Flexible Delivery Flat-Pack Module

An Overview of Energy Efficiency Opportunities in Chemical 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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Project Background

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

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

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

Content

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

Chemical Engineers will be a key part of the World’s response to climate change, from using the principles of green chemistry to design chemical processes and equipment to create significantly less greenhouse gases, to operating and managing plants to run on far less energy or even create their own. Chemical Engineers have critical skills the economy needs to thrive in a carbon constrained future. The following learning points provide a summary of the Chemical Engineering video – our ‘Allen keys’ to building the flat-pack content!

Watch the ‘***Chemical Engineering***’ MMB

1. Engineers have played a key role in the Industrial Revolution that has led to the amazing levels of development our world has experienced. In particular Chemical Engineers have made it possible for the world to harness fossil fuels to create energy for our growing societies.
2. The challenge for Chemical Engineers in the coming century will be to continue to innovate for the world’s societies and create alternatives to current practices that significantly minimise and even eliminate greenhouse gas emissions.
3. Many Chemical Engineering processes are significantly energy intensive, such as those involved in oil refineries or chemical plants, and this provides an opportunity to save a great deal of money through energy efficiency initiatives.
4. It is often the case that current chemical processes are being run at far from the optimum energy requirements. Optimising chemical processes say through the use of reactants or catalysts can lead to reductions in the total flows of material and/or heat, which in turn can reduce significant amounts of energy demand, such as by reducing the amount of pumping, heating or cooling, and materials handling required.
5. A key challenge for Chemical Engineers is to rethink how industries and communities generate heat and electricity. If a process to create heat or electricity is based on burning a fuel, such as natural gas, chances are that viable energy is being lost in the process and cogeneration system could deliver a greater energy yield for the burned fuel by capturing this wasted energy.
6. Chemical Engineers also need to work very closely with other disciplines in engineering. For example, a chemical process might require steam, and so it will be the Mechanical Engineer who has developed the steam process, and there can be many opportunities to reduce the energy requirements of the steam system, or to balance the loads to suit the supply of steam.
7. Chemical Engineers can look forward to some very exciting developments. For example, design inspired by nature – which we call ‘Biomimicry’ – can unleash totally new chemical processes that save enormous amounts of energy in many ways, for example by reducing process temperature or producing lighter, stronger materials with less process energy.
8. Another growing area is that of ‘Green Chemistry’ with one of the 12 Green Chemistry principles being to ‘Design for Energy Efficiency: Energy requirements for chemical processes should be minimised, using ambient pressure and temperature where possible’.

