Flexible Delivery Flat-Pack Module

An Overview of Energy Efficiency Opportunities in Electrical 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:

Project Partners:

Citation Details

Hargroves, K., Gockowiak, K., Wilson, K., and Desha, C., (2014) *Introduction to Energy Efficiency Opportunities in Electrical Engineering*, The University of Adelaide and Queensland University of Technology, 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 Nesimi Ertugrul, 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

Electrical Engineers will be a key part of the World's response to climate change, from designing new electrical equipment to be highly energy efficient, designing renewable energy technology, to balancing electricity grid loading to accommodate distributed variable loads. Electrical Engineers have critical skills the economy needs to thrive in a carbon constrained future. The following learning points provide a summary of the Electrical Engineering video – our 'Allen keys' to building the flat-pack content!

Watch the '***Electrical Engineering***' MMB

1. Electrical Engineers are critical to society responding to climate change and improving the energy efficiency of many sectors. For instance, moving away from large-scale centralised energy generation systems that use grids designed for electricity to flow in one direction, to systems that allow for distributed generation and storage will be a crucial platform for all sectors to receive and manage energy services.
2. It is a dynamic and exciting time for the energy sector. Changes will be driven by issues of energy pricing, energy reliability, and energy sustainability. According to the Australian Power Institute graduates in the next 5 years will need to have gained energy efficiency knowledge and skills to be productive and effective in their roles. Furthermore, key stakeholders throughout the supply chain will be looking to Electrical Engineers to assist them to deliver the environmental, economic and social outcomes.
3. An important opportunity for Electrical Engineers to improve energy efficiency and enhance economic outcomes is through minimising and avoiding wasted energy, as all energy used costs money regardless of whether it's wasted. Electrical Engineers are well placed to use emerging technologies and processes to deliver significant energy efficiency improvements, such as the use of advanced lighting technologies and the use of control systems to avoid redundant energy demand.
4. Awarded the 2014 Business Eco-efficiency Award by the Queensland Government,[2] the Carlton & United Breweries facility in Yatala, Queensland, is its third largest brewery in Australia and produces 2.5 billion litres of beer each year. Rising electricity prices and the emergence of new lighting technologies called for reconsideration of the lighting system and led to the installation of a system of meters to isolate energy costs to specific areas of the facility. While cost savings provide an incentive to change lighting fixtures, it is important that lighting quality is not compromised.
5. The metering found that across the plant lighting accounted for 16 per cent of the total electricity usage – well above the average lighting demand in the USA and Europe of between 6 and 10 per cent. Setting a goal of reducing that electricity usage to 6 per cent, and realising that the lighting levels were double what they needed to be according to Australian Standards, the brewery introduced a combination of three different lighting solutions in one building that better suited the space (T5 fluorescent tubing, induction high bay, and LED high bay lighting) and achieved a 50 per cent reduction in electricity demand. For instance, the replacement of older fittings with T5 fluorescent tubing in one area reduced electricity consumption by 30 per cent and doubled the quality and quantity of lighting.[3]

2. Energy Efficiency and Electrical 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.[4] 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*'.[5] 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.[6]

