Flexible Delivery Flat-Pack Module

An Overview of Energy Efficiency Opportunities in Mechanical Engineering

Produced by

The University of Adelaide and Queensland University of Technology (The Natural Edge Project)

The EEERE Project:

Energy **E**fficiency **E**ducation **R**esources for **E**ngineering

Consortium Partners:

Queensland University of Technology
The University of Adelaide
Victoria University Melbourne Australia
RMIT University
University of Wollongong
La Trobe University Australia

Project Partners:

Engineers Australia
aced
Australasian Association for Engineering Education
energy efficiency council
asbec Australian Sustainable Built Environment Council

Funded and Advised by:

Australian Government
Department of Industry

Citation Details

All resources developed for the EEERE project are made available to the public through the Creative Commons Attributes licence. Accordingly, this document should be cited in the following manner:

Hargroves, K., Gockowiak, K., Wilson, K., Lawry, N., and Desha, C. (2014) *An Overview of Energy Efficiency Opportunities in Mechanical Engineering*, The University of Adelaide and Queensland University of Technology (The Natural Edge Project), commissioned by the Australian Government Department of Industry, Canberra.

Acknowledgements

The team from Adelaide University and QUT that developed this document acknowledge the work of our colleagues at QUT David Sparks, Fiona McKeague, and Cheryl Desha who we supported to develop the accompanying video resources, along with the partners involved. The consortium thanks the 40 workshop participants (Brisbane, Sydney and Melbourne) including stakeholder partners, Engineers Australia College Members, industry and academic colleagues, who provided their time and ideas so generously during the stakeholder engagement parts of the project, and to those who have assisted in reviewing the drafted resources, in particular Alan Pears, energy efficiency expert, and Dr Cristian Birzer, University of Adelaide. We would like to thank the students at the University of Adelaide who provided review comments on the lecture and the accompanying video resource. The consortium thanks our project partners for their continued commitment to building capacity in delivering sustainable solutions, and the federal government for funding the initiative, in particular Mr Stuart Richardson, Mr Luiz Ribeiro, Ms Denise Caddy and Mr Nick Jackson, for their contribution to engineering capacity building. Material contained in this document includes content drawn from The Natural Edge Project (TNEP) Sustainable Energy Solutions Program and is adapted herein as per licencing agreements with CSIRO and Griffith University.

Project Background

Energy efficiency is widely recognised as the simplest and most cost-effective way to manage rising energy costs and reduce Australia's greenhouse gas emissions. Promoting and implementing energy efficiency measures across multiple sectors requires significant development and advancement of the knowledge and skills base in Australia, and around the world. Engineering has been specifically identified as a profession with opportunities to make substantial contributions to a clean and energy-efficient future. To further enable skills development in this field, the Department of Industry commissioned a consortium of Australian universities to collaboratively develop four innovative and highly targeted resources on energy efficiency assessments, for use within engineering curricula. These include the following resources informed by national stakeholder engagement workshops coordinated by RMIT:

1. *Ten **'flat-pack'** supporting teaching and learning notes for each of the key disciplines of engineering (University of Adelaide and Queensland University of Technology);*
2. *Ten short **'multi-media bite'** videos to compliment the flat-packs (Queensland University of Technology and the University of Adelaide);*
3. *Two **'deep-dive case studies'** including worked calculations (University of Wollongong); and*
4. *A '**virtual reality experience'** in an energy efficiency assessment (Victoria and LaTrobe Universities).*

These resources have been developed with reference to a 2012 investigation into engineering education[1] funded by the Australian Government's former Department of Resources, Energy and Tourism (RET), and through further consultation workshops with project partners and industry stakeholders. At these workshops, participants confirmed the need for urgent capacity building in energy efficiency assessments, accompanied by clear guidance for any resources developed, to readily incorporate them into existing courses and programs. Industry also confirmed three key graduate attributes of priority focus for these education resources, comprising the ability to: think in systems; communicate between and beyond engineering disciplines; and develop and communication the business case for energy efficiency opportunities.

Content

1. ‘Allen Key’ Learning Points (Following the Multi-Media Bite)

Mechanical Engineers will be a key part of the World’s response to climate change, from design of energy generation and distribution systems that use distributed renewable energy options to the optimisation and management of manufacturing systems to use significantly less energy. Mechanical Engineers have critical skills the economy needs to thrive in a carbon constrained future. The following learning points provide a summary of the Mechanical Engineering video – our ‘Allen keys’ to building the flat-pack content!

Watch the ‘***Mechanical Engineering***’ MMB

1. Mechanical Engineers can play a significant role in driving energy efficiency and can draw on a wide range of skills to improve energy efficiency in designing, manufacturing, installing, operating, maintaining, and decommissioning numerous types of equipment that use energy.
2. Mechanical Engineers provide a range of services to industry such as providing steam to industrial processes, producing and delivering electrical power, providing refrigeration, heating, ventilation and air-conditioning, along with creating demand for energy by moving fluids around systems that use pumps and fans.
3. Mechanical Engineers stand to gain from working closely with other engineering disciplines and professions to identify and implement energy efficiency improvements, particularly related to electronics, chemical processes, and structural issues. Hence engineers of all disciplines will need good communication skills in order to integrate the significant potential for energy saving opportunities that come from working with other disciplines, stakeholders, and project members.
4. Drivers for the energy management programs in industry beyond enhancing profits include: providing companies with a competitive edge; assisting efforts to become market leaders; and supporting companies to be good corporate citizens. Energy efficiency not only delivers direct cost savings through reduced energy demand but in many cases reduces utilisation of plant and equipment, resulting in reduced fossil fuel consumption and associated greenhouse gas emissions.
5. Given the rising costs of electricity and the concerns related to greenhouse gas emissions, reducing demand for electricity is of primary concern in many industrial and manufacturing plants in Australia. Reducing peak energy demand is also of increasing significance as due to its high cost to generate electricity suppliers reduce this cost by adjusting tariffs and contracts to transfer their costs to consumers that are adding to peak demand.
6. The process to analyse energy data to identify potential energy efficiency opportunities can be undertaken in a number of ways, including considering total energy use, energy demand over time, comparing energy performance to production indicators, benchmarking against other sites or processes, and developing an energy-mass balance.
7. Carlton and United Breweries is an example of what is possible. The company undertook a refrigeration optimisation that involved the modelling of the entire pumping system in order to identify wasted energy. The result of the modelling was an estimated saving of $140,000 per year based on an investment of $2 million dollars. In practice the energy efficiency measures delivered unexpected flow-on and indirect benefits and the program now saves in the order of $500,000 per year, more than three times the savings anticipated, and has reduced the refrigeration load from some 60% of the electricity bill down to 23%.

