ENGINEERING EDUCATION FOR ENERGY EFFICIENCY
Research Project – Final Report

AN INVESTIGATION INTO THE OPTIONS FOR INCREASING THE EXTENT OF ENERGY EFFICIENCY KNOWLEDGE AND SKILLS IN ENGINEERING EDUCATION

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The Natural Edge
PROJECT

National Framework
for Energy Efficiency

Attribution

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Acknowledgements - Research Team

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Project Leader: Mr Karlson 'Charlie' Hargroves, TNEP Director

Principle Researcher: Ms Cheryl Desha, TNEP Education Director

Research Team Members: Ms Angie Reeve, Associate Researcher.

Copy Editor: Mrs Stacey Hargroves, TNEP Professional Editor

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Any enquiries about this report should be directed to:

Ms Cheryl Desha

Education Director

The Natural Edge Project

cheryl@naturaledgeproject.net

www.naturaledgeproject.net

The Natural Edge Project (TNEP) is an independent non-profit Sustainability Think-Tank based in Australia. TNEP operates as a partnership for education, research and policy development on innovation for sustainable development. TNEP's mission is to contribute to, and succinctly communicate, leading research, case studies, tools, policies and strategies for achieving sustainable development across government, business and civil society. Driven by a team of early career Australians, the Project receives mentoring and support from a range of experts and leading organisations in Australia and internationally, through a generational exchange model.

Glossary

CBSM	Community Based Social Marketing
Course	A unit of work undertaken, which is part of the overall *Program* of study (i.e. 1/8 of a nominal full study year). It may be referred to as having anything from 3 to 12 *Credit Points* of value. This is also commonly referred to by universities as a 'Unit' or 'Subject'.
Credit Points	The metric used to indicate the amount of work required to complete a *Course* of study. Depending on the university metrics, a *Program* will have an allocated number of *Credit Points* to distribute among the year levels of the curriculum.
Curriculum	The redevelopment of curriculum, which may involve for one or more *courses* in a *program*, the review of *syllabus*, and *pedagogy*.
DRET	Department of Resources, Environment and Tourism, www.ret.gov.au
Impact	The contribution of an option on the extent of energy efficiency content within the engineering program curriculum
Laboratory	A scheduled class, usually held in a laboratory room, involving activities such as construction, testing and analysis of equipment, machinery or materials.
Likelihood	The chance that a lecturer in their own university context, would implement the option being considered
NFEE	National Framework for Energy Efficiency, www.ret.gov.au/Documents/mce/energy-eff/nfee/default.html
Module	A unit of work undertaken, which is part of an overall *Course* of study, and which may be taught over a period of one or more weeks within the course.
Pedagogy	The way in which the course is taught, otherwise referred to as the strategy or style of instruction.
Program	The award that a student works towards, and which is made up of a certain number of approved courses. This is sometimes referred to by universities as a 'Course'.
School/ Department/ Faculty	The level of coordination within a university context, where engineering programs are coordinated, and to which lecturers belong.
Sub-Topic	A minor topic within a course, which is associated with learning outcomes and assessment items for that course.
Syllabus	The document that includes statements of the aims and objectives of course and its content.
TNEP	The Natural Edge Project, www.naturaledgeproject.net
Workshop	A scheduled class, usually held in a tutorial room with desks in group formation, and involving the consideration of worked examples and problem-solving guided by a teaching team member, over 1-2 hours duration.

Executive Summary

Society is increasingly calling for professionals across government, industry, business and civil society to be able to problem-solve issues related to climate change and sustainable development as part of their work. In particular there is an emerging realisation of the fundamental need to swiftly reduce the growing demand for energy across society, and to then meet the demand with low emissions options.[1] A key ingredient to addressing such issues is equipping professionals with emerging knowledge and skills to address energy challenges in all aspects of their work.

The Council of Australian Governments has recognised this need, signing the *National Partnership Agreement on Energy Efficiency* in July 2009, which included a commitment to assist business and industry obtain the knowledge, skills and capacity to pursue cost-effective energy efficiency opportunities.[2] Engineering will play a critical part among the professions, with Engineers Australia acknowledging 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.*'[3]

Background Project Context — Section 1

In 2007 the National Framework for Energy Efficiency (NFEE) funded the first survey of energy efficiency education across all Australian universities teaching engineering education, which asked, '*What is the state of education for energy efficiency in Australian engineering education?*'.[4] Responses from 27 of the 32 universities teaching engineering education, in every state and territory in Australia, suggested that energy efficiency education is currently highly variable and *ad hoc* across universities and engineering disciplines. The report concluded that there is an urgent need to embed energy efficiency knowledge and skills into engineering curriculum, beyond once-off courses, special interest topics in later years, or highly specialised masters programs.

In responding to this identified gap in energy efficiency knowledge and skills, a significant barrier is the time lag in the higher education sector, in integrating new content within existing curriculum.[5] While flagship courses and specialised 'streams' on energy efficiency have begun to emerge for a small percentage of engineering students, there is a 'business-as-usual' timeframe of up to two decades to fully and appropriately embed new concepts across the engineering curriculum to reach the majority of the 6,000 graduates[6] entering the workforce each year in Australia from 3 year (technologist), 4 year (engineering) and 5 year (engineering double degree) programs, in addition to those engaged in formal (i.e. certificate, diploma or masters programs) and informal (short course or other professional development) learning. Hence, there is a need to swiftly increase the extent of Energy Efficiency Knowledge and Skills in Engineering Education at both undergraduate and postgraduate levels nationally.

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

[2] Department of Resources, Energy and Tourism (2009) 'National Framework for Energy Efficiency - Delivering Economic, Environmental and Social Benefits through Enhanced Energy Efficiency', www.ret.gov.au/Documents/mce/energy-eff/nfee/default.html, accessed 12 August 2009.

[3] Engineers Australia (undated) 'Energy Efficiency: The Importance of Energy Efficiency in Moving toward Sustainability', www.engineersaustralia.org.au/shadomx/apps/fms/fmsdownload.cfm?file_uuid=B5233BA9-B915-BC5E-F38B-1C699E629C92&siteName=ieaust, accessed 8 August 2009.

[4] Desha, C., Hargroves, K., Smith, M., Stasinopoulos, P., Stephens, R., and Hargroves S. (2007) *Energy Transformed: Australian University Survey Summary of Questionnaire Results*, The Natural Edge Project (TNEP), Australia, www.naturaledgeproject.net/Documents/Energy_Efficiency_Survey_-_Summary.doc, accessed 27 July 2008.

[5] Desha, C., Hargroves, K., and Smith, M. (2009) 'Addressing the Time Lag Dilemma in Curriculum Renewal towards Engineering Education for Sustainable Development', *International Journal of Sustainability in Higher Education*, vol 10, Issue 2, pp184-199; Heywood, J. (2005) *Engineering Education: Research and Development in Curriculum and Instruction,* IEEE Press and Wiley-Interscience, New Jersey.

[6] Kaspura, A. (2009) *The Engineering Profession: A Statistical Overview*, 6th Edition, Engineers Australia, Canberra.

This research project has been undertaken to provide guidance to assist engineering educators considering curriculum renewal in the area of energy efficiency education. The findings of this research are intended for use by engineering departments, accreditation agencies, professional bodies and government, to identify opportunities for moving forward (based on rigorous research), and then to strategically plan the transition. The project provides a significant opportunity to explore options to support lecturers, program co-ordinators and senior staff to strategically approach, in an informed way, the challenge of increasing the levels of education for energy efficiency. This process, focused on energy efficiency, will also provide valuable parallels for a range of sustainable engineering related topics. The authors look forward to receiving feedback from engineering educators as they read and use this report to bring about curriculum renewal in energy efficiency education.

Summary of Project Methodology Section 2

The project methodology involved a multi-stage process, including a literature review, a survey, and applying the relevant parts of the Community Based Social Marketing (CBSM) approach to education for energy efficiency within the engineering education community of practice. The aspects of CBSM that were relevant to this project included:

1. Identification of a broad list of desired behaviours (i.e. 'actions', or 'options') that lecturers could undertake to increase the extent of energy efficiency in the curriculum, with 19 identified.
2. Identification of the impact and likelihood of each of the 19 options, from a global literature review and national survey of engineering educators teaching courses involving energy related content.
3. Short-listing the 19 options to consider 10 in more detail, through phone and email survey consultation, with a sample of 23 engineering educators from the 2007 survey database.
4. Investigation of the barriers and benefits to the 10 shortlisted options relevant to the current Australian higher education context.
5. Consideration of strategies and tools that may be effective in reducing the barriers and improving the benefits of the options, to help educators embed energy efficiency content into engineering curriculum.

This report outlines the findings of these five steps for consideration by engineering departments, accreditation agencies, professional bodies and government (activities and funding priorities).

Summary List and Prioritisation of Identified Options Section 3

The following table summarises the full list of identified options for increasing the extent of energy efficiency content within engineering curriculum in Australian universities, and the averaged likelihood and impact scores from the literature review, phone poll and email survey. Items shaded and in italics were discounted as part of the short-listing process, due to either a likelihood score of 2.5/5 or less, or an impact of 3.2/5 or less.

Table E1. Behaviour data average scores, ordered from highest to lowest likelihood

Prioritised Full List	Description	Likelihood (Average)	Impact (Average)
1	Include a case study on energy efficiency	4.1	3.2
2	Include a guest lecturer to teach a sub-topic	4.0	3.6
3	Offer supervised research topics on energy efficiency themes	4.0	3.2
~~*4*~~	~~*Offer industry placements in energy efficiency (Work Integrated learning)*~~	~~*4.0*~~	~~*2.9*~~

Prioritised Full List	Description	Likelihood (Average)	Impact (Average)
5	Offer energy efficiency as a topic in a problem-based learning course	3.7	3.7
6	Include *assessment* that aligns with the energy efficiency theme within the course (e.g. exam questions and assignments)	3.7	3.4
7	Include tutorials that align with the energy efficiency theme in the course (e.g. presentations/ discussions/ problem solving)	3.7	3.3
~~*8*~~	~~*Show a DVD of a related documentary*~~	~~*3.6*~~	~~*2.8*~~
9	Overhaul the course to embed energy efficiency	3.4	3.7
10	Include one workshop on energy efficiency in the course (i.e. laboratory-style experiments)	3.1	3.5
11	Include a field trip related to energy efficiency	3.1	3.5
~~*12*~~	~~*Add energy efficiency readings to the required reading list*~~	~~*3.1*~~	~~*2.2*~~
~~*13*~~	~~*Show a DVD of a keynote lecture on energy efficiency*~~	~~*3.0*~~	~~*2.6*~~
14	Develop a new course on energy efficiency	2.9	4.1
~~15~~	~~Include a topic-specific lecture set (i.e. a sub-topic) within the course~~	~~*2.8*~~	~~*3.2*~~
~~16~~	~~*Include elective modules on energy efficiency within the course*~~	~~*2.4*~~	~~*3.3*~~
~~17~~	~~*Offer a 'major' stream in the engineering degree on energy efficiency*~~	~~*2.2*~~	~~*4.2*~~
~~18~~	~~*Include several workshops on energy efficiency in the course (i.e. including laboratory-style experiments)*~~	~~*2.0*~~	~~*3.6*~~
~~19~~	~~*Develop a new degree program on energy efficiency (e.g. B Energy Eng)*~~	~~*1.1*~~	~~*4.1*~~

The resultant plot of the behaviours is shown in the figure below, indicating an encouraging scenario with regard to the number of options that have relatively high impact and likelihood, providing a wide range of opportunities for addressing curriculum renewal for energy efficiency.

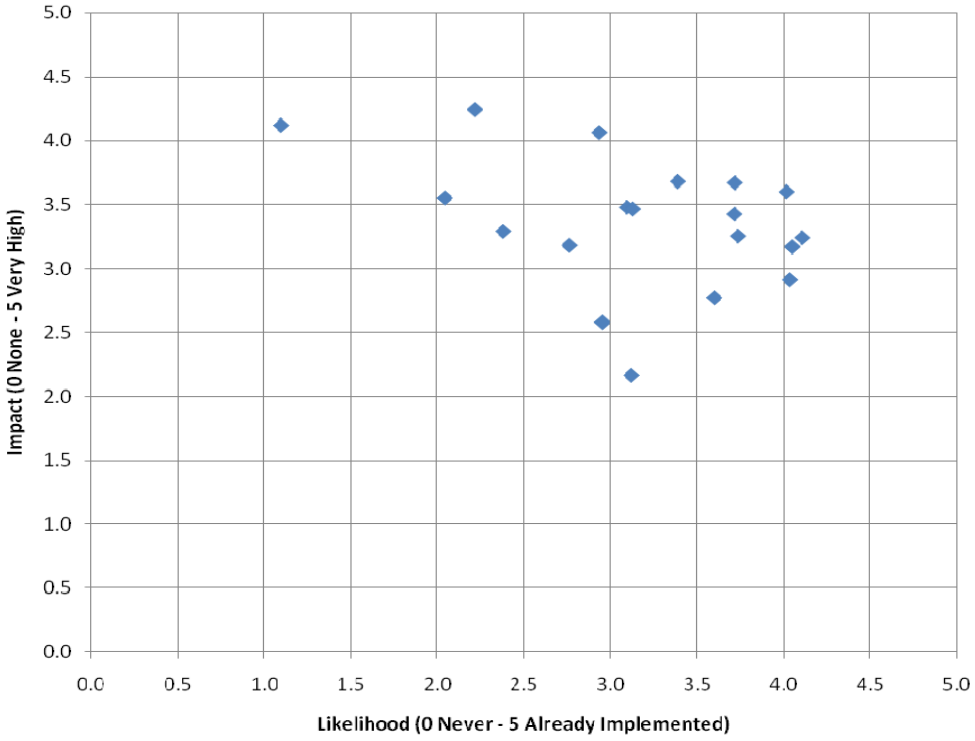

Figure E1. Plotted matrix, based on the results of the phone poll and email survey

The remaining 10 options were ranked by likelihood to create a shortlist as shown in the following table, for which the remaining tasks of this project were focused, including the investigation of barriers and benefits to the options being implemented, and an investigation of tools and methodologies that can be used to implement the options.

Table E2. 10 shortlisted options for increasing the amount of energy efficient in engineering curriculum

Option	Description	Likelihood (Average)	Impact (Average)
1	Include a case study on energy efficiency	4.1	3.2
2	Offer supervised research topics on energy efficiency themes	4.0	3.2
3	Include a guest lecturer to teach a sub-topic	4.0	3.6
4	Include tutorials that align with the energy efficiency theme in the course (e.g. presentations/ discussions/ problem solving)	3.7	3.3
5	Offer energy efficiency as a topic in a problem-based learning course	3.7	3.7
6	Include assessment that aligns with the energy efficiency theme within the course (e.g. exam questions and assignments)	3.7	3.4
7	Overhaul the course to embed energy efficiency	3.4	3.7
8	Include a field trip related to energy efficiency	3.1	3.5
9	Include one workshop on energy efficiency in the course (i.e. laboratory-style experiments)	3.1	3.5
10	Develop a new course on energy efficiency	2.9	4.1

Although this project has shortlisted 10 options for consideration, a department may not be interested in all options. There are no defined steps for selecting the final set of options to focus on, however the department may wish to create a staged list of options that will be gradually implemented over a period of time. This could be in the form of a 'tiered' prioritisation approach, using a combination of the considerations outlined in Section 3.2. For example:

A department may decide to address the first three shortlisted options immediately, but may also be interested in 'Offer a 'major' stream in the engineering degree on energy efficiency' as a top-left quadrant (low likelihood, high impact) option, which they understand will require some strategic interventions from the PVC level with regard to some funding allocation. They may also be interested in addressing 'Offer industry placements in energy efficiency (Work Integrated learning)' as a bottom-right quadrant (high likelihood, low impact) option, for awareness raising among staff (to help them 'step up' to other more challenging options later), and for the marketing benefits.

Summary List of Identified Barriers and Benefits Section 4

Before a department can begin to use the shortlisted options to develop strategies for implementation, the CBSM methodology identifies a critical step as understanding the barriers and benefits to the options of interest, *at the actual level of implementation of the option.* The following table summarises the common barriers and benefits for each of the 10 shortlisted options, to increasing the extent of energy efficiency in the curriculum. It also highlights a number of option-specific barriers and benefits. A detailed literature review of the barriers and benefits for each behaviour is attached to the main report.

Table E3. List of key barriers and benefits to energy efficiency education for the 10 shortlisted options

Key Barriers and Benefits to Implementation	1	2	3	4	5	6	7	8	9	10
Common Barriers										
– Lack of available data/ information	●	●		●	●	●	●		●	●
– Lack of time for preparation	●	●		●	●	●		●		●
– An overcrowded curriculum	●		●	●		●			●	●
– Prohibitive cost	●		●	●	●	●		●	●	●
– Lack of knowledge	●	●	●	●	●		●		●	●
– Lack of value attached	●		●			●				
– Lack of industry contacts		●	●					●		
– Resistance to top-down directive			●				●			
– Students' prior learning habits					●				●	
– Lecturer apathy		●					●			
– Administrative coordination							●	●		●
Other Barriers										
– Silo-culture	●									
– Annual topic renewal		●								
– Lack of quality guest lecturers			●							
– Difficulty in making a pedagogical shift					●					
– Lack of student maturity					●					
– Difficulty of assessment						●				
– Institutional organisational structure							●			
– Lack of collaboration among colleagues							●			
– Timetabling issues								●		
Common Benefits										
– Improved marketability	●	●					●	●		●
– Cross-functionality of content	●						●			●
– Additional research opportunities		●								●
– Networking opportunities for students		●	●					●		
– Networking opportunities for lecturers		●	●					●		
– Experience in incorporating emerging concepts into curriculum			●				●			
– Addressing the time-lag for graduates			●				●			
– Improved pedagogy - problem based learning				●	●	●			●	
– Improved pedagogy – generic skills				●	●	●			●	
– Lecturer professional development (content)		●				●				
Other Benefits										
– Improved student access to best practice	●									
– Improved pedagogy - use of case studies	●									
– Access to additional research funding		●								
– Improved student contact with employers		●								
– Lecturer access to disciplinary mentors			●							
– Curriculum load neutral					●					
– Improved enrolment										●

Summary List of Tools — Section 5.1

The selection of tools (to help address key barriers and benefits identified for a particular option) will be case-specific, given that each department will likely have a different set of 'prioritised' barriers and benefits to address. Drawing on the CBSM literature the following key tools are highlighted for reducing the 'high priority' barriers to curriculum renewal, and making the most of the identified 'benefits':

– *Incentives*	Both financial and non-financial incentives can be used to encourage staff to engage with curriculum renewal.
– *Convenience/ Removing External Barriers*	Making the curriculum renewal process more convenient than continuing with the old processes.
– *Commitment*	Publically announcing roles and responsibilities for the prioritised options within the department.
– *Social Diffusion*	Encouraging key staff members to implement the prioritised options, allowing take-up by other staff as they see benefits.
– *Prompts*	Reminding staff about a particular option (for example through reminders), delivered in close space and time to the change trying to be achieved.
– *Norms - Descriptive and Injunctive*	Encouraging staff to act based on observed behaviours of others, then later through formalising the requirement.
– *Communication*	Using a variety of mechanisms including 'attention', 'content', 'feedback', 'framing' and 'mediums' to keep the curriculum renewal efforts visible to staff.

Strategy Development Considerations — Section 5.2

The development of strategies involves identifying the key components that can use the nominated tools to bring about the behavioural change – in this case increasing the extent of energy efficiency content in the engineering curriculum. There may be more than one tool that would be appropriate to address a barrier or benefit, but this might drive up costs. Further, one strategy may be able to incorporate a number of tools, which may also reduce the overall cost of implementing the option. Despite the lack of literature and scarcity of precedents, this report has identified a number of components of strategies that may be of use to engineering departments considering how to increase the extent of energy efficiency within their programs (in no particular order), as follows:

- Providing financial assistance to integrate energy efficiency into the curriculum
- Creating a Working Party
- Permitting discussion about workload allocations
- Fostering interdisciplinary networks
- Providing seed funding for new technical research areas
- Providing seed funding for new teaching research
- Harnessing other institutional overhauls (e.g. departmental restructuring)
- Creating a clear timeline
- Setting future targets
- Identifying and using modular content

- Using web-based courses to teach energy efficiency
- Providing training
- Understanding 'Hot Topic' areas
- Directly involving potential employers
- Hosting topical event/s
- Investigating graduate employment opportunities
- Engaging external support for advice
- Clearly committing senior management support
- Recruitment of staff well versed in energy efficiency and engineering

In addition to opportunities at the departmental level, the report has also identified some key roles for government, professional bodies and accreditation agencies, which can drive timely curriculum renewal in the higher education sector:

- Including energy efficiency within EA accreditation criteria (competencies)
- Developing a clear understanding of graduate outcomes (graduate attributes)
- Content development support
- Government incentives and actions

Table of Contents

1. Introduction and Context to Area of Investigation

It is not new for engineering educators to reconsider both what they teach and how it's taught, with a number of examples of degrees and courses being updated in the last 2-3 decades to meet changing expectations and requirements of engineers, for example ethics and quality assurance.[7] However, engineering educators around the world are now witnessing an unprecedented shift in societal expectations of the engineering profession, to help address urgent and challenging 21st Century challenges such as climate change, sea level rise, ocean acidification, resource and fossil fuel scarcity, and the sustainability of human settlements. As sustainable development advocate and expert, Jonathan Porritt acknowledged at the 2007 Global Sustainability Forum on the future for engineering education (Imperial College, London), *"The 'business as usual' model, where profits come before sustainability, is absolutely finished. We now have a window of ten to 15 years to adopt a sustainable approach before we reach a global 'tipping point'- the point at which mankind loses the ability to command growth and development"*.[8]

A growing body of literature on the *need* for Engineering Education for Sustainable Development (EESD) includes a range of reports by professional, academic and governmental agencies, surveys, declarations, and numerous papers by academics from around the world on initiatives to embed sustainability within engineering curriculum. However, a literature review by the authors on the *state* of EESD[9] could not find a rigorous global or national review of the discipline, which is problematic for engineering educators in addressing what needs to be done. In the absence of such a reference point, the authors concluded from a subsequent literature review, a definitive common and growing global concern about the lack of sustainability content in engineering curriculum.[10] In discussing this concern, WFEO President and former President of The Institution of Engineers Australia, Barry Grear AO reflected to the authors that, *'In light of the wealth of information available to the engineering profession, there is significant impetus to review what we do and how we do it. However, our references to Sustainable Development are for the most part still at too high a level. There must be a greater degree of detail provided by educators so that students have to think very carefully about the issues at hand. It is sobering for our profession to realise that this is not yet the norm for most of our engineers in training'*.[11]

Within this context, it is unlikely that the engineering profession will be able to equip itself 'overnight' with the knowledge and skills needed to address the range of complex challenges facing society. Rather, capacity building is needed over time on many levels, requiring a process of curriculum renewal across undergraduate education, postgraduate (also called 'masters', or 'graduate') education, PhD research, and professional development for practising engineers and educators. In this context, previous examples and early leadership can provide guidance for institutions to move forward in embedding energy efficiency as an integral part of an engineer's education.[12] For example, a 2008

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[7] Heywood, J. (2005) *Engineering Education: Research and Development in Curriculum and Instruction,* IEEE Press and Wiley-Interscience, New Jersey.
[8] Porrit, J. (2007), "Keynote Speech: Global Sustainability Forum: The Future for Engineering Education", www3.imperial.ac.uk/globalsustainability, accessed 20 August 2008.
[9] Desha, C., Hargroves, K., and Smith, M. (2009) 'Addressing the time lag dilemma in curriculum renewal towards engineering education for sustainable development', *International Journal of Sustainability in Higher Education*, Vol 2, Issue 10, pp184-199, Emerald Group Publishing Limited, London, United Kingdom.
[10] Desha, C., Hargroves, K., and Smith, M. (2009) 'Addressing the time lag dilemma in curriculum renewal towards engineering education for sustainable development', *International Journal of Sustainability in Higher Education*, Vol 2, Issue 10, pp184-199, Emerald Group Publishing Limited, London, United Kingdom.
[11] Grear, B. (2008), *Personal communications with the authors*, 29 August 2008.
[12] El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education*, vol, 9 Issue 2, pp170-182.

review of engineering colleges, institutions and universities offering engineering degrees in the United States has suggested that sustainability is being addressed to some degree by a third of engineering and environmental science degrees.[13] Other research reveals a range of ways in which this has occurred. The most popular current approach appears to be to offer dedicated courses to sustainability, which generally concentrate on teaching the tools which can assist in sustainable engineering, such as 'Life Cycle Analysis' (LCA). Many schools have sought to teach sustainability by integrating these concepts into courses which teach relevant topics, such as transportation, materials design and engineering economics. Yet others have begun to teach sustainability technologies, such as renewable energy systems.

A small number of schools appear to be using a combination of these techniques within individual courses, which are usually once-off within programs, offered as electives, may be part of an informal list of courses which students could elect to take, or required as part of a given major or minor for the degree.[14] An example of a university integrating sustainability throughout the curriculum is Delft University (Netherlands). By identifying and acknowledging barriers to integrating new content, the university's faculty developed processes to minimise their influence and as a consequence: sustainability has been integrated into all engineering degrees; specialised courses have been developed; and a graduate program now also exists to provide a three pronged mechanism through which engineering students are given a thorough education in sustainability.[15] These trends and examples give weight to the plausibility of integrating significant bodies of new content into engineering curriculum in a timely manner, providing evidence for how this might occur and warnings of the barriers which might impede such progress.

This report distils from such examples a number of important learnings with regard to the impact of particular curriculum options – or 'behaviours' – on the extent to which new content is embedded in the curriculum, and the likelihood of this being taken up by lecturers. It presents a synthesis of the literature and current perspectives of engineering educators in Australia with regard to potential curriculum renewal options, their impact and likelihood, and barriers and benefits to them being implemented in engineering departments in Australia. It then provides some guidance on tools and strategies to reduce the barriers to increasing the extent of energy efficiency within the engineering curriculum, and to enhance the benefits of doing so.

This report is hence intended to support lecturers, program co-ordinators and senior staff to strategically approach, the challenge of increasing the levels of education for energy efficiency, discussing the reality that these will need to be tailored to individual departments, given the large degree of variability in curriculum and staffing within each university. The findings of this research are also intended for use by engineering departments, accreditation agencies, professional bodies and government, to identify opportunities for moving forward (based on rigorous research), and then to strategically plan the transition. Finally, it is hoped that this process, which addresses a wide range of pedagogical practices in learning and teaching, will provide valuable insight for higher education institutions considering embedding significant new content into curriculum, in a strategic, timely and cost-effective manner.

[13] Sharma, M.P. and Peters, R.W. (2008) 'A study of integration of sustainability in engineering curricula at U.S. colleges and universities', *American Society for Engineering Education*, AC 2008-1494.
[14] Allen, D.T., Murphy, C.F., Allenby, B.R., and Davidson, C.I. (2009) 'Incorporating Sustainability into Chemical Engineering Education', *Chemical Engineering Progress*, Jan 2009, vol 105, no 1, p47.
[15] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288.

1.1. The Importance of Engineering Education for Energy Efficiency

'Improving energy efficiency will also help to lower the energy intensity of the Australian economy overall, and this, together with a decrease in the emissions intensity of the production of that energy, will be the main contributor to Australia's carbon abatement.'

National Partnership Agreement on Energy Efficiency – Australian COAG Agreement, 2009[16]

Engineers and designers are increasingly being called upon to innovate in a range of new areas, including improving the energy efficiency (EE) of engineered systems, processes and products, along with developing and maintaining renewable and low greenhouse gas emissions energy generation technologies. Indeed, energy efficiency is likely to become a key consideration in coming years across a range of engineering and design professions. Since 1988, the Intergovernmental Panel on Climate Change (IPCC) has been warning that all nations need to stabilise their concentrations of carbon dioxide (CO_2) equivalent emissions, requiring significant global reductions in the order of 60-80 percent by 2050.[17] However, the International Energy Agency (IEA) also forecasts that if policies remain similar to those currently in place, world energy demand is set to increase by over 50 percent between now and 2030.[18] Hence, although renewable and low-emission options are already available, energy demand must be reduced to facilitate a timely and cost effective transition to a low carbon economy.

The Energy Supply Association of Australia (ESAA) now recognises that climate change is a key factor influencing decisions over Australian energy infrastructure, with energy investments in the order of AUD$30 billion needed over the next ten years.[19] The Environment Business Australia *Targets for Our Future* report[20] outlined key research which, for the first time, showed that Australia could achieve 50 percent reductions in greenhouse gas emissions by 2020, with 20 percent of these reductions arising from energy efficiency. This research has been confirmed by several other research projects, including the McKinsey Consulting group,[21] and studies by The Natural Edge Project (TNEP),[22] funded by CSIRO and NFEE. These studies show that through initial investment in energy efficiency, Australia can achieve significant emissions cuts, and become a regional hub for technologies and industries associated with lower greenhouse gas emissions, in a cost effective manner. Australia's energy consumption is predicted to continue to be dominated by fossil fuels for the next several decades,[23] hence energy efficiency may be one of the key elements which will allow society to reduce greenhouse gas emissions.[24]

A key ingredient to addressing such issues is equipping professionals with emerging knowledge and skills to address energy challenges in all aspects of their work. The Council of Australian Governments

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[16] Council of Australian Governments (2009) 'National Partnership Agreement on Energy Efficiency – Intergovernmental Agreement', p3, www.coag.gov.au/coag_meeting_outcomes/2009-07-02/docs/NP_energy_efficiency.pdf, accessed 12 August 2009.
[17] IPCC (2007) *Climate Change 2007: Impacts, Adaptation and Vulnerability*, Contribution of Working Group II to the Fourth Assessment Report of the International Panel on Climate Change, Cambridge University Press, Cambridge.
[18] International Energy Agency (2005) 'World Energy Outlook 2005: Middle East and North Africa Insights' cited in 'IEA Projects Growth in Middle East and North Africa Oil and Natural Gas Sectors through 2030', IEA Press Release, 7 November 2005, www.iea.org/Textbase/press/pressdetail.asp?PRESS_REL_ID=163, accessed 29 May 2009.
[19] Australian Business Roundtable on Climate Change (2006) *The Business Case for Early Action,* ABRCC, www.businessroundtable.com.au/html/recommendations.html, accessed 14 February 2008.
[20] Environment Business Australia (2007) *Targets for our Future*, Environment Business Australia, www.environmentbusiness.com.au/policy/080220-targets-for-our-future.pdf, accessed 13 February 2008.
[21] Gorner, S., Lewis, A., Downey, L., Slezak, J., Michael, J. and Wonhas, A. (2008) *An Australian Cost Curve For Greenhouse Gas Reduction*, McKinsey Consulting, Australia/New Zealand. This report argues that up to 30 percent reductions by 2020 as being possible, www.mckinsey.com/locations/australia_newzealand/knowledge/pdf/1802_carbon.pdf, accessed 4 March 2008.
[22] Smith, M., Hargroves, K., Stasinopoulos, P., Stephens, R., Desha, C. and Hargroves, S. (2007) *Energy Transformed: Sustainable Energy Solutions for Climate Change Mitigation*, The Natural Edge Project (TNEP), Australia, www.naturaledgeproject.net/Sustainable_Energy_Solutions_Portfolio.aspx, accessed 13 February 2008.
[23] ABARE (2008) *Energy in Australia, 2008,* Department of Resources, Energy and Tourism, Australian Government.
[24] Commonwealth Government of Australia (2008) *Carbon Pollution Reduction Scheme: Australia's Low Pollution Future,* White Paper, Australian Government.

has recognised this need, signing the *National Partnership Agreement on Energy Efficiency* in July 2009, which included a commitment to assist business and industry obtain the knowledge, skills and capacity to pursue cost-effective energy efficiency opportunities.[25] Engineering and design will play a critical part among the professions,[26] with Engineers Australia acknowledging 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.*'[27] Engineers and designers are likely to be responsible for the creation of both energy producing, and energy consuming systems, making their understanding of these systems imperative. Underpinning both economic and social development, energy efficiency could be considered as a thread which ties the sustainable growth of these two domains to the environment.[28]

In responding to the identified need for energy efficiency knowledge and skills, a significant barrier is the time lag evident in the higher education sector, in integrating new content for such capacity building into curriculum.[29] While flagship courses and specialised 'streams' on energy efficiency have begun to emerge for a small percentage of engineering students, there is still a 'business-as-usual' timeframe of more than a decade to embed new concepts across the engineering curriculum to reach the majority of the 6,000 graduates entering the workforce each year in Australia, in addition to students engaged in engineering post-graduate programs. Hence, there is a need to accelerate the embedding of energy efficiency content within engineering curriculum nationally.

