Flexible Delivery Flat-Pack Module

An Overview of Energy Efficiency Opportunities in Biomedical Engineering

Produced by

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

The EEERE Project:

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

Consortium Partners:

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

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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

Biomedical Engineers will be a key part of the World's response to climate change, from the design of medical equipment to reduce energy demands while enhancing value to patient and medical staff, to working with other engineers to deliver integrated energy efficiency solutions for medical facilities. Biomedical Engineers have critical skills the economy needs to thrive in a carbon constrained future. The following learning points provide a summary of the Biomedical Engineering video – our 'Allen keys' to building the flat-pack content!

Watch the '***Biomedical Engineering***' MMB

1. There is enormous potential for Biomedical Engineers to contribute to improving energy efficiency of medical equipment and facilities in a manner that enhances patient health, safety, and quality of care. Meeting the needs of medical staff and patients while reducing energy requirements is a unique challenge for Biomedical Engineers who will need to draw on many disciplines of engineering to deliver solutions.
2. As with most designs, the early stages of a Biomedical Engineering project present the best opportunity to lock in energy efficiency improvements. It is important that the design team draws on a multi-disciplinary approach to maximise the outcome for the client while reducing its energy intensity.
3. It is important to consider whole of life costing for medical devices from product development through to use and disposal. For instance, by identifying opportunities to combine components during manufacture not only reduces the manufacture time and use of clean rooms, but can reduce costs and energy demand from packaging and transporting the previously separated items.
4. Biomedical Engineers have the opportunity to show leaderships by presenting innovative solutions that not only meet client needs, but do so with less energy involved in manufacture and use. There are opportunities to reduce energy intensity of medical equipment and facilities through process improvement and the use of new technologies, especially in cases where there is a new clinical need that has not been met before.
5. An example of the way that Biomedical Engineers are contributing to energy efficiency in Australia is via telemedicine services. This involves the integration of health technology with information technology to reduce the need for patients to travel to see a doctor, especially in the case of routine physical check-ups that can be done remotely. This service reduces the need for patients to travel to doctors for some types of consultations, and in many cases reducing the use of fuel for transport.
6. Numerous opportunities exist to reduce wasted energy and improve energy efficiency medical facilities, such as by redesigning and optimising equipment, HVAC systems, lighting, sterilisation equipment, and laundry facilities. Further the potential reduce the use of single use/disposable items can provide both energy efficiency improvements and physical waste reduction.