2. Energy Efficiency and Mechanical Engineering

2.1. Why is Energy Efficiency important for Engineers?

In the 21st Century much of the world will experience untold wealth and prosperity that could not even be conceived only a century ago.[2] However as with most, if not all, of the human civilisations, increases in prosperity and population have accumulated significant environmental impacts that threaten to result in what Lester Brown refers to as '*environmentally-induced economic decline*'.[3] There have been a number of significant advances in technology over the last 300 years that have delivered a step changes in the way industry and society has operated, as shown in Figure 1. Given the now advanced level of technological development we are in a very strong position to harness this technology to create a '6th Wave' that can deliver significant reductions in a range of environmental pressures, such as air pollution, solid waste, water extraction, biodiversity loss and greenhouse gas emissions.[4]

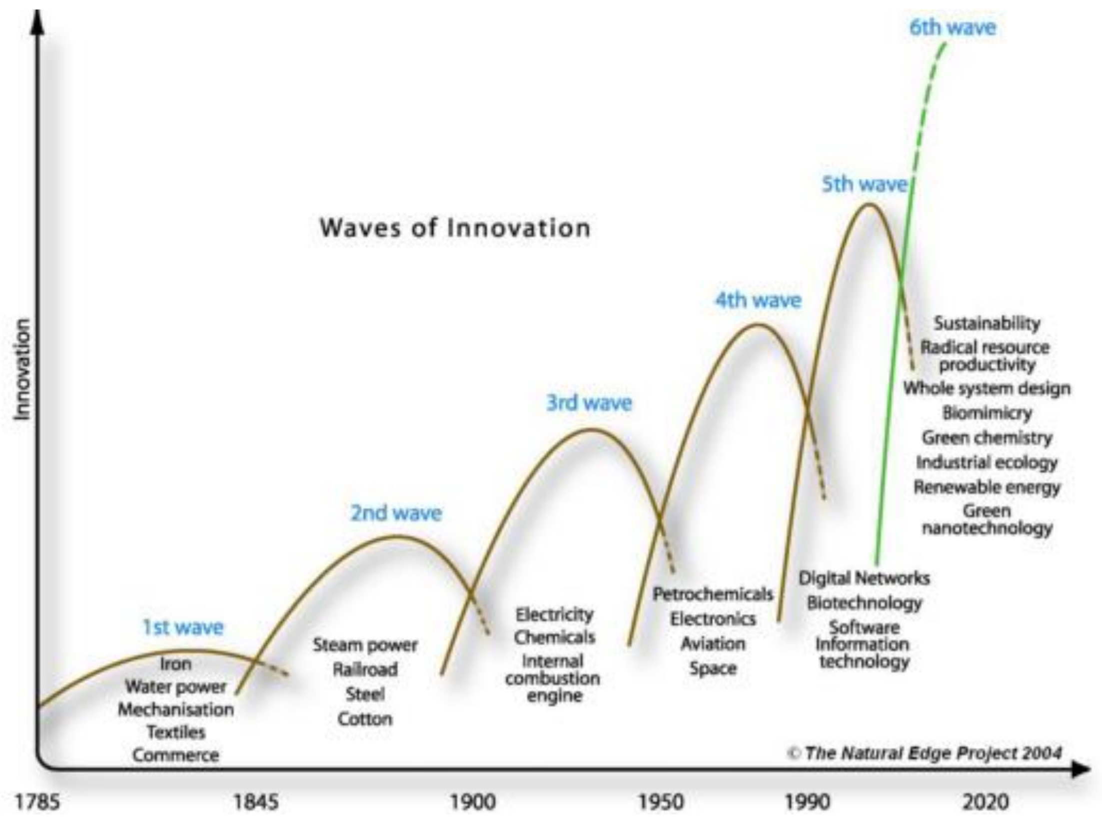


Figure 1: A stylistic representation of waves of innovation since the Industrial revolution[5]

What this means is that over the coming decades the impact we are having on the environment will have a direct negative effect on our economies and societies, this will, and is, lead to louder and lauder calls to reduce negative impacts on the environment which will need innovation and creativity. In particular there is a fundamental need to shift from fossil fuel based energy to low/no carbon energy sources, preferably renewable options, in order to significantly reduce greenhouse gas emissions. Building on the technologies and processes from the previous waves of innovation engineers are now in a strong position to deliver such a shift and create a range of innovative and creative solutions to the meet the needs of society, with a key part of this achieving greater efficiency of the use of resources and energy.

According to the World Business Council for Sustainable Development (WBCSD) in their 1992 publication 'Changing Course', the term 'efficiency' was used to seek to encapsulate the idea of using fewer resources and creating less waste and pollution while providing the same or better services, and entailed the following elements:

- A reduction in the material intensity of goods or services,
- A reduction in the energy intensity of goods or services,
- Reduced dispersion of toxic materials,
- Improved recyclability,
- Maximum use of renewable resources,
- Increased durability of products, and
- Greater service intensity of goods and services.

Each of these approaches provides valuable tools to reduce a range of environmental pressures, especially greenhouse gas emissions.

Identify a Mechanical Engineering example of the application of each element.

For each element identify the potential for collaboration with other engineers.

Since the late 1990's Engineers Australia has advocated for Engineers to play a key role in supporting the achievement of such ambitious targets, and cautions that, '*The need to make changes in the way energy is used and supplied throughout the world represents the greatest challenge to Engineers in moving toward sustainability.'*[6] By the end of 2014 this shift had built significant momentum with the European Union committing to reduce emissions by at least 40 per cent by 2030 (compared to 1990 levels), China setting the goal of 40 to 45 per cent by 2020 (compared to 2005 levels), India setting the goal of 20-25 per cent by 2020 (compared to 2005 levels), and the United States of America setting the goal of 26-28 per cent by 2025 (compared to 2005 levels). Further the Intergovernmental Panel on Climate Change (IPCC) reports that all nations will need to achieve significant reductions in greenhouse gas emissions in the order of 60-80 per cent by 2050.[7]

> ***These ambitious targets will create significant pressure to reduce emissions in the coming decades, in particular between 2015 and 2030; and all industries grapple with the challenge of reducing greenhouse gas emissions in a manner that delivers ongoing prosperity, jobs, and profits.***

A key part of this energy transition is to swiftly reduce the growing demand for energy across society as this will generate numerous cost savings that can be invested in the shift to low/no carbon energy, along with reducing demand levels that need to be met by the new energy solutions. Reducing the energy demand say of a building or a processing plant delivers the following benefits:

- *Generates cost savings* by reducing the energy charges, extending the life of equipment by reducing the loading, reducing operating times and levels of equipment and even allowing decommissioning of some equipment, and often reduces heat generated from equipment or lighting that adds load to the HVAC system.
- *Creates capital for investment* in the transition to the use of low/no carbon energy, often by investing in onsite renewable energy generation options that can harness waste heat from the existing system while providing security of supply for the operation of the building or plant.

- *Creates demand for new products and services* that will be needed around the world to assist industries and economies to reduce energy demand. This will translate into significant opportunities for Australian engineering firms that can innovate low/no carbon solutions ahead of international competition.[8]

Energy efficiency as a concept has gained significant attention over the last few decades, as governments and industries around the world have grappled with issues such as rapidly expanding needs for energy, the cost of supplying infrastructure to meet peak demand, the finite nature of fossil based energy reserves, and transition timeframes for expanding renewable energy supplies. Coupled with a growing number of cases of companies achieving significant fossil fuel consumption reductions in a timely and cost effective manner, energy efficiency is quickly becoming a core part of the practice of Engineers, as shown in Table 1.

Where can Mechanical Engineers reduce greenhouse gas emissions?

How could energy efficiency provide benefits to a Mechanical Engineering firm?

Table 1: *Example opportunities to significantly reduce greenhouse gas emissions*