2. Energy Efficiency and Chemical 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]

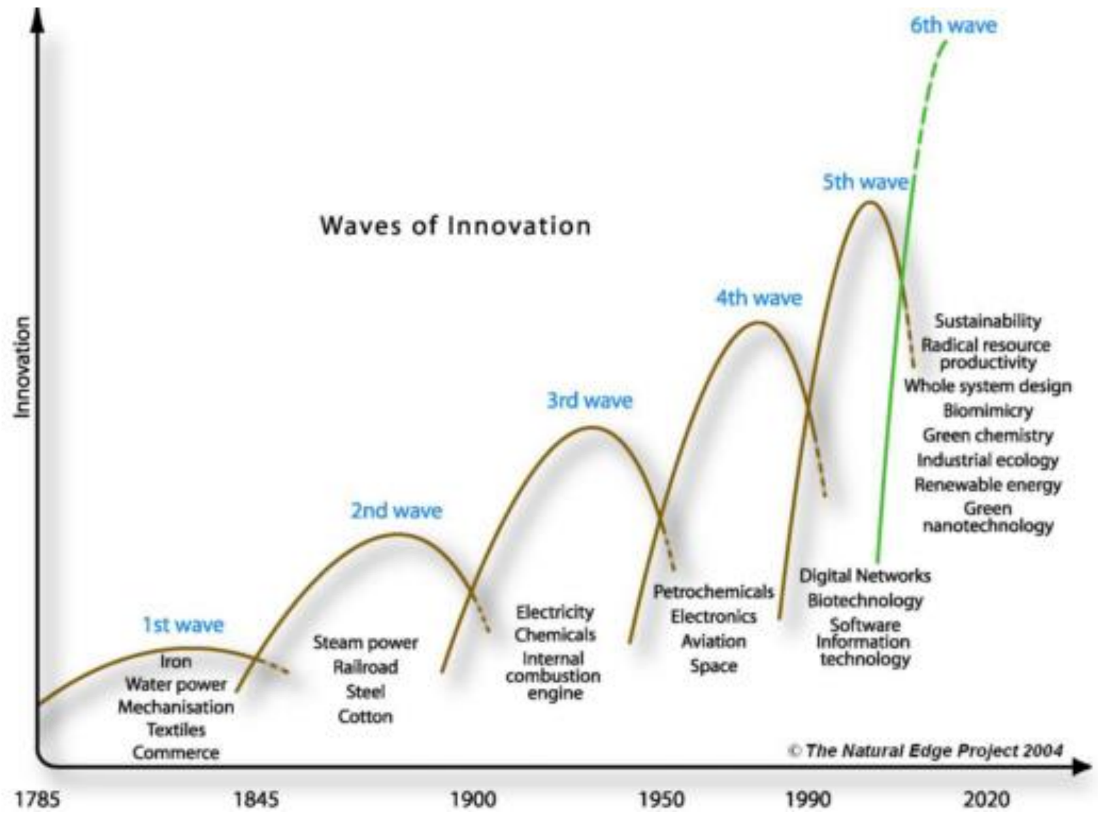

Figure 1: A stylistic representation of waves of innovation since the Industrial revolution[5]

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 Chemical 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 Chemical Engineers reduce greenhouse gas emissions?

How could energy efficiency provide benefits to a Chemical 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.

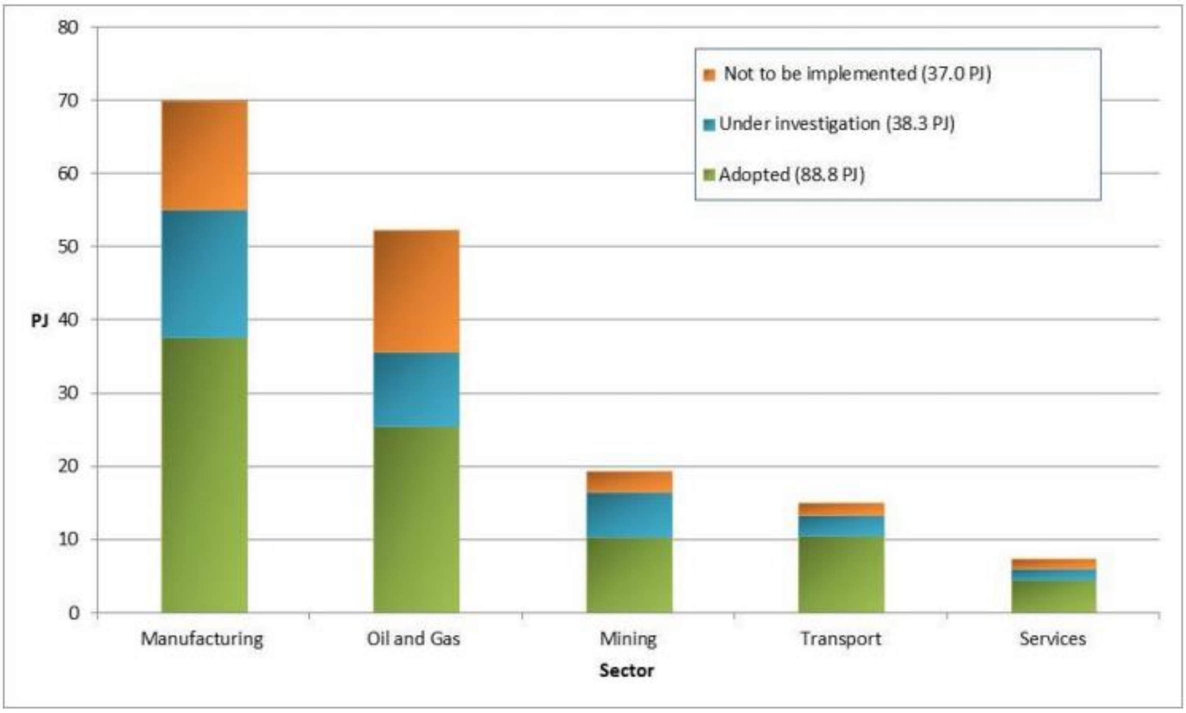

Figure 2: Summary of energy efficiency achievements in by participants in the Australian Government Energy Efficiency Opportunities (EEO) program (2006-11)[32]

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 Chemical 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 Chemical Engineers

According to the Institution of Chemical Engineers, *'sustainable development is the most significant issue facing society today ... The sustainable use of resources is vital and can be achieved by identifying better ways of deploying economic and regulatory measures to drive investment in process technologies which deliver sustainability*.'[35] As such, Chemical Engineering is in a position to make a substantial contribution to societies around the world in improving energy efficiency, particularly through industries involved in the production of such things as fuels, plastics, ceramics, chemicals, pharmaceuticals, metals, and glass.

