Flexible Delivery Flat-Pack Module

An Overview of Energy Efficiency Opportunities in Civil 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

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Queensland University of Technology

The University of Adelaide

Victoria University Melbourne Australia

RMIT University

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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

Civil Engineers will be a key part of the World's response to climate change, from reducing the embodied energy and energy intensity demands of roads, to designing to embedding renewable energy generation options into of civil infrastructure. Civil Engineers have critical skills the economy needs to thrive in a carbon constrained future. The following learning points provide a summary of the Civil Engineering video – our 'Allen keys' to building the flat-pack content!

Watch the '***Civil Engineering***' MMB

1. With climate change accelerating, Civil Engineers will play a key role in society's response because they will be called upon to design, retrofit, and adapt infrastructure to withstand the various impacts of climate change, while delivering significant reductions in greenhouse gas emissions. These considerations will affect the design, construction, operation and decommissioning of infrastructure such as buildings, roads, bridges, dams, and treatment plants.

2. When considering civil infrastructure it is important to consider opportunities for emissions reduction in each of these stages. Of particular importance is the operational phase since by considering the full life cycle of the infrastructure it is often that this is where the case that bulk of the emissions associated with civil infrastructure are generated; including the embodied energy of materials used, electricity needed for the operation of buildings, and fuel used for the running of vehicles on roads.

3. The design phase is a critical stage in the development of civil infrastructure as this not only influences practices in the construction phase can reduce operational greenhouse gas emissions and energy demand by: minimising the amounts of energy intensive materials needed by using recycled aggregates or low carbon cement; using daylighting and smart sensors to reduce lighting and HVAC requirements in buildings; and designing road alignments to reduce fuel consumption.

4. Conducting an energy efficiency assessment doesn't have to be a complicated process. It's a matter of looking at every aspect of energy use and asking '*What can I do better?*', '*What can I do cheaper?*', and '*What can I do more efficiently?*'. There is an increasing amount of information available to assist professionals to be able to make these judgements. Being able to work alongside and communicate with interdisciplinary teams is very important as it is often the case that such collaborative efforts stand to deliver the greatest energy efficiency improvements.

5. Construction, mining, and engineering services company Thiess has been using Energy Efficiency Action plans for several years to help them *identify, evaluate,* and *implement* energy efficiency solutions. In developing the action plans, engineers identify opportunities that are likely to save time and money for the client or that deliver greater value for the business, as well as benefit society. For instance in the design phase engineers considers the choice of materials that may have lower embodied energy, such as geo-polymer concrete that has between 50-70% less greenhouse gas emissions than normal concrete.

2. Energy Efficiency and Civil 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]

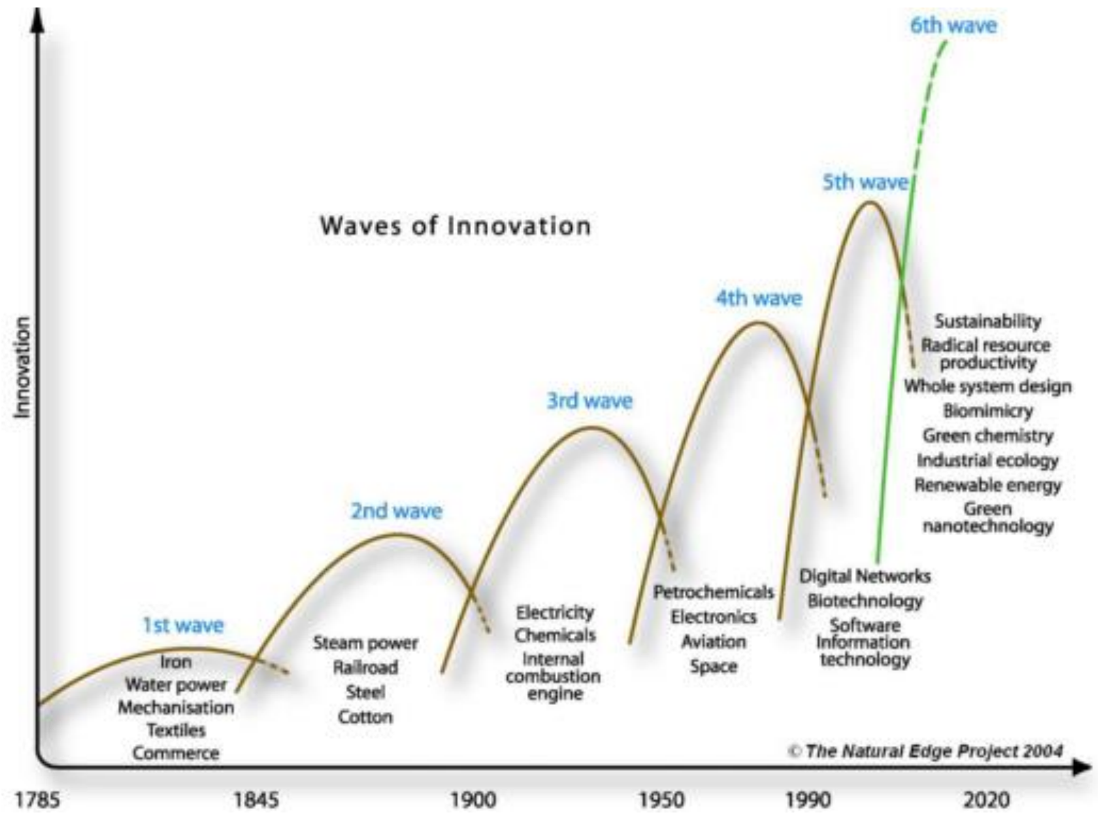

Figure 1: A stylistic representation of waves of innovation since the Industrial revolution[5]

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 civil 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 Civil Engineers reduce greenhouse gas emissions?