2 Energy Efficiency and Biomedical 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]

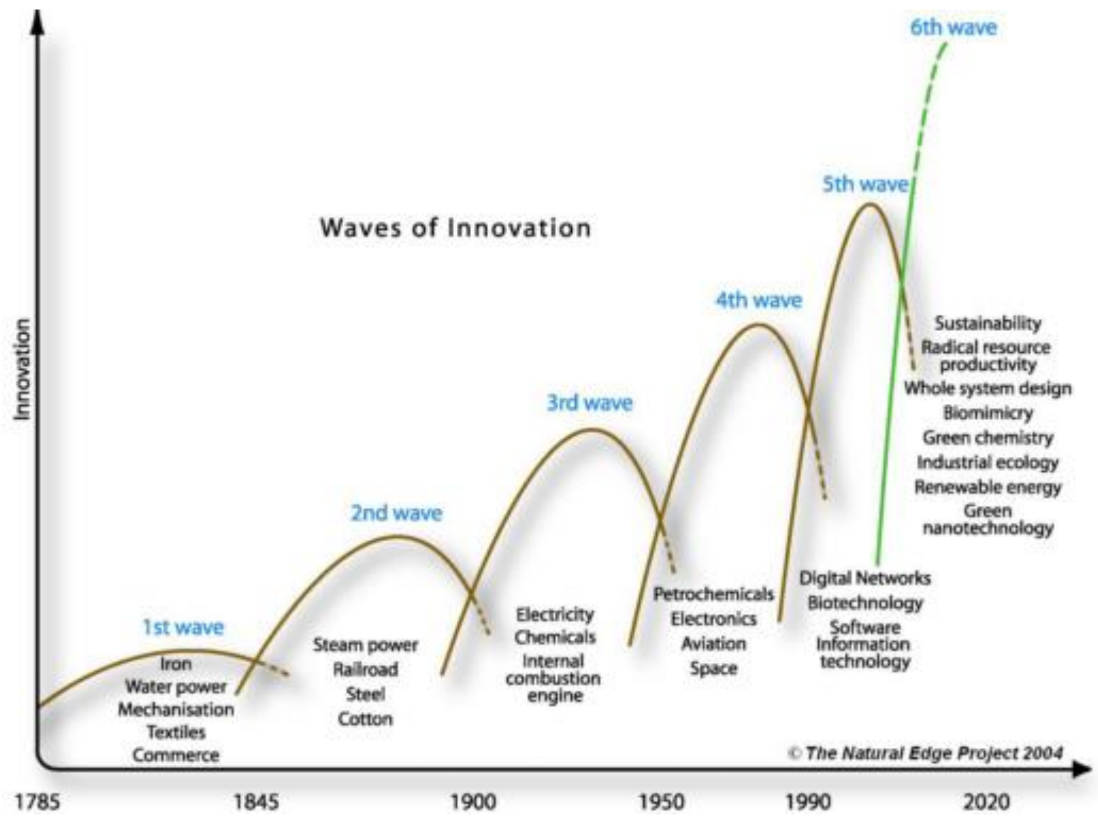

Figure 1: A stylistic representation of waves of innovation since the Industrial revolution[5]

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 Biomedical 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 Biomedical Engineers reduce greenhouse gas emissions?

How could energy efficiency provide benefits to a Biomedical 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.

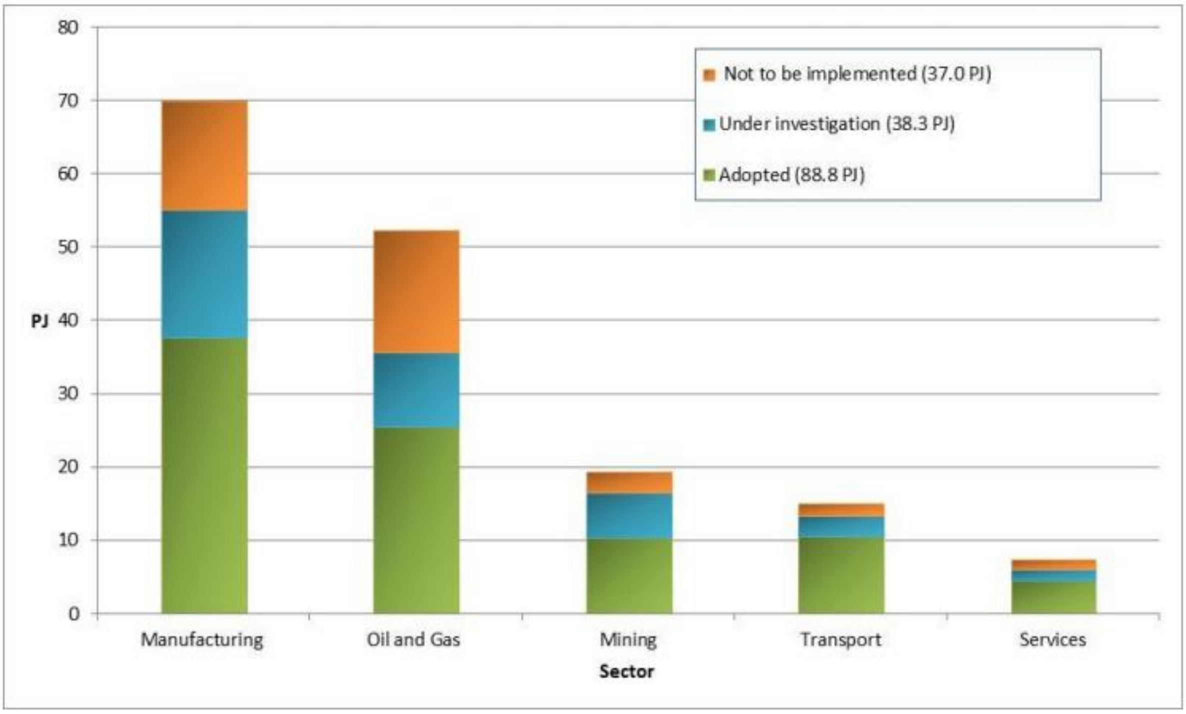

Figure 2: Summary of energy efficiency achievements in by participants in the Australian Government Energy Efficiency Opportunities (EEO) program (2006-11)[32]