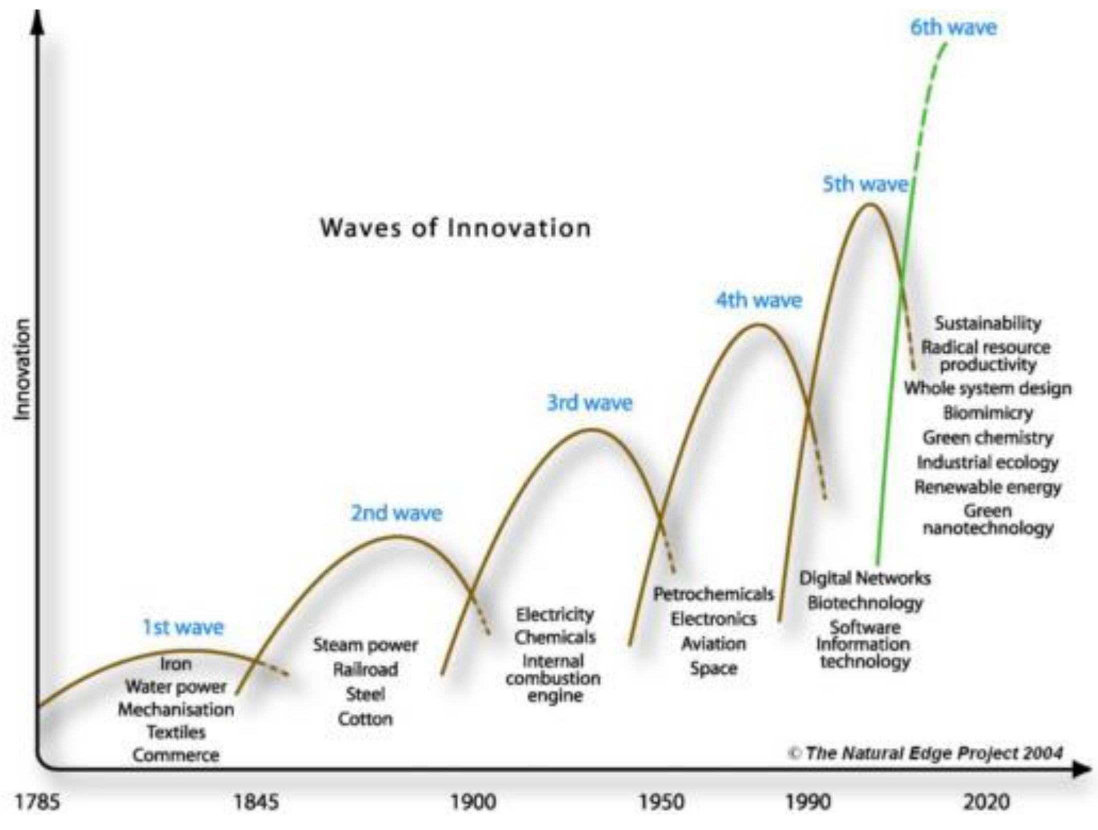

Figure 1: A stylistic representation of waves of innovation since the Industrial revolution[7]

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 an Electrical 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.*’[8] 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.[9]

> ***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.[10]

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 Electrical Engineers reduce greenhouse gas emissions?

How could energy efficiency provide benefits to an Electrical Engineering firm?

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

Sector	Best Practice Case Studies
Steel Industry[11]	Leading US steel company, Nucor Steel, is around 70% more energy efficient than many steel companies around the world,[12] 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.[13]
Cement Industry[14]	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%.[15] Geo-polymers can be used for most major purposes for which Portland cement is currently used.[16]
Paper and Pulp Industry[17]	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.[18] 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.[19]
Transport Vehicle Efficiency[20]	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.[21]
Transport Efficiency from Modal shifts. (Passenger)[22]	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).[23] Trains are even more efficient. Typically, rail systems in European cities are 7 times more energy-efficient than car travel in US cities.[24]
Transport Efficiency from Modal Shifts (Freight)[25]	Shifting freight transport from trucks to rail can also lead to large efficiency gains of between 75 and 85%.[26] 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)[27] as presented in Hargroves, K., and Desha, C. (2014)[28]

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*'.[29] As pointed out in the book '*Whole System Design: An Integrated Approach to Sustainable Engineering*',[30] 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.[31]

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.[32] 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: [33]

– 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*'.

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.

Watch an Introduction to the EEO Program

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.