How could energy efficiency provide benefits to a Civil 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*'.

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.

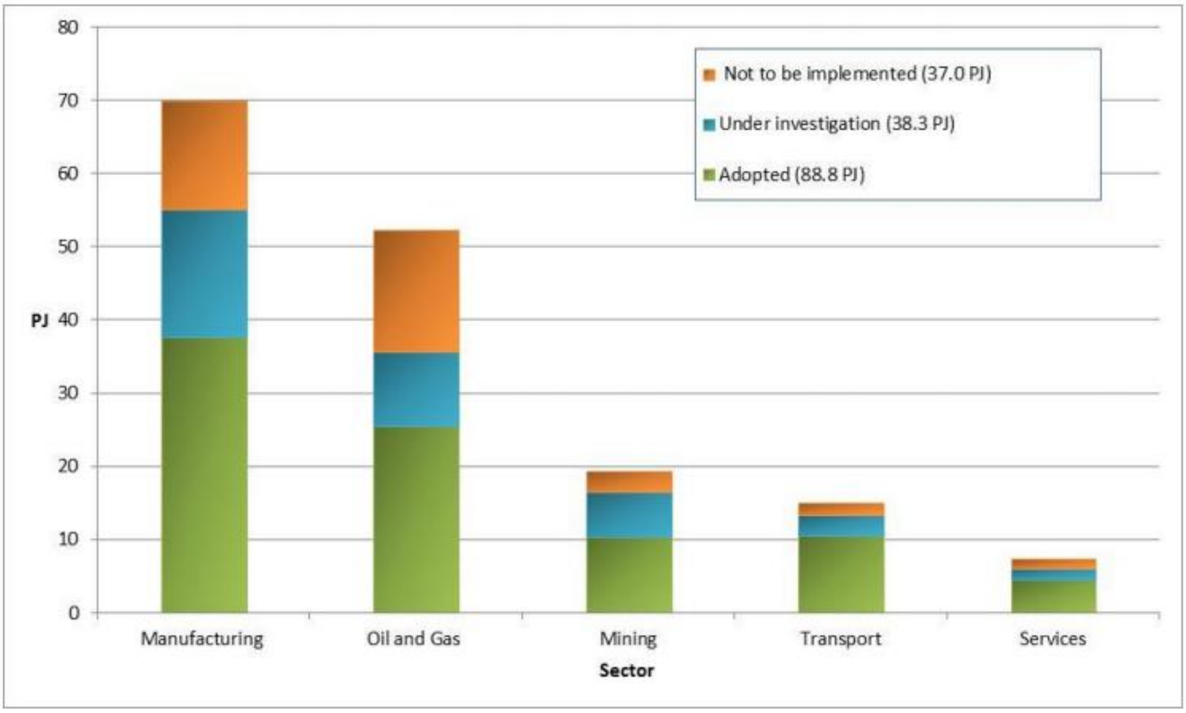

Figure 2: Summary of energy efficiency achievements in by participants in the Australian Government Energy Efficiency Opportunities (EEO) program (2006-11)[32]

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

3. Key Knowledge and Skills for Civil Engineers

According to the Institution of Civil Engineers, '*Civil engineering plays a crucial role in creating the infrastructure needed for modern life around the world. Practitioners in the civil engineering sector apply knowledge and experience to create projects that meet human needs and clean up environmental problems*.'[35] Civil Engineering can offer a great deal to society to increase the energy efficiency of infrastructure, and reduce the associated greenhouse gas emissions, for instance by designing:

- Buildings with low embodied energy materials and optimal use of materials
- Buildings with optimised energy demands, contributed to by onsite generation,
- Buildings that can be repurposed for multiple uses during or at the end of each use,
- Structures that can be easily disassembled to allow greater recycling rates,
- Roads that use greater levels of recycled materials, reduce vehicle fuel demand, and generate energy,
- Homes that are super insulated to minimise HVAC and harness passive heating and cooling,
- Transport systems that allow for multi-modal flexibility.