Chemical Engineering can offer a great deal towards achieving sustainable development and increasing energy efficiency by contributing to sustainable chemical plant design, improving process operation, reducing toxic chemical usage, and dramatically reducing waste. According to the Australian Government Energy Efficiency Exchange Portal '*Chemical processes underpin all industrial processes and affect the energy used in manufacturing most materials. There is a significant business opportunity for the chemicals sector to increase profits, market share and build customer loyalty through designing greener and more efficient chemical products, materials and services. Methods include:*

- *Making the same products in new ways that use less energy,*
- *Using lightweight plastic parts to improve fuel efficiency for transport vehicles,*
- *Reducing energy use in the manufacture and transport of packaging,*
- *New and novel catalysts developed by the chemical industry reduce the need for energy intensive chemical processes, e.g. novel catalysts enabling second generation biofuels,*
- *Materials for the construction industry that can significantly reduce energy use for building heating and cooling requirements, e.g. smart insulation materials, low emissivity windows, lighter materials, composites in construction and fittings,*
- *Improving the conversion efficiency and battery storage of renewable energy sources,*
- *Improving the materials used in the manufacture of wind turbines, solar panels, installation equipment and piping for geothermal systems, and*
- *Extending the shelf-life of goods and other perishables in food production and storage*.'[36]

In Chemical Engineering, discipline-specific considerations could include familiarity with:

- New scientific developments in materials synthesis (to help inform materials choices),
- Considering end-of-life of products/ materials, making reuse or reprocessing more energy efficient,
- Options to reduce energy demand of boilers, steamers, and other high energy using equipment,
- Optimising function or selection of heat exchangers to recover lost energy, and
- Advancement of technologies to improve the energy efficiency of chemical extraction processes.

Considering the graduate attribute of the "*Ability to Participate in/Contribute to Energy Efficiency Assessments*" there are a range of specific areas of knowledge and skills that are currently contained in programs and some that need to be developed. Discipline-specific considerations in Chemical Engineering for this graduate attribute could include:

- Ability to conceptualise and compare energy efficiency opportunities within manufacturing processes, and
- Ability to communicate energy efficiency challenges and opportunities in a given process.
- Optimising the design of chemical units and processes for maximum energy efficiency.

3. Energy Efficiency Examples in Chemical Engineering

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

3.1. Green Chemistry[i]

The following is an edited extract of findings by The Natural Edge Project as part of the 'Engineering Sustainable Solutions program', supported by Griffith university, Port of Brisbane and in collaboration with the Sustainable Living Challenge.

The design and development of safe and appropriate chemicals depends in part on the knowledge and capability of Chemists and Chemical Engineers. As scientists learn more about the theory and application of chemistry, and the relationships between chemicals and the environment, there are increasing opportunities to improve the design and production of chemicals for society. In 1998 Paul Anastas developed the '*12 Principles of Green Chemistry*' to help scientists and engineers to understand and implement the Green Chemistry philosophy.[37] The 12 Green Chemistry Principles are summarised as follows:

1) *Prevention:* It is better to prevent waste at the outset than to treat or clean it up.
2) *Atom Economy:* Chemical reactions should be designed so as many of the atoms as possible that are present in the starting materials, end up in the product rather than in the waste stream.
3) *Less Hazardous Chemical Syntheses:* Synthetic production methods should be designed to contain little or no toxic materials hazardous to human health and the environment.
4) *Designing Safer Chemicals:* Chemical products should be designed for safety as well as performing their intended function.
5) *Safer Solvents and Auxiliaries:* Benign solvent systems, solvent-free methods, or biphasic systems should be used for reactions that integrate preparation and product recovery.
6) *Design for Energy Efficiency:* Energy requirements for chemical processes should be minimised, using ambient pressure and temperature where possible.
7) *Use of Renewable Feedstocks:* Raw materials should be sourced from renewable feedstocks wherever technically and economically practicable.
8) *Reduce Derivatives:* Unnecessary derivisation (i.e. temporarily modifying the physical/ chemical process) should be avoided, to reduce waste products.
9) *Catalysis:* Catalysts should be used to lower the activation energy barrier of a reaction, and thereby use less energy.
10) *Design for Degradation:* Chemical products should be designed to decompose into benign substances at the end of their functional life, to prevent persistence in the environment.

[i] The following is an extract from 'Smith, M., Desha, C., Stasinopoulos, P., Hargroves, K., and Hargroves, S. (2008) 'Lesson 9: An Introduction to Green Chemistry' in *Sustainability Education for High Schools: Year 10-12 Subject Supplements. Module 3: Chemistry Innovations in Sustainable Development,* The Natural Edge Project (TNEP), Australia.'