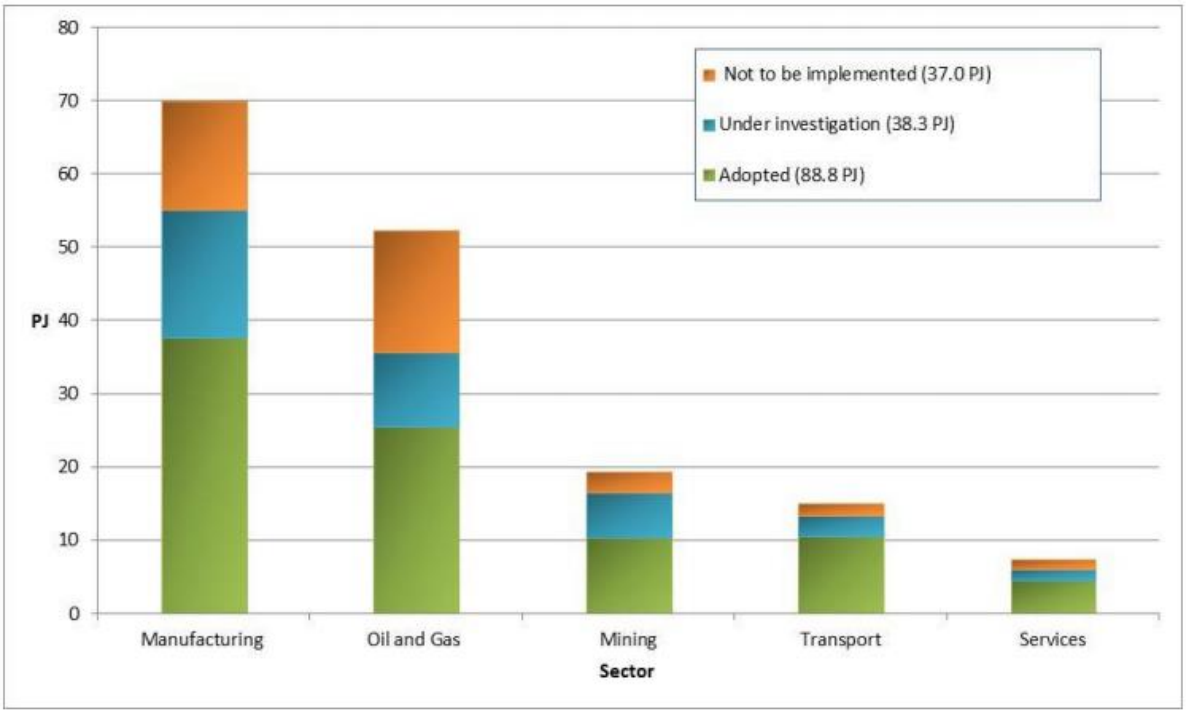

Figure 2: Summary of energy efficiency achievements in by participants in the Australian Government Energy Efficiency Opportunities (EEO) program (2006-11)[34]

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.[35] 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.[36]***

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 Electrical Engineers to achieve energy efficiency improvements in each of the sectors involved in the EEO Program (Figure 1).

3. Key Knowledge and Skills for Electrical Engineers

According to the Institution of Engineers Australia, Electrical Engineers work in a number of areas that can make a substantial contribution to societies around the world to reduce greenhouse gas emissions, particularly through greater energy efficiency in the following areas:

- Electricity generation, transmission, distribution,
- Electrical installations in buildings and on industrial sites,
- Electrical equipment manufacture,
- Instrumentation and control systems applications in industry,
- Communications networks,
- Electronic plant and equipment, and
- Integration and control of computer systems.

The contribution that Electrical Engineers can make to reducing greenhouse gas emissions may include designing renewable energy generation systems, smart electricity grids that can balance small scale decentralised generation, control systems to optimise energy efficiency in industrial and manufacturing processes, office equipment that consumes less energy and can be easily remanufactured, improved power management systems for industry, advanced heat recovery systems, electricity transmission infrastructure that reduced transmission losses, and automated building management systems that minimise energy wastage.

In Electrical Engineering, energy efficiency could include consideration of energy efficiency opportunities systemically across the fields of electricity, electronics and electromagnetism associated with large scale electrical systems (such as power transmission and motor control). Energy efficiency opportunities could be explored within power networks, or achieving energy efficiency in wireless networks (optimisation of network design with photovoltaics power). During stakeholder workshops that have informed this flatpack the following example energy efficiency graduate attributes were recommended:

- Ability to conceptualise and compare, evaluate, and optimise alternative approaches to electrical engineering problems, in consideration of energy efficiency and other sustainability issues,
- Effective communication and advocacy of complex electrical engineering aspects of energy efficiency issues to the community (as a technical expert), and
- Knowledge/cognisance of emerging energy efficiency fields, changes to equipment efficiency, lifecycle modelling and sustainability.