In Civil Engineering, energy efficiency considerations could include:

- Design to minimise material use and incorporate low embodied energy materials

- Ensuring quality and durability of materials used in built environment (reduces frequency of need to replace them) ,
- Consideration of energy flows through materials, such as thermal bridging effects and use of insulating materials,
- Ensuring a building project complies with green star rating system (including the effect that the development would have on its surrounding environment),
- Investigating available and emerging methods of heat/ energy recovery,

Research by the Sustainable Built Environment National Research Centre (SBEnrc) has found that there are five key areas in which roads can improve energy efficiency and respond better to climate change, namely: road design, aggregates, asphalt, concrete, and road lighting. As Figure 2 shows there are a number of new knowledge and skills that will be required for Civil Engineering graduates to deliver such opportunities. The research project identified numerous examples of leadership in each of these areas, including the following as shown in Figure 2:[36]

- *"Design*: Developed in 2006, JOULESAVE is a widely used European software that allows the road designer to rapidly quantify the energy requirements for all phases of road construction and to compare different options. To date, the software has shown that energy savings of up to 47 per cent in road construction, up to 20 per cent in the operational life of a road, and up to 30 per cent in maintenance are possible in many road projects.
- *Aggregates*: Testing by the City of Kwinana and Western Australian Main Roads found that a one kilometre stretch of Gilmore Avenue constructed with recycled concrete aggregate performed

better than a control road nearby made from non-recycled materials. This is supported by testing in Victoria by ARRB which found that on a particular project the life expectancy of the virgin rocks was 5 years and the strength was 270 MPa, compared to recycled crushed concrete which had a life expectancy of 441 years and a strength of 3,500 MPa.

- *Asphalt*: Bitumen is 100% recyclable. Reduced need for virgin bitumen reduces the demand for extraction and transport of crude, the refining of oil, and the transport of bitumen to an asphalt plant. According to Australian Asphalt Pavement Association CEO John Lambert, industry in Australia should be aiming to recycle 100 per cent of all asphalt pavement produced. Japan has been recycling asphalt pavement since the 1970s, and has a recycling rate of over 98%.
- *Concrete*: The Olympic Delivery Authority for the 2012 London Olympic Games stipulated in construction tenders that carbon footprint reductions would account for 25 per cent of the tender evaluation, resulting in a concrete with a 43 percent lower carbon intensity being selected, the '2012 Mix'.
- *Lighting and Signals*: Between 2001 and 2009 the New York City Department of Transportation converted nearly all of its traffic signals to LED. This generated annual energy savings of 81% and energy and maintenance cost savings of approximately US$6.3 million a year. According to the Transport Authorities Greenhouse Group Australia and New Zealand, over a 50 year period, an intersection on an undivided road is estimated to consume 1,346,000 kWh if incandescent lighting is used or 208,000 kWh if LED lighting is used. This equates to 310 – 1,840 t CO_2-e for incandescent lighting and 50 – 280 t CO_2-e for LED lighting." LED energy efficiency is continually improving, so further savings can now be captured.

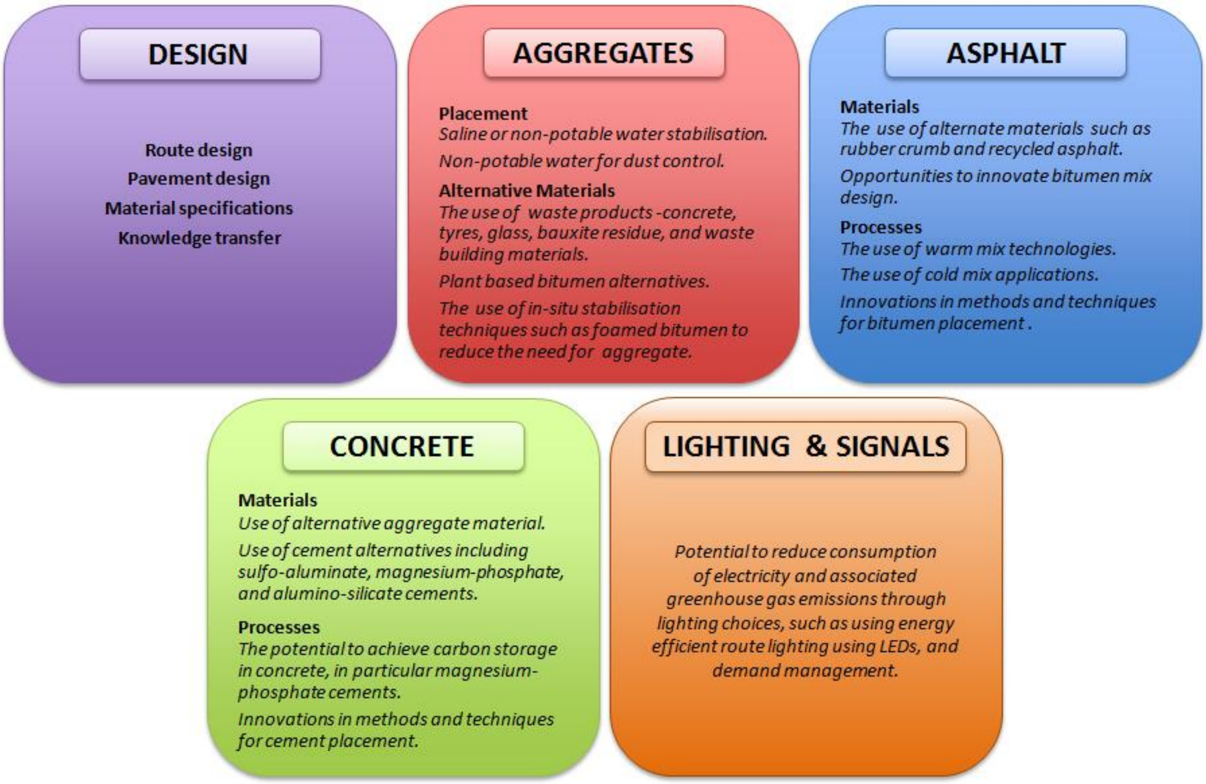

Figure 2: Options for reducing environmental pressures related to roads[37]