11) *Real-time analysis for Pollution Prevention:* Real-time, in-process monitoring and control should be allowed (i.e. budgeted) for in a chemical process, to avoid the formation of hazardous substances.

12) *Inherently Safer Chemistry for Accident Prevention:* The type and form of a substance used in a chemical process should be chosen to minimise the potential for chemical accidents, including releases, explosions, and fires.

Select a Principle of Green Chemistry and identify how it may be applied in industry to reduce energy demand.

3.2. Low Carbon Cements[ii]

The chemistry of cement plays a large role in the associated greenhouse gas emissions and Chemical Engineers have an opportunity to create a new generation of low carbon cements. The most common form of cement is Portland Cement (*named on 1824 by Joseph Aspdin because it looked like limestone from the Isle of Portland*) which is a 'calcium-silicate' based cement that requires the heating of limestone (calcium carbonate) in a kiln that can reach 1,850°C, which requires significant energy to achieve. Apart from the temperature requirements in the kiln Portland Cement also creates carbon dioxide as part of the chemical reaction that converts limestone to cement with as much as 1.1 tonne of carbon dioxide released for every tonne of cement produced.[38]

> ***Geopolymer concrete is a form of concrete that can demonstrate significant reductions in carbon emissions compared to Portland cement, in the order of 45-80 per cent,[39] and it has been used by ancient civilizations for centuries.***

In 2012 the US Federal Highway Administration 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*'.[40] 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.[41] 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.[42]

Australia is 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

[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'.

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*'. [43] 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. [44]

3.3. Recycling Paper

The recycling of paper is now widely undertaken around the world as a way to reduce the demand for natural resources for pulp and paper products, and according to Bureau of International Recycling, the recycling of paper can result in as much as 65 per cent energy savings, compared to virgin production.[45] In order to do so Chemical Engineers innovated a process that allowed pulp and paper mills to use recycled paper as a feedstock by blending water with recycled paper to produce an appropriate slurry, the removal of inks and other chemicals from the paper being recycled, and the filtering of the slurry to remove impurities.[46] Once the process was viable from a materials point of view a further innovation improved the quality of the paper products by combining virgin pulp with the recycled pulp to overcome the issue of recycled pulp having shorter fibres.

3.4. Ammonia Production

In the case of Incitec Pivot, an Australian chemical producer with an ammonia production facility in Queensland, the integration of new technologies into an existing process allowed them to make significant gains in energy efficiency, lowering costs, and increasing sustainability.[47] In steam-reformation ammonia production, the first stage of the process is to mix natural gas with steam in a refractory-lined gas-fired furnace. The assessment commissioned by Incitec Pivot identified that a different refractory coating could be used to improve furnace efficiency by altering the radiative characteristics of the furnace. This change would decrease fuel consumption, reduce the amount of energy carried away in the flue gas stream of the furnace, reduce NO_x emissions and increase the refractory coating life simultaneously. The outcomes of the project, with 60,000 GJ of energy, 3,000 tonnes CO_2 equivalent, and $2,000,000 per annum in gas cost savings expected, result in a payback period of just over a year.

Another efficiency opportunity was identified in the water supply circuit of the plant, which originally used 2 pumps to supply water for the steam reformation process – one electrically-driven pump, and one steam-turbine driven pump. Both pumps required refurbishment at the time of the assessment, which would improve pump performance and allow one pump to be taken off-line and kept as a reserve, but prior to the efficiency assessment it was unknown what the savings would be from taking a pump off-line. Evaluation of both pumps determined that the turbine-driven pump was 6 to 10 times more expensive to run than the electrically-driven pump, and the decision was made to refurbish both pumps and take the turbine-driven pump out of continuous service to be used in a backup role (improving system reliability). This change resulted in energy savings of 60,000GJ per annum, a reduction of CO_2 equivalent emissions of approximately 5,000 tonnes per annum, and $5,000,000 saved per year from reduced steam generation requirements, resulting in a payback period for the project of less than a year.[48]

3.5. Steel Production

As the 2010 book '*Factor Five: Transforming the Global Economy through 80% Improvements in Resource Productivity*' pointed out, the energy efficiency of steel manufacture can be increased by as much as 80 per cent. The following part contains material extracted from the book 'Factor Five' that has been edited to be relevant to mining and metallurgy education by Charlie Hargroves and Cheryl Desha, co-authors of '*Factor Five*'.