Sector	Best Practice Case Studies
Steel Industry[9]	Leading US steel company, Nucor Steel, is around 70% more energy efficient than many steel companies around the world,[10] using state-of-the-art electric arc furnace systems, adopting leading practices such as net shape casting, and by implementing options such as energy monitoring, systems for energy recovery and distribution between processes.[11]
Cement Industry[12]	Ordinary Portland cement manufacture is responsible for between 6-8% of global greenhouse emissions and this is rising with demand. The good news is that an Australian company Zeobond Pty Ltd, based in Melbourne, is now making geo-polymer cement which reduces energy usage and greenhouse gas emissions by over 80%.[13] Geo-polymers can be used for most major purposes for which Portland cement is currently used.[14]
Paper and Pulp Industry[15]	Catalyst Paper International improved their energy efficiency by 20% across all operations since 1990, saving the company close to US$26 million between 1994 and 2004. At the same time, they've reduced their greenhouse gas emissions by 69% through greater use of biomass and sourcing electricity from hydro power.[16] The pulp and paper sector has the potential in both existing and new mills to become renewable electricity power generators through the use of Black Liquor Gasification-Combined Cycle technologies.[17]
Transport Vehicle Efficiency[18]	Integrating technical advances in light-weighting, hybrid electric engines, batteries, regenerative breaking and aerodynamics is enabling numerous automotive and transport vehicle companies to redesign cars, motorbikes, trucks, trains, ships and aeroplanes to be significantly (50-80%) more fuel efficient than standard internal combustion vehicles. Plug-in vehicle technologies are opening up the potential for all transportation vehicles to be run on batteries charged by renewable energy.[19]
Transport Efficiency from Modal shifts. (Passenger)[20]	Shifting transport modes can also lead to significant energy efficiency gains. One bus with 25 passengers reduces energy and greenhouse gas emissions per capita by approximately 86% per kilometre compared to 25 single occupant vehicles (SOV).[21] Trains are even more efficient. Typically, rail systems in European cities are 7 times more energy-efficient than car travel in US cities.[22]
Transport Efficiency from Modal Shifts (Freight)[23]	Shifting freight transport from trucks to rail can also lead to large efficiency gains of between 75 and 85%.[24] Several countries are moving to improve the efficiency of their transport sectors by making large investments in rail freight infrastructure, including improving the modal interfaces. For instance, China has invested US$292 billion to improve and extend its rail network from 78,000 km in 2007, to over 120,000km by 2020, much of which will be dedicated to freight.

Source: Based on von Weizsäcker, Hargroves, K. *et al* (2009)[25] as presented in Hargroves, K., and Desha, C. (2014)[26]

Considering Buildings, efficiency expert Joseph Romm explains that key to delivering improved energy efficiency of buildings is the understanding that the design phase is critical, pointing out that, '*Although up-front building and design costs may represent only a fraction of the building's life-cycle costs, when just 1 per cent of a project's up-front costs are spent, up to 70 per cent of its life-cycle costs may already be committed*'.[27] As pointed out in the book '*Whole System Design: An Integrated Approach to Sustainable Engineering*',[28] the cost of design changes increases significantly through the design and construction process, and as such it is important that early in the concept design phase opportunities for energy efficiency are identified and incorporated into the design rather than retrofitted at a later date, especially as buildings and civil infrastructure are designed with an operational life of some 50-100 years.[29]

A key part of the design is to consider the potential for compounding energy efficiency savings. Energy efficiency expert Alan Pears uses the example of an electric motor driving a pump that circulates a liquid around an industrial site.[30] If each element in the chain is improved in efficiency by 10 percent, the overall efficiency is not improved by 10 per cent but rather 47 per cent as the overall efficiency is the product of the component efficiencies: 0.9 x 0.9 x 0.9 x 0.9 x 0.9 x 0.9 = 0.53. Applying this systems approach can deliver significant energy demand savings, such as: [31]

- By focusing first on reducing both the mass of a passenger vehicle and the aerodynamic drag by 50% this can reduce rolling resistance by 65%; making a fuel cell propulsion system viable and cost effective, and delivering significantly better fuel consumption per kilometre.
- By using the right-sized energy efficient components to reduce generated heat, a computer server can be designed to have 60% less mass and use 84% less power than the equivalent server, which would reduce cooling load in a data centre by 63%.

A key outcome of a focus on energy efficiency is that it often also delivers multiple benefits across the system can be often overlooked. For example energy efficient cleaning systems may use less water and detergents, light-weighting vehicles to improve fuel efficiency may reduce material consumption, reducing cooling loads in a building through external shading may extend the operating life of air-conditioning equipment, reducing pumping loads in a system may lead to decommissioning of unneeded pumps, reducing residential energy demand during peak times can significantly reduce overall capacity requirements and defer infrastructure upgrades.

2.2. Why is Energy Efficiency important for Engineering Students?

In 2006 the Australian Government created the Energy Efficiency Opportunities (EEO) Act with the objective to '*improve the identification, evaluation, and public reporting of energy efficiency opportunities by large energy-using businesses, to increase the uptake of cost effective energy efficiency opportunities*'.

Watch an Introduction to the EEO Program

The EEO Act was applicable to corporations that used over 0.5 petajoules of energy per year; this represented some 300 companies and just over half of Australia's total energy use. Participating companies were required to undertake an energy efficiency assessment and report to the government on the findings.

Between 2006 and June 2011 participants in the program identified the potential for annual energy savings of 164.2 PJ through a focus on energy efficiency across each major sector, as shown in Figure 2. As part of the program 89 PJ of energy was saved, the equivalent of 24 billion kWh's per year.

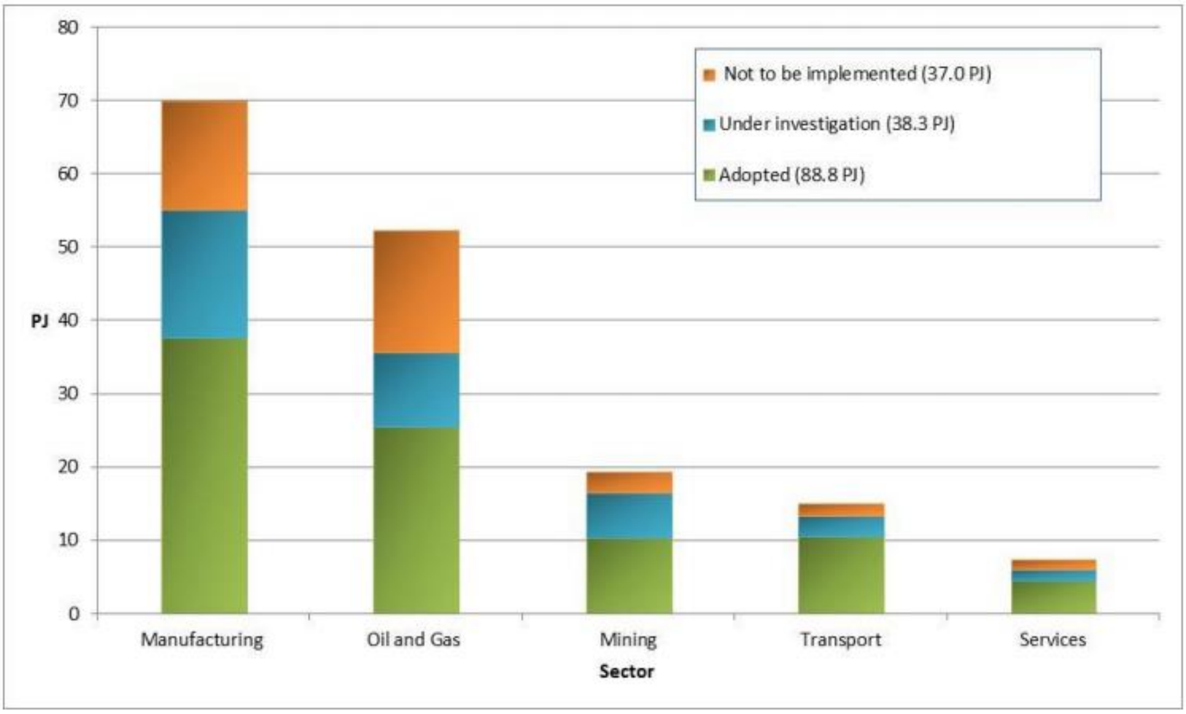


Figure 2: Summary of energy efficiency achievements in by participants in the Australian Government Energy Efficiency Opportunities (EEO) program (2006-11)[32]

This energy saving is estimated to have resulted in an annual economic benefit of just over $800 million, with the majority of investments to achieve the energy savings having either a 1 year or 2 year return on investment.[33] The significance of this program for engineering students is that the largest energy using companies in the country have developed processes to undertaken energy efficiency assessments and the ability to contribute to such assessments is likely to become a part of graduate recruitment preferences given the strong economic results from the EEO program.