4. Energy Efficiency Examples in Civil Engineering

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

4.1. Future of Roads[i]

The following is an extract of findings by the lead researcher from the Sustainable Built Environment National Research Centre, developed by Curtin University Sustainability Policy Institute and supported by Main Roads Western Australia, QLD Department of Transport and Main Roads, NSW Department of Roads and Maritime Services, and John Holland Group.

Roads are vital to the Australian economy and cover more than 814,000 kilometres, with some 157,000 kilometres being state-controlled. Current practices are often very efficient and seek to minimise costs related to construction and maintenance, including balancing earthworks to optimise cut and fill, utilising local sources to minimise the import of materials, using stabilising additives to adapt local marginal materials, and optimising pavement thickness for anticipated conditions and loads. There is now a wealth of evidence and precedent to show that road projects can improve sustainability outcomes through all phases, namely: design, construction, maintenance, and operation. For instance, the design phase provides significant opportunity to design roads that dramatically reduce vehicular emissions through pavement smoothness and alignment. A particular challenge is that of reducing the generation of greenhouse gas emissions in road construction, a challenge heightened by likely increases in prices of traditional aggregates and pavement options due to resource shortages and increasing transport costs across Australia.

In the coming decades the design, delivery, and maintenance of roads will be increasingly influenced by issues related to sustainability, presenting a range of opportunities for new and improved approaches. An example of this is the impact of increasing fossil fuel costs coupled with now ambitious international targets for greenhouse gas emissions reductions, which will require new thinking and strategies. Given that roads typically have a design life of 20 to 40 years, with bridges being designed for up to 100 years, the energy efficiency of civil projects needs to be carefully considered in the design stage. Road building is inherently an efficient practice that seeks to minimise costs related to construction and maintenance, with a range of practices that can be called upon as the basis of strategies to address current and future environmental issues.[38]

Just as the past decade has seen a focus on the footprint and alignment of roads to minimise ecological disturbance, coming decades will see a significant focus on responding to climate change. For example, alternative road base materials may provide opportunities for reducing greenhouse gas emissions, such as a shift from Portland cement to geo-polymer compounds;[39] roads may be designed to enable electricity generation through capturing solar, wind or kinetic energy; the electricity consumption of route and signal lighting can be significantly reduced using new lighting technologies; and congestion can be reduced on highways and motorways through the use of communication technology.[40]

[i] This section is an extract by the lead author of 'SBEnrc (2012) *The Future of Roads: How road agencies are facing a conflicted future,* Sustainable Built Environment National Research Centre (SBEnrc), Curtin University and Queensland University of Technology'.

Lower Embodied Energy Materials

Within the construction phase the most sizeable reductions in carbon intensity can be gained by altering the materials used in road construction, including aggregates, asphalt, steel and concrete. An example of the breakdown of emissions in the construction phase is shown in Figure 3 for the Mickelham Road Duplication Project in Victoria.

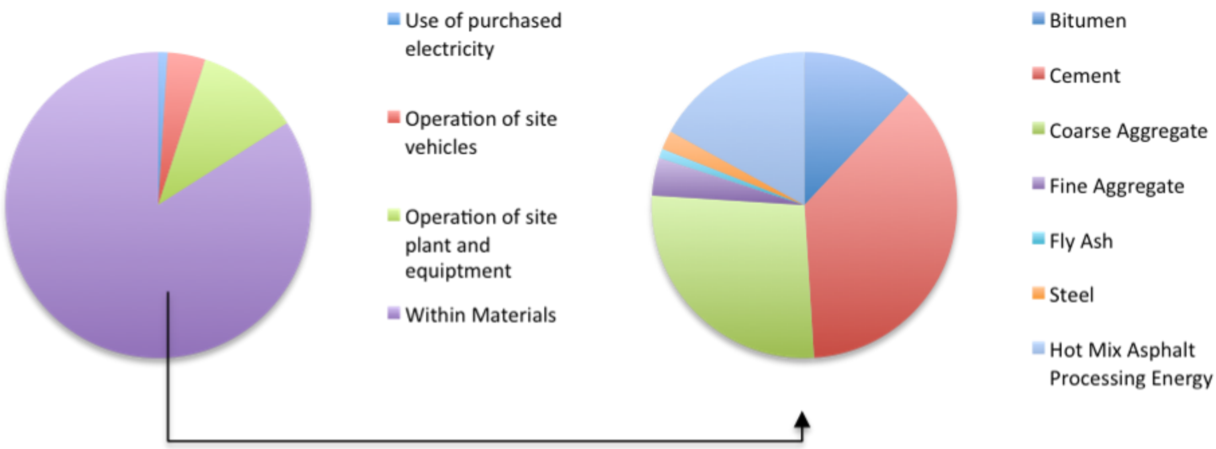

Figure 3: Relative greenhouse gas emissions sources during construction of the Mickelham Road Duplication Project in Victoria. *Source*: Humphrys, T. (2011)