Electric Arc Furnaces for Steel Production

The bulk of steel produced in the world uses either a 'Basic Oxygen Furnace' (BOF) or an 'Electric Arc Furnace' (EAF), each with different energy demands. A BOF generates heat for the steel making process by injecting pure oxygen at high pressures onto molten iron; and an EAF generates heat by running an electric current through electrodes to create an arc that melts iron and metal. Given the use of electricity the EAF process presents the possibility of using renewably generated electricity for steel making, substantially reducing the associated fossil fuel demand. According to a study in 1994, '*Electric arc steel furnaces use one-tenth of the fuel compared with traditional basic-oxygen blast furnace steel plants.*'[49] According to the OECD EAF technology emits over four times less CO_2 per unit of steel produced than BOF technology.[50] A study by the US Department of Interior and the US Geological Survey forecast in 1998 that EAF plants would produce the majority of steel in the world.[51] Both processes can use scrap steel as feedstock with the EAF process being most energy efficient when using 100% scrap steel, achieving a low as 9.1 GJ/t compared to an optimum minimum of 19.8 GJ/t for the BOF process, as shown in Figure 5.

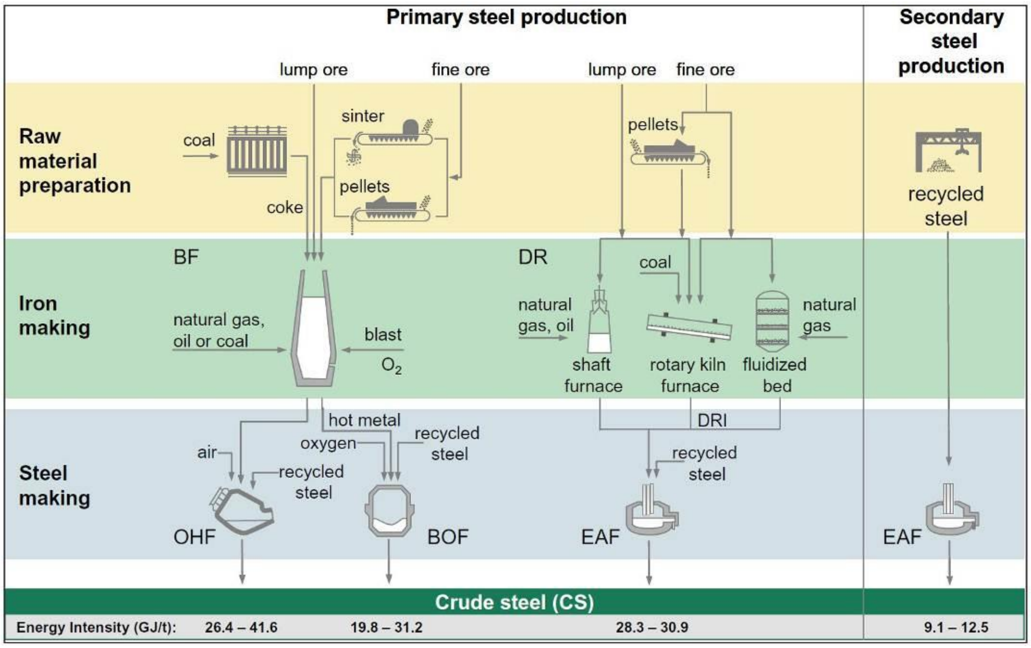

Figure 5: *Energy Intensity of various steel making processes (1) BOF Process (58% of global operations[52]), (2) EAF/DRI process (7%) and (3) EAF process (27%)*

Source: World Steel Association (2008)[53]

As the EAF process can produce all types of steel products this means that the smaller and cheaper plants have the potential to replace most BOF plants around the world.[54] Hence, as the EAF process can make steel cheaper, faster and more efficiently compared to the BOF processes, they are highly attractive in periods of economic downturn, allowing steelmaker Nucor to not only be one of the most profitable steel companies in the USA, but the only company in the sector to maintain its workforce, with all staff taking a 50% pay cut, during the 2008-2009 global financial crisis, despite over 25,000 worker layoffs in the steel sector in the US.[55]

Improving Energy Efficiency of Blast Oxygen Furness Steel Plants

As part of a transition to EAF plants Chemical Engineers can initially focus on improving the energy productivity of existing BOF processes. The 'Hismelt' process can reduce the energy intensity of a BOF process by up to 50 per cent as it allows the smelting reduction process to be undertaken without the need for a coke oven or a sinter plant, and can run on cheap non-coking coals.[56] This is particularly important to allow greater flexibility in the output levels of the process, as according to the Institute of Materials, Minerals and Mining, '*running traditional oxygen blast furnaces is expensive, as they are inflexible and generally uneconomic to run at anything less than full capacity*'.[57] Hence such innovations can significantly reduce both the operational and up-front capital costs, allowing the process to more cost effectively vary its output to optimise production with market price signals.[58]

Researchers at the Ernest Orlando Lawrence Berkeley National Laboratory have identified a number of specific energy efficiency technologies and measures that are available to improve the energy productivity of BOF's as shown in Table 1.