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

2.3 Key Knowledge and Skills for Biomedical Engineers

Much like all engineers, Biomedical Engineers are required to meet the needs of the users of the equipment and facilities they create. However in the case of Biomedical Engineering these conditions can be quite specialised to ensure the health and safety of patients and medical staff, or to ensure conditions for diagnostic work. Hence in order to deliver improvements in energy efficiency it is important to be able to demonstrate that energy saving measures do not compromise medical outcomes – which may involve educating clients on the latest advances and options.

This discipline includes engineers from a variety of backgrounds, bringing together knowledge of electronic, mechanical, chemical, and materials science, with the life sciences of medicine, biology and molecular biology.[35] As such, there are a wide variety of activities, products and services that consume energy within the scope of 'Biomedical Engineering', from product research and development, material selection and manufacturing of the product, operation and maintenance of equipment, through to use and end-of-life recycling, re-use, and disposal. Given that attention to sustainability and particularly energy use continues to grow,[36] energy efficiency presents opportunities for Biomedical Engineers in research and practice. This is particularly topical in Australia given the issues around diagnostic integrity and longer-term maintenance of more than $1 billion worth of generally ageing medical technology equipment in the nation's hospitals.[37] A focus on energy efficiency in medical facilities also has the potential to assist in post-disaster response and development aid where energy supplies to run equipment may be limited and unreliable.

According to the 2012 Australian Biomedical Engineering Conference, Biomedical Engineering spans a number of significant streams of application including 'clinical', 'rehabilitation', 'biomedical impact' and 'biomedical technology aids'. Across these streams, efficiency related knowledge and skills being recognised by the international Biomedical Engineering community include new and 'greener' designs, operating procedures, research techniques, and waste minimization strategies.[38] This also includes the design and manufacture of implant devices with lower energy requirements along with the decontamination and recycling of waste products and hospital equipment. This presents a range of new opportunities for Biomedical Engineers in energy related areas such as:

- An understanding of the life-cycle of components for biomedical devices,
- Systems thinking applied to delivery of services, so that upstream and downstream energy waste can be avoided; for example, 'virtual' systems to deliver services via the internet, reduction in travel by medical staff, patients or their friends,
- Familiarity with the energy performance of new testing, diagnosis, and implant equipment (to help inform procurement choices),
- Considering end-of-life of products and materials (making reuse or material recovery and reprocessing more energy efficient),
- Considering options to avoid one-time-use devices that have high embodied energy through effective processes to clean and sterilise,
- Options for onsite renewable energy generation for energy intensive equipment,
- Advancement of technologies used in sterilisation, and
- Improving the energy efficiency of medical (e.g. hospital and clinic) environments.

The following are examples energy efficiency specific graduate attributes that will prepare students for delivering energy efficiency savings in practice:

- An understanding of energy efficiency opportunities in a hospital setting,
- An ability to develop a comprehensive cost-benefit analysis of energy saving options for hospitals and medical facilities, and
- Ability to undertake a ‘whole of life and operation’ cost-benefit analysis for procurement of new equipment.

3 Energy Efficiency Examples in Biomedical Engineering

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

Energy efficiency gains can be made throughout the field of Biomedical Engineering, from monitoring of existing processes to identify areas of potential improvement, improvement of existing infrastructure to prolong the life of existing equipment and reduce running costs and greenhouse gas emissions; through process innovation in areas such as new processing methodologies and inputs; to improvements in medical equipment which address public safety and reduce risks of failure.