Energy efficiency (EE) education is a subset of 'education for sustainable development' (ESD), which the United Nations defines as encouraging *'changes in behaviour that will create a more sustainable future in terms of environmental integrity, economic viability, and a just society for present and future generations'*.[30] Sustainable energy issues include energy efficiency (reducing the amount of energy used by a process), energy demand management (improving the management of the se of energy) and energy supply (i.e. changing to low-carbon options). While EE is not considered to be a potential proxy or replacement indicator for sustainability content, it is an example of a new area of practice that needs to be rapidly integrated into engineering courses, in addition to topics like water and materials efficiency. Indeed, such topics can be included as ESD subtopics or instruments, but ESD is more than their individual contributions.

[25] Department of Resources, Energy and Tourism (2009) 'National Framework for Energy Efficiency - Delivering Economic, Environmental and Social Benefits through Enhanced Energy Efficiency', www.ret.gov.au/Documents/mce/energy-eff/nfee/default.html, accessed 12 August 2009.
[26] Engineers Australia (2003) 'Policy Position – Energy', www.engineersaustralia.org.au/shadomx/apps/fms/fmsdownload.cfm?file_uuid=D67982AB-F3B6-11D1-5AB6-332E1CE901BCandsiteName=ieaust, accessed 21 April 2009.
[27] Engineers Australia (2009) 'Energy Efficiency: The Importance of Energy Efficiency in Moving toward Sustainability', www.engineersaustralia.org.au/shadomx/apps/fms/fmsdownload.cfm?file_uuid=B5233BA9-B915-BC5E-F38B-1C699E629C92&siteName=ieaust, accessed 8 August 2009.
[28] Van, D. (2003) 'Teaching Design for Energy Sustainability', Proceeding of the 2003 American Society for Engineering Education Annual Conference and Exposition, American Society for Engineering Education, USA.
[29] Desha, C., Hargroves, K. and Smith, M. (2009) 'Addressing the Time Lag Dilemma in Curriculum Renewal towards Engineering Education for Sustainable Development', *International Journal of Sustainability in Higher Education*, vol 10, Issue 2, pp184-199; Heywood, J. (2005) *Engineering Education: Research and Development in Curriculum and Instruction,* IEEE Press and Wiley-Interscience, New Jersey.
[30] UN General Assembly (2002) *Proclamation of the Decade of Education of Sustainable Development (2005 - 2014)*, 57th Session, UN General Assembly.

1.2. Research Context – Results of 2007 Energy Efficiency Education Survey

In 2007 the National Framework for Energy Efficiency funded TNEP to undertake the first survey of energy efficiency education across Australian universities teaching engineering education, which asked, '*What is the state of education for energy efficiency in Australian engineering education?*'.[31] Responses from 27 of the 32 universities teaching engineering education, in every state and territory in Australia, suggested that energy efficiency education is currently highly variable and *ad hoc* across universities and engineering disciplines. The survey concluded the following:

- The state of education for energy efficiency in Australian engineering education is currently highly variable and *ad hoc* across universities and engineering disciplines. Energy efficiency education is not embedded across all engineering disciplines and the level of integration of topical energy efficiency issues into courses appears to be very low.
- Energy efficiency education across most disciplines appears to be based on the individual interests and research pursuits of the lecturer involved, rather than strategic integration across universities based on discipline needs.
- The inclusion of energy efficiency content in any course containing such content appears to be driven by formal program requirements and the personal and research motivations of the individual lecturers.
- While lecturers appear to be engaging with energy efficiency knowledge/information, there appears to be a low level of student exposure to energy efficiency theory.
- Almost all of the lecturers wanting assistance with accessing content about energy efficiency prefer the resources to be available through open access, online learning modules, rather than restricted access online modules, or intensive short courses.
- Key perceived challenges for lecturers in improving their course content, are:
  1) the potential for course content overload; and
  2) having insufficient time to prepare new materials. In addition some lecturers do not appear to be aware of content that is beyond 'introductory'.
- Lecturers appear uncertain as to whether they are meeting expectations with regard to the type of energy efficiency content in their courses, but they appear to clearly value:
  1) the inclusion of good content within their course;
  2) the inclusion of team project work and practical and industry relevant material; and
  3) a problem-based learning approach to learning. This list is important in suggesting that curriculum renewal strategies should aim to benefit courses in these areas.
- For more than half of the surveyed universities, lecturers reported that their course could include more (in-depth) energy efficiency content, particularly in:
  1) applying energy efficiency theory and knowledge; and
  2) including knowledge and information on the topic. There appears to be more hesitancy with regard to energy efficiency theory and principles, perhaps due to lecturers not being aware of content, or because of competing content areas.

[31] Desha, C., Hargroves, K., Smith, M., Stasinopoulos, P., Stephens, R., and Hargroves S. (2007) *Energy Transformed: Australian University Survey Summary of Questionnaire Results*, The Natural Edge Project (TNEP), Australia, www.naturaledgeproject.net/Documents/Energy_Efficiency_Survey_-_Summary.doc, accessed 27 July 2008; Desha, C., and Hargroves, K. (In Press) 'Surveying the State of Higher Education in Energy Efficiency, in Australian Engineering Curriculum', *Journal of Cleaner Production*, Elsevier.

- Of those courses where lecturers said more could be done, lecturers are keen to receive assistance, particularly through accessing case studies on energy efficiency examples in engineering (i.e. worked real-life examples that show how the theory and knowledge is applied).
- Lecturers are also keen to access lists of good material (for example audio-visual materials, textbooks and other references), and are keen to have access to a customised set of readings on energy efficiency for engineers generally. Lecturers do not appear keen to receive professional development (i.e. additional training) on energy efficiency.
- Some lecturers indicated preference for third party endorsement of materials, but comments indicated that the reason and messaging of the endorsement needs to be clear.

With these findings in mind, this report provides guidance to assist engineering educators considering curriculum renewal towards engineering education for sustainable development, to move forward, specifically in the area of energy efficiency education. The project forms 'Stage 2' of a larger research initiative by the authors, which is committed to assisting Australian universities (and in turn informing efforts around the world) to improve the levels of education for energy efficiency. The larger research initiative takes a multi-faceted approach, including the development of peer-reviewed education material and textbooks on the subject, by investigating the current status of energy efficiency education, and subsequently investigating a range of options to assist universities to embed energy efficiency education into their courses.

1.3. An Overview of the 2008-2009 Research Method

1.3.1. CBSM as a Research Framework

The Community Based Social Marketing (CBSM) is an emerging framework for interacting with a community to better understand how to foster sustainable behaviour (i.e. 'actions' or 'options') within that community. Developed by Dr Doug McKenzie-Mohr, CBSM is based upon social science research that demonstrates behaviour change is most effectively achieved through initiatives delivered at the community level which focus on removing significant 'barriers' (i.e. impediments or challenges) to a behaviour occurring, while at the same time enhancing the 'benefits' (i.e. incentives) for doing that behaviour.[32] Using this knowledge, CBSM has been used over the past decade to inform a range of programs around the world focused on fostering behaviours related to environmental impact reduction, such as air and water pollution.

Successful programs that use a CBSM framework are grounded in the rigorous consideration and thorough implementation of a number of key elements as follows:

- Establishing clarity of purpose in the overall program goal/s, including the identification of intended impacts within the program, considering stakeholder needs and expectations. Here we are considering increasing the extent of energy efficiency content in the engineering curriculum.
- Identifying the desired behavioural change/s to achieve the program goal, and uncovering the key barriers and benefits to achieving these behavioural changes.
- Selecting a strategy using 'tools' (for example communication tools, prompts or financial assistance) that have been shown to be effective in addressing the key barriers and benefits. In effect, the strategy is attempting to reduce the barriers, and increase the benefits, for the behaviour/s to be promoted and the reverse for any behaviour/s to be discouraged.
- Designing and delivering the pilot program/s, then the full program, ensuring sufficient monitoring and evaluation.

The process is largely linear, although there are some significant feedback loops where the evaluation process may refine the selection of behaviours, barriers, benefits or tools used in the proposed program. In particular, once the pilot program has been implemented and evaluated, the results are used to refine the program – and potentially deliver the refined pilot - before full implementation.

[32] McKenzie-Mohr, D. (1997) *Fostering Sustainable Behaviour: An Introduction to Community-Based Social Marketing (3rd Edition),* Gabriola Island B.C. New Society Press.

1.3.2. The Project Research Method

In this study the CBSM framework was applied to address the specific issue of 'increasing the extent of energy efficiency content into the curriculum', within the community of engineering educators in Australia. Hence, curriculum renewal 'behaviours' (herein referred to as options), and their barriers and benefits to implementation needed to be clearly understood. Following the framework, an informed senior management (i.e. Heads of Department and Program Convenors) should then be able to use this information to develop strategies for increasing energy efficiency knowledge and skills within their engineering programs, in a timely and cost effective manner.

The following paragraphs summarise the key steps in the research project:

1. Potential Options Identification - 2008 Survey and Literature Review

The first research task involved identifying a list of potential options that engineering educators in Australia could undertake to integrate energy efficiency education into the curriculum to enhance the extent of energy efficiency content in engineering degrees. The project team developed a list of 19 options from the 2008 survey and a review of literature, and this was reviewed by Dr Doug Mackenzie-Mohr (author of the CBSM methodology).

This literature review sought primarily to uncover evidence of attempts to integrate energy efficiency into engineering degrees in Australia, and to analyse the methods and means by which this was done. There was scant literature on this specific topic and hence the search was widened to consider sustainability and sustainable development both here in Australia and internationally. This produced significantly more results, and there are numerous examples from all over the world of universities working towards teaching sustainability to undergraduate and postgraduate engineering students. Using such literature to draw conclusions about both the impact and likelihood of similarly incorporating energy efficiency into engineering programs required consideration of the links and comparisons between sustainability and energy efficiency.

2. Preliminary List Review and Assessment – Phone Poll Interviews

The second task involved energy efficiency educators reviewing and commenting on the list of 19 identified options (to cross-check the global literature review results with the Australian context), and to provide guidance as to the potential probability and impact of each occurring. Initial efforts to seek this review in October – November 2008 (via email) produced limited results and in consultation with NFEE it was decided to undertake a more involved process of engagement, comprising a phone poll of recognised leaders followed by a wider invitation to review the material. This process resulted in improved participation and input. In December 2008 a phone poll interview process was undertaken with 13 energy educators across the country (ACT 1, NSW 1, NT 1, QLD 3, TAS 1, VIC 4, WA 1, SA 1), where the research team contacted one person from each institution randomly by email, seeking their participation. All respondents to the invitation were included in the subsequent phone poll. Each participant reviewed the initial list and in over a half hour phone interview, provided: 1) quantitative data to indicate the perceived potential impact and probability for each of the options; and 2) qualitative data regarding their rationale for the score, and perspective on the framing of questions.

3. Engineering Educators' Survey

The third task involved engaging with a wider sample of stakeholders to review and comment on the findings of the phone poll interviews, to further cross-check the findings of the literature review and phone-poll. The research team used the quantitative and qualitative data provided by the phone poll participants to: a) make some minor amendments to the wording of the questions for email delivery

(ensuring that the substance of the questions were not changed); and b) to aggregate the scores into a 'preliminary score' for each of the 19 options.

The survey containing the preliminary results was then issued to 72 engineering educators around the country (26 January – 13 February). Appendix A contains the 'Survey Response Form' which includes information about the survey requirements and the preliminary ranking of actions. The survey response form was also emailed to the 13 phone poll respondents so they could forward the survey to interested colleagues. This was timed to coincide with the return of engineering educators from Christmas/ New Year annual leave, and finish before they began focusing on teaching preparation for Semester 1. Traditionally this time of year is quiet for the academic sector (as indicated by 9 'out of office' messages), however, those academics in the office were considered to be more likely to spend the 5-10 minutes needed to complete the survey. The survey yielded 10 responses, which the research team considered a good response rate.

All respondents asked to remain/ be included on the mailing list for this research. One response was received from an engineering educator not already on the distribution list, which the research team considered a good sign that the project was reaching engineering educators outside of the catchment of the existing network. Emails regarding interest in the survey results were also received from the Moreland Energy Foundation and Swinburne University of Technology's National Centre for Sustainability, indicating that information about the survey had also circulated beyond the research team's database.

4. Engineering Educators' Survey Data Preparation and Analysis

The survey data, together with the phone poll data, was subsequently aggregated to generate a matrix of options. With regard to the data aggregation, where respondents included comments that indicated they agreed with the preliminary score and the impact/ likelihood cells were blank (as requested in the survey instructions), this cell was attributed to the average score from the phone poll survey. Where respondents did not include any comments and the impact/ likelihood cells were blank, this cell was attributed the average score from the phone poll. Where respondents included comments that indicated they disagreed with the preliminary score but did not put an alternative score, this cell was left blank in the spreadsheet, and the number of responses was reduced accordingly to calculate the average. Details regarding the analysis are provided in the following section.

1.4. Assumptions and Limitations

This report does not try to demonstrate the need for energy efficiency to be taught in engineering degrees, rather it assumes that the decision has been made to proceed. This report is hence an attempt to provide guidance to engineering educators and departments about how rapidly curriculum renewal might be achieved, and to identify some tools and strategies which can address key barriers to this occurring.

The report is a desktop study which has called upon the experience of engineering educators around Australia, those of the research team, and published literature. It is assumed that these sources can provide an accurate depiction of the state of engineering education and provide illumination on the question of how energy efficiency could be best integrated into engineering degrees. The report has also relied on the significant body of literature on sustainability and its inclusion in engineering education, to make inferences about energy efficiency education, based on the rationale that introducing energy efficiency content has many parallels to sustainability content, with similar barriers and benefits to doing so.

International experience has also been used throughout the literature review. There is an inherent assumption that drawing upon findings from these experiences is somewhat universal and hence they are applicable to the Australian context, and to that of individual universities. It is recognised that in reality, each country and each university may have unique circumstances influencing their ability to include energy efficiency in their engineering degrees.

One of the more significant barriers to each of the options and to any changes to the engineering curriculum may be the lack of consensus over which options are the more effective and whether the experiences of individual universities, lecturers and engineering institutions can be generalised for all such agents. The project team who worked on this report are themselves engineers, working within the fields of environmental engineering, sustainability and engineering education. Although every attempt to be non-biased and to avoid influencing the CBSM process has been made, their experiences and knowledge may nonetheless have influenced these findings.

Through analysis of the survey data and the review of literature, it became clear that the 19 options are not independent of each other, and that in fact both the impact and likelihood of each is highly dependent on whether other options are also undertaken. For instance, a standalone course on energy efficiency may have little impact on its own, if the concepts, skills and knowledge are not reinforced and integrated throughout other components of the course. Hence, on its own, it may have minimal impact, however, combined with such a wider policy of integration, its impact may be quite high. This ‘coupling effect’ is addressed in Section 5, through the consideration of strategies and tools (forming the next phase of consultation with the engineering education community of practice).

2. Findings of Literature Review – Identification of Options

2.1. Literature Review Method

As summarised in Section 1.3.2, a list of 19 options was developed by the project team based on responses to the 2008 NFEE survey[33] and prior experiences of the research team, and reviewed by Dr Doug Mackenzie-Mohr, author of CBSM methodology. The refined list of 19 options was subsequently reviewed by a subset of the survey database of Australian engineering educators, before being emailed to 62 engineering educators across all 31 universities teaching engineering education. In total, 13 phone poll respondents and 10 email respondents provided qualitative and quantitative feedback on the potential impact of each option in terms of teaching energy efficiency to engineering students, and the likelihood that each option would be undertaken. In parallel to the broad review, a literature review was also undertaken with regard to national and international experiences in embedding energy efficiency into engineering curricula, and the impact and likelihood of each of these options occurring in an engineering program. The resultant set of 19 behaviours is listed in **Table 1**, and a full literature review of each option is attached in Appendix B.

Table 1. Full list of options and their survey results for 'Impact' and 'Probability' (ordered by impact)

Behaviour (Option)	Likelihood Score ('0' never, to '5' already done)	Impact Score ('0' no impact, to '5' very high impact)
1. Include a case study on energy efficiency	4.1	3.2
2. Include a guest lecturer to teach a sub-topic	4.0	3.6
3. Offer supervised research topics on energy efficiency themes	4.0	3.2
4. Offer industry placements in energy efficiency (Work Integrated learning)	4.0	2.9
5. Offer energy efficiency as a topic in a problem-based learning course	3.7	3.7
6. Include assessment that aligns with the energy efficiency theme within the course (e.g. exam questions and assignments)	3.7	3.4
7. Include tutorials that align with the energy efficiency theme in the course (e.g. presentations/ discussions/ problem solving)	3.7	3.3
8. Show a DVD of a related documentary	3.6	2.8
9. Overhaul the course to embed energy efficiency	3.4	3.7
10. Include one workshop on energy efficiency in the course (i.e. laboratory-style experiments)	3.1	3.5
11. Include a field trip related to energy efficiency	3.1	3.5
12. Add energy efficiency readings to the required reading list	3.1	2.2
13. Show a DVD of a keynote lecture on energy efficiency	3.0	2.6
14. Develop a new course on energy efficiency	2.9	4.1
15. Include a topic-specific lecture set (i.e. a sub-topic) within the course	2.8	3.2

[33] Desha, C., Hargroves, K., Smith, M., Stasinopoulos, P., Stephens, R., and Hargroves, S. (2007) *Energy Transformed: Australian University Survey Summary of Questionnaire Results*, The Natural Edge Project (TNEP), Australia, www.naturaledgeproject.net/Documents/Energy_Efficiency_Survey_-_Summary.doc, accessed 27 July 2008.

Behaviour (Option)	Likelihood Score ('0' never, to '5' already done)	Impact Score ('0' no impact, to '5' very high impact)
16. Include elective modules on energy efficiency within the course	2.4	3.3
17. Offer a 'major' stream in the engineering degree on energy efficiency	2.2	4.2
18. Include several workshops on energy efficiency in the course (i.e. including laboratory-style experiments)	2.0	3.6
19. Develop a new degree program on energy efficiency (e.g. B Energy Eng)	1.1	4.1

The following pages summarise the key points made in the literature for each of the 19 options, including commentary with regard to how the reviewed literature compares with the aggregated average result of the survey, where:

- the likelihood that a lecturer in a department would implement this option is between '0' (i.e. never) and '5' (i.e. it has already happened); and
- the impact of this option being implemented, on the extent of energy efficiency content in the curriculum, is between '0' (i.e. no contribution) and 5 (i.e. very high).

The 19 options are discussed in order from highest to lowest likelihood, as identified from the literature review and survey, and respondents' comments on each option are also listed (in italics).

2.2. The Identification and Investigation of Options

2.2.1. Include a Case Study on Energy Efficiency

Survey Comments: Core to our program … Already included in our Energy Management unit – not sure how to assess contribution when it is already included – have generally used a half-way value … Case studies are supporting the learning process especially in different applications of Energy Efficiency … Routine in thermofluids courses.

Impact: In general, the literature suggests that this option could have a moderate to high impact on the extent of energy efficiency in the curriculum, however, the size of this impact depends greatly on the nature of the case studies provided, whether students are required to critically analyse such case studies, whether students engage in the process of developing and applying the principle discussed in the case studies and whether the skills and knowledge are transferred to other aspects of the students' learning and practice. This is slightly higher than the survey response of 3.2/5, which may be due to the authors of the publications being more enthusiastic about the merits of the option in comparison to the Australian engineering education community which has not yet had good access to quality case studies on sustainability (or energy efficiency) content.

Likelihood: The literature suggests that this option has a moderate likelihood of being taken up by staff, tempered by time and resourcing constraints facing engineering educators, and a shortage of staff trained in energy efficiency. It notes that the likelihood will increase if the case studies are already available, readily useable, and require minimal prior knowledge. The survey result of 4.1/5 indicates that the Australian engineering education community is more optimistic about the likelihood of this option occurring, perhaps due to the increasing popularity of, and familiarity with, problem-based learning as a teaching mechanism.

2.2.2. Include a Guest Lecturer to Teach a Sub-Topic

Survey Comments: Standard practice at fourth year … A single guest lecture but not a 'subtopic' … Has occurred in our Energy Management unit – does not lead to expansion of curriculum … This is possible but not essential … I do this.

Impact: The literature suggests that while a guest lecturer may be well received and have a high impact on the students' experience, the overall impact on the extent of energy efficiency content in the program would be low. As for the first option (i.e. Develop a new course on energy efficiency), an isolated experience or exposure to content is unlikely to adequately develop the desired graduate attributes relating to energy efficiency. From the survey it appears that the engineering education community perceives a higher – moderate to high – impact, with a result of 3.6/5. From the comments provided with the phone poll and returned surveys, it is suggested that this could be due to an assumption that this option would involve more than just one lecture.

Likelihood: There is a lack of literature discussing the likelihood of engineering educators to engage with guest lecturers to deliver new content in courses. The two papers forming part of this literature review (by Dutch and New Zealand researchers) that do mention guest lecturing indicate the likelihood to be high, if the guest lecturers are made available and are credible. This is in accord with the survey result of 4.0/5.

2.2.3. Offer Supervised Research Topics on Energy Efficiency Themes

Survey Comments: Happens extensively already. Very helpful contribution to curriculum … Will depend on course structure – our course is not strictly an Engineering program and so opportunities for industry placements are limited … Electrical Engineering, Energy Technologies, Control Systems, Sustainability etc. could have strong content of Energy Efficiency focus … Usually beyond our control, depends what work the company offers a student.

Impact: Based on the literature, it is suggested that this option would have a moderate to high impact on contributing to the learning and understanding of energy efficiency within an engineering degree, for the students involved in the projects. Taken within the context of the fact that this option refers to one project, within one course at the university (as discussed in other areas of this report), this option has a moderate impact overall, which accords with the survey result of 3.2/5.

Likelihood: The literature suggests that this option has a high likelihood of occurring, given the increasing emphasis on final year projects and the numerous possibilities for student topics. This is in accord with the survey result of 4.0/5.

2.2.4. Offer Industry Placements in Energy Efficiency

Survey Comments: Happens extensively already. Very helpful contribution to curriculum … Will depend on course structure – our course is not strictly an Engineering program and so opportunities for industry placements are limited … Electrical Engineering, Energy Technologies, Control Systems, Sustainability etc. could have strong content of Energy Efficiency focus … Yes through thesis … Usually beyond our control, depends what work the company offers a student … Usually beyond our control, depends what work the company offers a student.

Impact: The literature suggests that offering industry placements in energy efficiency (e.g. work integrated learning) has a low to moderate potential impact on the extent of energy efficiency in the engineering curriculum, due to the probable small number of students who would be exposed to an energy efficiency-related experience in the industry workplace. This is in accordance with the survey result of 2.9/5. The impact of such an initiative could be improved through students sharing their experiences via a presentation to the student cohort, although this would still be an overview which is limited to inspiring other students rather than providing a capacity building mechanism for their colleagues.

Likelihood: The likelihood of staff engaging in industry placements related to energy efficiency is considered from the literature to be high, given existing trends and the lack of requirements on staff. This is in accord with the survey result of 4.0/5.

2.2.5. Offer Energy Efficiency as a Topic in a Problem-Based Learning Course

Survey Comments: We should do this but don't. It has great learning potential for a systems engineering degree … Yes – looks OK … Not really applicable to our Energy Studies program – individual can generate problem-based projects for undertaking as a unit if they wish … Energy Efficiency can cover a wide range of knowledge and techniques. It is very likely to find it implemented in different disciplines … It is scattered throughout the course … Not at the moment, I concentrate on handling of hazardous waste.

Impact: Problem (or project) based learning (PBL) is assumed in this context to refer to a method of teaching in which a given problem incites the process of learning, as opposed to case study based learning where knowledge is provided, and then understanding of this is assessed via a case study which incorporates this knowledge in a real-life setting. The literature suggests that offering energy efficiency as a topic in a PBL course will have a high impact on the extent of energy efficiency content in the engineering curriculum. The survey result of 3.7/5 (i.e. a moderate to high impact) is slightly less optimistic than the literature, which could be due to the authors of the papers showing an attachment to, and therefore an optimistic opinion of, the merits of this option.

Likelihood: Problem based learning is being increasingly utilised by engineering departments around the world, suggesting that this option may be quite likely, which accords with the survey result of 3.7/5. Netherland researchers Erik de Graaff and Wim Ravesteijn (Delft University) note that while engineering departments were initially slow to innovate and update their engineering degrees, more recent pressures from society and the profession itself has led to departments looking for ways in which to teach students competencies such as risk taking and creativity. These skills, among others, can be effectively taught through PBL and such drivers have led to an increasing incidence of this teaching technique in higher engineering education.

2.2.6. Include Assessment that Aligns with the Energy Efficiency Theme within the Course

Survey Comments: Exam material is directly related to the curricula by regulations ... Can only do this if energy efficiency was a core part of the curricula … Our Energy Management unit naturally has assessment based on energy efficiency themes – not sure what Contribution means in this context … Assessments are essential part of curricula ... In order to make the course effectively related to the real world it shall include strong EE presence.

Impact: The literature suggests that including assessment that aligns with the energy efficiency theme within the course (i.e. including exam questions and assignments) will have a high impact on the extent of energy efficiency content in the curriculum, acting as a driver to ensure that the proposed content is embedded and given due attention within the course. The literature also suggests that this option will increase the impact of any other option which introduces new content to the course. Its impact will be limited depended on the type of assessment used (for instance, one which encourages deep learning, or shallow learning, and the amount by which this assessment and hence the teaching of energy efficiency is integrated into courses throughout a degree). The survey result of 3.4/5 is somewhat less optimistic about the impact than the literature. As for the problem-based-learning option, this difference could be due to the authors of the papers showing an attachment to, and therefore an optimistic opinion of, the merits of this option. Alternatively, it could be due to the Australian engineering education community having a slightly more conservative approach to assessment as a tool for driving the development of graduate attributes.

Likelihood: The literature suggests that including energy efficiency in assessment tasks is relatively straightforward and highly likely where it is already a component of the course, as it just requires the lecturer to draw attention to this aspect of the course. However, it may be less likely where the course lecturer has added energy efficiency perhaps as a concession to departmental requests rather than out of a strong belief that it is relevant to the course, and important enough to potentially displace the assessment of other aspects. These findings are in accord with the survey result of 3.7/5.

2.2.7. Include Tutorials that Align with Energy Efficiency Themes in the Course

Survey Comments: As above. I run extra tutorials that do, in part, have an energy efficiency focus because it fits my subject area … The department could do this but I don't see it as likely – more an individual lecturer choice ... Our [energy management] unit naturally includes this … Tutorials are essential part of learning ... In order to make the course effectively related to the real world it shall include strong Energy Efficiency topics.

Impact: The literature suggests that this option would have a high impact within the course in which it is applied, although the impact is still limited to having several tutorials within one course in the entire program, resulting in an overall moderate impact. This is in accord with the survey result of 3.3/5. As noted for other options, there is a risk that the skills and knowledge obtained in this course may not be developed further in other courses or be built upon to achieve strong graduate attributes in the area.

Likelihood: The literature suggests that the likelihood of staff engaging with students in tutorials related to energy efficiency is low to moderate, given the personal investment of time in preparation, and the need for staff to feel comfortable with the content. This is somewhat lower than the survey result of 3.7/5 (i.e. moderately to highly likely). As for earlier differences between the survey and literature with regard to workshops and elective modules, where the Australian engineering education community is increasingly exposed to problem-based learning tools and may therefore see tutorials on energy efficiency as a relatively straight-forward amendment to the curriculum.

2.2.8. Show a DVD of a Related Documentary

Survey Comments: Most students are self motivated to do things like this ... I do surveys in class to establish this … We use videos on key energy management topics – hence will not lead to expansion of curriculum … Very relevant for Engineering programs ... The units are currently already very packed with activities … Yes we do – Electric Car video.

Impact: The literature suggests that the potential impact of this option is low to moderate, depending on the quality of the recorded documentary or footage and its relevance to the course and student interest. This is in accordance with the survey result of 2.8/5.

Likelihood: The literature suggests that this option may be moderately likely, which is in accordance with the survey result of 3.6/5. Although engineering degrees are typically perceived to be quite 'full', a documentary DVD may be a good option for lecturers who feel that there is not enough time in the course for a module, nor sufficient time within their schedule to prepare a lecture.

2.2.9. Overhaul the Course to Embed Energy Efficiency

Survey Comments: I see this as likely and possible with good outcomes …'Overhaul' is a difficult word! - Evolutionary change is more apt … Too many other constraints in program … Our program has Energy Management as a core unit … Yes, it is already included.

Impact: Although there is little written about overhauling courses for energy efficiency content, literature does exist for overhauling courses to integrate the concepts of sustainability. This literature identifies a shift in mentality whereby the new concepts are used throughout the design process, enabling solutions beyond the realm of traditional engineering. If more than one course related to energy could be overhauled, this would improve the impact further. As such, the literature suggests that this option could have a moderate to high impact. This is in general accord with the survey result of 3.7/5.

Likelihood: The literature suggests that this option has a moderate likelihood of being implemented, dependent on how external accreditation pressures and assistance with curriculum renewal influences a time and resource constrained engineering educator community of practice. This is in accord with the survey result of 3.4/5. It also depends on the receptivity of departmental staff to shifting the mindset from end-of-pipe solutions to integrated 'beginning of pipe' solutions.

2.2.10. Include One Workshop on Energy Efficiency in the Course

Survey Comments: We could and should do this ... Curricula space pressure is the only constraint … We hope to do this more strongly in the future ... We are a little constrained as our units are available externally – limits the scope for lab-type activities … we do have a metering lab to expose students to aspects of electrical metering … Heat and Mass Transfer, Chemical Engineering Thermodynamics … Thermofluids courses.

Impact: The literature suggests that this option would have a low impact as, even though workshops (i.e. including laboratory-style experiments) may be an effective teaching tool, the limited application of this option (i.e. once) is unlikely to result in adequate student immersion in the topic and hence limit transference of knowledge to other areas. This finding is somewhat lower than the survey result of 3.5/5. From comments provided by the survey participants during the phone poll and in the written responses, it appears that this is due to the respondents assuming that a workshop is a more intense learning environment, where students will internalise the knowledge and skills more quickly than in a lecture environment.

Likelihood: Despite the limited time implication of running one workshop on energy efficiency, the literature suggests that the likelihood of this option being undertaken is still low to moderate, given the need for staff to invest time and resources into developing such a workshop. This is in accord with the survey result of 3.1/5.