Table 1: Indications that Steel Companies are improving the energy productivity of BOF plants

Iron Ore Preparation (Sintermaking) – *Sinter plant heat recovery* – *Use of waste fuels in the sinter plant* – *Reduction of air leakage* – *Increasing bed depth* – *Improved process control* ***Coke Making*** – *Coal moisture control* – *Programmed heating* – *Variable speed drive on coke oven gas compressors* – *Coke dry quenching* ***Iron Making - Blast Furnace*** – *Pulverized coal injection (medium and high levels)* – *Injection of natural gas* – *Top pressure recovery turbines (wet type)* – *Recovery of blast furnace gas* – *Hot blast stove automation* – *Recuperator on the hot blast stove* – *Improved blast furnace control* ***Steel Making - Basic Oxygen Furnace*** – *BOF gas & sensible heat recovery (suppressed combustion)* – *Variable speed drive on ventilation fans*	***Casting*** – *Adopt continuous casting* – *Efficient ladle preheating* – *Thin slab casting* ***Rolling*** – *Hot charging* – *Recuperative burners in the reheating furnace Controlling oxygen levels and variable speed drives on combustion air fans* – *Process control in the hot strip mill* – *Insulation of furnaces* – *Energy efficient drives in the hot rolling mill* – *Waste heat recovery from cooling water* – *Heat recovery on the annealing line (integrated only)* – *Automated monitoring & targeting system* – *Reduced steam use in the pickling line* ***Overall Measures*** – *Preventative maintenance* – *Energy monitoring and management systems* – *Variable speed drives for flue gas control, pumps, and fans* – *Co-generation*

Source: Worrell et al (1999)[59]

Improving Energy Efficiency of Electric Arc Furness Plants

In the case that a DRI process is used to reduce iron to supplement scrap steel inputs the FINEX process can be used to eliminate the sintering and coke making steps. This can result in substantial cost and energy savings, along with reductions in air pollution - with the emission of sulphur oxides (SOx) and nitrogen oxides (NOx) falling to 19% and 10%, respectively.[60] Assuming 100% scrap steel feedstock is available research shows that productivity of the EAF process can be improved by as much as 50%, with such options outlined in Table 6, such that "*a typical mid 1990s energy requirement was 550 kWh per ton of product, but best practice is now considered to be around 300 kWh, with 'ideal' theoretical performance around 150 kWh.*"[61] As with BOF plants, researchers at the Ernest Orlando Lawrence Berkeley National Laboratory have identified a number of specific energy efficiency technologies and measures that are available to improve the energy productivity EAF plants as shown in Table 2.

Table 2: Indications that Steel Companies are improving the energy productivity of EAF plants

Electric Arc Furnace Operation	***Rolling***
– *Improved process control (neural networks)*	– *Hot charging*
– *Flue gas monitoring and control*	– *Recuperative burners in the reheating furnace Controlling oxygen levels and variable speed drives on combustion air fans*
– *Transformer efficiency measures*	– *Process control in the hot strip mill*
– *Bottom stirring/gas injection*	– *Insulation of furnaces*
– *Foamy slag practices*	– *Energy efficient drives in the hot rolling mill*
– *Oxy-fuel burners/lancing*	– *Waste heat recovery from cooling water*
– *Post-combustion*	– *Heat recovery on the annealing line (integrated only)*
– *Eccentric bottom tapping (EBT)*	– *Automated monitoring & targeting system*
– *Direct current (DC) arc furnaces*	– *Reduced steam use in the pickling line*
– *Scrap preheating*	***Overall Measures***
– *Consteel process*	– *Preventative maintenance*
– *Fuchs shaft furnace*	– *Energy monitoring and management systems*
– *Twin shell DC arc furnace*	– *Variable speed drives for flue gas control, pumps, and fans*
Casting	– *Co-generation*
– *Adopt continuous casting*	
– *Efficient ladle preheating*	
– *Thin slab casting*	

Source: Worrell et al (1999)[62]