4. Energy Efficiency Opportunities in Electrical Engineering

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

4.1. Heating, Ventilation and Air-Conditioning (HVAC)[1]

The use of control systems can help to identify potential energy efficiency opportunities in HVAC systems. Complimenting options for reducing energy demand of HVAC systems through the design of such systems by Mechanical and ITE Engineers, Electrical Engineers provide options to develop control systems that can optimise the operation of HVAC systems and further reduce energy demand. According to the UK Carbon Trust, '*Making even small adjustments to systems can significantly improve the working environment and at the same time, save money'*.[37] Control systems that are adequately commissioned and programmed can reduce HVAC energy consumption through a number of ways, including: ensuring that the right amount of air-conditioning is provided when it is required, harnessing a building's thermal mass to achieving small reductions in operation time,[38] shutting down compressors when not needed, and reducing use during peak energy demand periods. There are several types of control systems available for HVAC systems:

– *Time-switches* are a simple, low-cost technology for activating and deactivating HVAC systems at specific times, such as activating an hour before a shift starts and deactivating an hour before a shift ends. *Intelligent time-switches* also learn the operating period and adjust activation and deactivation times accordingly; this can reduce operating time by 5-10 per cent. Time-switches should also incorporate holiday programming and timed overrides to allow extended use when required.

– *Thermostats*[39] are a popular control technology for HVAC systems. Thermostat location is an important consideration because poorly located thermostats can increase energy consumption.[40] Thermostats provide accurate readings when located on an interior wall (which is nearer to the average space temperature than exterior walls), or near a return duct (where flow is constant and unrestricted). Thermostats will provide inaccurate readings when located in direct sunlight, near artificial heat sources such as office and refrigeration equipment, or when isolated behind doors or curtains. Locating multiple thermostats in the same space with conflicting air-conditioning set-points will make HVAC systems work against each other and thus increase energy consumption.[41]

– *Energy management systems*[42] are popular in retail, food service, and other regularly occupied buildings. They allow advanced control, monitoring, and alarm of several HVAC system components. Control options include unit operation for either heating or cooling, fan operation and scheduling, and economiser control. Monitoring options include supply and return air temperature information. Alarm options include fan failure, dirty filters, compressor high- or

[1] 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.

low-pressure lockout, and economy cooling status. Energy consumption can be further reduced by adjusting controls for seasonal variations in ambient climate.[43] Each 1°C forward increase in set-point will increase energy consumption by about 15 per cent in winter and 10 per cent in summer.

– *Demand-controlled ventilation* adjusts outdoor air intake to maintain an optimal range of indoor carbon dioxide concentration; a typical indicator of indoor air quality. Preventing over-ventilation minimises undesirable heat transfer and humidity. Demand-controlled ventilation is most effective in spaces with highly variable occupancies such as auditoriums and meeting rooms, to prevent over-ventilation.[44]

Metering and monitoring is essential in order to ensure that the benefits of good design intentions and retrofits are not whittled away. Systems are now available which automatically record and communicate energy consumption, e.g. through the building automation system, or systems such as www.eco-tracker.com. Monitoring of maintenance contractor observations and recording (see above) will also help to safeguard energy efficiency and equipment.

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

4.2. Electric Motor Systems[2]

The energy efficiency of motor systems can be increased in a number of ways through the use of control systems that can provide real time information on the demands and performance of the system to allow optimisation. This information can be used to shut down and start up specific motors depending on demand rather than having them run all the time to cover periods when they are required.[45] Control technologies for motors can include:

- Calendar time switches, which prevent motors from starting up on public holidays and rostered days off,
- Level float switches, which control pumps that would otherwise be running continuously, and
- Thermostats, which allow chilled water pumps to operate only in warm weather.

Considering that motor energy consumption increases with the cube of operating speed,[46] matching the speed of the motor to the demand of the system can deliver significant energy efficiency improvements. Control systems such as variable speed drives can adjust the motor speed and torque to match the load. Variable speed drive energy consumption has been measured in industrial applications to be proportional to $\omega^{2.6}$ (where ω is rotational speed), so halving the speed of a given motor and load system will reduce the energy consumption to 16 per cent ($=0.5^{2.6}$) of the full speed energy consumption.