2.2.11. Include a Field Trip Related to Energy Efficiency

Survey Comments: We do this every year … Students see this as a highlight of their degree … We have always had some difficulty with this ... We remain optimistic … Our Energy Management class visits a nearby hospital and has a tour of the energy management features of the facility, also a visit to [an] ice storage facility … When possible, it is being planned … When possible.

Impact: In the absence of literature discussing this option, the authors conclude that including a field trip related to energy efficiency will have a moderate impact on the extent of such content in the curriculum as this option involves an activity occurring once, within one course in an engineering program. This is in accord with the survey result of 3.5/5. The knowledge gained through one field trip can be more intensely delivered and received than in a lecture environment, but needs supporting follow-up 'back in the classroom' to provide the systematic approach which is necessary for teaching a deep understanding of interdisciplinary, complex issues such as energy efficiency. This option also has the potential to provide a high impact on the students' perception of the importance of energy efficiency if it is relevant and engaging. This experience may be important in creating a shift in the mindset of students, which can then be developed in other courses.

Likelihood: In the absence of literature discussing this option directly, the authors conclude from what is available, that the option would be moderately likely, which is in accord with the survey result of 3.1/5. There are many factors upon which the introduction of a field trip is contingent, and the barriers identified in the literature, which typically inhibit a given lecturer's inclination to change or adapt their course, are considered relevant to this option. This said, this option represents an interjection into an existing course which does not necessarily entail significant knowledge on the behalf of the lecturer (if it is assumed that the field trip is able to 'speak for itself' to some extent), and the time involved in developing and organising such a trip may be largely administrative rather than academic. Depending on the structure of the university, a lecturer may hence be able to delegate a certain proportion of the work involved in developing and organising a field trip to administrative staff.

2.2.12. Add Energy Efficiency Readings to the Required Reading List

Survey Comments: I agree with the low scores here .... Student workload may stop this one … We really don't have 'required reading lists' so the scores are not so high … Naturally included in our Energy Management unit … External readings are a valid tool for learning.

Impact: The literature (through extrapolation) suggests that this option would have a low to moderate impact on the extent of energy efficiency content in the curriculum, depending on whether the readings formed part of subsequent assessment in the course, or were connected into the rest of the course. This is in general accord with the survey result of 2.2/5 – this low valuing of the option by the Australian engineering education community is perhaps also an indication of a low priority given to readings in engineering curriculum, together with the low rate of student reading of prescribed material.

Likelihood: Based on these inferences, it is assumed that this option is moderately likely, assuming that the reading options are made readily available to lecturers. This is in accord with the survey result of 3.1/5. It appears to be a potential way to address pressures to teach energy efficiency without significantly affecting lecturer time, as the students can complete the readings away from the classroom.

2.2.13. Show a DVD of a Keynote Lecture on Energy Efficiency

Survey Comments: This is likely and would be valuable in that it is someone apart from the lecturer providing information … DVD of lecture only could be boring … Unless a very dynamic presentation a 'live' presentation is to be preferred.

Impact: Based on the literature it is concluded that this option would have a low impact given that it is 1-2 hours within one course in a program. However, a targeted keynote on DVD may have an important role in alerting the students to career opportunities in energy efficiency, which could have a positive impact on other options, increasing student appreciation of the concepts and knowledge being taught. This is in accordance with the survey result of 2.6/5.

Likelihood: From the literature it is concluded that the likelihood of lecturers using DVDs of recorded lectures (assuming they are readily available) is moderately likely. This is in accord with the survey result of 3.0/5.

2.2.14. Develop a New Course on Energy Efficiency

Survey Comments: As above but more valuable ... This is quite possible … This is happening now ... Would like to develop better follow-on units from our basic Energy Management unit – resource constraints … There is effectively a trend to include EE in Engineering courses … Maybe in 2012 – next review.

Impact: The impact of this option appears to be variable, depending on how well the concepts which are taught are supported in other courses, and how well students are able to see the relevance and applicability of the knowledge and skills they gain, and can then transfer it across to other areas of their work and study. As a standalone, unsupported course, the literature suggests that this option would have a low impact. Supported as a flagship course in an integrated program that references and makes use of the knowledge and skills elsewhere, the impact could be high. The survey result of 4.1/5 indicates a much more positive perspective about this option in the Australian engineering education community. This could be due to the respondents assuming that one new course will make a substantial difference to the development of energy efficiency knowledge, which the literature suggests is not the case – rather the course needs to be supported by coverage in other courses in the program.

Likelihood: The likelihood of a new course being developed is considered low to moderate, given the widely perceived issue of already crowded curriculum, where room may not exist for a new or renewed course. This is in accord with the survey result of 2.9/5. In addition, limited staff availability (i.e. with already high workloads), limited staff expertise and budget constraints may make introducing a course on energy efficiency less likely.

2.2.15. Include a Topic-Specific Lecture Set (i.e. a sub-topic) within the Course, by the Lecturer

Survey Comments: We already do this. I'd like to see a fourth year special elective in this area ... Not enough academics at present to cover it … Naturally included in our core Energy Management unit – hence a high number in our situation.

Impact: There was a scarcity of literature which commented directly on this option. However, some inferences can be made from literature surrounding engineering education in general. The impact of this option is likely to be moderate, tempered by the issue of transferability discussed for earlier options; this impact could be enhanced if this option was undertaken as part of a wider collection of activities. The literature finding is in accord with the survey result of 3.2/5.

Likelihood: There are several issues documented in the literature which may affect the likelihood of this option, but overall the likelihood of topic-specific lecture sets being included within the course, by the lecturer, is considered low to moderate. This is in accord with the survey result of 2.8/5.

2.2.16. Include Elective Modules on Energy Efficiency within the Course

Survey Comments: Agree, this is unlikely and not so valuable … This is happening now … Already a core unit in our Energy Studies program – so warrants a high number in our system … This is very likely … inefficient use of resources.

Impact: The literature suggests that, given the limited scope of this option it would have a low to moderate impact on the extent of energy efficiency content in the curriculum. While it is recognised that student-led learning can lead to deeper learning, it may also be true that students may avoid topics such as energy efficiency through the program if they do not anticipate the relevance of the topic to their career, or see emphasis provided in assessment items. This finding is slightly less optimistic than the survey result of 3.3/5. This could be due to elective module-style learning perhaps being a popular technique in Australia where problem-based learning is growing in popularity.

Likelihood: As this option requires only moderate effort from lecturers related to scheduling and assessment, and as the content would not displace current materials, the literature suggests that lecturers would be likely to include energy efficiency as elective modules in existing courses, should this be an option. However, the survey result yielded a low likelihood of 2.4/5. From the comments received by the respondents via the phone poll and in written responses, it appears that this may be due to the practical constraints in making elective modules available to students, primarily in preparation and marking time.

2.2.17. Offer a 'Major' Stream in the Degree on Energy Efficiency

Survey Comments: Unlikely to be attractive to students … Should be integral with all engineering courses. This is happening now … Unlikely – due to resource constraints - agree with low number for likelihood … This is a field of the future … inefficient use of resources – lack of industry demand – industry want conventional courses.

Impact: The literature suggests that this option could have a significant impact. This is in accord with the survey result of 4.2/5. As a 'major stream' concentrates the teaching of energy efficiency in the later years of a degree (with perhaps five courses on energy efficiency in the last 1-2 years of study), students may have developed sufficiently to grasp the complex notions of energy efficiency and be more able to apply the principles. By taking several courses, these concepts are also likely to be reinforced and better transferred to other areas of learning and practice. The development of a major in this area also provides students with an understanding of mainstream engineering practice, potentially allowing for a wider application of the specialist knowledge gained through the major stream.

Likelihood: Experience from universities both in Australia and abroad suggest that this option is a sizeable undertaking, which may rely on wider restructuring of engineering departments to make it more feasible, hence it is considered unlikely to occur for most universities. This is in accord with the survey result of 2.2/5. However, this option does sidestep many of the barriers identified in the literature which can make implementing changes more difficult and may provide niche opportunities for engineering departments looking to provide a highly marketable point of differentiation.

2.2.18. Include Several Workshops on Energy Efficiency in the Course

Survey Comments: Curricula space issues again … This is happening now … Core Energy management unit in Energy Studies program effectively does this … Highly possible.

Impact: The literature documents how workshops (i.e. including laboratory-style experiments) can increase the effectiveness of energy efficiency education by encouraging students to apply knowledge to a contextual situation, and to develop relevant skills such as problem solving, collaboration, communication and project management. To the extent which workshops can be classed as 'problem based learning', it is considered that this option will have a moderate to high impact on the extent of energy efficiency content in the curriculum. This is in accord with the survey result of 3.6/5.

Likelihood: According to the literature, introducing workshops into a course on energy efficiency would be inline with current national and international trends and research into teaching, which suggests that hands-on, problem based learning is effective at producing a deeper understanding of complex, multi-disciplinary concepts such as energy efficiency. However, the reality of implementation is low, due to time constraints within a course, making it difficult to include new components, and a lack of finances limiting the ability of the course lecturer to purchase materials with which to run workshops and experiments. This is in accord with the survey result of 2.0/5.

2.2.19. Develop a New Degree Program on Energy Efficiency

Survey Comments: Again, should be integral with engineering thinking, not segregated ... Agree with scores … This is happening now ... Alternative energy … Unlikely – due to resource constraints – agree with low number for likelihood … This is unlikely to happen ... inefficient use of resources – lack of industry demand – industry want conventional courses.

Impact: The literature suggests that the development of a degree program (for example a Bachelor of Energy Engineering) focused on energy efficiency would have a high impact, producing engineers with highly specialised skills and a deep understanding of the complex relationships which can lead to energy efficiency in society. This is in accord with the survey result of 4.1/5. The integration of energy efficiency throughout all components of the degree would enable students to perceive energy efficiency as relevant to all aspects of their practice. The focus of energy efficiency education into a separate program may, however, miss the opportunity to educate all engineers about energy efficiency, and therefore the wider impact of this option on engineering practice would depend upon the engineering profession and society valuing the skills these graduates would have and employing their services.

Likelihood: Given the presumed costs, time and inertia (in terms of entrenched beliefs and systems) involved, the literature suggests that it is very unlikely to be taken up, which is in accord with the survey result of 1.1/5. It is not inconceivable, however, as evidenced by similarly large changes to engineering programs in Australian and other international universities.

3. Selection of a Shortlist of Options for Further Consideration

3.1. An Overview of the Impact-Likelihood Matrix

Once the list of options has been identified and the list of behaviours investigated with regard to their impact in meeting the program aims, and their probability in being undertaken, the next task in the CBSM method is to plot the results in the form of a matrix. This plot can then be used to help shortlist the options for consideration. Figure 1 highlights a number of quadrants or 'interaction zones' within the impact-likelihood matrix, where the following rationale can be applied:

- *Poor Outcome Zone:* Options that are scored within this zone have a 'none to moderate' anticipated impact, and a 'none to moderate' likelihood of occurring. They are hence usually discarded from further consideration.
- *Unlikely Outcome Zone:* Options that are scored within this zone have a 'moderate to high' anticipated impact, but only a 'none to moderate' likelihood of occurring unless there is a significant market, regulatory or institutional intervention. Hence, these options are more difficult to work with as they do not have as higher potential for a successful outcome without high level or external assistance.
- *Step-Up Zone:* Options that are scored within this zone have a 'moderate to high' anticipated likelihood, but only a 'none to moderate' impact. As focusing on an option in this quadrant is unlikely to lead to large impact outcomes, they are more difficult to demonstrate worthwhile time and effort.
- *Best Interaction Zone:* Options that are scored within this zone have a 'moderate to high' anticipated likelihood, and also a 'moderate to high' potential impact. These are hence favoured in considering which options to focus on in a program.

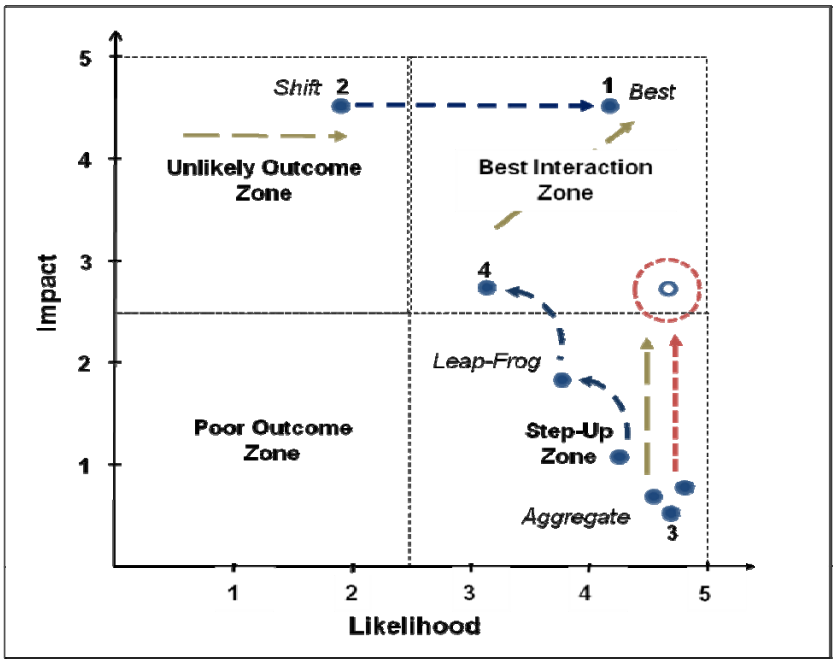

Figure 1. Impact-Likelihood Matrix
Source: Adapted from the CBSM Methodology by TNEP[34]

[34] Macenzie-Mohr, D. (1999) Mackenzie-Mohr D, Smith W., (1999), Fostering Sustainable Behavior: An introduction to community-based social marketing. New Society Publishers, Canada.

3.2. Considering the Potential Use of the Remaining List of Options

Although this report takes only the short-listed options further in considering barriers and benefits, further to the introductory explanation in this section, it should be remembered that these 10 'other' options may still be useful to consider. While options in the 'Best Interaction' zone are the most obvious for consideration, there are also a number of opportunities to use options in the top left and bottom right quadrants (see the numbers in Figure 2):

- Options in the 'Unlikely Outcome' zone (i.e. none to low likelihood, moderate to high impact) may become feasible to consider if there is a shift that causes the likelihood to significantly improve (moving the option into the 'Best Interaction' zone). This could entail for example a shift in accreditation requirements which explicitly include a range of energy efficiency knowledge and skills as required competencies (see "2" in the diagram).
- Options in the 'Step Up' zone (i.e. moderate to high likelihood, none to low impact) may become feasible if clustered together, with their combined impact potentially equalling an option in the 'Best Interaction' zone (see "3" in the diagram).
- Options in the 'Step Up' zone may also be used to 'step up' to an option within the 'Best Interaction' zone, where more challenging options are progressively implemented (see "4" in the diagram).

In addition, options in the 'Poor Outcome' zone (i.e. none to low likelihood, none to low impact) may also become feasible to consider (moving the option into the 'Step Up' zone) if there is a shift that causes the likelihood to significantly improve. This could entail for example the academic institution providing access to online text books, which may enable additional readings to be set much more easily for students (see "2" in the diagram)

3.3. Shortlisting the top 10 options for consideration

In consultation with Dr. Mackenzie-Mohr, the 23 survey responses were semi-quantitatively analysed together with the findings of the literature review. For the Impact and Likelihood results, the averages for the phone poll (13 responses) were checked with the averages for the email survey (10 responses), to see whether there were any major differences of opinion between the two groups. Generally speaking the phone poll respondents were more conservative than the email respondents about the likelihood of the options being undertaken, and the impact of the options (i.e. choosing lower scores). This could be due to email survey participants perceiving a need to over-state their position to encourage action, or alternatively phone-poll participants being reluctant to appear too enthusiastic when talking to the research team personnel. Given that the difference was consistent across all 19 options, it was not considered to be an impediment to using the data in an aggregated form (i.e. combining phone poll and email data).

Figure 2 presents the initial CBSM-style plot of the full options list from the aggregated respondent data, showing that, broadly speaking, respondents considered all 19 options to be of at least moderate impact and moderate likelihood. The data is also represented in **Table 1**. This quite optimistic result could be partly due to the respondents self-selecting their involvement in the research and therefore having an interest in improving the extent of energy efficiency in the curriculum, even though they were asked to consider the impact and likelihood of colleagues in the school undertaking such options. The results are also encouraging with regard to the relatively high impact and likelihood results for most options, indicating a wide range of opportunities for addressing curriculum renewal for energy efficiency.

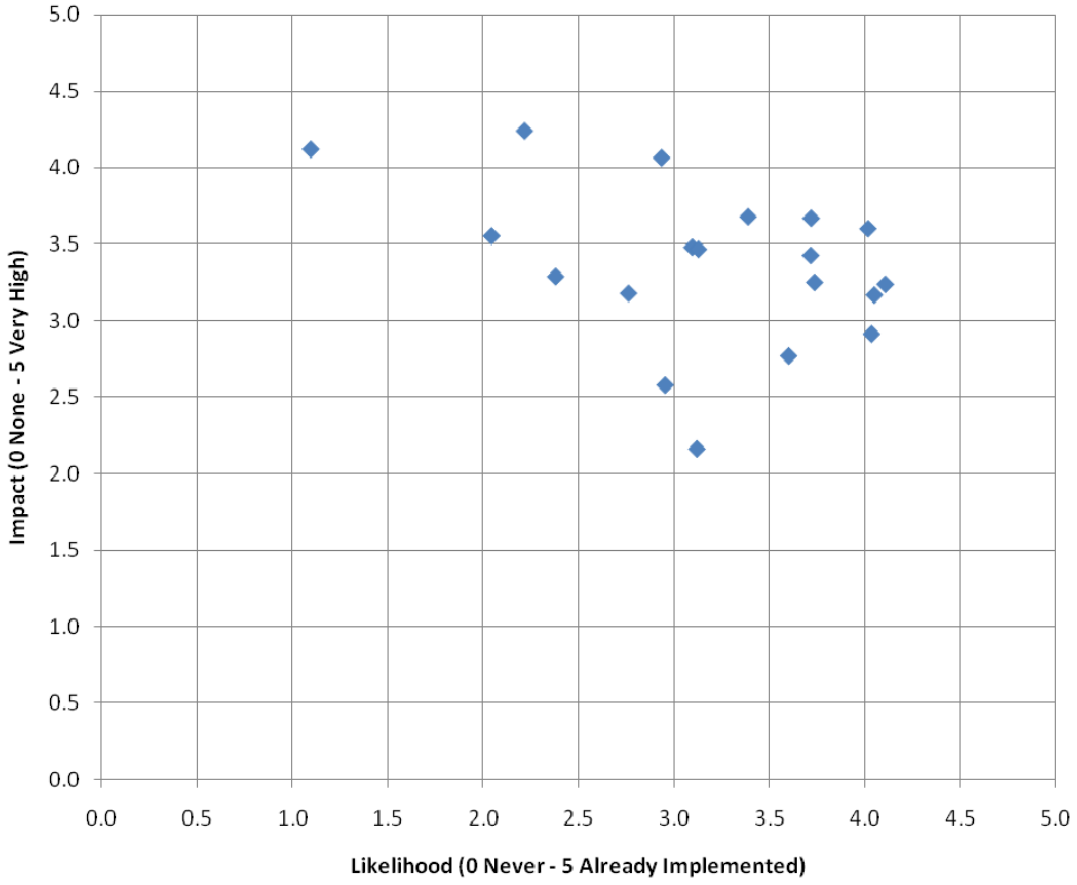

Figure 2. Plotted matrix, based on the results of the phone poll and email survey

Examining the review data and the literature review findings, it was recognised that options with a low impact could be set aside, in preference for higher impact option change initiatives. Further to consultation with Dr Mackenzie-Mohr, four were set aside from the priority list because their impact was 3.0 or less (i.e. the four options in **The remaining** 11 options were ranked by likelihood to create a shortlist of 10 options as shown in **Table 3**, for which the remaining tasks of this project were focused, including the investigation of barriers and benefits, and an investigation of tools and methodologies that engineering educators can use at a departmental level to improve the extent of energy efficiency education in engineering curriculum.

It is noted that from this short-listing process, one option ’15. Include a topic-specific lecture set (i.e. a sub-topic) within the course’ fell just outside of the top-10 options for improving the extent of energy efficiency content within engineering programs, and it is ordered as the 11th option in the full literature review (Appendix B), followed by the remaining options in decreasing order of likelihood.

Table 2 that have a ~~strike-through~~). Of the remaining 15 options, it was recognised that options with a very low likelihood may not be currently feasible without significant external interventions, such as by Engineers Australia or NFEE. Thus, in consultation with Dr. Mackenzie-Mohr, those four options which were rated by engineering educators to have an average likelihood of 2.5 or less were discounted for further consideration in this research project (which is aimed at change within the department at the level of the engineering educator), due to their very low probability of occurring without significant campaigning and change at an institutional level, professional practice or national policy level (the last four options in **The remaining** 11 options were ranked by likelihood to create a shortlist of 10 options as shown in **Table 3**, for which the remaining tasks of this project were focused, including the investigation of barriers and benefits, and an investigation of tools and methodologies that engineering educators can use at a departmental level to improve the extent of energy efficiency education in engineering curriculum.

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Table 2). It should be noted that while these options may currently be unlikely, a change in the political, social or academic climate may make these more likely, and should then be considered by educators.

The remaining 11 options were ranked by likelihood to create a shortlist of 10 options as shown in **Table 3**, for which the remaining tasks of this project were focused, including the investigation of barriers and benefits, and an investigation of tools and methodologies that engineering educators can use at a departmental level to improve the extent of energy efficiency education in engineering curriculum.

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Table 2. Behaviour data average scores, ordered from highest to lowest likelihood

Prioritised Full List	Description	Likelihood (Average)	Impact (Average)
1	Include a case study on energy efficiency	4.1	3.2
2	Include a guest lecturer to teach a sub-topic	4.0	3.6
3	Offer supervised research topics on energy efficiency themes	4.0	3.2
~~*4*~~	~~*Offer industry placements in energy efficiency (Work Integrated learning)*~~	~~*4.0*~~	~~*2.9*~~
5	Offer energy efficiency as a topic in a problem-based learning course	3.7	3.7
6	Include *assessment* that aligns with the energy efficiency theme within the course (e.g. exam questions and assignments)	3.7	3.4
7	Include tutorials that align with the energy efficiency theme in the course (e.g. presentations/ discussions/ problem solving)	3.7	3.3
~~*8*~~	~~*Show a DVD of a related documentary*~~	~~*3.6*~~	~~*2.8*~~
9	Overhaul the course to embed energy efficiency	3.4	3.7
10	Include one workshop on energy efficiency in the course (i.e. laboratory-style experiments)	3.1	3.5
11	Include a field trip related to energy efficiency	3.1	3.5
~~*12*~~	~~*Add energy efficiency readings to the required reading list*~~	~~*3.1*~~	~~*2.2*~~
~~*13*~~	~~*Show a DVD of a keynote lecture on energy efficiency*~~	~~*3.0*~~	~~*2.6*~~
14	Develop a new course on energy efficiency	2.9	4.1
15	Include a topic-specific lecture set (i.e. a sub-topic) within the course	2.8	3.2
16	*Include elective modules on energy efficiency within the course*	*2.4*	*3.3*
17	*Offer a 'major' stream in the engineering degree on energy efficiency*	*2.2*	*4.2*
18	*Include several workshops on energy efficiency in the course (i.e. including laboratory-style experiments)*	*2.0*	*3.6*
19	*Develop a new degree program on energy efficiency (e.g. B Energy Eng)*	*1.1*	*4.1*

Note: Items that are shaded and in italics have a likelihood average of 2.5 or less, or an impact of 3.0 or less.

Table 3. Ten shortlisted options for increasing the amount of energy efficient in engineering curriculum

Shortlisted Option	Description	Likelihood (Average)	Impact (Average)
1	Include a case study on energy efficiency	4.1	3.2
2	Offer supervised research topics on energy efficiency themes	4.0	3.2
3	Include a guest lecturer to teach a sub-topic	4.0	3.6
4	Include tutorials that align with the energy efficiency theme in the course (e.g. presentations/ discussions/ problem solving)	3.7	3.3
5	Offer energy efficiency as a topic in a problem-based learning course	3.7	3.7
6	Include assessment that aligns with the energy efficiency theme within the course (e.g. exam questions and assignments)	3.7	3.4
7	Overhaul the course to embed energy efficiency	3.4	3.7
8	Include a field trip related to energy efficiency	3.1	3.5
9	Include one workshop on energy efficiency in the course (i.e. laboratory-style experiments)	3.1	3.5
10	Develop a new course on energy efficiency	2.9	4.1

3.4. Prioritising Options to Focus On

Although this project has shortlisted 10 options for consideration, a department may not be interested in all options. Given the above findings of the literature review and survey, departments considering how to improve the extent of energy efficiency knowledge and skills within their engineering programs can create a strategy comprising one or more options, from an informed shortlist of 10 possible options that have been shown to have impact and which are likely to be implemented, in other university settings.

There are no defined steps for selecting the final set of options to focus on, however the department may wish to create a staged list of options that will be gradually implemented over a period of time. This could be in the form of a 'tiered' prioritisation approach, using a combination of the considerations outlined in Section 3.2. For example:

*A department may decide to address the first three shortlisted options in **Table 3** immediately, but may also be interested in 'Offer a 'major' stream in the engineering degree on energy efficiency' (#17 in **Table 2**) as a top-left quadrant (low likelihood, high impact) option, which they understand will require some strategic interventions from the PVC level with regard to some funding allocation. They may also be interested in addressing 'Offer industry placements in energy efficiency (Work Integrated learning)' (#4 in **Table 2**) as a bottom-right quadrant (high likelihood, low impact) option, for awareness raising among staff (to help them 'step up' to other more challenging options later), and for the marketing benefits.*

4. Review of Barriers and Benefits for the Shortlisted Options

Engineering for energy efficiency requires a departure from traditional design methodology and engineering paradigms, which creates a number of challenges (or 'barriers') to its integration within the curriculum. For example, it requires a multidisciplinary approach which considers the social, economic and environmental ramifications of any design, it must necessitate extensive collaboration with non-engineers and may require engineers to take the initiative in leading clients to energy efficient solutions and alternatives. Engineers may need to reconceptualise their position within society and responsibilities towards creating a more sustainable society, as noted by the former president of the American National Academy of Engineering Wm Wulf,

> *"Today's student engineers not only need to acquire the skills of their predecessors but many more, and in broader areas. As the world becomes more complex, engineers must appreciate more than ever the human dimensions of technology, have a grasp of the panoply of global issues, be sensitive to cultural diversity, and know how to communicate effectively."* [35]

In addition, the process of integrating energy efficiency knowledge and skills into the engineering curriculum can have a number of benefits, which may not be taken advantage of if not clearly understood. For example, students knowledgeable about energy efficiency opportunities may be more saleable to potential employers, and programs including energy efficiency content may lead to research interests by staff, expanding the research agenda for the department.

Hence, before a department can begin to use the shortlisted options identified in Section 3 to develop strategies for implementation, the CBSM methodology identifies a critical step as understanding the barriers and benefits to the options of interest, *at the detailed level of the option.*

As discussed in the previous sections, although there is a relatively small body of literature surrounding engineering education for energy efficiency,[36] there is a significant amount of literature that explores similar curriculum issues with respect to sustainability. However, even this literature does not include a systematic consideration of barriers or benefits with regard to which ones are more likely to affect a lecturer's decision to undertake a particular option (and hence which ones should be targeted for intervention). This further highlights the emerging nature of the field, where publications dealing with timely curriculum renewal are almost non-existent.

As experiences in integrating broader sustainability related content into engineering programs can allow a certain degree of forecasting as to what the barriers and benefits might be for improving the extent of energy efficiency knowledge and skills in the curriculum, the literature review included literature discussing curriculum issues with introducing sustainability content. Indeed, as New Zealand researcher Carole Boyle - who lists numerous barriers and benefits to this greater inclusion of sustainability in engineering education - notes, these are common to most fledging concepts.[37]

The following text and **Table 4** summarises the common barriers and benefits for each of the 10 shortlisted options, to increasing the extent of energy efficiency in the curriculum. It also highlights a number of option-specific barriers and benefits. The specific relevance of these barriers and benefits to each of the shortlisted options is outlined in detail in Appendix B.

[35] Wulf, W.A. and Fischer, G. (2002) 'A makeover for engineering education', *Issues in science and technology online,* The National Academic Press , Washington, D.C. Quoted by Kellum, Maher & Peters, 2008.
[36] Desha, C., Hargroves, K., Smith, M., Stasinopoulos, P., Stephens, R., and Hargroves, S. (2007) *Energy Transformed: Australian University Survey Summary of Questionnaire Results*, The Natural Edge Project (TNEP), Australia.
[37] Boyle, C. (2004) 'Considerations on educating engineers in sustainability' *International Journal of Sustainability in Higher Education,* vol 5, no 2, pp147-155.

Table 4. List of key barriers and benefits to energy efficiency education for the 10 shortlisted options

Key Barriers and Benefits to Implementation	1	2	3	4	5	6	7	8	9	10
Common Barriers										
– Lack of available data/ information	●	●		●	●	●	●		●	●
– Lack of time for preparation	●	●		●	●	●		●		●
– An overcrowded curriculum	●		●	●		●			●	●
– Prohibitive cost	●		●	●	●	●		●	●	●
– Lack of knowledge	●	●	●	●	●		●		●	●
– Lack of value attached	●		●			●				
– Lack of industry contacts		●	●					●		
– Resistance to top-down directive			●				●			
– Students' prior learning habits					●				●	
– Lecturer apathy		●					●			
– Administrative coordination							●	●		●
Other Barriers										
– Silo-culture	●									
– Annual topic renewal		●								
– Lack of quality guest lecturers			●							
– Difficulty in making a pedagogical shift					●					
– Lack of student maturity					●					
– Difficulty of assessment						●				
– Institutional organisational structure							●			
– Lack of collaboration among colleagues							●			
– Timetabling issues								●		
Common Benefits										
– Improved marketability	●	●					●	●		●
– Cross-functionality of content	●						●			●
– Additional research opportunities		●								●
– Networking opportunities for students		●	●					●		
– Networking opportunities for lecturers		●	●					●		
– Experience in incorporating emerging concepts into curriculum			●				●			
– Addressing the time-lag for graduates			●				●			
– Improved pedagogy - problem based learning				●	●	●			●	
– Improved pedagogy – generic skills				●	●	●			●	
– Lecturer professional development (content)		●				●				
Other Benefits										
– Improved student access to best practice	●									
– Improved pedagogy - use of case studies	●									
– Access to additional research funding		●								
– Improved student contact with employers		●								
– Lecturer access to disciplinary mentors			●							
– Curriculum load neutral					●					
– Improved enrolment										●

4.1. Prioritising Barriers and Benefits to Focus On

The extent to which these barriers and benefits affect a Department will be different for each academic institution, given the wide variety of variables influencing the way that a Department structures its bachelor and postgraduate engineering programs. Using the list of considerations (**Figure** 3) as a guide, a department can further shortlist the listed barriers and benefits described for each behaviour in this report, to the 2-3 barriers and benefits that will influence the extent to which energy efficiency knowledge and skills are integrated within the engineering curriculum.

- Institutional context (university level and department level)
- Market context (student expectations)
- Regulatory context (e.g. changing accreditation requirements)
- Existing and possible budgetary flexibility
- Existing staff capabilities (i.e. strengths and weaknesses in expertise)
- Existing staff attitude towards curriculum renewal
- Existing staff attitude towards learning and teaching versus research

Figure 3. Considerations for prioritising barriers and benefits

Such a prioritisiation process could be undertaken by senior management within the school, or alternatively the school could gauge the priority issues to address through one or more staff focus group sessions or a staff survey, where they may be asked, for the one or more curriculum renewal options being implemented, to rank the barriers and benefits in order of importance to them.

