.: Boral Concrete	http://www.boral.com.au/concrete/envisia-lower-carbon.asp?WT.mc_id=concrete-envisia-Home
Zeobond – Australian made geopolymer cement – 80% more energy efficient. Zeobond is based on 20 years of Melbourne University research – see below	http://www.zeobond.com/
Melbourne University Geopolymer Cement Research Group – 200 + publications available from http://chemeng.unimelb.edu.au/geopolymer/publications.html	

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Smith, M et al (2009) Eco-Cements – Factor 5 in Cement. CSIRO ECOS	http://www.ecosmagazine.com/?act=view_file&file_id=EC149p21.pdf
Lower energy intensity manufacturing - bricks	
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Example of low embodied energy bricks: Boral FireLight concrete bricks containing 75% ash from power generation and 5% recycled concrete.	http://www.boral.com.au/BuildSustainable/Residential/sustainable_living_solutions.asp
Case Study: Boral Midland Brick Plant Energy Saving Opportunities	http://www.boral.com.au/Images/common/pdfs/midland_energy_efficiency_opportunities.pdf
Case Study: Zero Carbon Bricks made in Tasmania – Astral Bricks	http://buildforliving.com.au/case-study/carbon-neutral-bricks/
Lower energy intensity manufacturing - traditional steel making	
UK Government – Iron and Steel – Energy Efficiency and Decarbonisation Pathways – (2015)	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/416667/Iron_and_Steel_Report.pdf
Worrell, E., Blinde., Neelis,M,,Blomen, E., and Masanet, E., (2010) Energy Efficiency Improvement and Cost Saving Opportunities for the U.S. Iron and Steel Industry An ENERGY STAR® Guide for Energy and Plant Managers. Energy Analysis Department Environmental Energy Technologies Division Ernest Orlando Lawrence Berkeley National Laboratory University of California. Sponsored by US EPA.	https://www.energystar.gov/ia/business/industry/Iron_Steel_Guide.pdf?25eb-abc5
CSIRO Steel Innovations: ● Using charcoal to replace a portion of the coal and coke used in steel making. ● Dry slag granulation - minimises the energy and water consumption associated with turning a waste product of the steelmaking process, slag, into a product that can be used to produce cement. Includes heat recovery process.	http://www.csiro.au/en/Research/MRF/Areas/Community-and-environment/Responsible-resource-development/Green-steelmaking and http://www.csiro.au/en/Research/MRF/Areas/Resourceful-magazine/Issue-07/green-steel
Benn, S., Giurco, D., Brown, P. J., & Agarwal, R. (2014). Towards responsible steel: preliminary insights. *Resources*, *3*(1), 275-290. Structures and processes underpinning the attempt of the Australian steel industry to establish a certification scheme for Responsible Steel.	suzanne.benn@uts.edu.au UTS Business School, University of Technology, Australia

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Emerging innovations in steel making	
Sadoway, D. R., 2014. A Technical Feasibility Study of Steelmaking by Molten Oxide Electrolysis, s.l.: Cambridge, Massachusetts Wang, D., Gmitter, A. J. & Sadoway, D. R., 2011. Production of Oxygen Gas and Liquid Metal by Electrochemical Decomposition of Molten Iron Oxide, s.l.: Journal of The Electrochemical Society Innovation in Molten oxide electrolysis Methods of Making Steel with Higher Energy Productivity - The Massachusetts Institute of Technology USA has been developing this approach. By using electric current, the direct conversion of iron oxide into pure liquid iron occurs with oxygen gas as the by-product. The MOE process emits no SOx, NOx or COx, and produces liquid metal of superior quality. It is estimated the energy efficiency gains this process offers at the industrial scale, are as high as 45% over the currently working highly efficient inte.g.rated steel plants. (Sadoway, 2014) A scale-up to an industrial prototype electrolysis cell is being pursued at Boston Electrometallurgical Corporation, the company recently received significant private funding to realize the scale-up goals	Donald R Sadoway dsadoway@mit.edu Department of Materials Science and Engineering, Massachusetts Institute of Technology, USA
Quader, M. A., Ahmed, S., Dawal, S. Z., & Nukman, Y. (2016). Present needs, recent progress and future trends of energy-efficient Ultra-Low Carbon Dioxide (CO 2) Steelmaking (ULCOS) program. *Renewable and Sustainable Energy Reviews*, *55*, 537-549.	M. Abdul Quader maquader.me@gmail.com Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, Malaysia
Ultra-Low CO2 Steelmaking (ULCOS): consortium of 48 European companies and organisations conducting cooperative research and development into reducing CO2 emissions from steel production.	http://www.ulcos.org/en/index.php
Top gas recycling blast furnace with CO2 CCS - separation of off gases so useful components can be recycled back into the furnace and used as a reducing agent	http://www.ulcos.org/en/research/blast_furnace.php
HIsarna smelter technology with CCS - uses a combination of three new ironmaking technologies: 1) coal preheating and partial pyrolysis in a reactor 2) melting cyclone for ore melting 3) smelter vessel for final ore reduction and iron production	http://www.ulcos.org/en/research/isarna.php
Example: HIsarna pilot plant furnace simplifies the blast furnace process by handling fine raw materials directly without the need for agglomeration or coking. Iron ore fines and coal are converted almost directly into liquid iron in a very energy efficient process.	http://www.tatasteeleurope.com/en/innovation/case-studies/hisarna-pilot-plant
Lower energy intensity manufacturing - other metals	
New electrolysis smelting process being investigated by MIT that could drive down processing costs and emissions.	https://www.australianmining.com.au/news/new-method-produce-metals-developed/
Design techniques	