Sourcing of lower embodied energy aggregates results in less mining and crushing energy demand and can be sourced closer to site to reduce hauling fuel consumption, such as a range of recycled and alternative products. A partnership between the Australian Road and Research Board (ARRB) and Engineers Australia was formed to create '*guidelines for making better use of local materials*'. The guidelines investigate the performance of 50 soil types across Australia, using a national materials register developed by the Queensland road agency prior to 1991. Local pavement materials are typically naturally-occurring weathered rocks, ridge gravels, stream gravels, sands and clays which are close to site and can be obtained and placed by readily available construction equipment. The guidelines highlight that a '*variety of materials, loams, soft sandstones, natural gravel, decomposed rock and industrial residuals have been and are being successfully used where traffic is not too heavy.*' Guidance is given on how to treat a soil for particular use as a sub-base or base course, or as a wearing course in the case of unsealed roads.

In Australia, there are a number of States with specifications and guidelines that regulate the use of recycled materials in roads, including:

- *Queensland:* The 2010 'MRS35 – Recycled Materials for Pavements' specifies stringent requirements that suppliers must consistently meet before providing recycled road base.
- *Western Australia:* The 2010/11 'Pavement Specification 501' specifies that alternative materials such as recycled materials and crushed glass must meet criteria equivalent to crushed rock.
- *New South Wales:* The 2001 'Specification for Supply of Recycled Materials for Pavements, Earthworks and Drainage' covers crushed concrete, brick and reclaimed asphalt blends.
- *Tasmania:* The 2011 Tasmanian road construction specifications include the use of recycled materials in the production of asphalt and for use as aggregates.

– *Victoria:* The 2011 'Sustainable Procurement Guidelines' from VicRoads specifies where recycled materials can be sourced from and the quality that is required.

Low Carbon Cements: Geo-Polymers[ii]

Geopolymer concrete is an alternative technology that can demonstrate significant reductions in carbon emissions compared to Portland cement, in the order of 45-80 per cent.[41] The US Federal Highway Administration have recently reported that '*the production of versatile, cost effective geopolymer cements that can be mixed and hardened essentially like Portland cement would represent a game changing advancement*'.[42] Geo-polymers utilise waste materials (including: fly ash and bottom ash from power stations; blast-furnace slag from iron-making plants; and concrete waste), to create alkali-activated cements. It demonstrates strong engineering performance, comparable to that of Portland cement concrete in structural applications. Geological resources for the feedstock are available on all continents, and recent studies of its use in the 1960s and 1970s in Ukraine and Russian buildings reveal it has better durability than Portland cement.[43] The manufacture of alkali activated binders omits the need for the bulk of the material to be processed in a kiln, thus greatly reducing greenhouse gas emissions. Only the silicate activator component (typically less than ten per cent of the binder mix) is super-heated in kilns, and a high proportion of industrial by-products, including fly ash and metallurgical slags, are added to complete the binder mix. In 2011 the Concrete Institute of Australia released a report that recommended the use of geo-polymer concrete by the construction industry.[44]

Australia is now among the world leaders in research and commercialisation of geo-polymer cement. After two decades developing the technology, University of Melbourne researchers formed Zeobond Pty Ltd in 2006 to commercialise it. They have created a new product called E-Crete that forms at room temperature, requires no kiln and uses industrial by-products as the main feedstock. The product looks similar to and performs in the same ways as Portland cement concrete. According to Zeobond Business Manager, Peter Duxson, '*As the scale of commercialisation is increased and more is invested in the supply chains, we expect the costs of making geo-polymer cements to come down significantly*'. [45] In February 2011, Queensland based Wagners introduced an innovative premixed concrete product that utilises geo-polymer binder technology. Winner of the 2011 Queensland Premiers ClimateSmart Sustainability Award the 'Earth Friendly Concrete' or EFC is reported to reduce the greenhouse gas emissions of a standard house slab and footings by just over 9 tonnes. Considering the number of slabs poured per year in Queensland this would represent nearly 275,000 tonnes a year of reduced greenhouse gas emissions compared to the use of Portland cement. [46]

[ii] This part is based on research findings from the 'SBEnrc (2012) *Reducing the environmental impact of road construction*, Sustainable Built Environment National Research Centre, Curtin University Sustainability Policy Institute and Queensland University of Technology'.

4.2. Harnessing road and transport infrastructure to generate electricity[iii]

The following is an edited extract of findings by the lead researcher from the Sustainable Built Environment National Research Centre, developed by Curtin University Sustainability Policy Institute and supported by Main Roads Western Australia, QLD Department of Transport and Main Roads, NSW Department of Roads and Maritime Services, and John Holland Group.

A key way to increase the energy efficiency of roads is to generate renewable energy onsite to power lighting, rather than drawing electricity from the grid which is predominantly generated using fossil fuel. Much progress has been made to date to demonstrate feasibility of incorporating renewable energy into road infrastructure, as the following summaries will demonstrate (such as tidal and wave power associated with bridges, solar and wind power associated with road easements and structures, thermal power associated with pavements, etc.). Note that the use of solar panels as road surfaces is not covered as it is yet to be shown to be technologically or economically viable.