3.1 Advanced Energy Management Information Systems

Sanofi Pasteur is the R&D and production facility for the global Sanofi pharmaceutical company, with over 90 buildings located in France; it is also the vaccines division, producing over 1 billion doses of vaccine each year for immunization of 50 million people across the world. To improve their energy auditing capability, the company installed an advanced energy management information system (EMIS), which enabled them to track and reduce energy consumption in line with their environmental policy. Sanofi Pasteur changed from measuring energy through separate metering devices for electricity, gas, and water, to a data consolidation process which allowed for comparative analysis and optimized energy performance across all installations. Staff could access real time energy consumption information in user-friendly formats on their PC or smartphone with the interface shown below, instead of disparately presented monthly data. This was done in 4 months through deployment of a cloud hosted EMIS using the existing infrastructure, with data presentation shaped by the user. Sanofi Pasteur found that one of the best ways to change behaviour was to give relevant information to users: the data offered ensured people understood the impact and options around their energy usage.[39]

Figure 2: Tracking energy usage graphically allows monitoring of the effects of process changes, and can highlight areas where improvements can be made[40]

3.2 Enhancements to Evaporation Process

TPI Enterprises processes poppy straw to manufacture alkaloids used in pharmaceutical products such as morphine and thebaine. The company is proactive in finding new solutions and operating methods, and is currently the only Australian manufacturer to use a water-based – rather than solvent-based – extraction process, which is not only cheaper but has a smaller environmental impact. As well as improvements to the extraction process, TPI Enterprises is looking to implement a more cost-effective and efficient evaporation system for processing the poppy straw.

Energy consumption through the use of natural gas, particularly to evaporate liquids, is a challenge than many pharmaceutical companies like TPI face when addressing ways to improve the efficiency of their production processes. This is an issue for the sector both in terms of operating costs (with rising energy prices), their emissions footprint, and the effect on their cost base in the face of the higher Australian dollar if they are exporters. These were the conditions under which TPI was looking for a way to reduce its energy consumption and cut power costs at its Cressy facility. As an export-focused operation, TPI needed to become more energy efficient due to all of the above circumstances. The company won a $353,650 grant from the Australian Government's Clean Technology Investment Program, and they will use this to implement a more cost-effective and efficient evaporation process, and also to fit a pre-evaporator to its current evaporator to enable capture and reuse of waste heat, and more efficient gas use in the evaporation process. Dr Russell McGifford, Technical Manager at TPI Enterprises, says that TPI expects the $707,300 project will reduce the carbon emissions intensity of its existing evaporators by 35 per cent, and save more than $360,000 in annual energy costs, resulting in a payback period of less than 2 years.[41]

According to Dr McGifford, '*The installation of the pre-evaporator will enable us to produce more alkaloids, which will in turn require us to hire more staff to handle the higher production load, and help us sell more of our products around the world... This should also have knock-on effects for the local community, as we try to source our raw materials locally*'. The Australian-owned company worked with a local firm to design and install the new pre-evaporator. In addition to the efficiency benefits, the new equipment will also allow TPI to boost production capacity, and take advantage of global demographic trends (such as ageing populations in developed nations) that are driving the demand for alkaloids. The company is also examining additional clean energy projects such as solar power generation and the use of biofuels, with Dr McGifford saying, '*We're very big on renewable energy and reducing our environmental footprint'.*[42]

Changes to process inputs and outputs can also result in significant gains. The gas used by TPI for production was identified as their largest cost outside of labour; with the company spending approximately $1 million per annum on gas.[43] The decision was made to switch from LPG to natural gas as their primary energy source. The plant conversion cost approximately $2 million, but with the cost of natural gas approximately one third of that for LPG, the payback period is expected to be less than 3 years, equating to savings of around $600,000 per annum. The price and supply stability of natural gas also provides advantages to TPI – the price of LPG is influenced by the world oil market, meaning that price fluctuations can be significant. Natural gas prices are significantly more stable, and supply is more secure, allowing TPI to estimate energy costs further in advance. Natural gas is also less emissions-intensive, because of the processing involved in its production, and because it is piped to the facility rather than trucked in, and the switch results in 5% savings in CO_2 emissions.[44]

Examining process outputs can also produce efficiency gains – TPI identified that some of the waste products from the manufacture of alkaloids from poppy straw could be converted into high-potassium fertiliser, which they then distributed at no cost to their farmers, increasing yields and minimising their waste production simultaneously.[45]

3.3 Cook Medical

Companies do not have to be producers of large, energy-intensive equipment to make enhancements to their energy efficiency. In the case of Cook medical, a privately owned and family-operated medical devices company from Indiana in the USA, innovation is their stock-in-trade, both in terms of the devices they manufacture and their approach to sustainability. For example, Cook Medical Australia recently developed an endovascular stent graft that treats aneurysm disease, and is unique in its field in that it is able to custom-make products to fit the particular anatomy of a patient based on the requirements of physicians.[46] According to R&D Engineer Kelly Coverdale, Cook Medical is driven by constant improvement, including identifying energy efficiency opportunities. Engineers are working together to provide the best solutions within research and development, production, regulatory and quality service environments at Cook Medical.