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Jensen, K. (2015). Optimizing structure, an investigation into lightweight structures. University of Waterloo Thesis investigating geometric structures utilising tensile forces to allow construction of lightweight, low embodied energy buildings.	https://uwspace.uwaterloo.ca/handle/10012/9337
Basbagill, J., Flager, F., Lepech, M., & Fischer, M. (2013). Application of life-cycle assessment to early stage building design for reduced embodied environmental impacts. *Building and Environment*, *60*, 81-92. Buildings are analysed using sensitivity analysis and design software to see which design decisions determine embodied impact. Designers can receive feedback on environmental impacts of choices early in design process. Cladding decisions consistently contribute most to embodied impact.	J. Basbagill basbagil@stanford.edu Department of Civil and Environmental Engineering, Stanford University, USA
Building inte.g.rated energy generation	
Example: roofing tile with inte.g.rated solar PV and thermal hot water manufactured from high strength, light weight composite material. Significantly lower embodied energy than concrete and metal sheet roofing.	http://tractile.com.au/
Example: building inte.g.rated photovoltaic roofing system utilising thin film PV technology	david.nolan@bluescope.com BlueScope Australia and New Zealand
Utilisation of waste and by-products	
Pullen, S., Chiveralls, K., Zillante, G., Palmer, J., Wilson, L., & Zuo, J. (2012). *Minimising the impact of resource consumption in the design and construction of buildings*. Griffith University. Discussion of reuse and use of recycled and low embodied energy materials to reduce the impact of resource consumption related to buildings. Includes case studies.	stephen.pullen@unisa.edu.au School of Natural and Built Environments, Barbara Hardy Institute, University of South Australia, Australia
Fontana, A., O'kane, P., O'Connell, D., Sahajwalla, V., & Zaharia, M. (2012). Injection of recycled tyres in EAF steelmaking as a slag foaming agent. *Steel Times International*, *36*(6), 17. Polymer Injection Technology - developed by OneSteel and UNSW to reduce the energy intensity of steel making. End of life polymers, including tyres, are partially substituted for coke, which also improves slag foaming and hence furnace efficiency.	Scientia Professor Veena Sahajwalla **veena@unsw.edu.au** Centre for Sustainable Materials Research and Technology, University of NSW, Australia
Case study: Protype micro-recycling factory under development. The pilot plant is a low cost solution to transforming waste printed circuit boards into valuable alloys and simultaneously destroying toxins. The micro-smelters may be taken to waste sites, reducing costs, energy use and emissions associated with transporting waste to large industrial scale smelters. http://www.sustainabilitymatters.net.au/content/waste/news/mining-e-waste-for-valuable-metals-1094109873	Scientia Professor Veena Sahajwalla **veena@unsw.edu.au** Centre for Sustainable Materials Research and Technology, University of NSW, Australia
Wealth from waste - a three year research program that focuses on 'mining' above ground resources i.e. metals contained in collections of discarded manufactured products and consumer goods	http://wealthfromwaste.net/?page_id=71