According to the American Council for an Energy Efficient Economy, *'Other technologies include microprocessor-based controllers that monitor system variables and adjust motor load accordingly,*

[2] 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.

and power-factor controllers that can trim the energy use of small motors driving grinders, drills, and other devices that idle at nearly zero loading most of the time. There are also application-specific controls such as those that sequence the operation of multiple compressors in a compressed air system'. [47]

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

4.3. Energy Efficient Facility Design

The biggest opportunities to enhance efficiency are usually made when a project can be designed from its inception with energy efficiency in mind. The Port of Brisbane, in designing a suite of new buildings, integrated environmentally sustainable development principles into the design from the outset. Lighting systems in the buildings were a focus of the designs – in workshops and storerooms, light sensors were installed to minimise the use of artificial lighting when there is sufficient daylight; translucent roof sheeting was installed where the use of natural light was possible to minimise the requirement for artificial lighting; and LED lighting was used for external and entrance lighting, reducing the power requirements for the lighting system and lasting up to five times longer than conventional lighting, saving on maintenance and replacement costs. The climate control systems were another focus of the development - using variable refrigerant volume heat pump/heat recovery systems optimises energy use by using a single climate control unit to heat multiple rooms, and transferring excess heat or cooling between rooms depending on demand to minimise power requirements, providing significant savings in operating costs. Using sustainable energy inputs was another focus of the design, and the use of solar hot water and power generation systems incorporated into the building further reduce the facility's energy requirements.[48]

The Port office in particular features a number of innovative technologies to enhance efficiency. This building, a 5-star WELS rated structure, uses a number of control technologies to reduce energy use. Lights within the building are controlled by both daylight and movement sensors, reducing energy use and responding to local lighting needs. Double-glazed windows are shaded by automatically deploying external blinds which adjust to sun levels on the north and east sides of the building, reducing the incident radiation on the building depending on the demand for cooling and reducing cooling requirements. The air conditioning system is another example of design for improved efficiency. A chilled water tank used to supply cooling for the air conditioning system reduces power demand during the day, as water is cooled overnight and then circulated through the active chilled beam cooling system (which uses fans to force hot air in the office space over the chilled beams hidden within the perforated ceiling, cooling the air and dropping it into the office space below) to provide indoor cooling, while cool air is supplied individually to workstations so that occupant can tailor their working environment. These design features don't just provide gains in terms of energy efficiency – the design of the new terminal is better for staff, increasing productivity and promoting a healthy work environment.[49]

5. Case Studies of Electrical Engineering and Energy Efficiency

*Building on the multi-media bite on Electrical Engineering and energy efficiency the following two examples of provide further details on the energy efficiency improvements related to Electrical 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.*

5.1. R.M. Williams

R.M. Williams was started in South Australia in 1932 and has since grown to an international brand with exports to 15 countries with more than 800 stockists worldwide. The organization's environment committee has led a sustained drive in reducing cost by increasing efficiency and optimization and has resulted in significant savings. Since 2004, some 17,800 tonnes of carbon dioxide emissions have been saved and waste to land fill reduced by 84 tonnes per annum.[50]

The Challenge

The company's primary manufacturing site in Salisbury, SA, employs 340 staff and has high energy use associated with lighting, HVAC, and dozens of 3-phase and single phase motors and large manufacturing equipment with different loads.

Identify 5 ways that Electrical Engineers can deliver energy savings in lighting systems in Australian manufacturing operations, support this with case studies.

The Solution

Asking "*where could energy savings be found*?" the team from Pangolin Associates undertook an energy audit and identified multiple energy savings measures with a payback period of less than 3 years that would reduce energy consumption by 21 per cent with costs savings of more than $66,000 per year.[51] From the recommendations a reduction of 84,500 KWh was achieved in 2012 through energy management techniques. For instance working with partners Energywise, a voltage power optimisation company, it was identified that the incoming voltage was above the recommended efficiency range for most plant equipment and the power factor was at sub-optimal levels. An Ark Energy Saving unit that optimizes incoming voltage for distribution throughout the site was installed to reduce the incoming voltage range of 235-245V to 220-230V and a power factor correction unit was used to reduce the amount of unused energy that remains in the electrical system,[52] achieving a combined demand reduction of 13 per cent with a payback period of just over 2 years.