The company has a strong focus on continuous improvement, which includes improving energy efficiency – as Kelly explains, '*From rolling several components into one from a manufacturing perspective, to reducing the manufacturing time, Cook is focussed on being cost efficient and therefore explores the whole of life costing of medical devices from product development right through to waste and disposal*'. Determining ways to improve efficiency through the whole life of a product provides many opportunities for improvement – as an example, Cook Medical Australia's Senior Engineer considered packaging and determined that small changes to the dimensions of two of the companies commonly used shipping boxes would reduce weight, saving shipping costs, and reducing waste material.[47]

Cook Medical Australia treats efficiency as an integral part of their business, and the reuse and recycling of resources has led to changes which significantly reducing energy use. This has included the use of sustainable source materials and responsible management of waste material streams. Sustainable source materials are used in many Cook products, such as:

- Product instructions are currently printed on recycled paper, and these are being phased out with the introduction of web-based instructions,
- Shipping boxes used by the company are made of recycled materials,
- Plastic recyclable pallets are used in shipping and are re-used, then recycled when damaged, and
- Green building materials and brownfield building sites are used in new construction projects.

Waste streams from production are also dealt with sustainably with first-generation clean plastic waste is recycled and sold to toy manufacturers, plastic trays are donated for use in school and artistic projects, and scrap metal is recycled. As a result of this work, Cook recycled over 93 tonnes of cardboard, nearly 2,400kg of metal, and approximately 115m^3 of plastic wrap in the first quarter of 2013.[48]

A small company can also improve energy efficiency beyond its own operations, through collaboration with its partners and customers. Cook Medical are involved in efforts to improve energy efficiency in partner hospitals through promotion of the sustainability roadmap for hospitals,[49] a guide to improving energy efficiency and sustainability for healthcare providers. Through this program, hospitals are encouraged to track key indicators in areas of energy, water, and waste management, and use this information as the basis for improvements which can then be quantified.[50] This approach examines both sustainability and cost implications of improvements to efficiency – for example, when discussing the effect of reduction in unnecessary waste from the healthcare industry, the point is made that waste disposal costs across the healthcare industry annually are approximately US$10 billion,[51] and that there are opportunities to decrease this cost by 40-70% through procurement and waste management optimisation.[52]

Cook Medical also shares the success stories of partners, like Intermountain Healthcare, which founded a waste stream management council to identify opportunities to decrease waste, and developed programs to reuse sharps containers (which are often disposed of after one use), saving over 108 tonnes of plastic waste; established a recycling system which recycled 670 tonnes of waste from 3 departments in 3 months, and increased the amount of packaging and pre-surgery products that are recycled by their surgical services team.[53] Cook Medical's work goes beyond promotion of this approach too - their Health Business Solutions team recently helped to implement electronic data interface technology at several private and public sector hospitals, a tool that greatly improves their efficiency, accuracy, and cost-savings.[54]

4 A Case Study of Biomedical Engineering and Energy Efficiency

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

4.1 Panasonic's Cascade Cooling System

Advances in manufacturing technology can provide opportunities for increasing energy efficiency, when incorporated into existing designs. Developments by Panasonic in the field of biomedical devices, specifically storage, have enabled them to increase energy efficiency, improve system performance, and lower user costs simultaneously, through the adoption of new technologies. Panasonic manufacture various medical devices, including different types of storage freezers, and their most recent models feature a number of technological advances to improve performance and efficiency.

The Challenge

Low-temperature storage freezers, used in cryopreservation, must hold samples at a low, stable temperature (-86°C), and can use up to 10 times as much energy as a domestic freezer to hold such low temperatures, potentially contributing significantly to energy consumption for medical laboratories, especially given the proliferation of research requiring sample storage, in areas such as gene therapy and transgenic organisms.[55]

The Solution

Panasonic have developed insulation, cooling circuit, and refrigerant technologies that not only increase efficiency (saving energy and money), but improve performance of low-temperature freezers.[56] The freezers utilise vacuum insulation panels, which use vacuum, rather than conventional insulation foam, to control heat flow, and as a result, the wall thickness of the freezers is reduced by half, and the storage capacity of the freezer is increased 30 per cent in comparison to a conventionally insulated freezer, while energy efficiency is also improved in comparison to conventional freezers. This reduces lab running costs, and means that less freezers, and therefore less energy, is required to store the same number of samples.