4.2. Common Barriers

4.2.1. Lack of available data / information

There is a lack of well written material – textbooks, case studies, examples of 'real' sustainable solutions,[38] and materials for teaching sustainability[39] - such that educators feel this is a significant barrier to embedding sustainability into their course. Australian researchers Abbas El-Zein *et al*[40] reiterated earlier findings by UK researchers Slobodan Perdan *et al*[41] which noted that there is a shortage of appropriate case studies which guide students through a structured thought-process to highlight the necessary steps through which sustainability is achieved. There are also still very few textbooks which truly cover topics such as sustainability engineering, according to New Zealand researcher Carol Boyle,[42] who also noted that there are few true examples of engineering which could be said to have achieved 'real sustainability'.

4.2.2. Lack of time for preparation

Research from both the USA and the Netherlands suggests that there is a limited time available to engineering educators to make any changes to courses, degrees, course materials, and to identify academically rigorous information,[43] due to existing pressures to meet research commitments, in addition to a teaching workload and service requirements.[44] Content development may therefore be given a lower priority, or avoided altogether.

4.2.3. An overcrowded curriculum

Engineering degrees are widely reported (in the USA, New Zealand and the EU) to be crowded with courses, with significant competition existing over what should be taught.[45] Although engineering departments might recognise the need to teach energy efficiency, pressure from faculty who feel that either it is already being taught adequately, or that it doesn't need to be taught at all, may be a barrier to displacing existing curriculum with energy efficiency material as there are limited credit points within a program to allocate to incorporating new topic areas.[46] The concern is that any additional information must displace existing 'fundamentals', as courses and programs are generally already saturated.

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[38] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.
[39] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.
[40] El-Zein, A., Airey, D., Bowden, P. & Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula, *International Journal of Sustainability in Higher Education,* vol, 9 Issue 2, pp170-182.
[41] Perdan, S., Azapagic, A. and Clift, R. (2000) 'Teaching sustainable development to engineering students', *International Journal of Sustainability in Higher Education*, vol 1, no 3, pp267-279.
[42] Boyle, C. (2004) 'Considerations on educating engineers in sustainability' *International Journal of Sustainability in Higher Education,* vol 5, no 2, pp147-155.
[43] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5 no 3, p278-288.
[44] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[45] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Boyle, C. (2004) 'Considerations on educating engineers in sustainability' *International Journal of Sustainability in Higher Education,* vol 5, no 2, pp147-155; Holmberg, J., Svanström, M., Peet, D.J., Mulder, K., Ferrer-Balas, D. and Segalàs, J. (2008) 'Embedding sustainability in higher education through interaction with lecturers: Case studies from three European technical universities', *European Journal of Engineering Education*, vol 33, no 3, pp271-282; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[46] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Boyle, C. (2004) 'Considerations on educating engineers in sustainability' *International Journal of Sustainability in Higher Education,* vol 5, no 2, pp147-155.

Where lecturers feel that the new material is less relevant, or that existing materials are indispensable, there will be significant resistance to these changes.

4.2.4. Prohibitive cost

Making any changes to a course within a university will have budget and cost implications. There is a noted lack of such funds available, and where courses are offered through various departments this may result in conflict over how such changes should be funded. Many of the options potentially involve lecturers investing a significant amount of time in developing new content because there is either little existing material to assist them, or quality material is difficult to locate.[47] Also, a number of the options potentially involve either additional laboratory equipment, costs to access particular databases or software, or travel and accommodation costs for field trips which can be a significant barrier to attempting curriculum change.

4.2.5. Lack of knowledge

DJ Peet and his fellow researchers from the Netherlands echoed those comments by Michael Robison and his colleagues from the USA, who have noted that lecturers often do not have adequate knowledge themselves of sustainability (or energy efficiency) to teach this within their courses.[48] Lecturers' perception of multidisciplinary topics such as energy efficiency, which combine social, economic and environmental components[49] is often that it is too vague to be explicitly taught in their course, particularly where such a course is of a specialised, technical nature. Conversely, but for similar reasons, the complex nature of energy efficiency may lead some lecturers to feel that it is implicitly being taught already in the course, making an overhaul unnecessary, even where these concepts and links are not clearly expressed to students. [50]

4.2.6. Lack of value attached

Lecturers may not value the importance or relevance of energy efficiency to their course, they may perceive it as less important than other aspects of the course, and may therefore resist including such material into their course.[51]

4.2.7. Lack of industry contacts

Lecturers may not have existing industry contacts who can provide energy efficiency problems that need researching. Because the lecturers may not know the field very well, they may struggle to identify colleagues internally or externally who could deliver suitable content. One respondent noted (in confidence) to the authors that there is an increasing demand from local industry to have students work on energy-efficiency related projects, an opportunity which needs to be taken advantage of.

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[47] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.

[48] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288; Boyle, C. (2004) 'Considerations on educating engineers in sustainability' *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.

[49] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education*, December 2001, vol 9, no 2, pp179-192.

[50] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.

[51] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Boyle, C. (2004) 'Considerations on educating engineers in sustainability' *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.

4.2.8. Resistance to top-down directive

Dutch researchers DJ Peet *et al* found that, as lecturers are often experts in their field, they can be resistant to suggestion that they should teach something which lies outside their field of knowledge.[52] The autonomy of lecturers is noted to be a significant barrier to overhauling or changing courses, particularly where the push for these changes comes from above. Lecturers may resist advice and recommendations from outsiders (particularly non-engineers) and from above (as in through the university system).[53]

4.2.9. Students' prior learning habits

Students' predisposition towards technical, quantitative subject matter[54] and an engineering culture which tends to neglect the bigger picture and focus rather on detail,[55] may make it difficult to introduce a multidisciplinary approach to energy efficiency, which may require qualitative aspects and a whole systems consideration of a problem.

4.2.10. Lecturer apathy

Lecturers have inertia when it comes to overhauling their courses, largely due to there being little incentive for them to do so. This can lead to a passivity, with which lecturers feel that the responsibility for demanding sustainability (or energy efficiency) lies elsewhere (such as with industry), and the role of an engineer is to design to such parameters only when they are specified, as opposed to educators being the instigators for energy efficient design.[56] The academic reward system also provides little incentive for lecturers to update or change their courses, focusing more on student numbers and academics producing research papers.

4.2.11. Administrative coordination

Even within a department, changing the curriculum can result in arguments between faculty over credit point allocation, and can inflame insecurities regarding power and position. The time-consuming nature of such logistics can be a barrier to beginning a new process, [57] and a lack of consensus on strategic direction within the school creates uncertainty over the value of undertaking curriculum renewal.

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[52] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.

[53] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288; Holmberg, J., Svanström, M., Peet, D.J., Mulder, K., Ferrer-Balas, D. and Segalàs, J. (2008) 'Embedding sustainability in higher education through interaction with lecturers: Case studies from three European technical universities', *European Journal of Engineering Education*, vol 33, no 3, pp271-282.

[54] El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182; Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.

[55] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288.

[56] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288.

[57] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288.

4.3. Common Benefits

4.3.1. Improved marketability

The university can market itself as capacity building students to meet the needs of society in the 21st Century. Student project work in energy efficiency may lead to marketing opportunities for the institution, with innovative outcomes that have business, community and environmental benefits. Considering new content for the curriculum can also help to demonstrate quality assurance and continual improvement to accreditation bodies, students and potential graduate employers. [58]

4.3.2. Cross-functionality of content

The multidisciplinary nature of energy efficiency may mean that a course which is overhauled may also become relevant to both junior and senior students, and across all engineering disciplines.[59] The benefit derived from this for lecturers would include high levels of enrolment in their course which may lead to increased funding as well as collaboration with colleagues from other departments, and other universities, as was the case with a multi-disciplinary subject taught at Delft University in the Netherlands which necessitated and provided opportunity for collaboration between academics of various disciplines.[60] The course was considered to be a joint learning exercise for the lecturers also, and resulted in a framework for sustainable business plan development with applications in industry and outside of the university. There is also evidence of well designed courses being able to be taught at multiple universities, as was the case for Michigan Tech and Yale University in the United States.

4.3.3. Additional research opportunities

Incorporating new content into a program provides opportunities for lecturers to explore research projects and professional pathways in leading edge topic areas.[61]

4.3.4. Networking 0pportunities for students

Research opportunities can provide networking opportunities for students and may result in higher graduate employment, or student engagement with industry, as was found to be the case at the University of Michigan by researchers Angela Leuking *et al,*[62] where engaging with industry, by physically visiting their place of business on a field trip, provided networking opportunities for students resulting in higher graduate employment, and higher student engagement with industry.

4.3.5. Networking opportunities for lecturers

Engaging with industry experts, such as bringing them in as guest lecturers, provides networking opportunities for students and may result in higher graduate employment, or student engagement with industry, as was found to be the case at the University of Michigan by researchers Angela Leuking *et*

[58] Holmberg, J., Svanström, M., Peet, D.J., Mulder, K., Ferrer-Balas, D. and Segalàs, J. (2008) 'Embedding sustainability in higher education through interaction with lecturers: Case studies from three European technical universities', *European Journal of Engineering Education*, vol 33, no 3, pp271-282.
[59] Zhang, Q., Zimmerman, J., Mihelcic, J. and Vanasupa, L. (2008) 'Civil and environmental engineering education (CEEE) transformational change: Tools and strategies for sustainability integration and assessment in engineering education', *American Society for Engineering Education, USA*, AC 2008-1670 .
[60] Bonnet, H., Quist, J., Hoogwater, D., Spaans, J. and Wehrmann, C (2006) 'Teaching sustainable entrepreneurship to engineering students: the case of Delft University of Technology', *European Journal of Engineering Education*, vol 31, no 2, pp155-167.
[61] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288.
[62] Leuking, A.D., Ross, D.A. and Walter, J.W. (2003) 'Environmental sustainability education at the University of Michingan" Collaboration with industry to provide experiential learning opportunities', American Society for Engineering Education Annual Conference and Exposition, USA.

al.[63] Lecturers also have the opportunity to collaborate, both internally with other university colleagues, and externally, with colleagues from other universities, industry and government. There may be the opportunity to tap into mentors in the industry who may have practical and/or theoretical experience in the field. For example, in the UK, the Visiting Professor Scheme has been very successful at connecting such experience with student learning.[64] Many of the options involve interaction with future employers to some extent, providing lecturers with an opportunity to network with engineers in industry positions.

4.3.6. Experience in Incorporating Emerging Concepts into Curriculum

The experience gained from incorporating energy efficiency material into engineering curriculum is a valuable one, allowing lecturers to be prepared for further changes to curriculum as the nature of engineering and its accreditation requirements change in the years to come. The literature suggests that quite often the process of curriculum renewal is not as strenuous as perceived, as Michael Robinson and his colleagues from the Rose-Hulman Institute of Technology in the USA[65] discovered. The lecturers of Rose-Hulman Institute of Technology found that where changes were focused on one course, it was possible for it to be undertaken by a single faculty and did not require the 'buy-in' of a whole department. This simplified the process as it reduces the number of agents which need to be convinced of the need for change. They also discussed a course which was overhauled in which the inclusion of sustainability within the course was not seen to have compromised other course materials, as that course was already needing to be overhauled in order to meet changing course and departmental expectations. Peter Bosscher, Jeffrey Russell and WB Stouffer from the University of Wisconsin[66] commented on the changing expectations of engineers and how this is filtering through and impacting on universities and engineering departments.

4.3.7. Addressing the time lag for graduates

Brisbane (Australia) based researchers Cheryl Desha *et al*[67] noted the time-lag inherent in engineering degrees and how updating and overhauling courses using a 'standard method' may take up to 15-20 years. This time delay can create potential risks for the engineering school and the university in terms of student enrolments, adherence to accreditation requirements and consequently program viability. Given that the half-life of engineering knowledge is about *'five years and shrinking'*,[68] this poses a considerable dilemma for engineering schools… and a significant opportunity - as overhauling a course to include energy efficiency creates the potential for other aspects of the course to be simultaneously updated. This may include not only knowledge, but new pedagogic techniques.

4.3.8. Improved pedagogy – problem based learning

An increasing number of universities world-wide are offering problem based courses, most likely in response to industry expectations, and hence accreditation board requirements, which require engineers to be proficient in a number of disparate capabilities and interdisciplinary skills.[69] Learning

[63] Leuking, A.D., Ross, D.A. and Walter, J.W. (2003) 'Environemntal sustainability education at the University of Michigan" Collaboration with industry to provide experiential learning opportunities', *American Society for Engineering Education Annual Conference and Exposition*, USA.
[64] Wallace, K. (ed) (2005) *Educating Engineers in Design, Lessons learnt from the Visiting Professors Scheme,* Royal Academy of Engineering, UK.
[65] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA.
[66] Bosscher, P.J., Russell, J.S. and Stouffer, W.B. (2005) 'The Sustainable Classroom: Teaching Sustainability to Tomorrow's Engineers', American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA.
[67] Desha, C.J., Hargroves, K. and Smith, M.H. (2009) 'Addressing the time lag dilemma in curriculum renewal towards engineering education for sustainable development', *International Journal of Sustainability in Higher Education,* vol 10, no 2, pp184-199.
[68] Crofton, F.S. (2000) 'Education for sustainability: opportunities in undergraduate engineering', *Journal of Cleaner Production*, vol 8, p399.
[69] Lehmann, M., Christensen, P., Du, X. and Thrane, M.(2008) 'Problem-oriented and project-based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education', *European Journal of Engineering Education*, vol 33, no 3, pp283-295.

about energy efficiency through PBL can lead students to request a similar format in other courses, providing incentive to other colleagues to teach using such methods and provide encouragement for those already doing so. It is also noted within the literature that the success of this type of teaching provides benefits to lecturers through the satisfaction of seeing students engage with the subject matter, think more critically and pursue deeper learning. It is also noted that PBL, which is aligned with assessment tasks, can encourage the development of graduate attributes (critical thinking, interpersonal and communication skills, reflective practise and an ability to analyse, synthesise, create and apply knowledge),[70] and may in turn assist the course lecturer and the university in promoting both the course and the degree to future students.

4.3.9. Improved pedagogy – generic skills

Renewing the curriculum with new content provides an opportunity to also review and improve on the method of teaching and learning, possibly introducing new methods such as Problem Based Learning (PBL). Teaching energy efficiency within any engineering program will require the application of PBL, a particularly useful tool for developing a deeper understanding of the concepts and practice of sustainability within the students. An increasing number of universities world-wide are offering problem based courses, most likely in response to industry expectations, and hence accreditation board requirements, which require engineers to be proficient in a number of disparate capabilities and interdisciplinary skills.[71] The success of a PBL course can lead students to request a similar format in other courses, providing incentive to other colleagues to teach using such methods and provide encouragement for those already doing so. It is also noted within the literature that the success of this type of teaching provides benefits to lecturers through the satisfaction of seeing students engage with the subject matter, think more critically and pursue deeper learning. This type of teaching may also provide benefits to a university in terms of the employability of their students, and in their ability to promote applicable degrees and courses to potential students.[72]

4.3.10. Lecturer Professional Development

Australian researchers Jafar Madadnia and his colleagues noted that in the experience of the University of Technology, Sydney, lecturers experienced significant satisfaction from observing students adopt deeper learning habits, and it is suggested that satisfaction gained by association with student research topics on energy efficiency can also significantly improve the lecturer's knowledge.

[70] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education*, December 2001, vol 9, no 2, pp179-192.
[71] Lehmann, M., Christensen, P., Du, X. and Thrane, M.(2008) 'Problem-oriented and project-based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education', *European Journal of Engineering Education*, vol 33, no 3, pp283-295.
[72] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education*, December 2001, vol 9, no 2, pp179-192.

5. Tools and Strategies for Overcoming Barriers & Enhancing Benefits

This step involves selecting tools and strategies that will be appropriate in addressing each of the barriers and benefits for the selected options. The aim is to find ways to reduce the barriers and increase the benefits for the option to be 'encouraged', and to increase the barriers and reduce the benefits for any options that that need to be 'discouraged'. Within the CBSM method, it is important at this stage to first focus on selecting tools, which can then be developed into an overall strategy for implementing one or more of the prioritised options. All of the tools to address the barriers and benefits should be selected *before* working on possible strategies and considering program budget and time constraints, to avoid limiting the process of strategic innovation.

In the area of integrating energy efficiency knowledge and skills into the curriculum, the documentation of precedents with regard to tools and strategies to encourage behaviours is in its very early stages, and the literature review uncovered very few examples of actual initiatives. However, a study of a range of journal papers and conference presentations on experiences in integrating sustainability knowledge and skills into engineering education has allowed for the compilation of a number of potential tools to support the shortlisted behaviours. This section outlines the findings of this literature review, in the form of a list of potential strategies and tools for consideration.

5.1. Considering and Selecting Tools

The selection of tools (to help address key barriers and benefits identified for a particular option) will be case-specific, given that each department will likely have a different set of 'prioritised' barriers and benefits to address. **Table 5** draws on the CBSM literature to provide a summary of the key tools available to select from in considering the best approach to reducing the 'high priority' barriers, and making the most of the identified 'benefits'.

Table 5. Tools for consideration and a brief description of each

Incentives: It may be appropriate to provide staff with positive (financial or non-financial) incentives to encourage them to engage in the new option/s for increasing the extent of energy efficiency knowledge and skills in the curriculum.
Convenience: ***(Removing External Barriers)*** Making the prioritised option more attractive and any undesirable options less attractive can be aided through increasing the convenience of the prioritised option, and decreasing the convenience of the old situation. For example, a new course evaluation template could be developed, which focuses on questions about the new options being implemented.
Commitment: Given the cultural expectation that people do what they say, the more public the commitment, the more likely that the option will be implemented. Being careful not to be 'coercive', and to provide people with option and choices, the commitment to curriculum renewal needs to be public (within the department) and durable, involving the relevant staff members directly. It is also important to enhance the person's self perception (for example by asking about what they are already doing in this area). Typically, this tool involves asking staff to first go along with a small request prior to a larger request.
Social Diffusion: Given that almost all decisions we make are driven/ affected by social diffusion (i.e. caring about other decisions made by people in our own social network), this may be used as a tool for rapid curriculum renewal, through encouraging key staff members to implement the prioritised options, and allowing an informal take-up by other staff as they see the benefits.
Prompts: Prompts may be used to remind staff about a particular option, for example through the use of email, or the inclusion of an energy efficiency related question/item in the course outline template. Prompts must be delivered in close space and time to the change trying to be achieved.
Norms: Almost all behaviours are governed by norms, hence they are important to build into programs, as most existing norms do not support the learning and teaching of energy efficiency. There are primarily two forms of norms to consider:

1. Descriptive Norms: Based on observed behaviours of others (based on the inclusion of energy efficiency learning outcomes in key courses within a program), the person makes a decision on how to act. 2. Injunctive Norm: Grow out of descriptive norms, where the norm is monitored and enforced, once the descriptive norms build momentum. For example, this might entail the introduction of a required energy efficiency related learning outcome in particular courses, after staff have been given an opportunity to introduce such an item on their own.
Communication *Attention:* The communication tool allows the program to capture attention, using vivid colours and messaging, humour, graphics and anecdotes. It also helps shift the new requirements from short to long term memory, and can enhance recall. *Content:* In creating the content of the messages, avoid using fear or extreme messages, focusing on the benefits. *Feedback:* Use public space to track the uptake of behaviour change initiatives (for example a common room), converting information that is largely intangible into something more tangible (for example through the use of signage). *Framing:* Note that the perception of losing something is stronger than to secure the equivalent gain, so communication about what the department may be missing out on might be more useful than what the department could gain. *Mediums:* The message needs to be kept constant, but through a variety of medium. There is a spectrum of effectiveness, from face to face, through to audio and written (which is effective for complicated messages).

Source: Adapted from McKenzie-Mohr (1997)[73]

Given this selection of tools, the following paragraph provides an example of how they may be selected for the barriers and benefits being considered, which will depend to a certain extent on the budget and resourcing availability within the department:

*A department may decide to focus on the highest impact and highest likelihood option 'Include a case study on energy efficiency' in one more courses. From the barriers and benefits list in this report (**Table** 4), the department may then decide that the key barriers are 'lack of knowledge', 'lack of time for preparation' and the key benefits to the successful implementation of this option are 'improved marketability' and 'improved pedagogy'. Given these barriers and benefits, the department may then identify several tools that could be used as follows, within an overall strategy for including a case study on energy efficiency'.*

Barrier 1: Lack of knowledge	– *Financial/ research incentives (to encourage professional development)* – *Descriptive Norms*
Barrier 2: Lack of time for preparation	– *Financial/ time Incentives (to create time for preparation)*
Benefit 1: Improved marketability	– *Communication*
Benefit 2: Improved pedagogy – case studies	– *Descriptive Norms* – *Communication*

[73] McKenzie-Mohr, D. (1997) Fostering Sustainable Behaviour: An Introduction to Community-Based Social Marketing (3rd Edition), Gabriola Island B.C. New Society Press.

5.2. Strategies Identified in the Literature to Address the Barriers and Benefits

The development of strategies involves identifying the key components that can use the nominated tools to bring about the behavioural change – in this case increasing the extent of energy efficiency content in the engineering curriculum. It may be the case that there is more than one tool that would be appropriate to address a barrier or benefit, but this might drive up costs. Working through the barriers and benefits, we may find that one strategy may be able to incorporate a number of tools, which may also reduce the overall cost of implementing the option.

The following pages draw on the findings of the 2007 survey and the literature reviewed in earlier sections, to highlight a number of potential key components of a department's strategy to implement one or more of the shortlisted 10 options in Section 3.2. The items are not listed in any order of preference:

Providing financial assistance to integrate energy efficiency into the curriculum: The provision of grants or financial assistance could address the financial barrier associated with introducing energy efficiency into engineering curricula is the lack of lecturer time to do so, and finances to facilitate this.

Creating a Working Party: The strategy might entail creating a core group of faculty members (potentially from various disciplines) who are responsible for overseeing and encouraging the integration of energy efficiency into engineering integration. The formation of a core group of individuals within a university who are responsible for integrating sustainable development (energy efficiency) throughout degrees and the department is an important tool for achieving consistency, deep penetration of these concepts into all aspects of the course, and the stability of courses as individual faculty members responsible for teaching and co-ordinating courses leave. This group can acquire the information necessary for a wide reaching overhaul of engineering degrees, and then disseminate this information to individual lecturers.[74] The literature warns against an overly top-down approach when trying to incite curriculum renewal, and cite experience in which a collaborative approach that works with lecturers (potentially through such a group) is effective in creating cultural shifts leading to the inclusion of sustainable development within courses.[75]

Permitting discussion about workload allocations: The strategy might entail giving lecturers permission to adjust their workload proportions (i.e. teaching, research, service) to focus on renewing course/s. As a significant barrier to upgrading courses is lack of time and finances to do so, this tool may assist lecturers in prioritising such upgrades and allocating time to do so.

Fostering interdisciplinary networks: The department's strategy may entail fostering interdisciplinary networks between academics to enable multidisciplinary input into energy efficiency courses. Multidisciplinary collaboration is seen as vital to ensure that a broader base of considerations can be included in design, and to obtain a bigger picture view of a problem that can provide numerous solutions, many of which may not have been visible from a disciplinary focus.[76] It is even argued that a multidisciplinary approach is not enough, as this still limits collaboration to those disciplines within the

[74] Holmberg, J., Svanström, M., Peet, D.J., Mulder, K., Ferrer-Balas, D. and Segalàs, J. (2008) 'Embedding sustainability in higher education through interaction with lecturers: Case studies from three European technical universities', *European Journal of Engineering Education*, vol 33, no 3, pp271-282.
[75] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288.
[76] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288; El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182; Ashford, N.A. (2004) 'Major challenges to engineering education for sustainable development', *International Journal of Sustainability in Higher Education,* vol 5, no 3.

network, whereas a trans-disciplinary model suggests that research and collaboration should transcend barriers and boundaries to open up the problem space for engineers, such that truly non-traditional solutions can be found.[77]

Providing seed funding for new technical research areas: Aligning engineering academic interest with energy efficiency through research may overcome barriers such as a lack of knowledge, and potentially the notion that energy efficiency might not be relevant to a particular course. This research may facilitate the creation of materials which could be used in the course also, and provide networks with colleagues who could appear as guest lecturers.

Providing seed funding for new teaching research: i.e. linking energy efficiency and engineering education, developing concepts and conceptual ideas/paradigms in this emerging field. In the case of many universities, research plays a key role in the activities of the lecturers, and in providing the direction for the university.[78] Thus, linking research to energy efficiency may assist in focusing lecturers' attention towards this area, it may enable them to dedicate the time and energy needed to become better informed of energy efficiency and how it integrates into engineering practice, and can assist in energy efficiency being consistently applied to the curriculum. In the Netherlands, one lecturer was noted to have said that if their research was not sustainable, research funds were not granted.[79]

Harnessing other institutional overhauls (e.g. departmental restructuring): The strategy might involve using existing organisational processes to strategically integrate energy efficiency into courses. For example, the University of Technology, Sydney (UTS) was able to integrate sustainability into their engineering degrees as part of a larger overhaul, which was undertaken largely for financial reasons. The degrees were consolidated by finding synergies, reducing administrative costs and overheads, and sustainability underpinned all areas of the degree. This overhaul assisted the university in meeting their goals to provide 'practice-based' engineering education, and to remain relevant and marketable in a changing field in which sustainability was seen to be becoming increasingly important.[80]

Creating a clear timeline: A key component of the strategy might be to create a robust and realistic expectation by department leaders, of the timeline for curriculum renewal and achievements, including an understanding of current strengths and current weaknesses, the current level of energy efficiency education, and what competitors are doing in the field. Peet *et al* and Theis *et al* discuss the benefits of such a review process and Bryce *et al* discuss the importance of momentum and engaging faculty for degree/university level change, through experiences from the University of Technology, Sydney.

Setting future targets: The strategy might entail the Program Convenor requiring that new content needs to be embedded by a particular timeframe, giving the lecturer permission (time, resourcing) to prioritise this and proceed. This tool may overcome the barrier of sustainability (and potentially also energy efficiency) being perceived as not relevant to a particular course, that the concepts are less important than those which they may potentially displace, or that they are already being implicitly taught in some fashion. There was also noted to be a perception within engineering ranks that concepts such as sustainability and energy efficiency did not need to be taught, as they would be included in

[77] Ashford, N.A. (2004) 'Major challenges to engineering education for sustainable development', *International Journal of Sustainability in Higher Education,* vol 5, no 3.
[78] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288.
[79] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288.
[80] Bryce, P., Johnston, S. and Yasukawa, K. (2004) 'Implementing a program in sustainability for engineers at University of Technology, Sydney – a story of intersecting agendas', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp267-277.

engineering designs if demanded by clients or that these concepts are best learned through professional practice. By requiring its inclusion, lecturers may be forced to reassess this position. The permission to do so, and provision of time and resources, will also assist in overcoming several barriers, as discussed above.

Identifying and using modular content: The department's strategy may involve identifying and using modular content on energy efficiency topics that lecturers can trust, that will fit straight into their courses. This tool can help to overcome barriers of lecturers having insufficient time or finances to review and upgrade courses to include energy efficiency. It may also be of assistance where lecturers feel insecure about the depth of their own knowledge of the field, as the modules provide the required content. Additionally, as with the case of Paten *et al,*[81] such modules may be accompanied by a trainer's guide, which can assist the lecturer in understanding how to use the materials and background information to ensure that the most is made of the provided tools. The more complete and the more accessible such modules are, the more they may help to overcome the variety of barriers which would otherwise impede the inclusion of such materials.

Using web-based courses to teach energy efficiency: Engineering for sustainable and energy efficient outcomes requires a different approach and engineering paradigm, with a broader focus and whole-systems method of designing. Teaching these new paradigms is noted to be difficult, as it requires students to synthesise a broader array of factors, including economic, social, technical and environmental. It is increasingly recognised that traditional teaching methods, which can tend to foster surface learning, are inadequate for these concepts, and that deeper learning needs to be encouraged. There is evidence to suggest that technology can foster such deep learning where appropriately applied, by providing a more constructivist learning environment in which the students take greater responsibility for their learning, peer-to-peer collaboration can be enhanced and linkages between various aspects of the course can be made.[82] As they are not limited by classroom size, web based courses can be offered to a larger number of students. In the case of the University of British Columbia (UBC) in Canada, a web based course *Introduction to Sustainable Development* was developed for the Civil Engineering program, but has since been offered to all engineering students and also to non-engineering students. It was noted that the web based course was able to make use of technologies which enhanced student interaction and active engagement with the course material.[83]

Providing training: Part of the department's strategy may be to provide in-house training for their staff, on energy efficiency and appropriate teaching techniques. A lack of knowledge of relatively new concepts, such as sustainability and energy efficiency, was cited as a significant barrier preventing many engineering educators from teaching these concepts in their courses.[84] Providing instruction to such educators may assist them in overcoming this barrier. Teaching energy efficiency, as with sustainability, may require educators to adopt teaching techniques which incite deeper learning techniques, as such concepts require students to think creatively, apply knowledge from diverse fields

[81] Paten, C., Palousis, N., Hargroves, K. and Smith, M. (2005) 'Engineering sustainable solutions program – Critical literacies for engineers portfolio', *International Journal of Sustainability in Higher Education,* vol 6, no 3, pp265 – 277.
[82] Yazon, J.M.O., Mayer-Smith, J.A. and Redfield, R.J. (2002) 'Does the medium change the message? The impact of a web-based genetics course on university students' perspectives on learning and teaching', *Computers and Education,* vol 38, pp267-285.
[83] Crofton, F.S. (2000) 'Education for sustainability: opportunities in undergraduate engineering', *Journal of Cleaner Production*, vol 8, pp397-405.
[84] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference and Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.

and to design using whole system approaches.[85] Thus assisting educators in making a shift in their teaching from traditional, instructivist based techniques to constructivist, deeper learning techniques may also enhance their ability to teach energy efficiency in their courses.

Understanding 'Hot Topic' areas: The strategy might entail considering what material in the topic area will be most attractive to students, at undergraduate and post-graduate level. It was noted that sustainability, and presumably energy efficiency also, require higher levels of student maturity to truly grasp and be able to apply the concepts.[86] Also, some authors remarked that these topics tend to have less technical content and as such can be de-prioritised by students who are more accustomed to quantitative, technical subjects.[87] This tool may be useful firstly in allowing lecturers to tailor the content they provide to ensure that it is well received and appropriate for the target audience, and also in providing evidence to lecturers that these topics are potentially of interest and relevance to their students.

Directly involving potential employers: e.g. through keynote speakers and advisory board members. Given that the employment rate of graduates, and graduate starting salaries, are performance indicators against which universities are assessed,[88] engaging local employers and key figures within the field may be an appropriate tool for encouraging lecturers to include energy efficiency in their courses. It may help illustrate the relevance of energy efficiency to engineering, and to specific areas of engineering, to both faculty and to students. This tool may also assist lecturers who are less familiar themselves with energy efficiency in providing knowledge to students, where these potential employers can provide guest lectures.

Hosting topical event/s: The strategy might involve coordinating and/or hosting a conference, symposium, forum etc focused on energy efficiency in engineering education and practice. Such conferences may assist in establishing multidisciplinary networks, and provide a mechanism through which engineering educators may collaborate, share information and teaching tools, and to increase knowledge of energy efficiency for engineering education.