5.2. MINUS40

Electrical engineering design, when focussed on sustainability, offers significant opportunities for improving efficiency, saving energy, and saving money simultaneously. Significant savings can be made at many different stages of a process; everything from changes in monitoring and use of existing systems, through embracing energy efficiency as a principal design goal for clean-sheet projects, to the choice of novel materials and technology when designing electrical systems.

The Challenges

An example of the role that monitoring of existing systems, and advances in technology can play in enhancing energy efficiency is the work that MINUS40 carried out with Swire Cold Storage facility in Lurnea, NSW on improving refrigeration efficiency at the site. Swire was already heavily involved in sustainability measures at their facilities and at the time of this project had already cut their carbon output by 40 per cent between 2007 and 2010, but further opportunities for savings were identified by MINUS40 through an audit of the plant.

1. The existing refrigeration compressors for the facility were energy efficiency when the facility was built between 2005 and 2009, but by 2010 the industrial refrigeration audit carried out by MINUS40 identified that there were already more efficient technologies that could be used to provide the required performance. The existing compressors used a control system which resulted in the compressors often running unloaded in cooler months of the year, leading to significant inefficiency.

When a system can be redesigned from a clean sheet and adapted to new requirements, significant gains in efficiency can be made. Working with Ford Australia, MINUS40 identified that a change to a climate control system at Ford's Lara proving ground could enable significant energy and cost savings to be made over the existing system.

2. The climate existing climate control system was shared between two facilities on the site, and had to provide heated and cooled air to the Squeaks and Rattles test facility, at temperatures ranging from -29°C to 50°C.

The Solutions

1. The control system was replaced with a variable speed drive system coupled with a control logic system for capacity modulation and compressor staging, which avoided unloaded running of the compressors. This alteration reduced energy consumption by more than 15 per cent through the cooler months of the year, saving the facility around 2830 GJ of energy per annum, and is expected to pay for itself in 4.5 years.[53]

2. The existing system was unable to reach the minimum temperature requirement, so a dedicated climate control system was designed for the building. The new design utilised a two-stage compressor system, and the control software was designed so that cooling could automatically change from one-stage to two-stage operation depending on the cooling requirements. This enabled components to be used for each cooling stage that were optimised for higher or lower temperatures, increasing efficiency when compared to a single-stage system that had to function over the whole temperature range, and meaning that at higher temperatures the low-temperature part of the circuit could be switched off, saving further energy, while the high-temperature compressors alternated between high-stage and single-stage modes depending on temperature requirements. Additionally, the installed control system, from a USA-owned brand with little local support, was replaced with an Australian-based system, reducing servicing costs and lead-time for modifications.[54]

6. 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'.[55]

6.1. Energy Efficiency Exchange (EEX)

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. (See Resource)

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.[56] (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.[57] (See Resource)

6.2. 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.[58] (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.[59] (See Resource)

Demand Management Approaches to Reduce Rising 'Base Load' Electricity Demand: Over the last century in Australia electricity demand has doubled almost every 20 years. The aim of this lecture is to communicate how best to reduce base load in Australia. This lecture is heavily based on the research and papers of Adjunct Professor Alan Pears (with permission).[60] (See Resource)

Demand Management Approaches to Reduce Rising 'Peak Load' Electricity Demand: Pursuing energy efficiency opportunities is a strong strategy to reduce peak load electricity demands and the need for new energy supply and infrastructure. This lecture outlines what can actually be done to reduce peak electricity demand.[61] (See Resource)

7. 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] 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.

[3] Strategic Lighting (Undated) *Projects,* Strategic Lighting-Specialist Lighting Engineers, http://strategic-lighting.com/projects, viewed 7th April 2014.

[4] 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.

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

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

[7] 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.

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

[9] 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.

[10] 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.