Harnessing Solar Energy in Road Easements and Structures

There are a growing array of options for incorporating solar energy generation into roads and pavements as demonstrated in the following case studies.

- *The Solar Highway Program (Oregon, USA)*: In 2008 a 1.75 MW solar array, containing just under 7,000 solar panels, was installed in the easement of Interstate 5 south of Wilsonville by the Oregon Department of Transport, shown in Figure 4. The primary value of the system is to provide electricity for the highway lighting, and it also generates renewable energy certificates.[47]

Figure 4: Oregon Solar Highway Project, 2008

Source: Solar Highway Program: From Concept to Reality, August 2011[48]

- *Photovoltaic Noise Barriers (PVNB):* Along with the use of easements an obvious place to consider the use of solar power is as part of the structure of noise reduction screening along roadways, such as along the A22 Autostrada at Brennero in Italy shown in Figure 5. According to World Highways in 2014 the energy generated from such structures can, '*help reduce the life-cycle cost of noise reduction devices by up to 30%.*'[iv]

[iii] The following is an extract of findings from the SBErnc presented in 'Hargroves, K,. Beattie, C., Wilson, K., Newman, P,. Matan, A., and Desha, C. (2014) *Key Opportunities for the Future of Roads to Contribute to Australia's Climate Change Response*, Engineers Australia National Convention 2014.'

[iv] Bellucci, P. (2014) Photovoltaic finish to road noise pollution, World Roads, 2014

Figure 5: A photovoltaic noise barrier installed along the A22 Autostrada at Brennero in Italy. *Source*: World Highways.

- *Solar Thermal:* Given that roads in Australia absorb heat during the day this heat may be able to be harnessed to create electricity. It has been suggested that this may be done by either running pipes through the hot asphalt or cement to heat water or installing thermoelectric wiring within the asphalt surface. A paper published in 2006 suggested that not only can heat be extracted for energy generation using thermoelectric generation techniques, but this will also lead to a reduction in the temperature of road surfaces, increasing operational life of surfaces.[v]

Figure 6: The use of pipework to extract heat from road surfaces for energy generation using aquifer heat exchangers in the Netherlands.
Source: Ooms Avenhorn Holding

Harnessing Energy from Vehicle Movement

There are a number of ways to harness vehicle movement to generate electricity in road infrastructure as demonstrated in the following case studies.

- *Wind Power*: As with solar power, road easements and structures may be suitable for the installation of wind power generation technologies. However a report by VicRoads published in 2013 presented findings of an investigation into the use of wind turbines to harness natural wind in road easements and found them to be unfeasible at this scale, in the order of 20kW. The report conclude that '*micro wind turbines not be considered as a method to generate renewable energy in Victoria unless it can be shown that a major saving in grid connection costs can be*

[v] Hasebe, M., Kamikawa, Y., Meiarashi, S., (2006) 'Thermoelectric Generators using Solar Thermal Energy in Heated Road Pavement', Thermoelectrics, 25th International Conference, 6-10 Aug. 2006.

achieved'.[vi] Hence it may not be feasible to rely on natural wind for wind energy generation, however there is another source of wind associated with roads that can be harnessed – that of moving vehicles, as shown in Figure 7.

Figure 7: Examples of wind generation systems that harness air movement from passing traffic

− *Piezoelectric Generators:* Along with the wind generated by vehicle movement energy may be able to be harnessed from the movement of vehicles and the pressure created in road surfaces, as shown in Figure 8.[vii] This concept, referred to as the 'Piezoelectric Effect', was discovered by the Curie's in 1880, when they found that strain or deformation of a piezoelectric material causes charge separation across the device, producing an electric field which can generate an electric current. There is currently ongoing research on the principles behind the effect, and the practical application to harnessing vehicle energy is in its early stages.

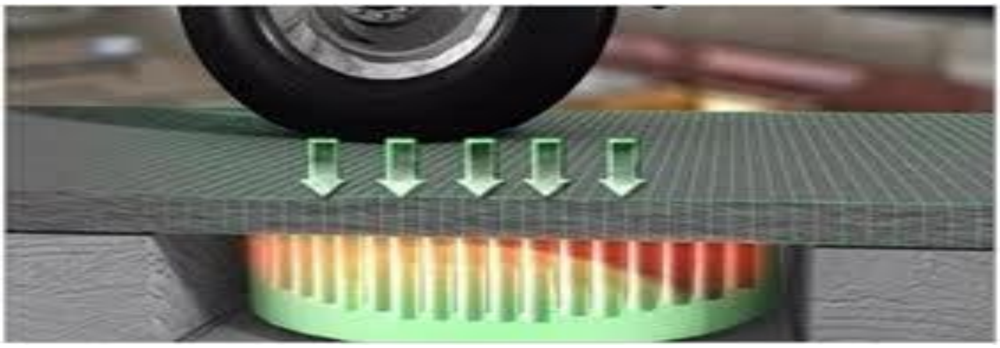

Figure 8: Piezoelectric device located under road surface
Source: Abbasi, A. (2013)