> ***In 2011 an investigation found that 6 out of the 10 largest engineering companies operating in Australia provided in-house training on energy efficiency to supplement graduates formal training, and 4 out of the 10 had included energy efficiency requirements in graduate recruitment criteria.***[34]

Of further interest to engineering students is that the participants in the program listed an aggregate of 38.3 PJ of energy saving opportunities (or some 10 billion KWh per year) as being 'under investigation', meaning that graduates can differentiate themselves by ensuring they are well versed in energy efficiency.

List a specific opportunity for mechanical engineers to achieve energy efficiency improvements in each of the sectors involved in the EEO Program (Figure 1).

2.3. Key Knowledge and Skills for Mechanical Engineers

According to the American Society of Mechanical Engineers 'sustainability' means '*engineering products and developing manufacturing processes that do not consume irreplaceable resources*'.[35] In Mechanical Engineering energy efficiency improvements provide an immediate option to swiftly reduce energy demands, and hence will play a vital role in helping meet future sustainability and emissions reduction goals. This presents a range of new opportunities for Mechanical Engineers in energy related areas such as:

– Machinery,
– Mechanical and mechatronic systems,
– Automated systems and robotic devices,
– Heat transfer processes,
– Thermodynamic and combustion systems,
– Fluid and thermal energy systems,
– Materials and materials handling systems,
– Manufacturing equipment, and
– Process plant.

As an indication of the knowledge and skills being recognised by the international Mechanical Engineering community in the area of sustainability and energy, at the American Society of Mechanical Engineers '*5th International Conference on Energy Sustainability*' in 2011, organisers listed the following themes for the call for papers, each highlighting opportunities for Mechanical Engineers:

– Alternate energy,
– Fuels and infrastructure,
– Energy systems design,
– Thermo-economic analysis,
– Micro and nano-technologies,
– Renewable energy,
– Combined energy cycles,
– Transportation,
– Solar heating and cooling, and
– Smart grid and energy storage.[36]

Here we use the example graduate attribute "*Ability to Participate in/Contribute to Energy Efficiency Assessments*" to demonstrate potential specific areas of knowledge and skills that could be developed related to energy efficiency. Discipline-specific considerations in Mechanical Engineering for this graduate attribute could include:

– Developing new manufacturing techniques that optimise energy efficiency,
– Improving energy input/output of electrical power plant (energy required to build and operate the plant vs. energy the plant produces),

- Analysing and changing the lifecycle of a product, and
- Suggesting improved business practices for transport of materials.
- Proficiency in calculating energy consumption in materials processing, including production, use, and disposal phases, and
- Ability to identify energy efficiency opportunities in the areas of design and optimisation of materials and manufacturing systems.

There are a number of complementary areas of knowledge and skills for Mechanical Engineering such as data collection and analysis; benchmarking; development of mathematical models of energy and mass flows through processes and systems; identification and quantification of pathways of energy waste; financial analysis of energy efficiency options; using above tools to determine and compare methods of reducing energy waste, prepare business cases and strategies.

Research commissioned by the Department of Resources, Energy and Tourism, and undertaken in collaboration with Engineers Australia in 2011 identified two key energy efficiency knowledge and skill areas for Mechanical Engineering education to prioritise, namely:[37]

- Knowledge of clean energy technologies that build on fundamental knowledge, for example including solar thermal and geothermal, and
- Proficiency in calculating energy consumption in materials processing, including production, use, and disposal phases.

With this in mind, the following sections highlight examples of energy efficiency innovation in Mechanical Engineering, in key areas where graduates are likely to be asked to practice.

3. Energy Efficiency Opportunities in Mechanical Engineering

Here we provide a summary of key materials outlining energy efficiency opportunities related to Mechanical Engineering. This section informs ***'Tutorial Exercise 6: Identify examples of energy efficiency opportunities in particular engineering disciplines'*** *from the Introductory Flat-Pack.*

3.1. Heating, Ventilation and Air-Conditioning (HVAC)[i]

A whole system approach can help to identify potential energy efficiency opportunities in existing and new HVAC systems. The first step in identifying energy efficiency opportunities is to ask what will be the heating and cooling load required. There are a range of factors that influence the load on a HVAC system. Reducing the load can reduce the size of the HVAC system required and thus the energy used, equipment costs, and maintenance costs. A number of load management techniques can be used including: reducing external environmental impacts on internal temperatures through design, layout and operation of a building;[38] reducing the heat generated internally by lighting, equipment, and people;[39] adjusting the temperature settings of the HVAC system by 10-15%, harnessing opportunities for natural ventilation reduces,[40] cleaning fans, filters, and air ducts can improve efficiency by up to 60 percent,[41] appropriate location and size of HVAC equipment,[42] and managing operating times and level of operation using control systems.

When considering the selection of new HVAC systems, once the load to deliver the required climate control has been reduced as above it is important to select the most energy efficient type within budgetary constraints. The energy efficiency of HVAC units varies greatly, with high efficiency units being as much as 30 per cent more efficient than standard efficiency units. Energy efficient units differ from standard efficiency units in several ways: they typically incorporate larger condenser and evaporator coils, use more efficient compressors, and have enhanced insulation.[43] When considering the ducting system for a new HVAC unit or set of units there are a few key factors that can have a sizable impact on the energy demand of the overall system. For instance increasing the duct size by 15 per cent is likely to increase the duct cost by 15 per cent but can reduce the friction rate by as much as 50 percent. Also the design of the ducting layout can affect pressure losses and increase the load on the HVAC unit. As shown in Figure 2 the poor design of a 90 degree elbow can result in some 13 times the pressure drop. In general ducting system design should favour straight round spiral ducts.[44]

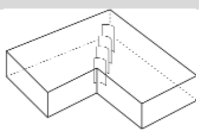
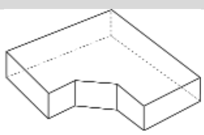
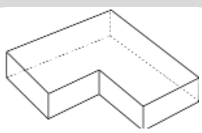
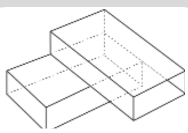
Relative pressure loss for various elbow design			
Best	*Good*	*Fair*	*Worst*
 x 1.0	 x 1.3	 x 4.7	 x 13.0

Figure 2: Comparing pressure drop across various square elbow designs[45]

Commissioning and adequate staff training are vital to ensure that building services and fabric

[i] The following is an edited extract from Smith, M., Hargroves, K., Stasinopoulos, P., Stephens, R., Desha, C., and Hargroves, S. (2007) *Engineering Sustainable Solutions Program: Sustainable Energy Solutions Portfolio*, The Natural Edge Project, Lecture 2.3.

operate as intended by the design team. Commissioning is a quality assurance process that ensures HVAC systems operate as energy efficiently as intended. Commissioning is integrated into the entire development process – design, construction, testing, post-occupancy and handover.[46] The post-occupancy commissioning phase provides an opportunity to test and adjust the HVAC system over a range of operating loads, especially the most common load for the building.

Once the building has been built and the HVAC system has been installed and properly commissioned, ongoing monitoring and maintenance are key steps to further fine turning energy savings and ensuring that the system is running as well as possible. Thorough maintenance procedures assist in maintaining HVAC system energy efficiency, maintaining occupant comfort, maximising equipment life and minimising component failure.

Identify 3 Australian case studies where the design of the HVAC has led to reduced energy demand and explain the main mechanisms used.