The Use of Alternate Fuels for Steel Production

Steel plants can use a range of alternate fuels such as waste plastic, rubber, oils and car tires, with appropriate emissions control. According to the American Iron and Steel Institute (AISI), the use of such fuel alternatives can be expanded to provide a viable fuel supply for steel production globally,[63] especially considering the growing levels of municipal solid waste generation that contains many of these substances. Other alternatives include coal gasification and the use of charcoal as a replacement for coke in primary steel production that can lead to GHG emissions reductions of over 60%.[64] Researchers at the University of New South Wales have shown that waste plastic can be used to offset energy requirements by up to 30%.[65] The research also shows that plastic not only replaces coal to provide the source of carbon, it reduces the energy consumption of the furnace as it provides additional combustible fuel. Professor Veena Sahajwalla reflects that, '… *if you look at its chemical composition, even something as simple as polyethylene that we all use in our day to day lives, has about 85% carbon and 15% hydrogen, so it's simply a carbon resource*'.[66]

4. Case Studies of Chemical Engineering and Energy Efficiency

Building on the multi-media bite on Chemical Engineering and energy efficiency the following example provides further details on the energy efficiency improvements related to Chemical 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. Winery Process Improvement

Large industrial plants typically offer significant opportunities for improving efficiency, saving energy and money simultaneously. As the subject of a case study, a winery can demonstrate many of the important factors to consider in improvement of process efficiency, with multiple process streams; the need to balance varying process parameters based on the required process output; and tight process parameters all acting as driving factors. They provide a number of good examples of ways in which efficiencies can be found; everything 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.

The Challenges

1. The location of Adelaide Hills wine makers Shaw+Smith is ideal for solar energy generation. However currently this option is not taken advantage of to generate energy for the operation of the winery. The company may be paying more for its energy than required, and in the process generating greenhouse gas emissions that could be avoided.

What would be an energy efficiency solar energy generation system suitable for a winery in the Adelaide Hills?

2. As part of its goal to be '*Australia's best wine company applying best practise principles in environmental management to enhance sustainable business activities and products*', Taylors Wines in the Clare Valley undertook a review of its operations and found that:
   a. The equipment used to drive a process was found to be inefficient and that equipment better-suited to the job may be needed, and
   b. A change in the timing of a process could result in significant energy savings through changing the energy input source.

What is the main energy consuming equipment in the winemaking process?

How can peak energy consumption be reduced or offset in a winery?

The Solution

1. In 2013 Shaw+Smith participated in the 'Winery Energy Saver Toolkit' program, under the Energy Efficiency Information Grant Program, funded by the Australian Government to help identify energy efficiency. An investigation into various forms of solar energy found that the most viable option was a solar cogeneration plant, which allows them to produce process energy in the form

of electricity and hot water through the combination of solar photovoltaic module and a thermal module. The system is mounted to track the sun and maximise energy production, and the result is a system that generates 8,000 kWh (28,800 MJ) of electrical energy per year, and 57,000 kWh (205,200 MJ) of thermal energy per annum – which equate to 3% of the total electrical consumption and 42% of the gas consumption, and mean that the system has a payback period of 3.1 years.[67] The installation of the cogeneration system would also deliver additional benefits that might not be immediately apparent when undertaking an efficiency assessment - it would reduce the load on the existing electrical transformer on site, allowing for the projected future growth of the winery, and saving infrastructure costs in the future as upgrades to electrical systems onsite will not be required as soon.

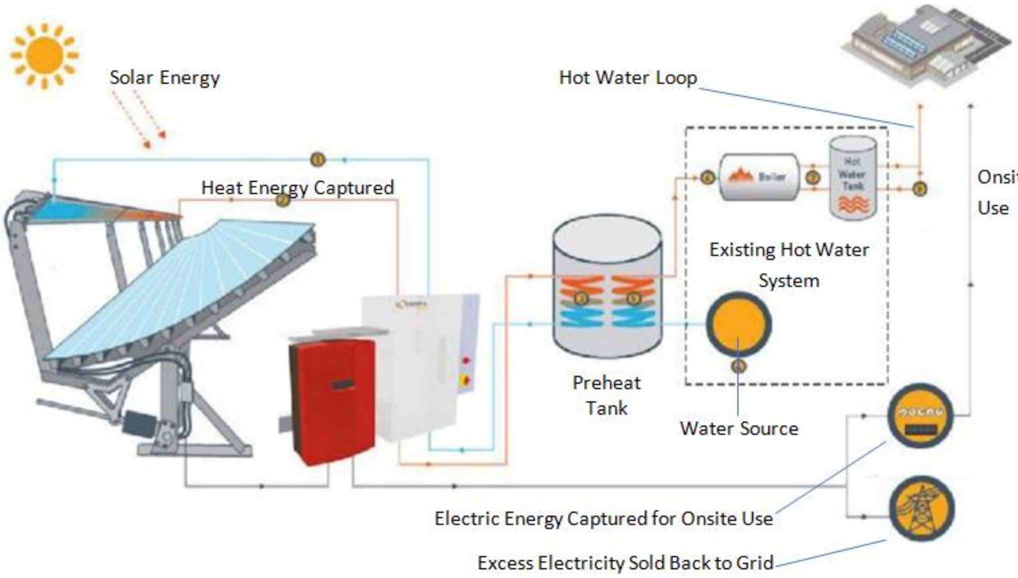

Figure 1: Cogenera T14 solar cogeneration plant functional schematic[68]