Upgrading lighting technologies and practices to save energy

LED lighting for streets and parks is now widely acknowledged as a viable energy saving option for the future of roads and is being utilised around the world. According to a strategy paper by the Australian, State and Territory and New Zealand governments, '*Street lighting is the single largest source of greenhouse gas emissions from local government, typically accounting for 30 to 60 per cent of their greenhouse gas emissions… The major lighting types are mercury vapour (12% of major road lighting national numbers – down from 25% in 2002/3) and high pressure sodium (86% of national*

[vi] VicRoads (2013*) Renewable Energy Roadmap*, VicRoads, July 2013.
[vii] Abbasi, A. (2013) 'Application of Piezoelectric Materials in Smart Roads and MEMS, PMPG Power Generation with Transverse Mode Thin Film PZT', *International Journal of Electrical and Computer Engineering* (IJECE), Vol. 3, No. 6, December 2013.

numbers – up from 75% in 2002/3)'.[49] There is a growing number of international case studies of significant value being created for governments that seek to rapidly retrofit street lighting to new technologies, such as a 2009 study from the United States that found that for a 10km stretch of double lane highway, with poles located 30 meters apart, using LED lighting over the conventional mercury lights would reduce as much as 75% of energy consumption with a payback period of 2.2 years, that is increased to 3.3 years if the LED's are powered by onsite solar energy.[50]

More recently the mayor of New York City, Mayor Bloomberg, announced that the city plans to replace all 250,000 high pressure sodium streetlights with LED's over a three year period.[51] Such projects are contributing to an expected rapid increase in the roll-out of LED's in streetlights globally, anticipated to rise from less than 3 million in 2012 to more than 17 million in 2020.[52] In 2008 the City of Los Angeles began a 4 year process to replace 141,089 streetlights with LEDs, becoming the largest retrofit of street lighting in the world, with staggering results in the amount of night light across the city, as shown in Figure 9. The program has a payback period of 7 years and following this the city estimates that it will benefit from some $10 million/year in savings in electricity and maintenance costs, while reducing greenhouse gas emissions by 47,583 tons/year.[53]

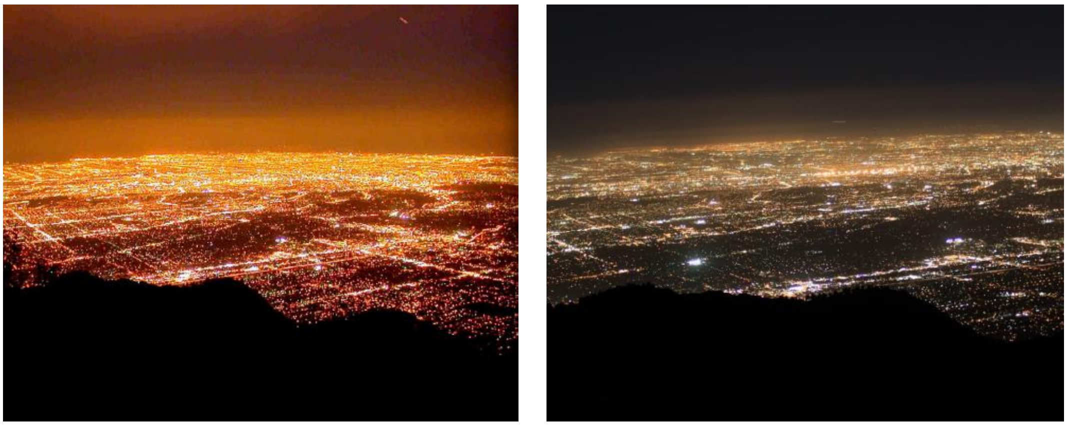

Figure 9: Los Angeles Basin View from Mount Wilson Before and After the Retrofit

In Australia, the City of Sydney has installed 2,600 LED street and park lights and is planning to replace a further 6,500 over the next three years, and the City anticipates saving $800,000 per year. A public survey revealed that over 90% of participants though the LED lighting was appealing and 75% thought that they improved visibility.[54] In Western Australia Main Roads WA has a rolling program, upgrading traffic signal lanterns with LED lamps, which started in 2012. Thus far 670 traffic signal controlled intersections have been upgraded to LED lamps with a further 50 planned for 2014. The overall cost savings from operation and maintenance is projected to be in the order of 71%. In addition, key environmental benefits will include a saving of 320 tonnes of GHG emissions annually and a reduction of materials sent to landfill due to the longer life of the lamps.