3.2. Boilers and Steam Distribution Systems[ii]

There is great potential for Mechanical Engineers to increase the energy efficiency of boilers and steam distribution systems resulting in lower energy demand. The basic function in any boiler is to burn fuel and use the heat to boil water and make steam. On an average industrial site, boilers can account for 20-60 per cent of energy costs.[47] The main benefits of supplying heat through steam are that: a) steam stores a relatively high amount of heat per unit of mass transported to loads, and b) steam transfers heat at a constant temperature for a given pressure as during the phase change from vapour to liquid, large amounts of heat are released from latent heat at a constant temperature. On an average industrial site, steam can account for as much as a third of all potential energy efficiency improvements.[48] There are numerous ways to increase the energy efficiency of boilers and steam distribution systems, such as:

- *Tube fouling*: Fire-side fouling occurs when soot accumulates on the fire side of the tubes. Water-side fouling occurs when chemical compounds in the water accumulate on the water side of the tubes (called scaling).[49] Accumulated solids act as insulation and prevent heat transfer between the fire and water in the pipe. Soot is removed relatively easily by simple brushing using a low- or high-pressure soot blower[50] and vacuum cleaner.[51] Removing scale is more difficult and is usually by mechanical means, acid cleaning or water treatment.[52]
- *Combustion efficiency*: Combustion efficiency is maximised by optimising excess air and developing combustion uniformity. Both too little53 and too much[54] excess air affects boiler energy efficiency and levels of pollution emissions. Complete and uniform combustion[55] requires a uniform fuel-air mixture and, in multi-burner boilers, having all burners functioning effectively. Analysers and 'oxygen trim' control systems assist in optimising excess air and developing a uniform fuel-air mixture.
- *Leaks*: Heat losses occur rapidly through air leaks. Air leaks also interfere with combustion analyser readings and control system calculations, and hence may encourage inappropriate

[ii] The following is an edited extract from Smith, M., Hargroves, K., Stasinopoulos, P., Stephens, R., Desha, C., and Hargroves, S. (2007) *Engineering Sustainable Solutions Program: Sustainable Energy Solutions Portfolio*, The Natural Edge Project, Lecture 3.2.

corrective action that can reduce energy efficiency. Air leaks in the boiler are identified using smoke sticks, butane flames or ultrasonic probes.[56] Steam leaks occur through faulty valves, joints, steam traps,[57] pipes and flexible hoses[58] and can result in substantial reduction in energy efficiency and increase in cost. According to Sustainability Victoria, '*a 1 mm diameter hole on a steam line at 700 kPa will result in an annual energy loss equivalent to 166 GJ (about AU$700) of natural gas per year*'.[59]

Further to technical options as mentioned above a load management strategy for bringing online and taking offline the right-sized boilers to match the required loads can greatly increase energy efficiency. Most boilers have peak efficiency somewhere between 60 and 90 per cent of load.[60] Boilers with large standby losses, for reasons such as insufficient insulation, will lose about the same amount of heat regardless of load and thus are more efficient at high loads. Boilers with small radiation heat losses are more efficient at lower loads. Favouring the most efficient boilers assists in maximising energy efficiency, and control technologies assist effective load management.[61] Intelligent control technologies can be used to automatically select the boiler and adjust the fuel feed to match the load. Simpler technologies such as shutdown timers can be used to take offline the boilers that become unloaded.

Identify 3 Australian case studies where the design of the Boiler System has led to reduced energy demand and explain the main mechanisms used.

3.3. Electric Motor Systems[iii]

Electric motors convert electrical power into mechanical rotational power. In most industrial applications, electric motors are used to move fluid by driving a pump, fan, or compressor, or to drive a conveyor. A motor system incorporates an electric motor, a power control system, a driven system, power transmission system and, where fluid is moved, a fluid distribution system. The energy efficiency of the motor system is determined by the efficiency of these components plus the design quality, the installation quality and the maintenance quality.[62]

In 2003 it was estimated that in Australia, every one per cent improvement in motor system efficiency avoided the use of about 400,000 MWh of electricity – the equivalent reduction in greenhouse gas emissions of taking 9,000 cars off the road.[63] This is significant as estimates indicate that, in many processes, electric motor system energy efficiency improvements of 30-60 per cent can be achieved through options such as using premium efficiency motors and better load management.[64] Premium efficiency motors are 2-10 per cent more efficient than standard efficiency motors[65] and given the 10-25 year design life,[66] premium efficiency motors are far more economical than standard efficiency motors over the long term despite the higher upfront costs. In addition, matching motor system sizes and operating speeds to loads can significantly reduce energy consumption, as motor energy consumption increases with the cube of operating speed.[67] Control systems can be used to efficiently adjust the motor speed and torque to match the load. Typical motor-driven systems include pumps, fans, compressors and conveyors. Simply load-matching a driven system can improve its operating efficiency by up to 50 per cent.[68]

[iii] The following is an edited extract from Smith, M., Hargroves, K., Stasinopoulos, P., Stephens, R., Desha, C., and Hargroves, S. (2007) *Engineering Sustainable Solutions Program: Sustainable Energy Solutions Portfolio*, The Natural Edge Project, Lecture 3.1.

It is important to note that efficiency improvements in parts of a system amass to an improvement greater than the sum of the individual improvements. In the case of a motor system, energy transfer through the component systems are in series, upstream to downstream. That is, energy is transferred from the electricity source to 1) the electrical power transmission system, 2) the power control system, 3) the electric motor, 4) the mechanical power transmission system, 5) the driven system, 6) the fluid distribution system, and finally 7) to the end-use. Reducing end-use load by 5 per cent will also reduce the load on every component system upstream (the whole motor system) by 5 percent.

Also, improving the efficiency of the fluid distribution system by 5 per cent will not affect the downstream end-use load, but will reduce the load on every component system upstream by a further 5 per cent. Continuing efficiency improvements upstream, each increment compounds with the previous increments. The result is that instead of consuming 95 per cent of the energy that a standard motor system would consume, the efficient motor system (with six efficient component subsystems in series) consumes only 74 per cent of the energy. Energy efficiency can be achieved in a range of ways including: motor design (minimising power transmission losses), load management (balancing motor output to requirements), load matching (matching the motor size and speed to the load), control systems (efficiently adjust the motor speed and torque to match changing loads). Further power losses can be reduced by ensuring adequately sized wires into the motor, and effective mechanical coupling to transfer the torque out of the motor to the system (ideally direct drive or gears and chains).

Identify 3 Australian case studies where the design of the Motor System has led to reduced energy demand and explain the main mechanisms used.

4. Case Studies of Mechanical Engineering and Energy Efficiency

Building on the multi-media bite on Mechanical Engineering and energy efficiency the following two examples of provide further details on the energy efficiency improvements related to Mechanical Engineering. This section is also designed to inform ***'Tutorial Exercise 7: Review industry case studies for areas of energy efficiency opportunities'*** *from the Introductory Flat-Pack.*

4.1. Carlton & United Brewery, Yatala, Queensland

The Carlton & United Breweries (CUB) facility in Yatala, Queensland, is its third largest brewery in Australia and produces 2.5 billion litres of beer each year for local sale and export. The brewery has recently been recognised as an industry leader in sustainability by being awarded the 2014 Business Eco-efficiency Award by the Queensland Government.[69] A key part of leadership comes from demonstrated improvements in energy efficiency. The upgrade in control systems and installation of more efficient equipment has resulted in a level of production efficiency that exceeds global best practice.

The Challenge

The equipment needed to make beer requires cooling, including piping, tanks, and equipment. The electricity demand for the current cooling system accounts for up to 60% of the plant's total electrical consumption. The existing system comprises of two 'ammonia-to-brine' heat exchangers that use a coolant fluid of a solution of ethyl alcohol and water, referred to as 'Brine'. The brine cooling plant was installed in 1994/1995 and provides sufficient cooling capacity for current production levels. The current microprocessor control system is resulting in fluctuating brine temperatures. The control system adjusts ammonia output while all other condenser fans, chillers, and pumps run at full capacity. A team of refrigeration consultants with long-term experience at the plant, in co-operation with onsite staff, were engaged to reduce the energy demand of this system.

What alternatives are there for providing cooling to the beer making process that require less energy consumption than 'Ammonia-to-Brine' systems?