The freezers also use natural refrigerants, which have lower global warming potential than HFCs (and are therefore more environmentally friendly); and a higher latent heat of evaporation, leading to more efficient cooling per refrigerant volume, leading to smaller compressors being required, and lower energy usage as a result. The design features result in up to 55 per cent reduction in energy use, and there are added flow-on benefits resulting from this reduction – lower energy use means less heat generation, so air-conditioning energy requirements and costs for laboratories are also decreased.[57]

Changes to fundamental technologies or processes can lead to even larger efficiency gains. In the same freezers, Panasonic have utilised a new cooling system design methodology, which significantly improves energy efficiency through use of a capillary tube heat exchanger that increases heat transfer efficiency at all stages in the system – heat exchange in the high and low temperature stages of the compressor, and between the two stages. The cooling system also uses the refrigerant at each stage to cool the lubricating oil for the condensers, improving their durability. The result is reduced energy consumption, which leads to energy savings, and also reduces load on the compressors, which coupled with the lubrication oil cooling system, increases compressor reliability. The whole system works to deliver energy and cost savings, while also increasing system reliability, providing improvements to both efficiency and performance, as outlined in Figure 3.[58]

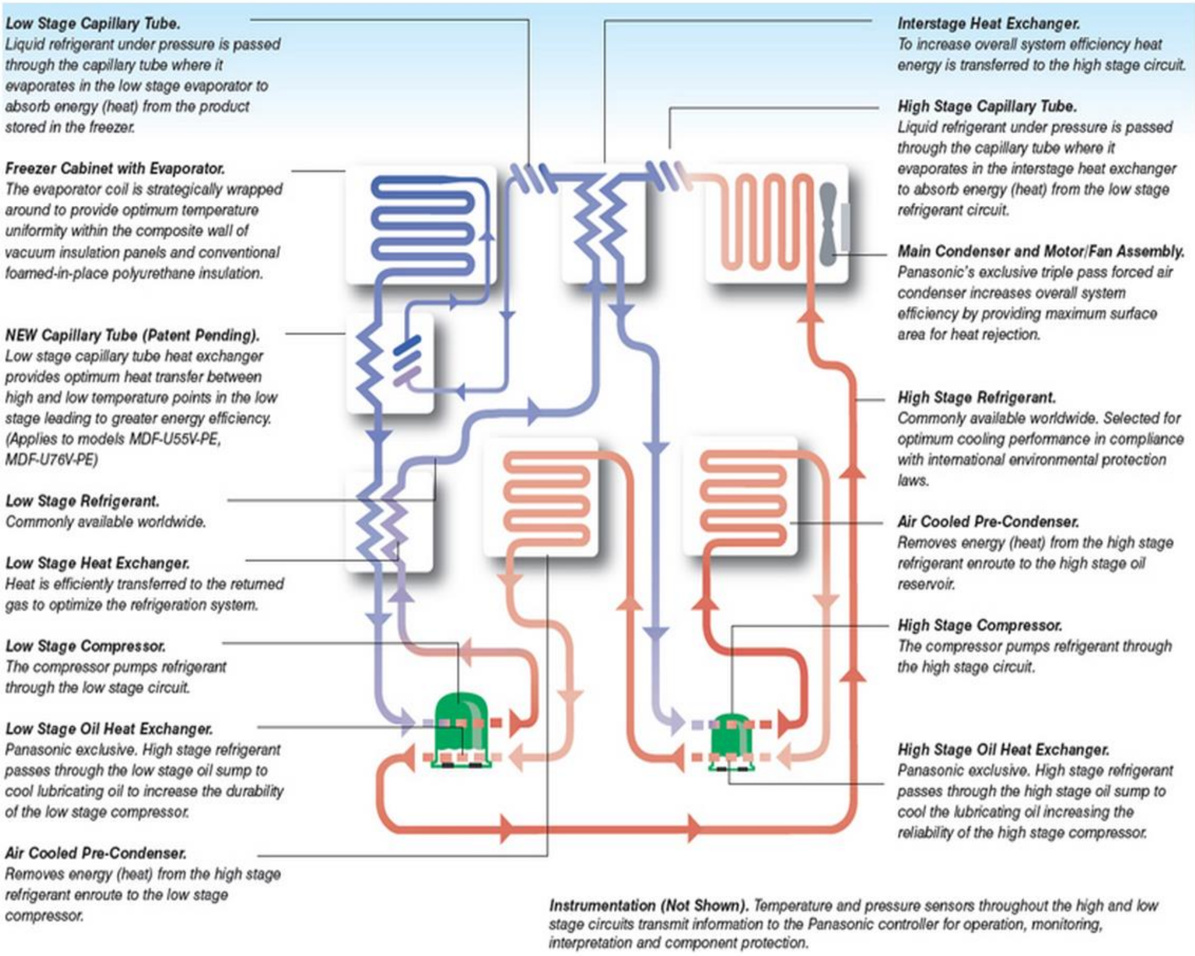

Figure 3: Cascade cooling system for ultra-low temperature freezers[59]

Efficiency-related developments have the most impact when they are tailored to the devices being developed. The dual-stage cooling system used for ultra-low temperature freezers is not required for the -30°C freezers built by Panasonic, but these make use of another technology – inverter compressor systems. A conventional compressor is either on or off, either running at full speed when cooling is required, or shutting off when there is no cooling demand. An inverter compressor is able to run at variable speeds, and this provides a number of advantages:

1. The compressor does not shut off, which avoids the need for compressor start-up, which is the least energy-efficient and highest-wear condition for a compressor,
2. It maintains temperature in a more stable way, as the amount of cooling can be varied, rather than just switched on or off, and

3. It can adjust more effectively to external temperature variations, such as lower temperatures at night when less cooling is required.

The result is a freezer which is higher performance (greater temperature stability), has longer service intervals due to the lower wear, and uses up to 60% less power than a conventional freezer – saving energy and money simultaneously.[60]