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Heat recovery from energy intensive industrial processes such as cement, steel and glass production using organic rankine cycle (ORC) turbogenerator technology. Recovered heat used to generate electricity or for thermal heat purposes such as district heating or in other industrial processes	http://www.hreii.eu/demo/en/index.php http://www.tasio-h2020.eu/home
Example: Sydney building material waste facility which recycles 90% of waste stream	http://www.dadi.com.au/genesis-xero-waste-facility.html
Example: proposal to build a Energy from Waste plant in Sydney using technology used in Europe and the UK. The plant would generate electricity from burning construction waste unable to be recycled and that would otherwise be landfilled. Of the metal and ash left from the process, the metal can be recycled. The waste to power plant would produce less greenhouse gases than if the waste is buried in landfill.	http://www.tngnsw.com.au/project-details.html
Example: reuse of 90% of demolition material from landscape works on the South Olympic Park Landscape in London e.g. use of reclaimed aggre.g.ates to face reinforced retaining walls and bridge abutments.	http://www.arup.com/projects/london_2012_landscape_engineering_the_olympic_park
Example: low energy robotic waste separation. Operates 24/7 with up to 98% accuracy. Utilises smart, trainable software.	http://zenrobotics.com/
Example: use of waste wheat or rice straw fibres to produce formaldehyde-free wall and ceiling panels with excellent thermal and acoustic insulating properties.	http://www.ortech.com.au/durra-panel http://novofibre.com/products/NOVO-BASE.php
Innovative business models	
Example: prefabricated housing	http://www.habitechsystems.com.au/
Example: buildings prefabricated in factory and craned into position onsite	http://www.parkwoodhomes.com.au/
Example: prefabricated bathroom modules	http://www.bedrockoffsite.com/
Example: prefabricated housing and commercial buildings	http://modscape.com.au/
Case study: The Leadenhall Building, London. 85% of the building components made offsite, reducing construction time by 6 months. Multidimensional Building Information Modelling was utilised to inte.g.rate data from the architects and structural engineers to optimise the benefits of off-site manufacturing of this structurally complex 224 metre tall building.	http://www.laingorourke.com/our-projects/all-projects/the-leadenhall-building.aspx
prefabAUS: prefabricated building industry association	http://www.prefabaus.org.au/
Article on the emerging Australian prefabricated building industry based on interviews with participants at the 2016 prefabAUS industry conference. Article notes 80% of Swedish residential construction market is prefab.	http://www.thefifthestate.com.au/articles/prefabaus-conference-shows-industry-on-a-roll-2/85595

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Hager, I., Golonka, A., & Putanowicz, R. (2016). 3D printing of buildings and building components as the future of sustainable construction? *Procedia Engineering*, *151*, 292-299.	Izabela Hager ihager@pk.edu.pl Cracow University of Technology, Poland
Kreiger, M. A., MacAllister, B. A., Wilhoit, J. M., & Case, M. P. (2015). The current state of 3D printing for use in construction. In *The Proceedings of the 2015 Conference on Autonomous and Robotic Construction of Infrastructure. Ames. Iowa* (pp. 149-158).	Me.g.an.A.Kreiger@usace.army.mil Construction Engineering Research Laboratory U.S. Army Engineer R&D Center
3D printed house example: 3D print canal house in Amsterdam Each room is printed separately on site before being assembled into one house. Each room consists of several parts which are joined together as large Le.g.o-like blocks. Focused mainly on polymer-based structures. Experimenting with filling structure with lightweight foaming eco-concrete to provide structural and insulation properties. Project expected to be completed in 2017.	http://3dprintcanalhouse.com/
3D printed house example: a mix of cement and construction waste used as printing material. Pieces are printed in a factory then shipped to site and assembled.	http://www.yhbm.com/
CSIRO Lab 22: provides industry with access to metal additive manufacturing (3D printing) technologies, training and CSIRO expertise prior to making a decision to invest in these technologies.	http://www.csiro.au/en/Research/MF/Areas/Metals/Lab22
Sheperd, P. (2016) We could 3D print buildings using robots and drones - here's how. The Conversation. Retrieved from https://theconversation.com/we-could-3d-print-buildings-using-robots-and-drones-heres-how-54297 3D printing could be used in construction to produce complex shapes not achievable using traditional building techniques, and resulting in considerably less waste. Possible solution to issue of large size of building components is using robotic arm on rails or automated flying drones which can print in open air on-site.	Paul Sheperd p.shepherd@bath.ac.uk Department of Architecture and Civil Engineering, University of Bath, UK
Elfes, A. (2013) Why the Australian manufacturing industry needs the next generation of robots. The Conversation. Retrieved from https://theconversation.com/why-the-australian-manufacturing-industry-needs-the-next-generation-of-robots-11888 Next generation robots may enable cost competitive manufacturing in a high wage, aging workforce country such as Australia.	Alberto.Elfes@csiro.au Science leader for robotics, CSIRO
Data analytics	
Example: application of data analytics to building services data	http://www.buenosystems.com.au/wp-content/uploads/2015/07/airah-technical-paper-wurfel-2014-applying-data-science-to-property.pdf
Example: portable sensors used to optimise building HVAC performance using real time data.	http://huxconnect.com/
Example: resource efficiency program for large commercial buildings. Optimise water, energy and indoor environment quality.	https://www.buildingsalive.com/

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Example: IOT based building diagnostics system to lower energy use, increase building operations efficiency and improve comfort.	https://buildingiq.com/
Other organisations with interest in building energy-related innovation	
Building Research Establishment, UK	https://www.bre.co.uk/
Australian Supply Chain Sustainability School - forum to encourage sustainability in the Australian construction industry	http://www.supplychainschool.org.au/
Ecospecifier Global - certified and verified sustainable products, including building products	http://www.ecospecifier.com.au/