[11] 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.

[12] 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.

[13] 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.

[14] 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.

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

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

[17] 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.

[18] 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.

[19] 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.

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

[22] 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.

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

[24] 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.

[25] 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.

[26] 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.

[27] 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.

[28] 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.

[29] 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'.

[30] 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.

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

[33] 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.

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

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

[36] 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

[37] Carbon Trust (2006) *Heating, Ventilation and Air Conditioning (HVAC): Saving Energy without Compromising Comfort*, Queen's Printer and Controller of HMSO. Available at http://www.carbontrust.co.uk/publications/publicationdetail?productid=CTV003. Accessed 8 October 2007.

[38] Sustainability Victoria (2006) *HVAC Tips (Heating, Ventilation and Air Conditioning),* Sustainability Victoria.

[39] Jacobs, P. (2003) *Small HVAC System Design Guide: Design Guidelines*, California Energy Commission, p 63.

[40] Jacobs, P. (2003) *Small HVAC System Design Guide: Design Guidelines*, California Energy Commission, p 63.

[41] Jacobs, P. (2003) *Small HVAC System Design Guide: Design Guidelines*, California Energy Commission, p. 63.

[42] Architectural Energy Corporation (n.d.) *Design Brief: Integrated Design for Small Commercial HVAC*, Energy Design Resources, p. 17.

[43] Sustainability Victoria (2006) *HVAC Tips (Heating, Ventilation and Air Conditioning),* Sustainability Victoria.

[44] Architectural Energy Corporation (n.d.) *Design Brief: Integrated Design for Small Commercial HVAC*, Energy Design Resources, p 15.

[45] Australian Greenhouse Office (2003) *Reference Manual – Motor repair and replacement*, AGO, Australia.

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

[47] 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.

[48] Port of Brisbane 2010, *Development Outcomes Fact Sheet,* Port of Brisbane, Pty Ltd, Brisbane, Australia

[49] Port of Brisbane 2010, Port Office *Fact Sheet,* Port of Brisbane, Pty Ltd, Brisbane, Australia

[50] Zero Waste SA 2012, *Up Close,* Government of South Australia.

[51] Pangolin Associates (2012) *Case Studies: RM Williams,* Pangolin Associates.

[52] Energy Wise 2013, *RM Williams Case Study,* Pangolan Associates.

[53] Office of Environment and Heritage 2012, *Case Study: Swire Cold Storage,* New South Wales Government, Australia.

[54] Minus40, 'Case Studies', http://www.minus40.com.au/case-studies\, accessed 28 November 2014

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

[56] Energy Efficiency Exchange 2014, 'Heating ventilation and Cooling', http://eex.gov.au/technologies/heating-ventilation-and-air-conditioning/, accessed 28 November 2014

[57] Energy Efficiency Exchange 2014, 'Motors and Motor Systems', http://eex.gov.au/technologies/motors/, accessed 28 November 2014

[58] Smith, M., Hargroves, K., Stasinopoulos, P., Stephens, R., Desha, C. and Hargroves, S. (2007) Energy Transformed: Sustainable Energy Solutions for Climate Change Mitigation – Lecture 2.3, The Natural Edge Project, CSIRO, and Griffith University, Australia.

[59] Smith, M., Hargroves, K., Stasinopoulos, P., Stephens, R., Desha, C. and Hargroves, S. (2007) Energy Transformed: Sustainable Energy Solutions for Climate Change Mitigation – Lecture 3.1, The Natural Edge Project, CSIRO, and Griffith University, Australia.

[60] Smith, M., Hargroves, K., Stasinopoulos, P., Stephens, R., Desha, C. and Hargroves, S. (2007) Energy Transformed: Sustainable Energy Solutions for Climate Change Mitigation – Lecture 4.3, The Natural Edge Project, CSIRO, and Griffith University, Australia.

[61] Smith, M., Hargroves, K., Stasinopoulos, P., Stephens, R., Desha, C. and Hargroves, S. (2007) Energy Transformed: Sustainable Energy Solutions for Climate Change Mitigation – Lecture 4.2, The Natural Edge Project, CSIRO, and Griffith University, Australia.