2. Taylor Wines also participated in the 'Winery Energy Saver Toolkit' program and identified the following in response to the challenges above:
    a. In the first case, an air flow audit identified that the air compressor system in the winery bottling plant represented a significant opportunity for energy savings, as the existing system operated with two 15kW compressors that were only under load 57 per cent of the time. It was determined that replacing these compressors with a single 25kW variable speed drive compressor would meet airflow requirements, and save 30 per cent in energy consumption, saving $4,800 per annum. Replacing the compressors would also mean that maintenance costs were reduced by $20,000 per annum, and that the resulting payback period for the project would be less than 2 years.
    b. In the second case, the waste water treatment facility run by the winery was determined to be a significant source of energy use, and the process was examined for possible efficiency improvements. It was identified that the peak energy consumption of the treatment plant could be offset by using solar energy to power the process, and to adjust the process timing so that peak solar energy production coincided with the peak power requirements of the process, and could provide all of the energy required. The system proposed, consisting of a 50kW solar power system, would produce 76,000 kWh of energy per annum, and save $23,000 per annum, paying for itself in less than 5 years.[69]

Key lessons

Identification of the sources of inefficiency in a system is a great starting point for optimisation, and determining energy usage associated with that source of inefficiency allows the overall impact to be assessed. This can help in prioritising the best starting points for improvement. In the case of the wine industry, the refrigeration of the product during processing constitutes a significant proportion of total winery energy consumption. The requirement for refrigeration, and the fact that it is most important around vintage time (January to April), which coincides with some of the hottest temperatures of the year, mean that 50-70 per cent of winery energy consumption is represented by refrigeration, and that any process improvements that can be made in this area have the potential to significantly affect total energy consumption, and energy costs, for a winery.

In the case of McLaren Vintners, approximately 4,700 tonnes of grapes are crushed annually, and the winery can store 4.6 million litres of wine in 202 stainless steel tanks. These tanks require refrigeration, and the result is total electrical consumption of approximately 1,000,000 kWh per annum, with usage particularly intense during vintage. While just over 100 of their tanks are already insulated, an assessment of the remaining tanks identified that insulating 44 of the them would decrease the energy required to refrigerate those tanks by over 90 per cent, reducing the energy consumption from 235,000 kWh over the 18 weeks of summer by 227,000 kWh. This represents 22 per cent of annual electricity costs on-site, an approximate annual cost saving of $63,330, and the resultant payback period is 4.5 years. This project is also a good example of efficiencies working synergistically – the reduced power requirement means that the refrigeration plant is run at a much lower load, and operates more efficiently as a result, saving even more energy.[70]

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'.[71]

5.1. The Natural Edge Project

Green Chemistry - An Introduction: The aim of this lesson is to introduce the topic of 'Green Chemistry' and to set the context for the following three lessons. This lesson introduces a number of key Green Chemistry principles that scientists and engineers can use to move towards sustainable development.[72] (See Resource)

Green Chemistry - Dealing with Greenhouse Gases: This lesson aims to highlight the potential role of Green Chemistry in helping to mitigate climate change through innovations in: 1) reducing greenhouse gas emissions, and 2) removing (sequestering) greenhouse gases from the atmosphere. The lesson briefly discusses the types of greenhouse gas (GHG) emissions and some exciting chemistry innovations in sequestering GHGs and reducing GHG emissions.[73] (See Resource)

Green Chemistry - Making Better Batteries: This lesson aims to introduce students to the issues and possible opportunities within the field of batteries, as well as the role batteries will play in enabling sustainable development. In particular, this lesson highlights the opportunities in hybrid-electric and electric vehicle applications, biodegradable batteries, and batteries that can support reliable renewable energy supply.[74] (See Resource)

5.2. International Resources

Chemical Engineers in Action: Chemical Engineers have been improving our well-being for more than a century. From the development of smaller, faster computer chips to innovations in recycling, treating disease, cleaning water, and generating energy, the processes and products that chemical engineers have helped create touch every aspect of our lives.[75] (See Resource)

Bureau of International Recycling: The Bureau of International Recycling promotes materials recycling and facilitates free and fair trade of recyclables in a sustainable and competitive world economy. A key part of the Bureau's work is to inform industry on the value of recycling with many of these processes designed and maintained by Chemical Engineers. (See Resource)

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