Investigating graduate employment opportunities: An appreciation of which graduate attributes which are currently being taught within the degree can enable those aspects of the course to be enhanced, while highlighting deficits which could be the focus of ongoing efforts to improve engineering degrees. Graduate outcomes, including employment rates and starting salaries, are key performance indicators for universities[89] and can be used in their marketing approaches to potential students. Similarly, evidence that such graduate attributes are being taught may foster interest in the university and their graduates from potential employers. Hence, the strategy might involve obtaining market knowledge about what potential employers are seeking.

Engaging external support for advice: The strategy might involve hiring consultants (preferably with an engineering background) to discuss energy efficiency with individual lecturers, and how it could be

[85] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.
[86] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.
[87] El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol, 9, Issue 2, pp170-182.
[88] DEST (2001) *Characteristics and Performance Indicators of Australian Higher Education Institutions, 2000,* Department of Education, Science and Training, Australian Government, www.dest.gov.au/NR/rdonlyres/6812B85F-8C4E-415D-9240-AF3C35AFFB77/947/characteristics00.pdf, accessed 8 May 2009.
[89] DEST (2001) *Characteristics and Performance Indicators of Australian Higher Education Institutions, 2000,* Department of Education, Science and Training, Australian Government, www.dest.gov.au/NR/rdonlyres/6812B85F-8C4E-415D-9240-AF3C35AFFB77/947/characteristics00.pdf, accessed 08 May 2009.

incorporated into their courses. The use of consultants to discuss with lecturers how energy efficiency is currently being taught within their course, what their own ideas are towards energy efficiency, and how it might be integrated can be a valuable tool.[90] It enables detailed recommendations to be given which are course specific, and may assist in overcoming the barrier of there being little consensus of the most effective way to integrate new materials into the course. The consultant (preferably one with an engineering background) can assist lecturers in translating energy efficiency into a relevant and teachable concept and to potentially see some of the benefits which arise from doing so. This tool may reduce the time constraints limiting lecturers' ability to introduce new materials to a course on their own by providing specialist advice which can streamline the process.

A survey of faculty, librarians and students at a US University revealed several barriers to the greater integration of sustainability into to the engineering programs offered at the University. It was suggested that in order to embed sustainability, the faculty and staff needed to undergo a process of rigorous self assessment to determine the effectiveness of their courses in their current form. In discussing the current level of integration, the attitudes of the staff and faculty became more evident, as did the barriers and benefits inhibiting each individual and the group in general. From this point, it was suggested that further research and discussion was needed to develop innovative ways of introducing sustainability into those courses and fields where it is currently seen to be less relevant or too difficult to include. This tool was seen to be effective as it is based on collaboration with all key stakeholders of the process, and engages them in the process of integrating sustainability throughout the curricula.[91]

Clearly committing senior management support: e.g. Commitment from senior management (for example the Head of School, Dean, Pro-Vice Chancellor) for energy efficiency education. Providing assurance to the lecturing staff within a department that their efforts in curriculum renewal are inline with university policy and strategic direction, and hence are aligned with career progression can also overcome the barriers of the perceived relevance of sustainability curriculum. This may also involve demonstrating that the university's curriculum renewal initiative is clearly part of a university-wide initiative (see Bryce *et al* for the experience at UTS, and theory of actor network theory).

Recruitment of staff well versed in energy efficiency and engineering: The recruitment of faculty to lead a change in the engineering curricula can overcome several barriers, such as a lack of knowledge of energy efficiency which may restrict existing lecturers from providing such content to students, a belief that energy efficiency isn't relevant to their particular course, or that time and financial constraints would not permit its inclusion. The need to obtain consensus from faculty members to implement widespread change throughout the curricula was an issue at the University of Technology, Sydney (UTS),[92] where sustainability was incorporated into engineering degrees as part of a larger overhaul and restructuring (which mainly occurred for financial reasons). It was noted that the process of suggesting, gaining acceptance for, and then integrating change required a progressive 'recruitment' of faculty members to an understanding of the need for and benefits of integrating sustainability into the curriculum. This requires motivated and engaged individuals within the faculty, and may be facilitated by the employment of new faculty.

[90] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288.
[91] Theis, R., Wakins, P. and Beck, M.A. (2008) 'Pathways to learning: Orchestrating the role of sustainability in engineering education', *American Society for Engineering Education*, USA, AC 2008-968.
[92] Bryce, P., Johnston, S. and Yasukawa, K. (2004) 'Implementing a program in sustainability for engineers at University of Technology, Sydney – a story of intersecting agendas', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp267-277.

5.3. Strategic support from Government and Professional Bodies

Further to the strategic opportunities available to departments and higher education institutions, the literature review identified a number of synergistic strategic opportunities for government, professional organisations, and accreditation agencies which are briefly highlighted in the following paragraphs:

Including energy efficiency within EA accreditation criteria (competencies): Clear direction from Engineers Australia and other professional organisations in terms of what is expected for programs with respect to energy efficiency (sustainability) content, now and in future accreditation rounds would be useful information when considering energy efficiency or sustainability material for courses.[93] The role of accreditation boards and professional bodies in catalysing curriculum renewal in engineering degrees is well established.[94] Evidence of this influence can be seen in Australia and North America in particular, where the more recent introduction of sustainability focused graduate requirements has catalysed some degree of curriculum renewal. Such bodies hold a high leverage position as the interface between educational institutions and the needs of society and the profession.[95]

Developing a clear understanding of graduate outcomes (graduate attributes): i.e. current and emerging with regard to sustainability knowledge and skills.[96] Accreditation requirements relevant to knowledge of energy efficiency becoming a necessary graduate attribute are contingent upon EA requiring graduate outcomes consistent with teaching energy efficiency to engineering students. This may require a departmental review process whereby the required outcomes are used to assess the courses, identifying the deficits and opportunities. This tool could be facilitated by the use of 'consultants', discussed elsewhere in this section.

Content development support: Development of case studies, textbooks and course materials to be used by universities and lecturers. The lack of case studies, textbooks and other course materials was cited by many authors as a significant barrier to the inclusion of sustainability into engineering degrees.[97] Presumably, and assuming the same is true of energy efficiency, the development of such materials would significantly facilitate the process of integrating energy efficiency into engineering curricula. Zhang *et al*[98] note that the lack of textbooks is a significant barrier to integrating sustainability into engineering courses and thus they are working to develop a green engineering textbook to be used within an 'Introduction to Environmental Engineering' course at the Michigan Technological University and Yale University, along with drop-in modules which can be used in conjunction with the textbook as taught within applicable courses. To a similar end, Paten *et al* have developed course modules with supporting case studies for an introductory level course on sustainability for engineers. The portfolio

[93] Paten, C., Palousis, N., Hargroves, K. and Smith, M. (2005) 'Engineering sustainable solutions program – Critical literacies for engineers portfolio', *International Journal of Sustainability in Higher Education,* vol 6, no 3, pp265-277; Mitchell, C. (2000) 'Integrating Sustainability in Chemical Engineering Practice and Education, Concentricity and its Consequences', *Trans IChemE,* Institution of Chemical Engineers, vol 78, Part B, July.

[94] Splitt, F.G. (2002) 'Environmentally smart engineering education: A brief on a paradigm in progress', *Journal of Engineering Education,* October, vol 91, Issue 4, p447; Mitchell, C. (2000) 'Integrating Sustainability in Chemical Engineering Practice and Education, Concentricity and its Consequences', *Trans IChemE*, Institution of Chemical Engineers, vol 78, Part B, July; Theis, R. Wakins, P. and Beck, M.A. (2008) 'Pathways to learning: Orchestrating the role of sustainability in engineering education', *American Society for Engineering Education*, USA; Paten, C., Palousis, N., Hargroves, K. and Smith, M. (2005) 'Engineering sustainable solutions program – Critical literacies for engineers portfolio', *International Journal of Sustainability in Higher Education,* vol 6, no 3, pp265-277.

[95] Splitt, F.G. (2002) 'Environmentally smart engineering education: A brief on a paradigm in progress', *Journal of Engineering Education*, October, vol 91, Issue 4, p447.

[96] Desha, C., and Hargroves, K. (In Press) *Engineering Education and Sustainable Development - 'A Guide for Rapid Curriculum Renewal',* The Natural Edge Project, Earthscan, London.

[97] Boyle, C. (2004) 'Considerations on educating engineers in *sustainability' International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288; Perdan, S., Azapagic, A. and Clift, R. (2000) 'Teaching sustainable development to engineering students', *International Journal of Sustainability in Higher Education*, vol 1, no 3, pp267-279.

[98] Zhang, Q., Zimmerman, J., Mihelcic, J. and Vanasupa, L. (2008) 'Civil and environmental engineering education (CEEE) transformational change: Tools and strategies for sustainability integration and assessment in engineering education', *American Society for Engineering Education, USA,* AC 2008-1670.

comes with a trainers' guide to ensure that course lecturers are able to understand and make use of the materials provided and ease their integration into a course or program.[99]

Government incentives and actions: Government has the ability to drive the integration of energy efficiency into engineering education.[100] By providing research funds - *'policies which will require energy efficiency to be incorporated into engineering projects, by potentially providing funding to universities to overhaul their engineering degrees and courses* (REF) and by creating a marketplace for graduates with an energy efficiency education, Government funding can overcome the barrier of prohibitive costs.[101]

[99] Paten, C., Palousis, N., Hargroves, K. and Smith, M. (2005) 'Engineering sustainable solutions program – Critical literacies for engineers portfolio', *International Journal of Sustainability in Higher Education,* vol 6, no 3, pp265 – 277.
[100] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.
[101] Ashford, N.A. (2004) 'Major challenges to engineering education for sustainable development', *International Journal of Sustainability in Higher Education,* vol 5, no 3.

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APPENDIX A:

Engineering Educator Survey

ENGINEERING EDUCATION FOR ENERGY EFFICIENCY

STAGE 2 INVESTIGATION

NETWORK CONTRIBUTION TO DRAFT LIST OF CURRICULUM RENEWAL ACTIONS

BACKGROUND TO THE RESEARCH

This research initiative is committed to assisting Australian Universities (and in turn informing efforts around the world) to improve the levels of education for energy efficiency. We are taking a multi-faceted approach, including the development of peer-reviewed education material and text books on the subject,[102] by investigating the current status of education in the area, and by investigating a range of options to assist universities to embed education for energy efficiency into their courses.

In partnership with the methodologies creator, Doug McKenzie-Mohr,[103] our team has been given the opportunity by the NFEE to apply the relevant parts of the Community Based Social Marketing (CBSM) approach to education for energy efficiency. This approach has been found to be highly successful in informing a range of programs across the world related to sustainable development that have a strong community component, in our case the university community.

The first task of the project was to identify a list of potential behaviours ('actions') that engineering educators in Australia could undertake to integrate energy efficiency education into the curriculum, and we developed a list of 19 behaviours from the 2007 survey and a review of literature.

The second task was to have energy efficiency educators review and comment on the identified behaviours, and provide guidance as to the potential probability and impact of each occurring, from an open invitation in October 2008, and 13 university-randomised phone poll interviews with energy educators from across the country who responded to the 2007 survey (ACT 1, NSW 1, NT 1, QLD 3, SA 1, TAS 1, VIC 4, WA 1). Each participant reviewed the initial list and provided quantitative data to indicate the perceived potential impact and probability for each of the behaviours.

The next task (and the purpose of this document) is to engage with energy efficiency educators nationally to review and comment on the findings of the phone poll interviews. This process will result in a short list of behaviours and quantitative data which will inform the remaining tasks in the project.

We see this as an exciting opportunity to explore options to support lecturers, program co-ordinators and senior staff to strategically approach in an informed way the challenge of increasing the levels of education for energy efficiency and perhaps provide precedent for other topic areas related to sustainable development.

Contributions to the draft list of actions must be received by

Friday 13 February 2009

Email: c.desha@griffith.edu.au

The Natural Edge PROJECT

[102] Smith, M., Hargroves, K., Stasinopoulos, P., Stephens, R., Desha, C., and Hargroves, S. (2007) Engineering Sustainable Solutions Program: Sustainable Energy Solutions Portfolio, The Natural Edge Project (TNEP), Australia.' Available at www.naturaledgeproject.net/Sustainable_Energy_Solutions_Portfolio.aspx.

[103] Macenzie-Mohr, D. (1999) Mackenzie-Mohr D, Smith W., (1999), Fostering Sustainable Behavior: An introduction to community-based social marketing. New Society Publishers, Canada.

INFORMED CONSENT

Title of Research: Engineering Education for Energy Efficiency: Stage 2 Investigation – Barriers and Benefits Analysis

Investigator: The Natural Edge Project (hosted in-kind by Griffith University and the Australian National University) on behalf of the National Framework for Energy Efficiency (NFEE). NFEE is a joint initiative of Federal, State and Territory Government Agencies. It aims to unlock the significant but un-tapped economic potential associated with the increased uptake of energy efficient technologies and processes across the Australian economy.

Research Aim: This project seeks to build on the findings of the survey and investigate a range of options (based on the Community-Based Social Marketing (CBSM) methodology) for enhancing curriculum renewal in engineering schools in Australia. The completed questionnaires will be collated, analysed and presented in a public summary.

Confidentiality: All information gathered from the study will be treated as confidential. The identity of participants will not be disclosed to any unauthorised persons; only direct members of the research team will have access to the data collected as part of the study. Any information that may compromise the anonymity or cause risk to the professional reputation of participants will not be disclosed. ***Persons will only be personally identifiable if prior consent has been sought and granted.***

Ethical Conduct: This research is in accordance with Griffith University's research commitment to the *National Statement on Ethical Conduct in Research Involving Humans*.

Voluntary Participation: Undertaking this survey is voluntary and the decision not to participate will in no way upon your relationship with the university. Please feel free to forward this document to other colleagues to also participate.

Questions: Any queries regarding this project may be directed to the research team at The Natural Edge Project (TNEP):

Mr Charlie Hargroves charlie@naturaledgeproject.net, Phone: +61 7 3735 5062
Ms Cheryl Desha, cheryl@naturaledgeproject.net, Phone: +61 7 3735 6635

Room 0.28F/G, Building N55, Nathan Campus, Griffith University,170 Kessels Road,
Nathan QLD 4111

AGREEMENT:

By completing and returning these comments, I agree to permit the information that I provide to be used to inform the production of three education modules and contribute to the creation of academically reviewed and publicly available reports, research papers, and theses relating to education for sustainable development.

EXPLANATORY NOTES FOR CONTRIBUTION:

Based on your replies and the outcome of the national survey we have created a preliminary list and prioritisation of actions/behaviours that could be considered within the next 2 years of the Department's operations.

For each action listed in the following table, 13 energy efficiency educators within our network have provided advice on:

1. The likelihood that a lecturer in a department will undertake this action.
   Scale: 0 (never) to 5 (it has already happened)
2. If the action could be undertaken, the contribution of this action on the extent of energy efficiency content within the engineering program curriculum.
   Scale: 0 (no contribution) to 5 (significant)

The resultant average scores are noted in the following table, ranked from most to least likely.

Given your own department's context (i.e. including existing challenges and opportunities) we invite you, as a lecturer, to consider whether you think the likelihood and impact rankings we have allocated to the actions reflect your situation?

The table should take approximately 5 - 10 minutes to complete. Please feel free to forward this document to other colleagues to also participate.

Please note:

- The research team is *not* considering the impact on individual student experiences, but rather on the curriculum itself.
- Please do not use ranges. You may use ½ marks (for example 3.5) for the response.
- There are no 'right' or 'wrong' responses, and all correspondence will be treated in strict confidence within the project team. All contributions will be appropriately acknowledged in the report documentation.

NAME AND CONTACT DETAILS:

Please tick this box if you **do not wish to** receive further information about this project: ☐

Please provide your contact details below:

NAME:

UNIVERSITY:

CONTACT EMAIL:

For each of the following actions … *N/b "Course": Unit of work undertaken as part of the overall degree program of study (ie 1/8 of a nominal full study year). Also commonly referred to as a "Unit" or "Subject".*	Prioritised Results (Consultation to Date)		Your Contribution		
	Likelihood that this action would happen in your department?	If this action could happen, contribution to the extent of energy efficiency content in your degree program curriculum?	Do you agree with these scores? Please provide comment …	If you disagree with the allocated score, please provide your score here:	
	Scale: 0 (never) to 5 (already happened)	Scale: 0 (no contribution) to 5 (significant)		Likelihood	Contribution
Offer industry placements in energy efficiency (e.g. Work Integrated learning)	*4.1*	*2.9*			
Include a case study on energy efficiency	*3.9*	*2.8*			
Offer supervised research topics on energy efficiency themes	*3.8*	*2.9*			
Include a guest lecturer to teach a sub-topic	*3.8*	*3.4*			
Offer energy efficiency as a topic in a problem-based learning course	*3.7*	*3.6*			
Show a DVD of a related documentary	*3.6*	*2.8*			
Include *assessment* that aligns with the energy efficiency theme within the course (e.g. exam questions and assignments)	*3.5*	*3.3*			
Include *tutorials* that align with the energy efficiency theme in the course (e.g. presentations/ discussions/ problem solving)	*3.5*	*3.1*			
Overhaul the course to embed energy efficiency	*3.2*	*3.7*			
Include a field trip related to energy efficiency	*3.0*	*3.5*			
Show a DVD of a keynote lecture on energy efficiency	*3.0*	*2.6*			

For each of the following actions … *N/b "Course": Unit of work undertaken as part of the overall degree program of study (ie 1/8 of a nominal full study year). Also commonly referred to as a "Unit" or "Subject".*	Prioritised Results (Consultation to Date)		Your Contribution		
	Likelihood that this action would happen in your department?	If this action could happen, contribution to the extent of energy efficiency content in your degree program curriculum?	Do you agree with these scores? Please provide comment …	If you disagree with the allocated score, please provide your score here:	
	Scale: 0 (never) to 5 (already happened)	Scale: 0 (no contribution) to 5 (significant)		Likelihood	Contribution
Add energy efficiency readings to the required reading list	*2.9*	*1.9*			
Include one workshop on energy efficiency in the course (i.e. laboratory-style experiments)	*2.9*	*3.4*			
Include a topic-specific lecture set (i.e. a sub-topic) within the course, by the lecturer.	*2.7*	*3.1*			
Develop a new course on energy efficiency	*2.6*	*3.8*			
Include elective modules on energy efficiency within the course	*2.0*	*2.9*			
Offer a 'major' stream in the engineering degree on energy efficiency	*1.8*	*4.2*			
Include several workshops on energy efficiency in the course (i.e. including laboratory-style experiments)	*1.7*	*3.5*			
Develop a new degree program on energy efficiency (e.g. Bachelor of Energy Engineering)	*0.9*	*4.3*			

Thank you for assisting us with this survey – please email your response to: cheryl@naturaledgeproject.net, by **Friday 13 February**.

APPENDIX B:

Behaviour Literature Review

Behaviours are discussed in order of final ranking by likelihood, as determined by the results of the phone poll and survey.

The list is ordered as follows, beginning with the 10 Shortlisted behaviours (bolded):

Ref Number	Description	Likelihood (Average)	Impact (Average)
1	**Include a case study on energy efficiency**	**4.1**	**3.2**
2	**Include a guest lecturer to teach a sub-topic**	**4.0**	**3.6**
3	**Offer supervised research topics on energy efficiency themes**	**4.0**	**3.2**
4	**Offer energy efficiency as a topic in a problem-based learning course**	**3.7**	**3.7**
5	**Include *assessment* that aligns with the energy efficiency theme within the course (e.g. exam questions and assignments)**	**3.7**	**3.4**
6	**Include tutorials that align with the energy efficiency theme in the course (e.g. presentations/ discussions/ problem solving)**	**3.7**	**3.3**
7	**Overhaul the course to embed energy efficiency**	**3.4**	**3.7**
8	**Include one workshop on energy efficiency in the course (i.e. laboratory-style experiments)**	**3.1**	**3.5**
9	**Include a field trip related to energy efficiency**	**3.1**	**3.5**
10	**Develop a new course on energy efficiency**	**2.9**	**4.1**
11	Include a topic-specific lecture set (i.e. a sub-topic) within the course	2.8	3.2
~~*12*~~	~~*Offer industry placements in energy efficiency (Work Integrated learning)*~~	~~*4.0*~~	~~*2.9*~~
~~*13*~~	~~*Show a DVD of a related documentary*~~	~~*3.6*~~	~~*2.8*~~
~~*14*~~	~~*Add energy efficiency readings to the required reading list*~~	~~*3.1*~~	~~*2.2*~~
~~*15*~~	~~*Show a DVD of a keynote lecture on energy efficiency*~~	~~*3.0*~~	~~*2.6*~~
16	*Include elective modules on energy efficiency within the course*	*2.4*	*3.3*
17	*Offer a 'major' stream in the engineering degree on energy efficiency*	*2.2*	*4.2*
18	*Include several workshops on energy efficiency in the course (i.e. including laboratory-style experiments)*	*2.0*	*3.6*
19	*Develop a new degree program on energy efficiency (e.g. B Energy Eng)*	*1.1*	*4.1*

N/b Further to communications with Dr Doug McKenzie-Mohr, '~~strike-through~~' options were discounted from the shortlist due to a low impact score. 'Italicised' options were discounted from the shortlist due to low likelihood scores.

1. Include a Case Study on Energy Efficiency

Impact **[Survey: 3.2]**

In general, the literature suggests that this option could have a moderate to high impact on the extent of energy efficiency in the curriculum, however the size of this impact depends greatly on the nature of the case studies provided, whether students are required to critically analyse such case studies, whether students engage in the process of developing and applying the principle discussed in the case studies and whether the skills and knowledge are transferred to other aspects of the students' learning and practice. This is slightly higher than the survey response of 3.2/5, which may be due to the authors of the publications being more enthusiastic about the merits of the option in comparison to the Australian engineering education community which has not yet had good access to quality case studies on sustainability (or energy efficiency) content.

One of the benefits provided by case studies is that they provide real life evidence that theories and concepts can in fact work, and can illuminate the variety of issues which may surround such a theory or concept.[104] The experience of the University of Technology, Sydney (UTS) in requiring postgraduate students enrolled in its 'Energy Conversion' course to develop their own case study on sustainable energy conversion,[105] indicates that such 'real world' examples can have a significant impact on student learning. The results found by UTS, however, may be also influenced by the other aspects of the course, which strongly focus on student learning - such as learning how to understand and critically think (as opposed to knowledge based learning). It was found that the case study project assisted the students *in 'develop*[ing] *their understanding of the complexity of sustainability and their valuing of sustainability as an important aspect of Engineering'.*[106] UTS included the case study as a component of the Energy Conversion course as it is perceived that real-world experience is important for the professional development of students, and to enable the students to perceive the relevance of the subject matter. The views of faculty on case studies as a tool for educating were shared by a panel of independent national and international reviewers in their assessment of Aalborg University in Denmark, which has for 20 years conducted project-based engineering education. It was found by these reviewers that the graduates were more adaptable and had developed qualities such as problem solving, team work, and communication.[107]

El Zein *et al*[108] found that, in the case of the School of Civil Engineering at the University of Sydney, case studies were vital as a means of engaging students in the learning processes of the course, as opposed to simply teaching learning objectives or subject matter. Case studies which are interactive and require students to consider various stakeholder interests, policy and a variety of factors which would lie outside the traditional, 'technical' engineering domain, provide deep learning, and while such case studies (provided and worked through in workshops in a sustainability and engineering ethics course) had not been shown to permanently change the attitudes of the students towards decision making, they were still considered crucial to students' understanding and adopting the position of various stakeholders. The authors note that the use of case studies in itself in not adequate, the case studies must be relevant and compelling to the

[104] Paten (formerly Desha), C., Palousis, N., Hargroves, K. and Smith, M. (2005) 'Engineering sustainable solutions program – Critical literacies for engineers portfolio', *International Journal of Sustainability in Higher Education,* vol 6, no 3, pp265-277.
[105] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education,* December 2001, vol 9, no 2, p188.
[106] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education,* December 2001, vol 9, no 2, p188.
[107] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education,* December 2001, vol 9, no 2, p179-192.
[108] El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol, 9 Issue 2, pp170-182.

students and must encourage students to investigate the issues being raised and reflect on their own thoughts and ideas. For these reasons, El Zein *et al* suggest that 'off the shelf' case studies are often inadequate and it is necessary for engineering educators to develop course specific materials – a process which is often prohibitively expensive within the temporal and financial constraints of universities.

The views of these authors on the impact of using case studies can perhaps be somewhat summarised by comments made by Paten *et al*,[109] who note that case studies are effective as they can provide evidence that the concepts being taught (which in the case of sustainability and energy efficiency may be outside the realm of 'traditional' engineering practice and as such, students may require some evidence) do work, and they may give some indication of the potential outcomes of these principles. This agrees with writing by Bosscher *et al*[110] and Robinson *et al*[111] who note that case studies are a means of illustrating the multidisciplinary nature of sustainability (and similarly would do so for energy efficiency), integrating the social and economic with the environmental and give proof of its viability.

As part of the Royal Academy of Engineering (RAE) Visiting Professor (VP) Scheme, a number of case studies have been prepared for use throughout several universities in the UK. They are intended to provide students with a real life context for the design principles they are taught, and through the use of 'visiting Professors', students are guided through the case studies to ensure they understand how theory relates to practice. The literature suggests that this has been a very successful program, as noted by the RAE: '*The role of the VPs in describing their processes through case studies and guiding project work is of tremendous value. And the experience of the VPs has confirmed that teaching enlightens the teacher at least as much as the student!'* The Academy noted that they felt that this body of well-researched and properly presented case studies was among the best ways of highlighting relevant issues and illustrating how the engineering principles and practice being taught can address those issues.[112]

Likelihood **[Survey: 4.1]**

The literature suggests that this option is has a moderate likelihood of being taken up by staff, tempered by time and resourcing constraints facing engineering educators, and a shortage of staff trained in energy efficiency. It notes that the likelihood will increase if the case studies are already available, readily useable, and require minimal prior knowledge. The survey result of 4.1/5 indicates that the Australian engineering education community is more optimistic about the likelihood of this option occurring, perhaps due to the increasing popularity of, and familiarity with, problem-based learning as a teaching mechanism.

With respect to developing case studies to provide to students, there is a noted lack of available materials, which provides a significant obstacle to engineering educators, who then are limited to developing such materials themselves if they want to pursue this option.[113] Case studies

[109] Paten, C., Palousis, N., Hargroves, K. and Smith, M. (2005) 'Engineering sustainable solutions program – Critical literacies for engineers portfolio', *International Journal of Sustainability in Higher Education,* vol 6, no 3, pp265-277.
[110] Bosscher, P.J., Russell, J.S. and Stouffer, W.B. (2005) 'The Sustainable Classroom: Teaching Sustainability to Tomorrow's Engineers', American Society for Engineering Education Annual Conference and Exposition, American Society for Engineering Education, USA.
[111] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference and Exposition, American Society for Engineering Education, USA.
[112] Wallace, K. (ed) (2005) *Educating Engineers in Design, Lessons learnt from the Visiting Professors Scheme,* Royal Academy of Engineering, UK.
[113] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155; El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as

which incite deeper learning in students and foster the sort of inter-linkages between theory and practice require careful scaffolding to lead students through the learning experience, with sign-posts for key learning points and levels of detail that can be selected, by either the lecturer or students, depending on their prior knowledge and skill levels.[114] Well written case studies contain an engaging variety of explanatory text and logically presented worked calculations. Developing case studies which depict such achievements can be difficult and time-consuming and, as noted by Sydney researchers Abbas El-Zein *et al*, can have development costs which are out of proportion with those available to most courses and course lecturers.[115] Universities in the UK have addressed this problem to a certain degree through the use of the Visiting Professors Scheme, in which a group of professors visit all participating universities, sharing resources and providing students with up-to-date case studies of their own practical experience.[116]

An initiative by the University of Technology, Sydney (UTS) differs from the notion of providing case studies to students, but it nonetheless provides evidence for the potential of 'real world' examples to enhance student learning. The university required students to develop their own case study throughout the semester in a recently revised postgraduate course on energy conversion technology within a sustainability context. The students were able to select the topic of the case study and their research project was aimed at integrating an appreciation of sustainable energy systems with the development of professional and personal qualities that are expected of engineering graduates. The feedback from the course with regard to this project was largely positive, with students reporting a deeper understanding of the significance of sustainable energy systems and how to implement the principles by considering concurrent factors such as the environmental, society, technology, and the economy.[117] The authors noted that the development of the case study component required significant time in consultation, attention and feedback. There was also considerable time and effort involved in developing the course to include the case study (as well as other student-centric aspects of the course), however, it was anticipated that these efforts would be largely weighted towards the first year in which such a course was offered, and would be less in following years.[118] As of 2009, this course was still being offered.[119]

Key Barriers

– ***Lack of available data/ information:*** There is a lack of well written material demonstrating how energy efficiency theory has been applied to the 'real world'.[120] Australian researchers Abbas El-Zein *et al*[121] reiterated earlier findings by UK researchers Slobodan Perdan *et al*[122]

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decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol, 9 Issue 2, pp170-182.

[114] El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182; Desha, C. and Hargroves, K. (In Press) *Engineering Education and Sustainable Development - 'A Guide for Rapid Curriculum Renewal'*, The Natural Edge Project, Earthscan, London.

[115] El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182.

[116] Wallace, K. (ed) (2005) *Educating Engineers in Design, Lessons learnt from the Visiting Professors Scheme,* Royal Academy of Engineering, UK.

[117] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education,* December 2001, vol 9, no 2, p179-192.

[118] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education,* December 2001, vol 9, no 2, pp179-192.

[119] University of Technology, Sydney (2009) 'UTS Handbook 2009: 49321 Energy Conversion', www.handbook.uts.edu.au/subjects/49321.html, accessed 16 May 2009.

[120] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.

[121] El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula, *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182.

which noted that there is a shortage of appropriate case studies which guide students through a structured thought-process to highlight the necessary steps through which sustainability is achieved. Off-the-shelf case studies, it is suggested, are frequently inadequate as they provide only the end-point. In addition, as New Zealand researcher Carol Boyle noted in 2004, there are few true examples of engineering which could be said to have achieved 'real sustainability', from which to develop holistic case studies for students.[123]

- ***Lack of time for preparation:*** Research from both the USA and the Netherlands suggests that there is a limited time available to engineering educators to develop new course material such as case studies, due to existing pressures to meet research commitments, in addition to a teaching workload and service requirements.[124] Content development may therefore be given a lower priority, or avoided altogether.
- ***An overcrowded curriculum:*** Engineering degrees are widely reported (for example in the USA, New Zealand and the EU) to be crowded with courses, with significant competition existing over what should be taught.[125] Although engineering departments might recognise the need to teach energy efficiency, pressure from faculty who feel that either it is already being taught adequately, or that it doesn't need to be taught at all, may be a barrier to displacing existing courses with an energy efficiency course.
- ***Prohibitive cost:*** The cost of this innovation can be high relative to a typical course budget, given the need for additional research and content development.[126]
- ***Lack of knowledge:*** DJ Peet and his fellow researchers from the Netherlands echo those comments by Michael Robison and his colleagues from the USA, who have noted that lecturers often do not have adequate knowledge themselves of sustainability (or energy efficiency) to teach this within their courses.[127]
- ***Lack of value attached:*** Lecturers may not value the importance or relevance of energy efficiency to their course, they may perceive it as less important that other aspects of the course, and may therefore resist including such case study material into their course.[128]

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[122] Perdan, S., Azapagic, A. and Clift, R. (2000) 'Teaching sustainable development to engineering students', *International Journal of Sustainability in Higher Education*, vol 1, no 3, pp267-279.

[123] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.

[124] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288.