5. A Case Study of Energy Efficiency in Civil Engineering

Building on the multi-media bite on Civil Engineering and energy efficiency the following example provides further details on the energy efficiency improvements related to Civil 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. Downer EDI

Large industrial processes typically offer significant opportunities for improving efficiency, saving energy and money simultaneously. As the subject of a case study, a company like Downer, in the transport infrastructure industry, can demonstrate many of the important factors to consider in improvement of industrial efficiency, as they work through a process stream from production of road asphalt, through transport, to the construction and maintenance of roads. They provide a number of good examples of ways in which efficiencies can be found; ranging from assessment of single components or inputs in existing systems, through upgrades to site infrastructure and assessment of equipment efficiency, to fundamental process alterations when technology progresses. According to Downer's 2010 Sustainability Report, '*The longevity of our organisation is contingent upon our capability to deliver environmental sustainability across our operations and those of our clients. To create a platform for future growth, we continue to seek opportunities to improve our own resource efficiency, and to be innovative in the technologies and services that we provide to our clients'*.[55]

The Challenges

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

1. The Alice Springs road crew depot use mobile camp generators in remote areas where reliability is paramount. The management called for a review of the energy demands of the generators to identify potential energy savings.
2. Asphalt plants represent a significant amount of energy demand for Downer EDI and similar road construction companies. The management called for the development of a benchmarking system to investigate the potential for reducing the energy demand of the asphalt plants.
3. Asphalt plants also require large quantities of binder and aggregates that is typically sourced from virgin sources. The management called for an investigation into alternative sources of asphalt feedstock's to identify possible reductions in embodied energy of input materials.

The Solutions

1. A performance assessment was carried out on a smaller, more energy-efficient generator set, which provided 35kVA rather than the 55kVA of the standard generators, and it was determined that changing over to the smaller generators would work, if the crews using them could sequence tasks for optimum power utilisation whilst operating from the generators. The smaller generators were brought into service, and saved 35,000 litres of diesel per annum, and resultant energy savings of 1,350 GJ per year.[56] Another study into mobile camp power usage identified that a change of power source, in this case to solar power for the lighting towers used for night

work, would save 6,000 litres of fuel per tower, eliminating the diesel usage, and the requirement to transport the fuel for the towers.[57] As battery technologies improve, the potential to use storage to optimise loading of diesel generators, and to utilise solar or wind energy, is enhanced. Optimising end-use energy efficiency also allows for reduction in size and capital cost of generation plant. Heat recovery systems to generate additional electricity (eg using the Kalina cycle) or provide heat for processes are also becoming increasingly economic.

2. As efficiency improvement is not a one-off task, continuous improvement of processes can deliver significant savings in both cost and energy, as in the case of Downer's energy benchmarking program. A benchmarking program was created to examine asphalt plant burner fuel use across the Downer's production facilities in order to make comparisons between different plants and highlight areas of potential improvement. Examples of the potential improvements identified include: enhancing communication between the plant operators and road surfacing crews; improving work scheduling resulting in higher production efficiency, reduced plant wastage, and reduced returned asphalt; improving moisture control in raw materials – lower moisture content corresponds to reduced energy requirements in the drying process, and therefore lower burner fuel use; and the replacement of burner fuel at the company's Wodonga site, which originally required preheating to 67°C, with a fuel that ignited at ambient temperature, eliminating the need for a heat exchanger in the process. As a result of the benchmarking program, Downer saved 24,300 GJ of energy, and $300,000 in energy costs, in 2008/9 when compared to 2007/8, and 28,000 GJ of energy in 2009/10 when compared to 2008/9.[58]

3. Downer has adopted new production processes for their asphalt to create Ecophalt that incorporates 'Recycled Asphalt Product' (RAP) into the process. RAP consists of asphalt that is past its service life and is already removed from roads requiring resurfacing,[59] and has until recently been disposed of as landfill, and the use of this product in Downer Ecophalt not only reduces waste, but also means that new binder and aggregate are required in significantly lower volumes – in 2009, Downer replaced 122,000 tonnes of new aggregate, and 6,100 tonnes of new binder with 136,000 tonnes of RAP, saving energy and emissions associated with the manufacture of aggregates and bitumen.[60] Ecophalt is also warm asphalt mix (WAM) rather than conventional hot-mix asphalt WAM, and can be laid at lower temperatures than conventional asphalt. The result is significant energy savings: the mix does not have to be kept as hot during production – 23% energy savings are achieved over standard asphalt mix; product storage and transport are at lower temperatures, meaning that it is more versatile; and the lower temperature improves safety for workers and the public when the asphalt is being laid. The change to new production facilities is not trivial – the cost of the project is $11.4 million, but the savings from reduced energy costs, at approximately $500,000 per annum over the life of the plant, mean that it is an investment worth making.[61]

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'.[62]

6.1. The Natural Edge Project (TNEP)

Designing a Sustainable Transport Future: This lecture seeks to explain the implications of world oil production peaking, as well as providing an overview of the low carbon options now available to reduce oil usage. This lecture suggests there needs to be an integrated approach to addressing both the need to reduce greenhouse gas emissions and oil dependency.[63] (See Resource)

6.2. The Sustainable Built Environment National Research Centre (SBEnrc)

The Future of Roads: In the coming decades the design, construction, operation, and maintenance of roads and transport infrastructure will face a range of new challenges and as such will require a number of new approaches. Such challenges will result from a growing number of interconnected environmental, social, and economic factors, which are set to apply significant pressure on the future of roads.[64] (See Resource)

Strategies and Solutions for the Future of Roads: Road agencies face growing pressure to respond to issues related to climate change, resource shortages, and shifting transport mode preferences. A key part of this response will be to reduce the dependency on fossil fuel based energy (and the associated greenhouse gas emissions) of transport infrastructure.[65] (See Resource)

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