The Solutions

Asking "*where could energy savings be found*?" the team undertook a system based approach to create an integrated control system with upgrades to plant equipment to yield considerable improvements in efficiency. The key elements of the system include:

- *Technology Upgrades*: The ammonia-brine heat exchangers were upgraded to more efficient welded-plate variations and variable speed drives were installed on the pumps and compressors to allow for matching of cooling demand rather than running them at full capacity all the time.
- *Sensors and Monitoring*: An extensive system of sensors was installed to measure the brine temperature and the temperature of the equipment to control of the variable speed drives installed on the pumps and compressors. This allowed for each piece of equipment to run according to load requirements, ensuring the most efficient operation. After a prolonged period of monitoring and testing, the software was updated to deal better with real life conditions and further benefits were gained.

- *Reviewing Practices*: Working closely with brewery staff, peak chiller demand was reduced and other inefficiencies identified and reduced through an improvement to production practices.

The upgrades to the system reduced the number of brine pumps in operation from 15 down to 8, and at low chiller loads the improvements allow for only 4 of the pumps to be in use. Expected savings of over US$100,000 per annum highlight the financial benefits that result from energy efficiency measures.

Key Lessons

The upgrades to the Yatala Brewery emphasize the potential for various industries to reduce energy consumption through efficiency measures, such as technology upgrades, sensors and monitoring, and reviewing practices. Of particular note is the involvement of consultants with extensive previous experience with the plant and the close interaction with staff based on their level of trust built up over past projects that allowed for improvements in process and ensured expected gains to be realised through adherence to new practice.

4.2. Santos Oil and Gas Installations

Large industrial plants typically offer significant opportunities for improving efficiency, saving energy and money simultaneously. Santos, as one of the larger Australian resources companies, provides a number of good examples of ways in which efficiencies can be found, through everything from repurposing of existing equipment, to upgrades to more current technology, to major process alterations. In the case of the Santos facility in the Cooper Basin, Santos *"completed an extensive review of coolers which are used for finer inlet temperature control. At some sites, the coolers were providing little or no benefit while still consuming energy. Where feasible these coolers have been decommissioned, which will deliver an annual energy saving of approximately 35,000 GJ".*[70]

The Challenges

Santos has faced a number of challenges to reduce energy use on its sites, such as:

1. The liquid recovery plant at Santos' Moomba facility has identified that the two gas-turbine-driven compressors which recovered liquid hydrocarbons from the gas processed at the facility were running at such low flow-rates that the flow had to be recycled to ensure safe, stable operation of the systems.

2. At the Ballera gas plant the CO_2 removal process is running with excess capacity with two primary treatment units and one standby unit. One of the two primary units in the system is in operation because historically both units were used to meet demand; and because of the long start-up time in the event that second unit was required.

3. At the Mereenie Oilfield there is a camp for accommodating personnel working in the area powered by a diesel generator with a typical load of 75kW. Adjacent to the camp, the treatment plant associated with the oilfield also has power generation equipment on-site, which was identified to have spare capacity.

4. At the Scotia facility in South East Queensland a diesel generator is used to provide power for an on-site administrative office. A number of diesel engines are used across the site using technology that has been superseded.

The Solutions

Asking "*where could energy savings be found*?" the Santos team considered a range of options for each challenge and created the following solutions:

1. At the liquid recovery plant at Santos' Moomba facility changes to the process to allow the system to run on a single compressor when lower volumes were being processed rather than recycling flow to maintain the operation of the two original compressors. This meant that a compressor could be removed in each plant, saving significant energy and maintenance costs. The changes to the compressor system resulted in less gas consumption, improved process stability, and greater efficiency of the compressors. The energy savings were estimated at 350 TJ (350,000 GJ) of gas per annum, with a payback period of less than 2 years.
2. The CO_2 removal system at the Ballera gas plant was reviewed leading to one of the treatment units being decommissioned in a manner that allowed for it to be recommissioned with minimal remediation at a later date. The reduction in energy demand was in the order of 670 TJ/year saving of energy, or approximately 22% of the annual energy use of the plant, with a payback period of 2 years and then saving around $6 million per year.[71]
3. At the Mereenie Oilfield and it was determined that by utilising this excess power capacity to power the camp, 2000 GJ of energy (or around 52,000L of diesel fuel) could be saved per annum, while diesel would no longer have to be transported to the site for power generation purposes.
4. At the Scotia facility the diesel generator used to provide power for an on-site administrative office was replaced with a 40kW solar PV unit on the roof of the office, supplemented by a diesel back-up generator. This technology upgrade is estimated to save around 47,000 litres of diesel per year. The payback period on the investment was estimated to be less than 4 years due to the high cost of transporting diesel fuel to the site. Across the site the diesel engines were upgraded with new turbochargers that increased the fuel efficiency and lifespan of the engines. The turbocharger upgrades are expected to reduce diesel consumption by about 5%, resulting in savings of approximately 545,000 litres of diesel per annum. While the turbocharger upgrades have a longer payback period than the solar installation, the alterations are being implemented, as the long-term savings outweigh costs.

Key Lessons

From Santos' 2012 Sustainability Report: '*Saving energy makes good business sense, conserving our product and reducing our emissions footprint. Ongoing energy efficiency assessments are part of our regular business in all areas of our operations. For us it is about finding ways to work smarter and looking at initiatives and infrastructure upgrades that can deliver energy savings'.*[72]

5. Key Supporting Resources

The following resources are recommended by the research team to assist lecturers to expand the content contained in this introductory level lecture. For guidance as to embedding such materials into existing course see the 2014 book 'Higher Education and Sustainable Development: A Model for Curriculum Renewal'.[73]

5.1. Energy Efficiency Exchange (EEX)

Heating, Ventilation and Air Conditioning: HVAC electricity consumption typically accounts for around 40% of total building consumption and 70% of base building (i.e. landlord) electricity consumption. It also contributes to manufacturing facility energy use and costs. HVAC dominates peak building electricity demand, so improving its efficiency can reduce peak demand electricity charges.[74] (See Resource)

Process Heat, Boilers and Steam Systems: Process heating and steam production are significant sources of energy use for Australian industrial companies and some commercial sub-sectors. For example, on a typical industrial site, boilers can account for 20–60% of energy costs and represent up to 35% of all potential energy efficiency improvements.[75] (See Resource)

Pumps and Fans: Pumps and fans are used widely throughout industry. Together, they account for around 40% of the end uses of motive power in Australian industry. Potential energy savings in pump and fan systems can be as much as 50% and in some cases even higher.[76] (See Resource)

Motors and Motor Systems: Optimising motor systems has the potential to save more electricity than in any other electricity end-use. Investing in motor efficiency also makes sense given the total cost of supplying electricity to a motor can overtake the motor purchase price in just two weeks. Effective management of electric motors will also improve their reliability, minimise the risk of lost production time and minimise life-cycle costs.[77] (See Resource)

Compressed Air: Approximately 10% of the electricity supplied to Australian industry is used to compress air. Many industrial businesses use compressed air to operate equipment such as hand tools, pumps, valve actuators, pistons and large-scale processes.[78] (See Resource)

Waste Heat Minimisation and Recovery: Waste heat minimisation and recovery are two of the most effective ways to reduce energy costs and greenhouse gas emissions. Reducing heat loss not only reduces energy and maintenance costs, but can also lower unwanted emissions of air pollutants while improving the productivity of furnaces, ovens, boilers and other heating equipment.[79] (See Resource)

5.2. The Natural Edge Project (TNEP)

Opportunities for Improving the Efficiency of HVAC Systems: This lecture reviews the energy efficiency opportunities in HVAC systems. This lecture addresses the question of how can more efficient HVAC systems be designed? This lecture also looks at seven ways to reduce the overall load required from HVAC systems.[80] (See Resource)

Opportunities for Improving the Efficiency of Boiler and Steam Distribution Systems: The aim of this lecture is to cover the key components of design, operation and maintenance for boiler and steam distribution systems.[81] (See Resource)

Opportunities for Improving the Efficiency of Motor Systems: This lecture reviews the energy efficiency opportunities in motors systems and covers key components of design, operation and maintenance.[82] (See Resource)

References

[1] Desha, C. and Hargroves, K. (2012) *Report on Engineering Education Consultation 2012*, a report and accompanying Briefing Note, Australian Government Department of Resources, Energy and Tourism, Canberra.