[125] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education,* vol 5, no 2, pp147-155; Holmberg, J., Svanström, M., Peet, D.J., Mulder, K., Ferrer-Balas, D. and Segalàs, J.(2008) 'Embedding sustainability in higher education through interaction with lecturers: Case studies from three European technical universities', *European Journal of Engineering Education*, vol 33, no 3, pp271-282; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288.

[126] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288.

[127] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288; Boyle, C. (2004) 'Considerations on educating engineers in *sustainability' International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.

[128] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288.

- *Silo-culture:* An academic culture which encourages distinct disciplinary studies, may reduce the possibility of involving various academia who could share the task of contributing diverse, specialist knowledge to such a case study. [129]

Key Benefits

- ***Improved marketability:*** Case studies can be shared with other institutions, promoting the institution where the material originated. William Gaughran and colleagues discuss the benefits for the University of Limerick in Ireland, where course materials developed through collaboration with three other EU universities were then made available to other universities and to industry.[130]
- ***Cross-functionality of content:*** Case studies can potentially be used across courses in an engineering program (building on the student's experience as they progress through various courses). English researchers Slobodan Perdan and colleagues discuss the benefits of doing so in Surrey University, where a multidisciplinary approach to teaching sustainability was embodied in learning programmes and activities in engineering. Through a comprehensive IT-based learning resource comprising a set of multidisciplinary case studies and support material, students were helped to understand the concepts inherent in sustainability and how solutions can be developed.[131]
- *Improved Student Access to Best Practice:* Case studies can provide students with access to best practice examples of how energy efficiency theory can be applied in the workplace, without having to rely on the lecturer to keep up-to-date with what is happening in industry.
- *Improved Pedagogy – Use of Case Studies:* Case studies can assist lecturers in meeting current pedagogic best practice, with the benefit of using case studies, as noted by several authors.[132]

[129] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288; El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182.

[130] Gaughran, W., Burke, S. and Quinn, S. (2007) 'Environmental Sustainability in Undergraduate Engineering Education', *American Society for Engineering Education,* USA, AC 2007-2020.

[131] Perdan, S., Azapagic, A. and Clift, R. (2000) 'Teaching sustainable development to engineering students'*, International Journal of Sustainability in Higher Education*, vol 1, no 3, pp267-279.

[132] Perdan, S., Azapagic, A. and Clift, R. (2000) 'Teaching sustainable development to engineering students'*, International Journal of Sustainability in Higher Education*, vol 1, no 3, pp267-279; El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182.

2. Offer Supervised Research Topics on Energy Efficiency Themes

Impact **[Survey: 3.2]**

Based on the literature, it is suggested that this option would have a moderate to high impact on contributing to the learning and understanding of energy efficiency within an engineering degree, for the students involved in the projects. Taken within the context of the fact that this option refers to one project, within one course at the university, which (as noted in other areas of this report), this option has a moderate impact overall, which accords with the survey result of 3.2/5.

Project based learning (PBL) is considered to provide a constructivist learning environment which is increasingly gaining recognition as a means of fostering deep learning, resulting in greater understanding, assimilation and application of knowledge.[133] El-Zein *et al*[134] believe that concepts such as sustainability (it is felt that this rationale would apply also to energy efficiency) require a certain level of maturity to be learned and understood, as it requires an individual to step outside an egocentric mentality to consider a relatively complex interplay of diverse factors from a wide base of disciplines, including social, economic, environmental and technological. They furthermore contend that these concepts don't lend themselves to the traditional classroom setting of lectures and workshops, and potentially a supervised research topic could provide such a setting. Madadnia *et al*[135] would agree, following evidence cited from their case study of the University of Technology, Sydney (UTS) in which students worked in teams to produce a case study based on a real life example in an Energy Conversion course. The course was designed in line with strong international evidence which shows that project based study creates skills such as problem solving, communication, adaptability and cooperation. It was found that this self directed project allowed students to take greater ownership of their study, leading to greater reflection on the issues and concepts and overall, deeper learning.

Likelihood **[Survey: 4.0]**

The literature suggests that this option has a high likelihood of occurring, given the increasing emphasis on final year projects and the numerous possibilities for student topics. This is in accord with the survey result of 4.0/5.

Several obstacles to teaching sustainability, particularly in a traditional fashion (with lecturer provided course materials, case studies, textbooks *et cetera*) may be similarly relevant to energy efficiency. Many authors in the literature have noted that a lack of time and funds to develop such materials themselves provides a strong disincentive to engineering educators to create, or update, their courses to include such subject matter.[136] This option may, hence, be more likely, as the onus for the research of such topics lies with the students themselves (it is assumed that materials are available in the form of research papers, press releases, websites and other

[133] Lehmann, M., Christensen, P., Du, X. and Thrane, M. (2008) 'Problem-oriented and project-based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education', *European Journal of Engineering Education*, vol 33, no 3, pp283-295.
[134] El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182.
[135] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education,* December 2001, vol 9, no 2, pp179-192.
[136] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288; El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182.

formats which are accessible to students). This said, lecturers must still have adequate knowledge of the subject matter to provide worthwhile guidance and feedback to students.

Madadnia *et al*[137] suggest that supervised research can be time consuming for a lecturer, depending on the format of the course, as it may require the lecturer to provide assistance and feedback outside of the course hours, and in a timely fashion. There may also be time required for the lecturer to familiarise themselves with the topic (as mentioned earlier). Madadnia *et al* made mention that the lecturers involved with the Energy Conversion subject at UTS were pleased with the results and derived personal satisfaction from the enhanced learning experience gained by the students. Knowledge of this potential satisfaction may make this option more likely to occur.

Key Barriers

- ***Lack of available data/ information:*** Depending on the research topic of interest to industry, and given the emerging energy efficiency industry, there may not be much data or information that is easily accessible for a student's project to be undertaken within the constraints of the university semester.
- ***Lack of time for preparation:*** The time consuming nature of developing and implementing supervised research topics involves consultation, significant attention, and prompt feedback to queries, which can all be outside of prescribed course hours.[138]
- ***Lack of knowledge:*** Where a range of research topics are offered to students, it would be assumed that a lecturer would need to provide feedback and assistance to students on the full range of topics. Supervisors may need professional development, involving more time for teacher learning each year.[139]
- ***Lack of industry contacts:*** Lecturers may not have existing industry contacts who can provide energy efficiency problems that need researching. One respondent to the 2008 survey noted to the authors (in confidence) that there is an increasing demand from local industry to have students work on energy-efficiency related projects.
- ***Lecturer apathy:*** Where teaching workloads are high and there is pressure for lecturers to teach outside their area of research expertise, they may not be inclined to set research tasks for students that do not align with their primary research area.
- *Annual topic renewal:* Gül Okudan and his fellow researchers from Pennsylvania State University in the USA[140] noted that many industry based research topics are assigned only once, and consequently the topics cannot be improved on for the following year's students. Course preparation is therefore substantial from year to year, as opposed to other courses where preparation requirements decline after the first year or two.[141]

[137] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education,* December 2001, vol 9, no 2, pp179-192.
[138] Madadnia, J., Koosha, H. & McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education*, December 2001, vol 9, no 2, pp179-192.
[139] Madadnia, J., Koosha, H. & McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education*, December 2001, vol 9, no 2, pp179-192; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.
[140] Okudan, G.E., Mohammed, S. and Ogot, M. (2006) 'An investigation on industry-sponsored design projects' effectiveness at the first-year level: potential issues and preliminary results', *European Journal of Engineering Education*, vol 31, no 6, pp693-704.
[141] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education*, December 2001, vol 9, no 2, pp179-192.

Key Benefits

- ***Additional research opportunities:*** Student research topics may provide avenues for further academic research for the lecturer.
- ***Access to additional research funding:*** Student research topics may also provide additional opportunities for lecturers to seek research funding – for the students' projects, and then further research thereon.
- ***Improved student connections with potential employers:*** As research projects generally occur in the final years of a student's studies, this initiative provides them with an opportunity for work experience, or an internship with the company of their choice.
- ***Networking opportunities for lecturers:*** Advertising for student research topics may assist lecturers in making more industry connections, which may also have future research funding opportunities.
- ***Networking for students:*** Such research opportunities provide networking opportunities for students and may result in higher graduate employment, or student engagement with industry, as was found to be the case at the University of Michigan by researchers Angela Leuking *et al.*[142]
- ***Improved marketability:*** Student project work in energy efficiency may lead to marketing opportunities for the institution, with innovative outcomes that have business, community and environmental benefits.
- ***Lecturer professional development:*** Australian researchers Jafar Madadnia and his colleagues noted that in the experience of the University of Technology, Sydney, lecturers experienced significant satisfaction from observing students adopt deeper learning habits, and it is suggested that satisfaction gained by association with student research topics on energy efficiency can also significantly improve the lecturer's knowledge.

[142] Leuking, A.D., Ross, D.A. and Walter, J.W. (2003) 'Environmental sustainability education at the University of Michingan" Collaboration with industry to provide experiential learning opportunities', American Society for Engineering Education Annual Conference and Exposition, USA.

3. Include a Guest Lecturer to Teach a Sub-Topic

Impact **[Survey: 3.6]**

The literature suggests that while a guest lecturer may be well received and have a high impact on the students' experience, the overall the impact on the extent of energy efficiency content in the program would be low. As for the option of developing a new course on energy efficiency, an isolated experience or exposure to content such as through a guest lecture is unlikely to adequately develop the desired graduate attributes relating to energy efficiency. From the survey it appears that the engineering education community perceives a higher – moderate to high – impact of 3.6/5. From the comments provided with the phone poll and returned surveys, it is suggested that this could be due to an assumption that this option would involve more than just one lecture.

Several authors have noted the importance of guest lecturers who can provide both a 'real-world' example of energy efficiency, and/or an interdisciplinary perspective for students, with respect to teaching and understanding sustainability.[143] While an isolated guest lecture may achieve more in student experience than actual development of knowledge and skills, a programmed delivery from a variety of guest lectures may provide a mechanism to deliver expertise that is otherwise not available among the permanent staff in the engineering department. For example, Delft University (Netherlands), reviewed its chemical engineering degree and realised that it fell short of the expectations that industry had of graduates. As part of this review, and the renewal of the degree, they created a subject which taught business skills (through, for example, writing a business plan) to their third year students. Guest lecturers were invited each week to give a presentation, which fit in with the weekly timetable of a lecture from the main course lecturer, and tutorials which revised materials from the lecturers as well as assistance with the business plan. According to the researchers, this format is assisting the University in maintaining links with industry, in educating students with the skills and knowledge which is expected by industry, and in providing topic-specific information which may lie outside the realm of knowledge of the course lecturer. [144]

However, the literature notes that having a guest lecturer participate in a course does not automatically mean that the knowledge and skills will be developed among the student body. The impact of a guest lecturer may be highly inconsistent, and depend upon several factors such as whether they are paid (and thus devote time to preparing and tailoring their lecture), whether they are able to tailor their lecture to the context of the class, whether the information provided by the guest lecturer is integrated into other aspects of the course and included in assessment items, and whether the guest lecturer is a skilled, charismatic speaker.[145]

Likelihood **[Survey: 4.0]**

There is a lack of literature discussing the likelihood of engineering educators to engage with guest lecturers to deliver new content in courses. The two papers forming part of this literature

[143] Crofton, F.S. (2000) 'Education for sustainability: opportunities in undergraduate engineering', *Journal of Cleaner Production,* vol 8, pp397-405; Warburton, K. (2003) 'Deep learning and education for sustainability', *International Journal for Sustainability in Higher Education,* vol 4, Issue 1, p44; Legg, R. Tekippe, M., Athreya, K.S. and Mina, M. (2005) 'Solving multidimensional problems through a new perspective: The integration of design for sustainability and engineering education', American Society for Engineering Education Annual Conference and Exposition, USA; Theis, R., Wakins, P. and Beck, M.A. (2008) 'Pathways to learning: Orchestrating the role of sustainability in engineering education', *American Society for Engineering Education*, USA, AC 2008-968.
[144] Bonnet, H., Quist, J., Hoogwater, D., Spaans, J. and Wehrmann, C (2006) 'Teaching sustainable entrepreneurship to engineering students: the case of Delft University of Technology', *European Journal of Engineering Education*, vol 31, no 2, pp155-167.
[145] Desha, C. and Hargroves, K. (In Press) *Engineering Education and Sustainable Development - 'A Guide for Rapid Curriculum Renewal'*, The Natural Edge Project, Earthscan, London.

review (by Netherland and New Zealand researchers) appear to regard the likelihood of guest lecturing as high, if the guest lecturers are made available and are credible. This is in accord with the survey result of 4.0/5.

It was noted by several authors that a significant barrier to teaching engineering students sustainability principles can be a lack of knowledge of the field by the educators themselves.[146] As such, including a guest lecturer may be a more feasible means of providing content to students where lecturers feel that they themselves are not sufficiently well versed on the topic to do so themselves. However, staff may be hesitant to engage with guest lecturers if they have had previous bad experiences in guest lecturers missing the key learning points and instead covering irrelevant material. The likelihood of this option occurring may also be limited by a lecturer's ability to access such a guest lecturer (due to lack of contacts, lack of course funds to reward such a lecturer or because no such guest lecturer is available near to the university or college), and their ability to offer remuneration to guest lecturers for their time in preparation and attending.

Key Barriers

- ***An overcrowded curriculum:*** This option would presumably replace other lectures which were previously being taught in the course, and it may be difficult to convince lecturers that energy efficiency is more important than this material.
- ***Lack of knowledge:*** DJ Peet and his fellow researchers from the Netherlands echoed those comments by Michael Robison and his colleagues from the USA, who have noted that lecturers often do not have adequate knowledge themselves of sustainability (or energy efficiency) to teach this within their courses.[147]
- ***Lack of industry contacts:*** Because the lecturers may not know the field very well, they may struggle to identify colleagues internally or externally who could deliver suitable content. An academic culture which fosters specialisation may diminish an academic's awareness of potential guest lecturers in other disciplines.[148]
- ***Resistance to top-down directive:*** Dutch researchers DJ Peet *et al* found that, as lecturers are often experts in their field, they can be resistant to suggestion that they should teach something which lies outside their field of knowledge.[149]
- ***Lack of value attached:*** Lecturers may not value the importance or relevance of energy efficiency to their course, they may perceive it as less important than other aspects of the course, and may therefore resist including such material into their course.[150]

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[146] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5 no 3, pp278-288; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.

[147] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.

[148] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288; El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182.

[149] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.

- ***Prohibitive cost:*** Guest lecturers may expect to be reimbursed for their preparation, travel and delivery of their lecture/s, which may be a barrier if such funding is not available. Furthermore, lecturers may be reluctant to dispense with limited funds and to risk course time if they are not certain that a guest lecturer will provide the information which they felt was necessary.
- *Lack of quality guest lecturers:* Quality guest lecturers are hard to find, either within the institution (service teaching) or from outside. As guest lecturers may not be accustomed to speaking or to teaching students, they may be unfamiliar with the situation and present a lecture which has little relevance to the course in general.

Key Benefits

- ***Networking opportunities for students:*** Guest lecturers provide networking opportunities for students and may result in higher graduate employment, or student engagement with industry, as was found to be the case at the University of Michigan by researchers Angela Leuking *et al.*[151]
- ***Networking opportunities for lecturers:*** Guest lecturers can additionally provide opportunities for the lecturers themselves to collaborate, both internally with other university colleagues, and externally, with colleagues from other universities, industry and government. A multi-disciplinary subject taught at Delft University in the Netherlands necessitated and provided opportunity for collaboration between academics of various disciplines.[152] The course was considered to be a joint learning exercise for the lecturers also, and resulted in a framework for sustainable business plan development with applications in industry and outside of the university.
- *Lecturer access to disciplinary mentors:* There may be the opportunity to tap into mentors in the industry who may have practical and/or theoretical experience in the field. For example, in the UK, the Visiting Professor Scheme has been very successful at connecting such experience with student learning. Guest lecturers are able to transfer the lessons learned from their experience and provide a realistic context for the principles students are learning, while themselves reflecting on the processes and principles underlying their work.[153]

[150] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288.

[151] Leuking, A.D., Ross, D.A. and Walter, J.W. (2003) 'Environmental sustainability education at the University of Michingan" Collaboration with industry to provide experiential learning opportunities', American Society for Engineering Education Annual Conference and Exposition, USA.

[152] Bonnet, H., Quist, J., Hoogwater, D., Spaans, J. and Wehrmann, C (2006) 'Teaching sustainable entrepreneurship to engineering students: the case of Delft University of Technology', *European Journal of Engineering Education*, vol 31, no 2, pp155-167.

[153] Wallace, K. (ed) (2005) *Educating Engineers in Design, Lessons learnt from the Visiting Professors Scheme,* Royal Academy of Engineering, UK.

4. Include Tutorials that Align with the Energy Efficiency Theme in the Course (e.g. presentations/ discussion/ problem solving)

Impact **[Survey: 3.3]**

The literature suggests that this option would have a high impact within the course in which it is applied, although the impact is still limited to having several tutorials within one course in the entire program, resulting in an overall moderate impact. This is in accord with the survey result of 3.3/5. As noted for other options, there is a risk that the skills and knowledge obtained in this course may not be developed further in other courses or be built upon to achieve the desired graduate attributes.

The impact of this option may depend on the style and nature of the tutorial itself. For example, El Zein *et al*[154] cite a case from the Civil Engineering department at the University of Sydney, where third year students had been taught (since 2003) an overhauled course on sustainability and ethics. In the tutorial (which they refer to as a 'workshop') component, students sat in groups and discussed decision making scenarios by analysing the various stakeholder positions, considering relevant policy, and potentially performing certain calculations. These discussions then evolved into a plenary session with the lecturer and a tutor to assist in guiding the students' learning. It is noted that these workshops encouraged deep learning and allowed students to engage with, and apply, the knowledge and concepts which had been taught. The significant barriers to shifting students' techno-centric decision making systems towards one which includes a wider range of factors (as is necessary for sustainability, or energy efficiency decision making) have not been fully eliminated by these sessions, and the educators aim to expose students to a social sustainability perspective rather than necessarily bring about a permanent change in attitude.

This example is supported by literature surrounding problem based learning (PBL) and deep learning. University of Queensland researcher Kevin Warburton notes that student directed 'discovery learning' is likely to result in a deeper understanding of issues in which independent thought, cross linkages, analysis and synthesis and creativity are fostered.[155] Ryan Legg and colleagues from Iowa State University note that teamwork is an essential skill for engineers working with interdisciplinary concepts, such as energy efficiency, and is recognised by accreditation boards such as ABET in America. [156]

The literature surrounding problem based learning has been highlighted previously as an effective method of teaching which results in a deeper understanding of learning objectives, particularly in the case of complex topics such as sustainability and energy efficiency. Canadian researcher Jessamyn Yazon and colleagues from the University of British Columbia noted a wealth of literature in their 2002 paper, suggesting that teaching through problem solving, interaction, collaboration and communication, both between students and with the course educator, will result in greater reflection on, and engagement with, the material being taught.[157] Their discussion over the dominant pedagogic paradigms in university education illuminates the shortcomings of lecture-based, passive learning styles which, although comfortable to many

[154] El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182.
[155] Warburton, K. (2003) 'Deep learning and education for sustainability', *International Journal for Sustainability in Higher Education,* vol 4, Issue 1, p44.
[156] Legg, R., Tekippe, M., Athreya, K.S. and Mina, M. (2005) 'Solving multidimensional problems through a new perspective: The integration of design for sustainability and engineering education', American Society for Engineering Education Annual Conference and Exposition, USA.
[157] Yazon, J.M.O., Mayer-Smith, J.A. and Redfield, R.J. (2002) 'Does the medium change the message? The impact of a web-based genetics course on university students' perspectives on learning and teaching', *Computers and Education,* vol 38, pp267-285.

students, promote shallow learning with a focus on exams. While Yazon *et al* provide this discussion within the context of their use of online interactive learning tools, it suggests that the inclusion of tutorials that align with the energy efficiency theme in the course would have a greater impact if it could help students appreciate what they will likely use in their career.

Likelihood **[Survey: 3.7]**

The literature suggests that the likelihood of staff engaging with students in tutorials related to energy efficiency is low to moderate, given the personal investment of time in preparation, and the need for staff to feel comfortable with the content. This is somewhat lower than the survey result of 3.7/5 (i.e. moderately to highly likely). As for earlier differences between the survey and literature with regard to workshops and elective modules, where the Australian engineering education community is increasingly exposed to problem-based learning tools, they may see tutorials on energy efficiency as a relatively straight-forward amendment to the curriculum.

In the example noted above, El Zein *et al*[158] make clear that such tutorials (which incorporate case studies) are ineffective if the case studies and tutorials are not able to engage with students and encourage them to investigate the concepts and relationships between the various issues and stakeholders themselves, and to reflect on their own thought processes and outcomes. The consequence of this is that most 'off-the-shelf' case studies are not able to be used, and that lecturers need to develop course specific examples which are relevant to engineering students (please note that El Zein *et al* are not referring only to real life case studies alone, but also fictitious examples which still provide a real life style scenario). This may make tutorials of this nature less likely, as it would entail significant work on the behalf of the lecturer in preparing such materials. As is noted by other authors, however, this workload is often concentrated in the first year or two that a course is run, and reduces significantly in ensuing years.[159]

Key Barriers

- ***Lack of knowledge:*** DJ Peet and his fellow researchers from the Netherlands echoed those comments by Michael Robison and his colleagues from the USA, who have noted that lecturers often do not have adequate knowledge themselves of sustainability (or energy efficiency) to teach this within their courses.[160]
- ***Prohibitive Cost:*** Many of the options potentially involve lecturers investing a significant amount of time in developing new content because there is either little existing material to assist them, or quality material is difficult to locate. In particular, depending on the size of the class, smaller sized tutorials may take up extra time, need extra tutors, and therefore require extra funding to facilitate.[161]

[158] El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182.
[159] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education,* December 2001, vol 9, no 2, pp179-192.
[160] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.
[161] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288.

- ***Lack of available data/information:*** An Australian research team from Sydney found that there is a shortage of appropriate case studies that allow students to engage with the process needed for sustainable engineering practice.[162] There are also still very few textbooks which truly cover topics such as sustainability engineering, according to New Zealand researcher Carol Boyle.[163] Consequently, running tutorials which might seek to engage students in deeper learning through problem solving, case studies and engaging in a discussion of the theory and concepts of energy efficiency may be greatly impeded by lecturers having to either develop such case studies and course materials themselves, or to run tutorials without them.
- ***Lack of time for preparation:*** Research from both the USA and the Netherlands suggests that there is a limited time available to engineering educators to make any changes to courses, degrees, course materials, and to identify academically rigorous information,[164] due to existing pressures to meet research commitments, in addition to a teaching workload and service requirements.[165] Content development may therefore be given a lower priority, or avoided altogether.
- ***An overcrowded curriculum:*** Engineering degrees are widely reported (in the USA, New Zealand and the EU) to be crowded with courses, with significant competition existing over what should be taught.[166] Although engineering departments might recognise the need to teach energy efficiency, pressure from faculty who feel that either it is already being taught adequately, or that it doesn't need to be taught at all, may be a barrier to for example, displacing existing topics in tutorials with energy efficiency material as there are limited credit points within a program to allocate to incorporating new topic areas.[167] The concern is that any additional information must displace existing 'fundamentals', as courses and programs are generally already saturated. Where lecturers feel that the new material is less relevant, or that existing materials are indispensable, there will be significant resistance to these changes.

Key Benefits

- ***Improved pedagogy – problem based learning:*** An increasing number of universities world-wide are offering problem based courses, most likely in response to industry

[162] El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182.
[163] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education,* vol 5, no 2, pp147-155.
[164] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[165] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[166] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education,* vol 5, no 2, pp147-155; Holmberg, J., Svanström, M., Peet, D.J., Mulder, K., Ferrer-Balas, D. and Segalàs, J. (2008) 'Embedding sustainability in higher education through interaction with lecturers: Case studies from three European technical universities', *European Journal of Engineering Education*, vol 33, no 3, pp271-282; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[167] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education,* vol 5, no 2, pp147-155.

expectations, and hence accreditation board requirements, which require engineers to be proficient in a number of disparate capabilities and interdisciplinary skills.[168]

- ***Improved pedagogy – generic skills:*** There is also increasing pressure from the industry and professional associations, for engineering students to have an understanding of sustainability and to be able to apply it to their practice; i.e. deeper learning experiences and soft-skill development.[169] This option may provide benefits to a university in terms of the employability of their students, and in their ability to promote applicable degrees and courses to potential students.

[168] Lehmann, M., Christensen, P., Du, X. and Thrane, M.(2008) 'Problem-oriented and project-based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education', *European Journal of Engineering Education*, vol 33, no 3, pp283-295.
[169] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155; Theis, R. Wakins, P. and Beck, M.A. (2008) 'Pathways to learning: Orchestrating the role of sustainability in engineering education', *American Society for Engineering Education*, USA, AC 2008-968.

5. Offer Energy Efficiency as a Topic in a Problem-Based Learning Course

Impact **[Survey: 3.7]**

Problem (or project) based learning (PBL) is assumed in this context to refer to a method of teaching in which a given problem incites the process of learning, as opposed to case study based learning where knowledge is provided, and then understanding of this is assessed via a case study which incorporates this knowledge in a real-life setting. The literature suggests that offering energy efficiency as a topic in a PBL course will have a high impact on the extent of energy efficiency content in the engineering curriculum. The survey result of 3.7/5 (i.e. a moderate to high impact) is slightly less optimistic than the literature, which could be due to the authors of the papers showing an attachment to, and therefore an optimistic opinion of, the merits of this option.

The impact of including energy efficiency as a topic in an existing problem-based learning (PBL) course may be inferred to a degree from the effectiveness of PBL as a learning methodology. PBL literature suggests that it develops students' process based skills, such as problem solving, applying technical knowledge, collaboration, communication and project management. It also helps to provide, and then reinforce, linkages between various 'elements' of a system, assuming that a real world problem will be more complex than a theoretical problem, which may focus on one issue at a time.[170] Within this context, it could be inferred that this option will have a high impact as it will assist students to transfer knowledge (for instance regarding energy efficiency) towards practical situations. It also helps to develop a thought process whereby key questions are asked that may illuminate a larger context of a given problem, such that traditional technological solutions are avoided where they may fix a symptom rather than an underlying cause.

Victorian University researcher Euan Nichol and colleagues note that problem based learning is particularly effective (i.e. high impact) in delivering sustainability objectives in engineering projects as it teaches students to consider multiple solutions, and to consider a wider range of factors which may be influencing the design problem, as opposed to textbook learning, which may provide a linear train of thought between problem identification and a prescribed solution.[171] PBL can also assist students in integrating learning from a variety of disciplines due to the nature of most PBL projects, which include students from a variety of disciplines.[172] American researcher Doanh Van (Union Uniersity) agrees an interdisciplinary knowledge is vital for engineering energy efficiency systems, proposing that while energy sustainability is the common thread which underlies the sustainability of our social, economic and environmental systems, each system has somewhat unique demands and circumstances, hence requiring interdisciplinary understanding to find solutions that satisfy them all.[173]

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[170] Lehmann, M., Christensen, P., Du, X. and Thrane, M.(2008) 'Problem-oriented and project-based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education', *European Journal of Engineering Education*, vol 33, no 3, pp283-295; de Eyto, A., Mc Mahon, M., Hadfield, M. and Hutchings, M. (2008) 'Strategies for developing sustainable design practice for students and SME professionals', *European Journal of Engineering Education*, vol 33, no 3, pp331-342; Saverty, J.R. and Duffy, T.M. (2001) *Problem Based Learning: An instructional model and its constructivist framework*, Centre for Research on Learning and Technology, Indiana University, USA; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.

[171] Evans, G., Nichol, E., Sillitoe, J. and Webb, J. (1998) 'Students' perspectives: do they learn much outside of lectures and tutorials?' Proceedings of the 10th Australian Conference on Engineering.

[172] Lehmann, M., Christensen, P., Du, X. and Thrane, M.(2008) 'Problem-oriented and project-based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education', *European Journal of Engineering Education*, vol 33, no 3, pp283-295.

[173] Van, D. (2003) 'Teaching Design for Energy Sustainability', Proceeding of the 2003 American Society for Engineering Education Annual Conference and Exposition, American Society for Engineering Education, USA.

Likelihood **[Survey: 3.7]**

Problem based learning is being increasingly utilised by engineering departments around the world, suggesting that this option may be quite likely, which accords with the survey result of 3.7/5. Netherland researchers Erik de Graaff and Wim Ravesteijn (Delft University) note that while engineering departments were initially slow to innovate and update their engineering degrees, more recent pressures from society and the profession itself has led to departments looking for ways in which to teach students competencies, such as risk taking and creativity. These skills, among others, can be effectively taught through PBL and such drivers have led to an increasing incidence of this teaching technique in higher engineering education.

PBL varies from traditional teaching, requiring lecturers to create a learning environment and attempt to guide the meta-cognitive processes rather than the flow of information itself, and thus the literature suggests that this option is less likely to occur. Jafar Madadnia and colleagues from the University of Technology, Sydney note that a project based learning approach requires additional time and effort on the behalf of lecturers, and may involve retraining.[174] The role of the lecturer is a significant departure from traditional teaching methods - diverse and potentially time consuming.[175] Indeed, American researcher John Savery and colleagues from the Centre for Research on Learning and Technology (Indiana University) describe teaching a PBL course as being a facilitator who poses insightful questions to students, inciting a 'puzzlement' with which students are motivated to seek the relevant information themselves, rather than simply providing information.[176]

Key Barriers

- ***Lack of knowledge:*** DJ Peet and his fellow researchers from the Netherlands echoed those comments by Michael Robison and his colleagues from the USA, who have noted that lecturers often do not have adequate knowledge themselves of sustainability (or energy efficiency) to teach this within their courses.[177] In regards to problem based learning (PBL), John Saverty and Thomas Duffy from Indiana University in the USA[178] explored PBL, and the role of the lecturer or facilitator. PBL is student centred and typically requires students to find the information they need, to monitor their own knowledge and thinking and to discover for themselves what questions need to be asked. As such, it requires a well informed lecturer, as they must be able to answer students' questions and to facilitate discussions.
- ***Lack of available data/ information:*** Teaching a PBL course would require the availability of information for students, such as textbooks and case studies, from which potential solutions could be found. As noted by Carol Boyle, there is a lack of such resources, and

[174] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education,* December 2001, vol 9, no 2, pp179-192.
[175] Lehmann, M., Christensen, P., Du, X. and Thrane, M.(2008) 'Problem-oriented and project-based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education', *European Journal of Engineering Education*, vol 33, no 3, pp283-295.
[176] Saverty, J.R. and Duffy, T.M. (2001) *Problem Based Learning: An instructional model and its constructivist framework*, Centre for Research on Learning and Technology, Indiana University, USA.
[177] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.
[178] Saverty, J.R. and Duffy, T.M. (2001) *Problem Based Learning: An instructional model and its constructivist framework*, Centre for Research on Learning and Technology, Indiana University, USA.

educators often find themselves as a loss trying to find true examples of engineering which could be said to have achieved 'real sustainability'.[179]

- ***Lack of time for preparation:*** Research from both the USA and the Netherlands suggests that there is a limited time available to engineering educators to make any changes to courses, degrees, course materials, and to identify academically rigorous information,[180] due to existing pressures to meet research commitments, in addition to a teaching workload and service requirements.[181] Content development may therefore be given a lower priority, or avoided altogether.
- ***Prohibitive cost:*** Many of the options potentially involve lecturers investing a significant amount of time in developing new content because there is either little existing material to assist them, or quality material is difficult to locate.[182]
- *Lack of student maturity:* Carol Boyle commented in 2004 on the lack of maturity in students, and how this is a barrier to their ability to understand complex, interdisciplinary topics such as sustainability (and energy efficiency).[183] While it is widely recognised that PBL can teach students diverse skills and stimulate them to apply what may otherwise have been disconnected aspects of their learning, Boyle suggests that students are only truly able to understand and undertake this sort of process thinking in the final year of their study.
- ***Students' prior learning habits:*** It is furthermore contended that PBL can challenge prior learning habits and a traditional engineering focus on end-of-pipe solutions. These may both be barriers to the success of a PBL course and inhibit lecturers' willingness to engage with such pedagogy. PBL courses may be a departure from the surface based learning habits acquired by students throughout high school and early years of university. Creating a shift from this towards deep learning habits, requiring critical thinking and analysis, such as PBL, can require continuous effort on the behalf of staff, and collaboration with both other staff and with students.[184]
- *Difficulty in making a pedagogical shift (lecturer):* Martin Lehmann and his colleagues in Denmark[185] noted in 2008 that PBL requires the engineering educator to shift their role from one of transferring knowledge, on to facilitating the students' learning process. Jafar Madadnia *et al*[186] commented on the difficulty that this can pose for lecturers, firstly in shifting students out of their ingrained, surface learning techniques and habits, and allowing time to learn these new teaching techniques themselves. They also commented that it can

[179] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education,* vol 5, no 2, pp147-155.
[180] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5 no 3, p278-288.
[181] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[182] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[183] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.
[184] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education*, December 2001, vol 9, no 2, pp179-192.
[185] Lehmann, M., Christensen, P., Du, X. and Thrane, M.(2008) 'Problem-oriented and project-based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education', *European Journal of Engineering Education*, vol 33, no 3, pp283-295.
[186] Madadnia, J., Koosha, H. & McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education*, December 2001, vol 9, no 2, pp179-192.

require significant partnership and collaboration with other staff, which may be an additional barrier to academics used to operating independently.