Looking to the Future

Looking further into the future, significant energy savings may result from the widespread adoption of a suite of technologies developed in the field of Biomedical Engineering, in areas such as:

- Advanced point-of-care technologies,
- Information search capacity and management, and
- Advances in medical implants, diagnostic technology, medical robotics, and tissue engineering.

Point-of-care technologies which allow remote or automated monitoring of diseases such as diabetes, hypertension, and cancers can reduce the required doctor time per patient, increasing the efficiency of healthcare delivery. Surgical robotics and telepresence technology allows expert surgeons to consult and perform surgery on patients remotely, saving time, costs and energy used in travel. This can allow patients to stay at home, or be assessed at local facilities, avoiding travel and time waste for both patient and medical staff, while maintaining their links with their local community.

More effective information use and the utilisation of massive computing power to model and predict patient health outcomes can provide personalised treatments, and assist in the delivery of preventative medicine. Improved medical implant technology, from neural prostheses to advanced cardiovascular implants, will allow people to spend less time in medical care, lowering the load on hospitals and reducing requirements for expansion of hospital sites. Quantifying these savings is difficult, as these developments are at very early stages, but there is potential for significant improvements to energy efficiency from these technological advancements, when the delivery of healthcare is examined in a broader context.[61]

5 Key Supporting Resources

The following resources are recommended by the research team to assist lecturers to expand the content contained in this introductory level lecture. For guidance as to embedding such materials into existing course see the 2014 book 'Higher Education and Sustainable Development: A Model for Curriculum Renewal'.[62]

5.1 International Resources

Environmental Sustainability in Hospitals - The Value of Efficiency (May 2014): This guide provides case studies and examples from hospitals and care systems around the United States that are benefiting from sustainability efforts. Additional resources found in this guide include a sample hospital sustainability statement, information on benchmarking tools and a sample energy efficiency project.[1] (See Resource)

Sustainability Roadmap for Hospitals: Developed by leaders in health care facility design and construction, operations and maintenance, supply chain, and environmental services, the 'Sustainability Roadmap for Hospitals' provides access to reliable, unbiased resources that can help organizations integrate sustainable practices into the health care environment.[2] (See Resource)

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