[2] Hargroves, K., and Desha, C. (2014) 'Energy Productivity and Decarbonization of the Global Economy: Factor Five Resource Productivity', *Energy and Environment*, WENE-217, Wiley Interdisciplinary Reviews.

[3] Brown, L.R. (2008) Plan B 3.0: Mobilizing to Save Civilization, W.W. Norton & Company, New York.

[4] Smith, M., Hargroves, K. and Desha, C. (2010) *Cents and Sustainability: Securing Our Common Future through Decoupling Economic Growth from Environmental Pressure*, Earthscan, London.

[5] Hargroves, K. and Smith, M. (authors and eds) (2005) *The Natural Advantage of Nations: Business Opportunities, Innovation and Governance in the 21st Century*, Earthscan/Routledge, The Natural Edge Project, London.

[6] Engineers Australia (1997) *Towards Sustainable Engineering Practice: Engineering Frameworks for Sustainability*, Engineers Australia, Canberra, Australia. (https://www.engineersaustralia.org.au/environmental-college/sustainability-resources)

[7] IPCC (2007) *Climate Change 2007: Impacts, Adaptation and Vulnerability*, Contribution of Working Group II to the Fourth Assessment Report of the International Panel on Climate Change, Cambridge University Press, Cambridge.

[8] Desha, C., Hargroves, K., and Smith, M. (2009) '*Addressing the time lag dilemma in curriculum renewal towards engineering education for sustainable development*', International Journal of Sustainability in Higher Education, vol 10, no 2, pp184-199.

[9] See von Weizsäcker, E., Hargroves, K., Smith, M., Desha, C. and Stasinopoulos, P. (2009) Factor 5: Transforming the Global Economy through 80% Increase in Resource Productivity, Earthscan, UK and Droemer, Germany, Chapter 3.

[10] Boyd, B.K. and Gove, S. (2000) 'Nucor Corporation and the U.S. Steel Industry', in Hitt, M.A., Ireland, R.D. and Hoskisson, R.E. (eds) Strategic Management: Competitiveness and Globalization, 4 Edition, Southwestern Publishing.

[11] Worrell, E., Price, L. and Galitsky, C. (2004) Emerging Energy-Efficient Technologies in Industry: Case Studies of Selected Technologies, Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, California, USA.

[12] See von Weizsäcker, E., Hargroves, K., Smith, M., Desha, C. and Stasinopoulos, P. (2009) Factor 5: Transforming the Global Economy through 80% Increase in Resource Productivity, Earthscan, UK and Droemer, Germany, Chapter 3.

[13] The Natural Edge Project (2009) 'Factor 5 in Eco-Cements', CSIRO ECOS Magazine, Issue 149.

[14] CSIRO (undated) 'Geopolymers: Building Blocks of the Future', www.csiro.au/science/ps19e.html, accessed 30 October 2014.

[15] See Smith, M., Hargroves, K., Desha, C. and Stasinopoulos, P. (2009) *Factor 5: The Pulp and Paper Online Sector Study*, The Natural Edge Project, Australia.

[16] von Weizsäcker, E., Hargroves, K., Smith, M., Desha, C. and Stasinopoulos, P. (2009) Factor 5: Transforming the Global Economy through 80% Increase in Resource Productivity, Earthscan, UK and Droemer, Germany.

[17] Worrel, E., Price, L. and Galitsky, C. (2004) Emerging Energy-Efficient Technologies in Industry: Case Studies of Selected Technologies, Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, California, USA.

[18] See von Weizsäcker, E., Hargroves, K., Smith, M., Desha, C. and Stasinopoulos, P. (2009) Factor 5: Transforming the Global Economy through 80% Increase in Resource Productivity, Earthscan, UK and Droemer, Germany, Chapter 5.

[19] Light Rail Now (2008) 'CTrain Light Rail growth continues with North East extension', News Release, January 2008, Light Rail Now, Texas, USA.

[20] See von Weizsäcker, E., Hargroves, K., Smith, M., Desha, C. and Stasinopoulos, P. (2009) Factor 5: Transforming the Global Economy through 80% Increase in Resource Productivity, Earthscan, UK and Droemer, Germany, Chapter 5.

[21] Northern Territory Government (2007) 'NT Greenhouse Gas Emissions - Transport' http://www.nt.gov.au/nreta/environment/greenhouse/emissions/transport.html, accessed 4 April 2010.

[22] Newman, P. and Kenworthy, J. (2007) 'Transportation energy in global cities: sustainability comes in from the cold', Natural resources forum, vol 25, no 2, pp91-107.

[23] See von Weizsäcker, E., Hargroves, K., Smith, M., Desha, C. and Stasinopoulos, P. (2009) Factor 5: Transforming the Global Economy through 80% Increase in Resource Productivity, Earthscan, UK and Droemer, Germany, Chapter 5.

[24] Frey, C. and Kuo, P. (2007) 'Assessment of Potential Reduction in Greenhouse Gas (GHG) Emissions in Freight Transportation', Proceedings, International Emission Inventory Conference, US Environmental Protection Agency, Raleigh, NC, May 15-17, 2007.

[25] von Weizsacker, E., Hargroves, K., Smith, M., Desha, C. and Stasinopoulos, P. (2009) Factor 5: Transforming the Global Economy through 80% Improvements in Resource Productivity, Earthscan, London.

[26] Hargroves, K., and Desha, C. (2014) 'Energy Productivity and Decarbonization of the Global Economy: Factor Five Resource Productivity', Energy and Environment, WENE-217, Wiley Interdisciplinary Reviews.

[27] Romm, J. (1994) cited in Hawken, P., Lovins, A. and Lovins, H. (1999) *Natural Capitalism: Creating the Next Industrial Revolution*, Earthscan, London, Chapter 6:' Tunnelling Through the Cost Barrier'.

[28] Stasinopoulos, P., Smith, M., Hargroves, K. and Desha, C. (2008) Whole System Design: An Integrated Approach to Sustainable Engineering, The Natural Edge Project, Earthscan, London.

[29] Stasinopoulos, P., Smith, M., Hargroves, K. and Desha, C. (2008) Whole System Design: An Integrated Approach to Sustainable Engineering, The Natural Edge Project, Earthscan, London.

[30] Pears, A. (2004) *Energy Efficiency – Its potential: some perspectives and experiences*, Background paper for International Energy Agency Energy Efficiency Workshop, Paris, April 2004.

[31] Stasinopoulos, P., Smith, M., Hargroves, K. and Desha, C. (2008) Whole System Design: An Integrated Approach to Sustainable Engineering, The Natural Edge Project, Earthscan, London.

[32] Australian Government (2013) Energy Efficiency Opportunities Program, The First Five Years: 2006–2011, Overview., Commonwealth of Australia.

[33] Australian Government (2013) Energy Efficiency Opportunities Program, The First Five Years: 2006–2011, Overview., Commonwealth of Australia.

[34] Desha, C., Hargroves, K. and El Baghdadi, O. (2012) 'Review of Postgraduate Energy Efficiency Course Content and Recommendations for Use of Existing Course: Vocational Graduate Certificate in Building Energy Analysis (Non-Residential)', Report to the National Framework for Energy Efficiency, The Natural Edge Project (TNEP), Australia

[35] ASME (n.d.) "Sustainability", www.asme.org/kb/topics/sustainability, accessed 18 March 2012.

[36] ASME (2011) "Call for papers", http://www.asmeconferences.org/esfuelcell2011/CallForPapersDetail.cfm, accessed 18 March 2012.