Key Benefits

- *Curriculum load neutral:* This option allows lecturers to still cover largely the same material, and simply adds a new design consideration into the design problems. Presumably this will require these new concepts of energy efficiency to have been taught either elsewhere in the degree or the course, however, from these authors' experiences this option has the benefit of not resulting in any loss of content from the course.[187]
- ***Improved pedagogy – problem based learning:*** The success of a PBL course can lead students to request a similar format in other courses, providing incentive to other colleagues to teach using such methods and provide encouragement for those already doing so. It is also noted within the literature that the success of this type of teaching provides benefits to lecturers through the satisfaction of seeing students engage with the subject matter, think more critically and pursue deeper learning. It is also noted that PBL, which is aligned with assessment tasks, can encourage the development of graduate attributes (critical thinking, interpersonal and communication skills, reflective practise and an ability to analyse, synthesise, create and apply knowledge),[188] and may assist the course lecturer and the university in promoting both the course and the degree to future students.
- ***Improved pedagogy – generic skills:*** PBL courses may provide benefits to the university and the lecturer through graduate employability. Jafar Madadnia and his fellow researchers from UTS, Australia[189] noted that a national and international panel of independent experts who reviewed the twenty year project based engineering education offered at Aalborg University in Denmark found that '*the graduates are more readily adaptable, with strong qualities in the field of problem shooting, cooperation, communication and synthesising project work*'.

[187] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA.
[188] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education*, December 2001, vol 9, no 2, pp179-192.
[189] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education*, December 2001, vol 9, no 2, pp179-192.

6. Include Assessment that Aligns with the Energy Efficiency Theme within the Course (e.g. exam questions and assignments)

Impact **[Survey: 3.4]**

The literature suggests that this option will have a high impact on the extent of energy efficiency content in the curriculum, acting as a driver to ensure that the proposed content is embedded and given due attention within the course. The literature also suggests that this option will increase the impact of any other option which introduces new content to the course. Its impact will be limited depended on the type of assessment used - for instance, one which encourages deep learning, or shallow learning, and the amount by which this assessment and hence the teaching of energy efficiency is integrated into courses throughout a degree. The survey result of 3.4/5 is somewhat less optimistic about the impact than the literature. This difference could be due to the authors of the papers showing an attachment to, and therefore an optimistic opinion of, the merits of this option. Alternatively, it could be due to the Australian engineering education community having a slightly more conservative approach to assessment as a tool for driving the development of graduate attributes.

Curriculum theory suggests that the approach students take to learning, and learning outcomes is largely related to their perception of assessment requirements.[190] As noted by Australian researcher Paul Ramsden in his 1992 book *Learning to Teach in Higher Education, 'from our students' point of view, the assessment always defines the actual curriculum'.*[191] As such, the literature suggests that a course which ties key learning outcomes to the assessment tasks will have a greater potential to develop the key attributes the course is trying to teach. In the example of the University of Technology, Sydney, an energy efficiency course was taught in which critical reflection was integrated into many aspects of the course and assessment tasks, which included a progressive case study (written by the students), reflective journal and a final examination.[192] The case studies in particular were intended to assist students in integrating the technical, social, environmental, political and economic factors which influence energy efficiency, a process which presumably assisted students in learning how to consider such notions concurrently. In the end of semester student evaluations, there was strong support for the way in which the course was taught, and for the assessment requirements (88 percent positive support for the reflective exercises, 94 percent support for the case study).

Underlying the concepts of assessment is the question over the type of assessment which is used, and which kind of learning this facilitates. Warburton[193] suggests three learning types for sustainability related knowledge and skills: deep learning, surface learning and strategic learning. Of these, deep learning is considered necessary for complex, interdisciplinary concepts such as energy efficiency and requires attention to underlying meaning and making linkages between various pieces of information, critical thinking and independent thought. The other two learning types involve (respectively) primarily rote learning and simple description, and learning only what is necessary to complete the assessment tasks. Thus the impact of this

[190] Biggs, J. (1999) 'What the Student Does: teaching for enhanced learning', *Higher Education Research and Development*, vol 18, Issue 1, pp57-75; Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education,* December 2001, vol 9, no 2, pp179-192; Lehmann, M., Christensen, P., Du, X. and Thrane, M.(2008) 'Problem-oriented and project-based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education', *European Journal of Engineering Education*, vol 33, no 3, pp283-295.

[191] Ramsden, P. (1992) *Learning to Teach in Higher Education*, Routledge, London, p187, cited in Biggs, J. (1999) 'What the Student Does: teaching for enhanced learning', *Higher Education Research and Development*, vol 18, Issue 1, pp57-75.

[192] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education,* December 2001, vol 9, no 2, pp179-192.

[193] Warburton, K. (2003) 'Deep learning and education for sustainability', *International Journal for Sustainability in Higher Education,* vol 4, Issue 1, p44.

option is noted with caution, as although assessment can serve to focus students' attention on various aspects of a course, it can also lead to superficial learning which is unlikely to provide any great impact in the longer term.

As noted by El-Zein *et al*[194] and Peet *et al*,[195] teaching complex notions such as energy efficiency or sustainability in isolated courses do not provide a systematic approach which is needed for these concepts to become a dominant paradigm, and to ensure that the knowledge and skills learned in such courses are transferred and applied in other courses and in practice. Highlighting energy efficiency content through the option of creating assessment items serves to draw attention to such knowledge and skills, aiding their full integration within the engineering curriculum.

Likelihood **[Survey: 3.7]**

The literature suggests that including energy efficiency in assessment tasks is relatively straightforward and highly likely where it is already a component of the course, as it just requires the lecturer to draw attention to this aspect of the course. However, it may be less likely where the course lecturer has added energy efficiency perhaps as a concession to departmental requests rather than out of a strong belief that it is relevant to the course, and important enough to potentially displace the assessment of other aspects. These findings are in accord with the survey result of 3.7/5.

In the UTS example discussed above, it was noted that the assessment tasks provided did require additional time to administer. Staff found that considerable time was needed for consultation, attention and prompt feedback, however, it was anticipated that this time would be minimised in the following years, and that much was due to 'teething problems'.[196] Such factors may make it less likely for engineering educators to change assessment tasks, as it may involve more time in consultation, or marking. The approach taken by UTS is by no means the only way of assessing key learning outcomes, however, this may provide an indication of what may be required in order to do so.

Boyle[197] notes that lack of acceptance of principles of sustainability (and presumably energy efficiency) are a significant barrier to their inclusion within engineering curricula. Even though they may be covered in a course outline, in reality they may receive only a cursory treatment. From their experience at Delft University in the Netherlands, Peet and his fellow researchers found that lecturers can be highly resistant to top down demands that changes be implemented to their courses, and often have a strong belief that interdisciplinary concepts (such as energy efficiency) are less important than more traditional engineering concepts. Although their discussion relates more specifically to the manner in which changes are incited, the discussion nonetheless reveals a prevailing mentality which can result in energy efficiency components of a course being de-prioritised.[198] Given the comments made by Australian researchers Jafar Madadnia, Homa Koosha and Jo McKenzie (UTS), [199] as well as Kevin Warburton (the University

[194] El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol, 9 Issue 2, pp170-182.
[195] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[196] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education,* December 2001, vol 9, no 2, pp179-192.
[197] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.
[198] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[199] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education,* December 2001, vol 9, no 2, pp179-192.

of Queensland)[200] regarding the nature of assessment to direct students' focus and learning, lecturers may resist changing assessment tasks to include energy efficiency where they feel it is of a lower priority.

Key Barriers

- ***Lack of time for preparation:*** Research from both the USA and the Netherlands suggests that there is a limited time available to engineering educators to make any changes to courses, degrees, course materials, and to identify academically rigorous information,[201] due to existing pressures to meet research commitments, in addition to a teaching workload and service requirements.[202] Changes to assessment may therefore be given a lower priority, or avoided altogether.
- *Difficulty of assessment*: If it is to be assumed that energy efficiency is similar to sustainable engineering in that both require a whole systems perspective and the integration of interdisciplinary concepts, it might also be assumed that in order to assess energy efficiency effectively, assessment must challenge students to apply concepts rather than simply regurgitate them, to be innovative and to integrate diverse concepts and considerations.[203] In the case of UTS, where student-focussed learning and assessment was used to teach sustainability to engineers, Madadnia and his colleagues[204] noted that this assessment methodology consumed significant amounts of the lecturer's time in consultation and marking, although this was more heavily weighted towards the earlier years of the course's development.
- ***Prohibitive Cost:*** Several authors from both the USA and the Netherlands have noted the financial constraints which may inhibit lecturers' ability to dedicate both the required time during the teaching semester, and to developing assessment. [205]
- ***Lack of value attached:*** Lecturers may not value the importance or relevance of energy efficiency to their course, they may perceive it as less important than other aspects of the course, and may therefore resist including such material into their course.[206]
- ***Lack of available data/information:*** A lack of available examples of energy efficiency integrated into engineering practice may restrict a lecturer's ability to develop realistic

[200] Warburton, K. (2003) 'Deep learning and education for sustainability', *International Journal for Sustainability in Higher Education,* vol 4, Issue 1, p44.
[201] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[202] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[203] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education*, December 2001, vol 9, no 2, pp179-192; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.
[204] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education*, December 2001, vol 9, no 2, pp179-192.
[205] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288.
[206] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.

assessment items, and may also inhibit students' ability to study and complete assessment items.

- ***An overcrowded curriculum:*** As for option 4, the issue with stipulating assessment requirements that embed energy efficiency knowledge and skills, is that these then need to be focused on within the curriculum, implicitly requiring curriculum renewal, with its associated barriers. In addition, lecturers may perceive that energy efficiency assessment may be displacing more fundamental assessment items.

Key Benefits

- ***Improved pedagogy – problem based learning:*** Jafar Madadnia *et al*[207] from the University of Technology, Sydney commented on the success of student focused assessment, as discussed above, noting that colleagues within the engineering department were approached by students from the case study course, who requested that a similar approach be taken in other classes.
- ***Improved pedagogy – generic skills:*** With respect to certain types of assessment, in this case a project based student-led assessment task, it was noted within the literature that the success of this type of teaching provides benefits to lectures through the satisfaction of seeing students engage with the subject matter, think more critically and pursue deeper learning. It is also noted that PBL which is aligned with assessment tasks can encourage the development of graduate attributes (critical thinking, interpersonal and communication skills, reflective practise and an ability to analyse, synthesise, create and apply knowledge)[208] and may assist the course lecturer and the university in promoting both the course and the degree to future students.
- ***Lecturer professional development:*** It would be assumed that lecturers would benefit from this option by being able to show that their assessment items covered the materials taught in the course and that those students which pass the course have an understanding of energy efficiency.

[207] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education*, December 2001, vol 9, no 2, pp179-192.
[208] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education*, December 2001, vol 9, no 2, pp179-192.

7. Overhaul the Course to Embed Energy Efficiency

Impact **[Survey: 3.7]**

Although there is little written about overhauling courses for energy efficiency content, literature does exist for overhauling courses to integrate the concepts of sustainability. This literature identifies a shift in mentality whereby the new concepts are used throughout the design process, enabling solutions beyond the realm of traditional engineering. If more than one course related to energy could be overhauled, this would improve the impact further. As such, the literature suggests that this option could have a moderate to high impact. This is in general accord with the survey result of 3.7/5.

In 2000, Canadian researcher Crofton[209] noted that courses which lie too far outside the traditional knowledge base of engineers, and which have a less technical base, may be perceived as being less important to students (i.e. have 'easy credit points'), and students may be less able to transfer the information across to other aspects of their study. Hence, modifying an existing course provides an opportunity to situate new content within an already familiar context, reducing the potential for 'side-lining' or siloing the information, or reducing its importance. Crofton also noted that this option could have even more impact if it is combined with developing new courses, which could introduce or lead on from the concepts taught in an overhauled existing course.[210] As discussed earlier, Desha *et al* refer to this option as developing the emerging concepts in 'armada' courses through overhauling, which can then support the 'flagship' new courses.[211]

This literature aligns with the 2001 paper by University of Technology, Sydney (UTS) researchers Madadnia *et al* who concluded that courses will be more effective if they focus on changing a student's way of *'seeing, experiencing, understanding, conceptualising something in the real world rather than as a quantitative change in the amount of knowledge someone possesses'*.[212] Situating the new content within existing engineering topics can help students to make these real-world links, avoiding what Crofton refers to as, *'merely adding more information'*.[213] Rather, it works within the existing knowledge context, and learning mechanisms, of engineering students, changing the problem solving parameters provided to students, and encouraging them to seek the best practice outcomes.

Likelihood **[Survey: 3.4]**

The literature suggests that this option has a moderate likelihood of being implemented, dependent on how external accreditation pressures and assistance with curriculum renewal influences a time and resource constrained engineering educator community of practice. This is in accord with the survey result of 3.4/5. It also depends on the receptivity of departmental staff to shifting the mindset from end-of-pipe solutions to integrated 'beginning-of-pipe' solutions.

In a 2007 survey of US engineering colleges, just 23 percent of the courses surveyed were those in which sustainability has been embedded, in comparison to nearly half of the courses

[209] Crofton, F.S. (2000) 'Education for sustainability: opportunities in undergraduate engineering', *Journal of Cleaner Production*, vol 8, pp397-405.
[210] Crofton, F.S. (2000) 'Education for sustainability: opportunities in undergraduate engineering', *Journal of Cleaner Production*, vol 8, p403.
[211] Desha, C., Hargroves, K., and Smith, M. (2009) 'Addressing the time lag dilemma in curriculum renewal towards engineering education for sustainable development', *International Journal of Sustainability in Higher Education*, vol 10, no 2, pp184-199.
[212] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education*, December 2001, vol 9, no 2, p182.
[213] Crofton, F.S.(2000) 'Education for sustainability: opportunities in undergraduate engineering', *Journal of Cleaner Production*, vol 8, pp397-405.

being 'dedicated' sustainability courses.[214] This suggests that it is more difficult to change an existing course than to create a new one to run alongside existing courses. Authors from around the world have remarked on similar difficulties in overhauling courses and programs, which can include a lack of knowledge of sustainability among engineering educators; a reluctance from these educators to accept a 'top down' push to include sustainability in their courses; a feeling that sustainability is not relevant to an educators' courses; a resistance to accepting advice and assistance from 'non-engineers'; funding and time availability to overhaul courses; and the degree of autonomy which lecturers and educators have over the content being taught in their courses.[215] These existing factors may reduce the likelihood of courses being overhauled to embed energy efficiency principles. New Zealand researcher Carol Boyle notes that these problems may be further exacerbated by the paucity of textbooks currently available, which shifts the responsibility for providing such materials to the course provider.[216]

In 2004 Boyle outlined a key impediment to overhauling courses to incorporate sustainability concepts, as the need for a fundamental shift from 'end-of-pipe' solutions to an integrated and at times radically new way of designing and engineering.[217] According to Boyle, traditional concepts of engineering, which lead to traditional solutions to problems, are often considered to be the basics – the underlying framework is not questioned – and as such continue to be taught. This methodology generally identifies the main problem, and students learn to work around ancillary problems using tried and tested techniques to provide a solution - which is inherently end-of-pipe. In contrast, energy efficiency education requires a 'whole systems' approach which includes the wider social, environmental and economic contexts. This altered framework may illuminate alternative, less traditional, solutions to the central problem, where the underlying causes of what was originally perceived to be the main problem may even be eliminated, creating a 'beginning-of-pipe' solution.

University of Technology, Sydney (UTS) researchers Madadnia *et al* describe how their institution overhauled a postgraduate course to teach energy conversion technology, including renewable, non-renewable and alternative energy systems, within the political, social, technological and environmental contexts existing today. It is noted that this is difficult to teach at times, given the political and social ramifications of some energy conversion technologies (for instance nuclear power). Reflective practices were used to assist students in learning how to critically analyse and understand sustainability principles, rather than just learning the knowledge and information provided.

Key Barriers

- ***Resistance to top-down and external directives:*** The autonomy of lecturers is noted to be a significant barrier to overhauling or changing courses, particularly where the push for these changes comes from above. Lecturers may resist advice and recommendations from

[214] Allen, D., Allenby, B., Bridges, M., Crittenden, J., Davidson, C., Hendrickson, C., Matthews, C., Murphy, C., and Pijawka, D. (2008) *Benchmarking Sustainability Engineering Education: Final Report*, EPA Grant X3-83235101-0, Centre for Sustainable Engineering, America, www.csengin.org/benchmark.htm, accessed 12 March 2009 .
[215] Crofton, F.S. (2000) 'Education for sustainability: opportunities in undergraduate engineering', *Journal of Cleaner Production,* vol 8, pp397-405; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288; Boyle, C. (2004) 'Considerations on educating engineers in *sustainability' International Journal of Sustainability in Higher Education*, vol 5, no 2 p147 – 155; and El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182.
[216] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.
[217] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.

outsiders (particularly non-engineers) and from above (as in through the university system).[218]

- ***Lecturer apathy:*** Lecturers have inertia when it comes to overhauling their courses, largely due to there being little incentive for them to do so. This can lead to a passivity or sense of apathy, with which lecturers feel that the responsibility for demanding sustainability (or energy efficiency) lies elsewhere (such as with industry), and the role of an engineer is to design to such parameters only when they are specified, as opposed to educators being the instigators for energy efficient design. [219]
- *Institutional organisational structure:* A department is often responsible for certain courses, even if the course is offered to students outside of that department. Overhauling such a course can result in tension regarding how this work would be funded.[220]
- ***Administrative coordination:*** Even within a department, changing the curriculum can result in arguments between faculty over credit point allocation, and can inflame insecurities regarding power and position. The time-consuming nature of such logistics can be a barrier to beginning a new process. [221]
- *Lack of collaboration among colleagues:* Furthermore, Peet *et al* argue from their experience in the Netherlands that individual lecturers often do not have the means themselves to improve the quality of the course which they teach – presumably the quality is reliant on the department and even the university as a whole. This may lead to a disempowerment of lecturers and become a barrier to their taking personal action to overhaul a course. [222]
- ***Lack of knowledge:*** Lecturers' perception of multidisciplinary topics such as energy efficiency, which combine social, economic and environmental components[223] is often that it is too vague to be explicitly taught in their course, particularly where such a course is of a specialised, technical nature. Conversely, but for similar reasons, the complex nature of energy efficiency may lead some lecturers to feel that it is implicitly being taught already in the course, making an overhaul unnecessary, even where these concepts and links are not clearly expressed to students. [224]
- ***Lack of available data/information:*** In overhauling a course to include energy efficiency, the lack of course materials (textbooks, case studies, modules) may also be a barrier.[225] The absence of these would require then that the course lecturer develops these themselves (which would require time and finances to do so), or that the course be run without them and

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[218] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288; Holmberg, J., Svanström, M., Peet, D.J., Mulder, K., Ferrer-Balas, D. and Segalàs, J.(2008) 'Embedding sustainability in higher education through interaction with lecturers: Case studies from three European technical universities', *European Journal of Engineering Education*, vol 33, no 3, pp271-282.
[219] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[220] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[221] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[222] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[223] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education*, December 2001, vol 9, no 2, pp179-192.
[224] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[225] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.

thus presumably rely more heavily on the information communicated by the lecturer (which may be inhibited by the level of knowledge and appreciation of the topic).

Key Benefits

- *Experience in incorporating emerging concepts into curriculum:* The experience gained from incorporating energy efficiency material into engineering curriculum is a valuable one, allowing lecturers to be prepared for further changes to curriculum as the nature of engineering and its accreditation requirements change in the years to come. The literature suggests that quite often the process of curriculum renewal is not as strenuous as perceived, as Michael Robinson and his colleagues from the Rose-Hulman Institute of Technology in the USA[226] discovered. The lecturers of Rose-Hulman Institute of Technology found that where changes are focused on one course, such as in this option, it is possible for it to be undertaken by a single faculty and does not require the 'buy-in' of a whole department. This may simplify the process as it reduces the number of agents which need to be convinced of the need for change. They also discuss a course which was overhauled at the Rose-Hulman Institute of Technology in which the inclusion of sustainability within the course was not seen to have compromised other course materials as that course was already needing to be overhauled in order to meet changing course and departmental expectations. Peter Bosscher, Jeffrey Russell and WB Stouffer from the University of Wisconsin[227] commented on the changing expectations of engineers and how this is filtering through and impacting on universities and engineering departments.
- *Addressing the time-lag for graduates:* In a previous paper,[228] the authors of this research project have noted the time-lag inherent in engineering degrees and how updating and overhauling courses using a 'standard method' may take up to 15-20 years. This time delay can create potential risks for the engineering school and the university in terms of student enrolments, adherence to accreditation requirements and consequently program viability. Given that the half-life of engineering knowledge is about *'five years and shrinking'*,[229] this poses a considerable dilemma for engineering schools – and a significant opportunity in that by overhauling a course to include energy efficiency, other aspects of the course may be simultaneously updated. This may include not only knowledge, but new pedagogic techniques.
- ***Cross-functionality of content:*** The multidisciplinary nature of energy efficiency may mean that a course which is overhauled may also become relevant to students from other disciplines. The potential increase in student enrolments would be considered a benefit to the department and lecturers.
- ***Improved marketability:*** Similarly, in overhauling the course, opportunity for additional promotion both within and outside of the university may be created, resulting in increased enrolments.

[226] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA.
[227] Bosscher, P.J., Russell, J.S. and Stouffer, W.B. (2005) 'The Sustainable Classroom: Teaching Sustainability to Tomorrow's Engineers', American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA.
[228] Desha, C.J., Hargroves, K., Smith, M.H. (2009) 'Addressing the time lag dilemma in curriculum renewal towards engineering education for sustainable development', *International Journal of Sustainability in Higher Education,* vol 10, no 2, pp184-199.
[229] Crofton, F.S. (2000) 'Education for sustainability: opportunities in undergraduate engineering', *Journal of Cleaner Production*, vol 8, p399.

8. Include a Field Trip Related to Energy Efficiency

Impact **[Survey: 3.5]**

In the absence of literature discussing this option, the authors conclude that including a field trip related to energy efficiency will have a moderate impact on the extent of such content in the curriculum, as this option involves an activity occurring once, within one course in an engineering program. This is in accord with the survey result of 3.5/5. The knowledge gained through one field trip can be more intensely delivered and received than in a lecture environment, but needs supporting follow-up 'back in the classroom' to provide the systematic approach which is necessary for teaching a deep understanding of interdisciplinary, complex issues such as energy efficiency. This option also has the potential to provide a high impact on the students' perception of the importance of energy efficiency if it is relevant and engaging. This experience may be important in creating a shift in the mindset of students, which can then be developed in other courses.

There was little coverage in the literature regarding the impact of this option on the curriculum. Several assumptions are therefore made to extrapolate from the literature some measure of how effective a field trip might be in increasing the extent of energy efficiency content within the engineering program curriculum. It is assumed that a field trip is somewhat more 'practically based' than a lecture, in that students can be more actively involved in the learning environment and see first hand the application, or potentially lack, of a certain technology or concept. It is also assumed that 'a' field trip refers to one field trip, including measures by which the field trip is referred to elsewhere in the course.

Several authors have noted that engineers typically have prior learning experiences that preconditions them towards learning technically based subject matter.[230] Other authors have commented on an increasingly accepted awareness of the benefits of using problem and project based learning to create deep learning.[231] While it may be a large extrapolation to suggest that a field trip is either more technically based, or project based (which would depend on the type and nature of the field trip), it could be expected that a field trip has the potential to be more interactive, involve students reflecting on previously learned knowledge, and provide a real-life example of what may have otherwise been theoretical concepts for students.

Likelihood **[Survey: 3.1]**

In the absence of literature discussing this option directly, the authors conclude from what is available, that the option would be moderately likely, which is in accord with the survey result of 3.1/5. There are many factors upon which the introduction of a field trip is contingent, and the barriers identified in the literature which typically inhibit a given lecturer's inclination to change or adapt their course are considered relevant to this option. This said, this option represents an interjection into an existing course which does not necessarily entail significant knowledge on the behalf of the lecturer (if it is assumed that the field trip is able to 'speak for itself' to some extent), and the time involved in developing and organising such a trip may be largely

[230] Crofton, F.S. (2000) 'Education for sustainability: opportunities in undergraduate engineering', *Journal of Cleaner Production,* vol 8, pp397-405; Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education,* December 2001, vol 9, no 2, pp179-192.
[231] Lehmann, M., Christensen, P., Du, X. and Thrane, M.(2008) 'Problem-oriented and project-based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education', *European Journal of Engineering Education*, vol 33, no 3, pp283-295; de Eyto, A., Mc Mahon, M., Hadfield, M. and Hutchings, M. (2008) 'Strategies for developing sustainable design practice for students and SME professionals', *European Journal of Engineering Education*, vol 33, no 3, pp331-342.

administrative rather than academic. Depending on the structure of the university, a lecturer may hence be able to delegate a certain proportion of the work involved in developing and organising a field trip to administrative staff.

Peet *et al*[232] and Crofton[233] identify a number of external factors that may influence the likelihood of activities such as field trips occurring, including the existence of a site or activity which would be worthy of a field trip, university policies towards field trips and practical feasibility issues (including liability, the availability of transport, class sizes, timetabling), and the cost of running field trips. It may also depend on there being time available within a course to run a field trip, and several authors commented on both time and financial constraints in courses as being a barrier to other options.

Further to this, Boyle[234] and Peet *et al*[235] note that one of the most significant barriers to implementing change within a course can be reluctance on the behalf of the lecturer themselves, who may see energy efficiency (as with sustainability) as being either irrelevant to the course being taught, or that in their estimate it is being taught to a sufficient level, that the introduction of new material would necessarily displace vital fundamentals, that their understanding of sustainability (or equally energy efficiency) is insufficient to teach the topic to students or that the lecturer simply does not accept the concept of sustainability (or energy efficiency) themselves. With this mindset, lecturers may see field trips as the responsibility of other staff, or not worth the time.

Key Barriers

- ***Administrative coordination:*** Introducing a field trip to a course may encounter several practical barriers. Universities may also have restrictions on where students are able to go, potentially for legal reasons.
- ***Prohibitive cost:*** Financial restrictions may determine the type of field trip possible. The availability of course time is noted throughout the literature as being a barrier to including new subject matter into engineering degrees and it is assumed that a field trip would consume teaching time which may otherwise have been spent teaching other topics.[236]
- ***Lack of time for preparation:*** Research from both the USA and the Netherlands suggests that there is a limited time available to engineering educators to make any changes to courses, degrees, course materials, and to identify academically rigorous information,[237] due to existing pressures to meet research commitments, in addition to a teaching workload and service requirements.[238]

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[232] Crofton, F.S. (2000) 'Education for sustainability: opportunities in undergraduate engineering', *Journal of Cleaner Production,* vol 8, pp397-405; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[233] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[234] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.
[235] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[236] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288; Boyle, C. (2004) 'Considerations on educating engineers in *sustainability' International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.
[237] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[238] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA;

- ***Lack of industry contacts:*** Lecturers may not have existing industry contacts who can provide energy efficiency problems that need investigating. Because the lecturers may not know the field very well, they may struggle to identify colleagues internally or externally who could help provide suitable opportunities for field trips.
- *Timetabling issues:* In order to conduct such a field trip, it would be necessary that a site of educational value was within a certain distance of the university, and that modes of transport were available to take students to and from the site.

Key Benefits

- ***Improved marketability:*** A field trip may provide linkages with industry which would be of benefit to students and academia alike, and could potentially increase gradate employment rates.
- ***Networking opportunities for students:*** Engaging with industry, by physically visiting their place of business on a field trip, provides networking opportunities for students and may result in higher graduate employment, or student engagement with industry, as was found to be the case at the University of Michigan by researchers Angela Leuking *et al.*[239]
- ***Networking opportunities for lecturers:*** Lecturers also have the opportunity to collaborate, both internally with other university colleagues, and externally, with colleagues from other universities, industry and government. There may be the opportunity to tap into mentors in the industry who may have practical and/or theoretical experience in the field.

Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.

[239] Leuking, A.D., Ross, D.A. and Walter, J.W. (2003) 'Environmental sustainability education at the University of Michigan Collaboration with industry to provide experiential learning opportunities', American Society for Engineering Education Annual Conference and Exposition, USA.

9. Include One Workshop on Energy Efficiency in the Course (i.e. laboratory-style experiments)

Impact **[Survey: 3.5]**

The literature suggests that this option would have a low impact as, even though workshops may be an effective teaching tool, the limited application of this option (i.e. once) is unlikely to result in transference of knowledge to other areas, nor to result in energy efficiency as a dominant engineering design paradigm for students. This finding is somewhat lower than the survey result of 3.5/5. From comments provided by the survey participants during the phone poll and in the written responses, it appears that this is due to the respondents assuming that a workshop is a more intense learning environment, where students will internalise the knowledge and skills more quickly than in a lecture environment.

The impact of including a workshop on energy efficiency may be inferred somewhat from the Aalborg Model, derived from Aalborg University in Denmark, which has for many years focused on problem based learning (PBL) as opposed to subject based learning.[240] While the scope of such PBL at Aalborg University extends beyond just workshops, many of the learning principles (e.g. 'learning by doing') may be applicable. PBL research suggests that it develops students' process based skills, such as problem solving, applying technical knowledge, collaboration, communication and project management. It also helps to provide, and then reinforce, linkages between various 'elements' of a system, assuming that a real world problem will be more complex than a theoretical problem, which may focus on one issue at a time.[241] In this way, it could be inferred that including workshops and laboratory-style experiments, in which students have to actually apply knowledge and problem solve, would enhance the impact of a course seeking to teach energy efficiency.

American researcher Kathryn Hollar (Rowan University) suggests that hands-on learning experiences in a field of study are a valuable tool as they provide a more authentic experience of the learning objectives which can often incorporate team work, and introduce technical components.[242] This may be relevant where the course is more qualitative than what engineering students are accustomed to, which as noted by researchers Madadnia *et al*[243] can affect the students' perception of what they are learning.