[37] Department of Resources, Energy and Tourism (2011) Energy Efficiency Graduates Attributes Project: Energy Efficiency Advisory Group – Project 1, Lead Member: Queensland University of Technology, Report to the Department of Resources, Energy and Tourism, August 2011, Canberra.

[38] Smith, M., Hargroves, K., Stasinopoulos, P., Stephens, R., Desha, C., and Hargroves, S. (2007) *Engineering Sustainable Solutions Program: Sustainable Energy Solutions Portfolio*, The Natural Edge Project, Lecture 2.1.

[39] Smith, M., Hargroves, K., Stasinopoulos, P., Stephens, R., Desha, C., and Hargroves, S. (2007) *Engineering Sustainable Solutions Program: Sustainable Energy Solutions Portfolio*, The Natural Edge Project, Lecture 2.2.

[40] Jacobs, P. (2003) *Small HVAC System Design Guide: Design Guidelines*, California Energy Commission, pp. 37, 59-60.

[41] Carbon Trust (2006) *Heating, Ventilation and Air Conditioning (HVAC): Saving Energy without Compromising Comfort*, Queen's Printer and Controller of HMSO.

[42] ACCA (1990) cited in Jacobs, P. (2003) *Small HVAC System Design Guide: Design Guidelines*, California Energy Commission, p. 19. Sustainability Victoria (2006) *HVAC Tips (Heating, Ventilation and Air Conditioning)*, Sustainability Victoria.

[43] Architectural Energy Corporation (n.d.) *Design Brief: Integrated Design for Small Commercial HVAC*, Energy Design Resources, p. 8.

[44] CEE (2001) cited in Jacobs, P. (2003) *Small HVAC System Design Guide: Design Guidelines*, California Energy Commission, pp 50-51.

[45] Architectural Energy Corporation (n.d.) *Design Brief: Integrated Design for Small Commercial HVAC*, Energy Design Resources, p 13.

[46] Penny, J. (2004) 'Commissioning controls for energy efficiency', *EcoLibruim*, July 2004, pp 21-24.

[47] Australian Greenhouse Office (2005) *Energy Audit Tool: Boilers*, AGO, Australia.

[48] Sustainability Victoria (2006) *Fact Sheets and Calculation Fact Sheets: Boiler Optimisation*, Victorian State Government, Australia.

[49] Sustainability Victoria (2006) *Fact Sheets and Calculation Fact Sheets: Boiler Optimisation*, Victorian State Government, Australia, p 6.

[50] Sustainability Victoria (2006) *Fact Sheets and Calculation Fact Sheets: Boiler Optimisation*, Victorian State Government, Australia.

[51] Pacific Gas and Electricity (1997) *Energy Efficient Operations and Maintenance Strategies for Industrial Gas Boilers*, PG&E, USA, p4.

[52] Pacific Gas and Electricity (1997) *Energy Efficient Operations and Maintenance Strategies for Industrial Gas Boilers*, PG&E, USA, p 5.

[53] Sustainability Victoria (2006) *Fact Sheets and Calculation Fact Sheets: Boiler Optimisation*, Victorian State Government, Australia.

[54] Pacific Gas and Electricity (1997) *Energy Efficient Operations and Maintenance Strategies for Industrial Gas Boilers*, PG&E, USA, p6.

[55] Pacific Gas and Electricity (1997) *Energy Efficient Operations and Maintenance Strategies for Industrial Gas Boilers*, PG&E, USA, p 8.

[56] Pacific Gas and Electricity (1997) *Energy Efficient Operations and Maintenance Strategies for Industrial Gas Boilers*, PG&E, USA, p 3.

[57] Sustainability Victoria (2006) *Fact Sheets and Calculation Fact Sheets: Boiler Optimisation*, Victorian State Government, Australia.

[58] Australian Greenhouse Office (2005) *Energy Audit Tool: Boilers*, AGO, Australia.

[59] Sustainability Victoria (2006) *Fact Sheets and Calculation Fact Sheets: Boiler Optimisation*, Victorian State Government, Australia.

[60] Sustainability Victoria (2006) *Fact Sheets and Calculation Fact Sheets: Boiler Optimisation*, Victorian State Government, Australia.

[61] Australian Greenhouse Office (2005) *Energy Audit Tool: Boilers*, AGO, Australia.

[62] Australian Greenhouse Office (2003) *The Motor System*, AGO, Australia.

[63] Australian Greenhouse Office (2003) *Reference Manual – Introduction: setting the scene*, AGO, Australia.

[64] Australian Greenhouse Office (2003) *The Motor System*, AGO, Australia.

[65] Nadel, S. *et al* (2002) *Energy-Efficient Motor Systems: A Handbook on Technology, Program, and Policy Opportunities*, (2nd Ed), American Council for an Energy-Efficient Economy, USA, Chapter 1: Overview and Summary.

[66] Australian Greenhouse Office (2003) *Reference Manual – Introduction: setting the scene*, AGO, Australia.

[67] Australian Greenhouse Office (2003) *The Motor System*, AGO.

[68] Nadel, S. *et al* (2002) *Energy-Efficient Motor Systems: A Handbook on Technology, Program, and Policy Opportunities*, (2nd Ed), American Council for an Energy-Efficient Economy, USA, Chapter 1: Overview and Summary.

[69] Queensland Government Department of Environment and Heritage Protection, Premiers Sustainability Awards 2014, available at http://www.ehp.qld.gov.au/premiersawards/sponsors.html#business_eco_efficiency_award, accessed 30 September 2014.

[70] Santos (2012) Energy Efficiency Opportunities Report, Santos Ltd.

[71] ABC (2014) Gas price to double: analyst, ABC Rural. Available at http://www.abc.net.au/news/2014-02-24/analyst-gas-prices/5279052, accessed 30 October 2014.

[72] Santos (2012) Sustainability Report 2012 - Delivering Sustainability, Santos Limited.

[73] Desha, C., and Hargroves, K (2014) Higher Education and Sustainable Development: A Model for Curriculum Renewal, Earthscan, Routledge.

[74] Energy Efficiency Exchange (2014), 'Heating, Ventilation and Air Conditioning', http://eex.gov.au/technologies/heating-ventilation-and-air-conditioning/, accessed 27 November 2014

[75] Energy Efficiency Exchange (2014), 'Process Heat, Boilers and Steam Systems', http://eex.gov.au/technologies/process-heating-and-steam-systems/ , accessed 27 November 2014

[76] Energy Efficiency Exchange (2014), 'Pumps and Fans', http://eex.gov.au/technologies/pumps-and-fans-2/, accessed 27 November 2014

[77] Energy Efficiency Exchange (2014), 'Motors and Motor Systems', http://eex.gov.au/technologies/motors/, accessed 27 November 2014

[78] Energy Efficiency Exchange (2014), 'Compressed Air', http://eex.gov.au/technologies/compressed-air-2/, accessed 27 November 2014

[79] Energy Efficiency Exchange (2014), 'Waste Heat Minimisation and Recovery', http://eex.gov.au/technologies/waste-heat-minimisation-and-recovery/, accessed 27 November 2014

[80] Smith, M., Hargroves, K., Stasinopoulos, P., Stephens, R., Desha, C., and Hargroves, S. (2007), *2.3-Opportunities for Improving the Efficiency of HVAC Systems*, The Natural Edge Project, Australia

[81] Smith, M., Hargroves, K., Stasinopoulos, P., Stephens, R., Desha, C., and Hargroves, S. (2007), *3.2-Opportunities for Improving the Efficiency of Boiler and Steam Distribution Systems*, The Natural Edge Project, Australia

[82] Smith, M., Hargroves, K., Stasinopoulos, P., Stephens, R., Desha, C., and Hargroves, S. (2007), *3.1-Opportunities for Improving the Efficiency of Motor Systems*, The Natural Edge Project, Australia