Likelihood **[Survey: 3.1]**

Despite the limited time implication of running one workshop on energy efficiency, the literature suggests that the likelihood of this option being undertaken is still low to moderate, given the need for staff to invest time and resources into developing such a workshop. This is in accord with the survey result of 3.1/5.

[240] Lehmann, M., Christensen, P., Du, X. and Thrane, M.(2008) 'Problem-oriented and project-based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education', *European Journal of Engineering Education*, vol 33, no 3, pp283-295.
[241] Lehmann, M., Christensen, P., Du, X. and Thrane, M.(2008) 'Problem-oriented and project-based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education', *European Journal of Engineering Education*, vol 33, no 3, pp283-295; de Eyto, A., Mc Mahon, M., Hadfield, M. and Hutchings, M. (2008) 'Strategies for developing sustainable design practice for students and SME professionals', *European Journal of Engineering Education*, vol 33, no 3, pp331-342.
[242] Hollar, K.A. and Sukumaran, B. (2002) 'Teaching Students Sustainability: An Interdisciplinary Design Project for Sophomore Engineering Student', Proceedings of the 2002 American Society for Engineering Education Zone I Conference United States Military Academy, West Point, New York, USA.
[243] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education,* December 2001, vol 9, no 2, pp179-192.

Hollar provides an example of a hands-on style learning experience which was developed in 2002 at the Rowan University Department of Civil and Environmental Engineering (New Jersey, USA). Second year engineering students were required to undertake a design project in which they assessed the energy consumption of the University and devised a plan for them to implement energy efficiency measures, potential renewable energy sources and to analyse the cost benefit of doing so. Holler suggests that this approach could be equally applicable to most universities and 'easily adapted' to core courses. This may suggest that a workshop measure such as the one detailed in this example could be easily implemented.

However, as several authors from around the world have noted, engineering courses and programs tend to be already saturated, providing little room for the introduction of new material.[244] Hence, this option may be less likely to occur. This option may also be made less likely where such a workshop requires the purchase of laboratory equipment (particularly for just one workshop), as well as the preparation of additional notes and assessment.

Key Barriers

- ***Prohibitive cost:*** Making any changes to a course within a university will have budget and cost implications. There is a noted lack of such funds available, and where courses are offered through various departments this may result in conflict over how such changes should be funded. Workshops and laboratory experiments may require the purchase of equipment and material, with associated financial constraints that may thus inhibit lecturers' ability to undertake this option.
- ***Lack of knowledge:*** For such a workshop to be run, the lecturer would need considerable knowledge of energy efficiency, however, the lack of knowledge of sustainability was cited throughout the literature as a barrier to its greater inclusion in engineering education and it is possible that the same would be true for energy efficiency.
- ***An overcrowded curriculum:*** Including a workshop on energy efficiency would presumably result in another workshop which was taught in previous years being removed from the course curriculum, unless it were possible to integrate the two. In the former instance, this option may encounter further barriers in the form of lecturers feeling that energy efficiency is less important, or less relevant, than other materials being taught in the course.
- ***Lack of available data/ information:*** There is a lack of well written material, from textbooks, case studies and examples of 'real' sustainable solutions,[245] through materials for teaching sustainability, which educators perceive as a significant barrier to embedding sustainability into their courses.[246] Australian researchers Abbas El-Zein *et al*[247] reiterated earlier findings by UK researchers Slobodan Perdan *et al*[248] which noted that there is a shortage of appropriate case studies (which can be used in such forums as workshops) to

[244] Barger, M. and Hall, M.W. (1998) 'Sustainability in Environmental Engineering Education', *American Society for Engineering Education*, USA, Session 3551; Abdul-Wahab, S.A., Abdulraheem, M.Y. and Hutchinson, M. (2003), 'The need for inclusion of environmental education in undergraduate engineering curricula', *International Journal of Sustainability in Higher Education,* vol 4, Issue 2, pp126-137; El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula, *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182.
[245] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.
[246] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.
[247] El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182.
[248] Perdan, S., Azapagic, A. and Clift, R. (2000) 'Teaching sustainable development to engineering students', *International Journal of Sustainability in Higher Education*, vol 1, no 3, pp267-279.

guide students through a structured thought-process to highlight the necessary steps through which sustainability is achieved. There are also still very few textbooks which truly cover topics such as sustainability engineering, according to New Zealand researcher Carol Boyle,[249] who also noted that there are few true examples of engineering which could be said to have achieved 'real sustainability'.

- ***Students' prior learning habits:*** Engineering students' predisposition towards technical, qualitative learning[250] and an engineering culture which tends to neglect the bigger picture and focus rather on detail[251] may make it difficult to conduct workshops on energy efficiency, which may require qualitative aspects and a whole systems consideration of a problem.

Key Benefits

- ***Improved pedagogy – generic skills:*** Renewing the curriculum with new content provides an opportunity to also review and improve on the method of teaching and learning, and workshops can assist lecturers in meeting current pedagogic best practice.
- ***Improved pedagogy – problem based learning:*** An increasing number of universities world-wide are offering problem based courses, most likely in response to industry expectations, and hence accreditation board requirements, which require engineers to be proficient in a number of disparate capabilities and interdisciplinary skills.[252] The success of a PBL course (often including one or more workshops) can lead students to request a similar format in other courses, providing incentive to other colleagues to teach using such methods and provide encouragement for those already doing so. This type of teaching may also provide benefits to a university in terms of the employability of their students, and in their ability to promote applicable degrees and courses to potential students.[253]

[249] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education,* vol 5, no 2, pp147-155.
[250] El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182.
[251] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[252] Lehmann, M., Christensen, P., Du, X. and Thrane, M.(2008) 'Problem-oriented and project-based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education', *European Journal of Engineering Education*, vol 33, no 3, pp283-295.
[253] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education*, December 2001, vol 9, no 2, pp179-192.

10. Develop a New Course on Energy Efficiency

Impact **[Survey: 4.1]**

The impact of this option appears to be variable, depending on how well the concepts which are taught are supported in other courses, and how well students are able to see the relevance and applicability of the knowledge and skills they gain and can transfer it across to other areas of their work and study. As a standalone, unsupported course, the literature suggests that this option would have a low impact. Supported as a flagship course in an integrated program that references and makes use of the knowledge and skills elsewhere, the impact could be high. The survey result of 4.1/5 indicates a much more positive perspective about this option in the Australian engineering education community. This could be due to the respondents assuming that one new course will make a substantial difference to the development of energy efficiency knowledge, which the literature suggests is not the case – rather the course needs to be supported by coverage in other courses in the program.

In 2000, Canadian researcher Fiona Crofton proposed that separate courses may be ineffective in transferring skills and knowledge, particularly where the subject matter or teaching methodologies are not well aligned with the traditional 'engineering' courses (which may be technical and quantitative in nature), as students may perceive such courses as less important and may not be able to integrate concepts which are qualitative in nature (such as energy efficiency) with the more quantitative aspects of their learning. [254] While these comments were made in reference to students taking courses outside of the engineering faculty (for instance, a social science course on ethics, or sustainability), this suggests that a new course may have a lower impact than, for instance, integrating energy efficiency into an existing, relevant course. With specific reference to the creation of specialised courses, within the engineering faculty, to teach topics (in this case, sustainable development), Crofton commented that, *'If the objective is to develop students' abilities rather than simply add knowledge, the approach will only be relevant if new courses are consistent with the educational goals and overall structure and composition of the curriculum'.*[255]

These suggestions are supported by Australian researchers (University of Sydney) El-Zein *et al*[256] and Netherlands researchers (Delft University) Peet *et al*[257] who found that while sustainability courses might engage students during the course, they do not provide the systematic approach to decision making that would be necessary to apply the information and insights gained from the course. This is not to suggest that such a course would have no impact on its own, for as indicated by Paten *et al,*[258] who introduced a general sustainability course to first year environmental engineering students at Griffith University (Queensland, Australia), student knowledge of sustainability increased, and students participated in *'informed, challenging and engaging'* discussions. Whether this gained knowledge was then able to influence the students' decision making in other subjects and eventually their work was not part of the study.

[254] Crofton, F.S. (2000) 'Education for sustainability: opportunities in undergraduate engineering', *Journal of Cleaner Production*, vol 8, p403.
[255] Crofton, F.S. (2000) 'Education for sustainability: opportunities in undergraduate engineering', *Journal of Cleaner Production*, vol 8, p403.
[256] El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182.
[257] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[258] Paten, C., Palousis, N., Hargroves, K. and Smith, M. (2005) 'Engineering sustainable solutions program – Critical literacies for engineers portfolio', *International Journal of Sustainability in Higher Education,* vol 6, no 3, pp265-277.

A 2008 reflective paper by researchers from three universities which have sought to include sustainability and sustainable development in their university courses (not just engineering) since the 1980s (Chalmers University of Technology, Sweden) and the 1990s (Delft University of Technology, Netherlands and Universitat Politécnica de Catalunya (UPC), Spain) showed that while each pursued different strategies to achieve this goal, they converged on the same few principles that centre on an integrated curriculum which includes specialist courses.[259] This includes compulsory courses for all students in sustainable development, as well as the development of specialist streams in both undergraduate and postgraduate courses in sustainable design, and a 'deep curriculum revision' which would embed education for sustainable development in all courses. The authors note that for sustainability to truly become part of the engineering paradigm, it must be integrated into all aspects of an engineering degree, and not merely included as an 'add-on' within isolated courses. This conclusion is supported by Desha *et al*[260] who identify the need for leading-edge, topic-specific 'flagship' courses to be supported with regard to links to content, vocabulary and skills by more mainstream 'armada' courses within the program, to develop graduates with desired sustainability-related attributes.

Likelihood **[Survey: 2.9]**

The likelihood of a new course being developed is considered low to moderate, given the widely perceived issue of already crowded curriculum where room may not exist for a new or renewed course. This is in accord with the survey result of 2.9/5. In addition, limited staff availability (i.e. with already high workloads), limited staff expertise and budget constraints may make introducing a course on energy efficiency less likely.

A 2007 survey by American researchers Allen *et al*[261] found that in the United States, courses containing sustainability content - albeit often at an introductory or overview level - are taught in a variety of institutions, and across the spectrum of engineering programs including chemical, civil, environmental and mechanical. While their research does not specifically refer to energy efficiency, the findings suggest a willingness to consider teaching sustainability related topics within engineering departments. Crofton summarises research that suggests that while some individuals, colleges and universities have made commendable progress towards educating engineering students about *'the interdependence of systems and forming a sustainable relationship between humans and the environment'* (both underlying tenets of energy efficiency), this was still not a high priority for engineering departments and was not well integrated into programs and courses.[262] These findings are supported by the 2007 NFEE survey of Australian universities, which noted a high level of general interest in energy efficiency and sustainability across the 32 engineering departments, with more than 60 courses identified as containing some energy efficiency content.[263]

From these results, it could be inferred that educators will readily create a dedicated course on energy efficiency. However, the present existence of courses already allocated to the introductory and overview topic of 'sustainable engineering' may make it less likely that

[259] Holmberg, J., Svanström, M., Peet, D.J., Mulder, K., Ferrer-Balas, D. and Segalàs, J. (2008) 'Embedding sustainability in higher education through interaction with lecturers: Case studies from three European technical universities', *European Journal of Engineering Education*, vol 33, no 3, pp271-282.
[260] Desha, C., Hargroves, K., and Smith, M. (2009) 'Addressing the time lag dilemma in curriculum renewal towards engineering education for sustainable development', *International Journal of Sustainability in Higher Education*, vol 10, no 2, pp184-199.
[261] Allen, D.T., Murphy, C.F., Allenby, B.R., and Davidson, C.I. (2009) 'Incorporating Sustainability into Chemical Engineering Education', *Chemical Engineering Progress*, Jan 2009, vol 105, no 1, p47.
[262] Crofton, F.S. (2000) 'Education for sustainability: opportunities in undergraduate engineering', *Journal of Cleaner Production*, vol 8, p399.
[263] Desha, C., Hargroves, K., Smith, M., Stasinopoulos, P., Stephens, R., and Hargroves, S. (2007) *Energy Transformed: Australian University Survey Summary of Questionnaire Results*, The Natural Edge Project (TNEP), Australia, www.naturaledgeproject.net/Documents/Energy_Efficiency_Survey_-_Summary.doc, accessed 27 July 2008.

additional courses dedicated to energy efficiency could be included, in what is widely referred to as a 'crowded curricula'.[264] In addition, the development of specialised courses on energy efficiency requires time, finances, appropriate staff as well as space within the curriculum.[265] University of Technology, Sydney (UTS) researchers Madadnia *et al* describe how their institution addressed these issues by reviewing its engineering degrees to include sustainable development and life-cycle analysis as key elements in new courses for undergraduate engineering students. This was in response to pressures from the Institute of Engineers, Australia to the engineering profession to become more sustainable, and from industry expectations of graduates. Sustainability is said to have become the *'foundation idea'* of the new curriculum, *'a basic ethic, and the fundamental rationale for education*'.[266] It is recognised that this change required, as it would elsewhere, the commitment and co-operation of all levels at the University, and particularly the academic staff involved with the new courses. The authors noted that it put *'enormous pressure and responsibility*' on those educators involved, who were expected to provide both technical and non-technical learning to students and who needed to themselves develop certain skills and value systems to be more inline with the revised curriculum. [267]

There is caution among the engineering educator community that just taking this 'new course' approach to incorporating new requirements into engineering degrees may result in a blow-out of courses that students are required to take, and may require staff expertise and resourcing which may not be available in the department.[268]

Key Barriers

- ***An overcrowded curriculum:*** Engineering degrees are widely reported (in the USA, New Zealand and the EU) to be crowded with courses, with significant competition existing over what should be taught.[269] Although engineering departments might recognise the need to teach energy efficiency, pressure from faculty who feel that either it is already being taught adequately, or that it doesn't need to be taught at all, may be a barrier to displacing existing courses with energy efficiency material as there are limited credit points within a program to allocate to incorporating new topic areas.[270] The concern is that any additional information must displace existing 'fundamentals', as courses and programs are generally already

[264] Crofton, F.S. (2000) 'Education for sustainability: opportunities in undergraduate engineering', *Journal of Cleaner Production*, vol 8, p397; Abdul -Wahab, S.A., Abdulraheem, M.Y. and Hutchinson, M. (2003) 'The need for inclusion of environmental education in undergraduate engineering curricula', *International Journal of Sustainability in Higher Education,* vol 4, no 2, pp126-137; El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182.
[265] Crofton, F.S. (2000) 'Education for sustainability: opportunities in undergraduate engineering', *Journal of Cleaner Production*, vol 8, p397.
[266] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education*, December 2001, vol 9, no 2, p181.
[267] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education*, December 2001, vol 9, no 2, p181.
[268] Desha, C., Hargroves, K., Smith, M., Stasinopoulos, P., Stephens, R., and Hargroves, S. (2007) *Energy Transformed: Australian University Survey Summary of Questionnaire Results*, The Natural Edge Project (TNEP), Australia, www.naturaledgeproject.net/Documents/Energy_Efficiency_Survey_-_Summary.doc, accessed 27 July 2008.
[269] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education,* vol 5, no 2, pp147-155; Holmberg, J., Svanström, M., Peet, D.J., Mulder, K., Ferrer-Balas, D. and Segalàs, J. (2008) 'Embedding sustainability in higher education through interaction with lecturers: Case studies from three European technical universities', *European Journal of Engineering Education*, vol 33, no 3, pp271-282; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[270] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education,* vol 5, no 2, pp147-155.

saturated. Where lecturers feel that the new material is less relevant, or that existing materials are indispensable, there will be significant resistance to these changes.

- ***Prohibitive cost:*** Making any changes to a course within a university will have budget and cost implications. There is a noted lack of such funds available, and where courses are offered through various departments this may result in conflict over how such changes should be funded. Many of the options potentially involve lecturers investing a significant amount of time in developing new content because there is either little existing material to assist them, or quality material is difficult to locate.[271] Also, developing a new course in energy efficiency can potentially involve either additional laboratory equipment, costs to access particular databases or software, or travel and accommodation costs for field trips which can be a significant barrier to attempting curriculum change.
- ***Lack of time for preparation:*** Research from both the USA and the Netherlands suggests that there is a limited time available to engineering educators to make any changes to courses, degrees, course materials, and to identify academically rigorous information,[272] due to existing pressures to meet research commitments, in addition to a teaching workload and service requirements.[273] Content development may therefore be given a lower priority, or avoided altogether.
- ***Lack of available data/ information:*** The lack of supporting well written material (i.e. textbooks, case studies, examples of 'real' sustainable solutions),[274,275] can be a significant barrier to creating an energy efficiency focused course. Australian researchers Abbas El-Zein *et al*[276] reiterated earlier findings by UK researchers Slobodan Perdan *et al*[277] which noted that there is a shortage of appropriate case studies which guide students through a structured thought-process to highlight the necessary steps through which sustainability is achieved. There are also still very few textbooks which truly cover topics such as sustainability engineering, according to New Zealand researcher Carol Boyle,[278] who also noted that there are few true examples of engineering which could be said to have achieved 'real sustainability'.
- ***Lack of knowledge:*** DJ Peet and his fellow researchers from the Netherlands echoed those comments by Michael Robison and his colleagues from the USA, who have noted that lecturers often do not have adequate knowledge themselves of sustainability (or energy

[271] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[272] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[273] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[274] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.
[275] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.
[276] El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182.
[277] Perdan, S., Azapagic, A. and Clift, R. (2000) 'Teaching sustainable development to engineering students', *International Journal of Sustainability in Higher Education*, vol 1, no 3, pp267-279.
[278] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education,* vol 5, no 2, pp147-155.

efficiency) to teach this within their courses.[279] Lecturers' perception of multidisciplinary topics such as energy efficiency, which combine social, economic and environmental components[280] is often that it is too vague to be explicitly taught in their course, particularly where such a course is of a specialised, technical nature. Conversely, but for similar reasons, the complex nature of energy efficiency may lead some lecturers to feel that it is implicitly being taught already in the course, making an overhaul unnecessary, even where these concepts and links are not clearly expressed to students. [281]

- ***Administrative coordination:*** Even within a department, changing the curriculum can result in arguments between faculty over credit point allocation, and can inflame insecurities regarding power and position. The time-consuming nature of such logistics can be a barrier to beginning a new process, [282] and a lack of consensus on strategic direction within the school creates uncertainty over the value of undertaking curriculum renewal.

Key Benefits

- ***Improved marketability:*** There is evidence of well designed courses being able to be taught at multiple universities, as was the case for Michigan Tech and Yale University in the United States, where an interdisciplinary course entitled 'Green Engineering and Sustainability' was taught at both Universities by separate instructors. In developing the course, opportunity for additional promotion both within and outside of the university may be created. Considering new content for the curriculum can also help to demonstrate quality assurance and continual improvement to accreditation bodies, students and potential graduate employers. [283]
- ***Cross-functionality of content:*** The new course may also be offered to both junior and senior students, and across all engineering disciplines.[284] The benefit derived from this for lecturers would include high levels of enrolment in their course which may lead to increased funding as well as collaboration with colleagues from other departments, and other universities.
- ***Research opportunities:*** New courses may provide research / paper opportunities – as with the case of Paten *et al*[285] in Australia, which could be used to spearhead a campaign to shifting the focus of university and various degrees towards energy efficiency. Given widespread concern over and interest in this topic, a new course in energy efficiency may provide promotional material for the university and attract students to their degrees.

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[279] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, USA; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.

[280] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education*, December 2001, vol 9, no 2, pp179-192.

[281] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.

[282] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288.

[283] Holmberg, J., Svanström, M., Peet, D.J., Mulder, K., Ferrer-Balas, D. and Segalàs, J. (2008) 'Embedding sustainability in higher education through interaction with lecturers: Case studies from three European technical universities', *European Journal of Engineering Education*, vol 33, no 3, pp271-282.

[284] Zhang, Q., Zimmerman, J., Mihelcic, J. amd Vanasupa, L. (2008) 'Civil and environmental engineering education (CEEE) transformational change: Tools and strategies for sustainability integration and assessment in engineering education', American Society for Engineering Education.

[285] Paten, C., Palousis, N., Hargroves, K. and Smith, M. (2005) 'Engineering sustainable solutions program – Critical literacies for engineers portfolio', *International Journal of Sustainability in Higher Education,* vol 6, no 3, pp265-277.

- *Improved enrolment:* Higher enrolment may be possible if the new course is offered through various departments. The multidisciplinary nature of energy efficiency may mean that a course which is overhauled may become relevant to students from other disciplines also.

11. Include a Topic-Specific Lecture Set (i.e. a Sub-Topic) within the Course, by the Lecturer

Impact **[Survey: 3.2]**

There was a scarcity of literature which commented directly on this option. However, some inferences can be made from literature surrounding engineering education in general. The impact of this option is likely to be moderate, tempered by the issue of transferability discussed for earlier options. This impact could be enhanced if this option was undertaken as part of a wider collection of options. The literature finding is in accord with the survey result of 3.2/5.

The impact of this option is likely to depend on several factors. Firstly, whether students are able to transfer knowledge from this lecture set to other aspects of their course, degree and eventual practice. El-Zein *et al*[286] and Peet *et al*[287] note that teaching complex concepts such as energy efficiency or sustainability in isolated courses tend to lack a systematic approach which is needed for these concepts to become a dominant paradigm, and to ensure that the notions learned in such courses are transferred and applied in other courses and in practice. Also, whether this lecture set is assessed in some form, as well as the nature of that assessment. There is evidence to suggest that assessment helps to align students with learning objectives.[288] By implication, aspects of a course which are *not* included in the assessment items may be given a lower priority by students, if not potentially ignored altogether. Warburton[289] cautions against some types of assessment however, and notes that assessment should be considered in terms of its ability to promote deeper learning. The type of assessment is hence also likely to affect the impact of this option.

Likelihood **[Survey: 2.8]**

There are several issues documented in the literature which may affect the likelihood of this option, but overall the likelihood of topic-specific lecture sets being included within the course by the lecturer is considered low to moderate. This is in accord with the survey result of 2.8/5.

There are many references in the literature to engineering courses and degrees being perceived as relatively saturated, allowing little room for additional material.[290] Consequently, lecturers may find it difficult to create time and space within a course for such a lecture set. This is compounded by a perception of many engineering lecturers that broad topics such as sustainability or energy efficiency do not directly apply to their field of interest, and as such may be reluctant to include this within their courses.[291] Furthermore, many lecturers have a limited knowledge of such areas, which constrains their ability to develop course materials and teach

[286] El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182.
[287] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[288] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education,* December 2001, vol 9, no 2, pp179-192.
[289] Warburton, K. (2003) 'Deep learning and education for sustainability', *International Journal for Sustainability in Higher Education,* vol 4, Issue 1, p44.
[290] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference and Exposition, American Society for Engineering Education, USA; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[291] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference and Exposition, American Society for Engineering Education, USA; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.

energy efficiency.[292] A lack of appropriate material, such as textbooks and case studies, leaves lecturers with the responsibility of providing such information themselves,[293] and given the time and financial constraints of many lecturers, this may make this option less likely.

It is noted that there is work in progress to develop these types of materials, and as in the case of Yale University, and Michigan Technological University in the United States, drop-in modules which can be used by any lecturer to teach environmental engineering.[294] The authors of this research project have also developed more than 30 hours of lecture material on energy efficiency opportunities.[295] It is conceivable that the development of such modules make this option more likely. Also, the possibility that lecture notes and course materials could be used elsewhere may provide incentive to lecturers to develop these themselves.

[292] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[293] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.
[294] Zhang, Q., Zimmerman, J., Mihelcic, J. and Vanasupa, L. (2008) 'Civil and environmental engineering education (CEEE) transformational change: Tools and strategies for sustainability integration and assessment in engineering education', *American Society for Engineering Education,* AC 2008-1670.
[295] Smith, M., Hargroves, K., Stasinopoulos, P., Stephens, R., Desha, C. and Hargroves, S. (2007) Energy Transformed: Sustainable Energy Solutions for Climate Change Mitigation, The Natural Edge Project (TNEP), Australia. See www.naturaledgeproject.net, 'curriculum and course notes'.

12. Offer Industry Placements in Energy Efficiency (e.g. Work Integrated Learning)

Impact **[Survey: 2.9]**

The literature suggests that this option has a low to moderate potential impact on the extent of energy efficiency in the engineering curriculum, due to the potentially small number of students who would be exposed to an energy efficiency-related experience in the industry workplace. This is in accordance with the survey result of 2.9/5. The impact of such an initiative could be improved through students sharing their experiences via a presentation to the student cohort, although this would still be an overview which is limited to inspiring other students rather than providing capacity building opportunities for them.

The Royal Melbourne Institute of Technology (Melbourne) initiated a project in 2004 for final year undergraduate mechanical engineering students in which they were placed in teams into local firms to work with them to achieve a reduction in their greenhouse gas emissions through a combination of energy efficiency, waste reduction and/or the use of renewable energy.[296] The program, entitled 'The Greenhouse Challenge Plus Support Program' was extended in 2007 to include students from related engineering disciplines, the Bachelor of Social Science (Environment), Bachelor of Industrial Design (Architecture and Design) and the Bachelor of Business (Management). This collaborative approach, which included industry partners, the Australian Greenhouse Office and North Link, was aimed at enabling students to appreciate and tackle the variety of aspects and disciples which are involved in reducing greenhouse gas emissions. While the complex logistical nature of the project impeded the results to an extent, it was reported that this project, and it's multidisciplinary approach, provided students with an opportunity to experience the process of achieving reductions in greenhouse gases, at least in part through energy efficiency, in a real world setting. American researcher Angela Leuking and her colleagues[297] found similar results from their study at the University of Michigan, in that industry placements allow students to experience and apply learning concepts (such as sustainability, or energy efficiency) in a real world context.

Gűll Okudan and colleagues from Pennsylvania State University noted in a 2006 paper that industry sponsored design projects are overwhelmingly supported by evidence which finds that they are successful for four principle reasons: [298] 1) students are confronted by a complex array of issues, as is the nature of 'real world' problems (as opposed to textbook problems) and are as a result forced to extend their knowledge and skills to adapt; 2) students are generally more motivated in an industry sponsored learning environment, where they perceive that the industry partner values the outcomes; 3) in most cases, the scope of such industry projects requires a collaboration between students, or between the student and industry, which promotes teamwork and project management; and 4) students receive exposure to industry cultures and practices. Such factors may provide evidence of the effectiveness, and hence impact, of using industry sponsored projects and by extrapolation, industry placements, to teach energy efficiency. These four points are likely to be equally relevant in the context of a placement.

[296] Bunting, A. *et al* (2007) *Greenhouse Gas Reduction in Industry: A Multidisciplinary Approach to Project-Based Learning*, RMIT
[297] Leuking, A.D., Ross, D.A. and Walter, J.W. (2003) 'Environmental sustainability education at the University of Michigan Collaboration with industry to provide experiential learning opportunities', American Society for Engineering Education Annual Conference and Exposition, USA.
[298] Okudan, Gül E., Mohammed, Susan and Ogot, Madara (2006) 'An investigation on industry-sponsored design projects' effectiveness at the first-year level: potential issues and preliminary results', *European Journal of Engineering Education*, vol 31, no 6, pp693-704.

Likelihood **[Survey: 4.0]**

The likelihood of staff engaging in industry placements related to energy efficiency is considered from the literature to be high, given existing trends and the lack of requirements on staff. This is in accord with the survey result of 4.0/5.

The likelihood of this option could be inferred from the increasing prevalence of such placement programs in a plethora of contexts, in engineering programs, and the support they receive from engineering departments.[299] Some drawbacks on the behalf of faculty have been noted with respect to industry-sponsored projects, including (please note that these may or may not apply to industry placements): [300]

1. Industry sponsored projects (and presumably also industry placements) are unique, one-off projects which hence cannot be improved upon for the following year's students;
2. As a consequence of the first point, the time and effort required by faculty to administer these projects is maintained each year (this is opposed to standard courses, in which the preparation time for the coursework is assumed to be largely focused on the first year);
3. From a student's perspective, their motivation may decrease where it is not possible to find a project which strongly aligns with their own areas of interest or study;
4. Some projects are felt to be gender specific, creating a bias which can de-motivate students; and
5. Students may also be de-motivated and not learn where they feel that they lack the necessary skills and knowledge to perform within in an industry sponsored project (or placement).

[299] Okudan, G.E., Mohammed, S. and Ogot, M. (2006) 'An investigation on industry-sponsored design projects' effectiveness at the first-year level: potential issues and preliminary results', *European Journal of Engineering Education*, vol 31, no 6, pp693-704.
[300] Okudan, G.E., Mohammed, S. and Ogot, M. (2006) 'An investigation on industry-sponsored design projects' effectiveness at the first-year level: potential issues and preliminary results', *European Journal of Engineering Education*, vol 31, no 6, pp693-704.

13. Show a DVD of a Related Documentary

Impact **[Survey: 2.8]**

The literature suggests that the potential impact of this option is low to moderate, depending on the quality of the recorded documentary and its relevance to the course and student interest. This is in accordance with the survey result of 2.8/5.

Sydney researchers Kester Lee and Manjula Sharma[301] (University of Sydney) suggested that watching a DVD or video in class produces a passive learning environment in which students may be inundated with information, and not be able to then apply this information elsewhere. They found methods of enhancing the use of DVDs as learning tools, which involved showing only short sections and then engaging students in group work and discussions related to the content of the DVD. This produced an active learning environment, which provoked interest and curiosity among students. These authors noted, however, that most DVDs are not structured with this 'active learning' process in mind, and may be unsuitable.

This use of multimedia to give students greater control over their learning was also explored in the USA by Katherine Jennings and her colleagues Erik Epp and Gabriela Weaver (Perdue University). Their 2007 paper found that interactive DVDs, which combine significant user interaction and control with documentary style videos, background information, problems to assess and reinforce learning and links to further information, enhanced learning, increased their ability to apply that learning to real life situations, and stimulated students' interest in the field.[302] Similarly, recent research conducted in the UK by Chris Evans into the use of podcasting as a teaching tool revealed that this technology has advantages over more traditional teaching techniques by facilitating 'mobile learning' (learning conducted while in transit or in unexpected spare time) and by providing students with what they perceive as a more effective revision tool.[303]

North American researcher Katherine Cennamo[304] (Purdue University, Indiana) found from a review of several studies that students may have preconceptions about television (and presumably DVDs) that these are intended for 'relaxation' and passive learning. Consequently, it was found that students may expend less energy in trying to process and learn from this medium than others. As mental effort - being the amount of energy expended in trying to consciously and purposefully understand the information being provided - is noted to influence learning achievement, this would suggest that a DVD could have a lower impact. Roger Schank, a US professor based at the Northwestern University in Illinois,[305] noted that passive learning is not the learning process to which students are used to, having engaged in active learning throughout their infancy. Although school level education may have instilled a preference for passive mediums, more active approaches are advocated in which students learn by 'doing'.

A documentary may be produced to a high quality, providing footage of real life examples of energy efficiency, using global examples, visual case studies and potentially graphics to explain more complex concepts. This may lead to a higher impact than a classroom lecture.

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[301] Lee, K.J. and Sharma, M.D. (2008) 'Incorporating active learning with videos: A case study from physics', *Teaching Science – The Journal of the Australasian Science Teachers Association,* vol 54, Issue 4, pp45-47.
[302] Jennings, K.T., Epp, E.M. and Weaver, G.C. (2007) 'Use of a multimedia DVD for Physical Chemistry, Analysis of its effectiveness for teaching content and applications to current research and its impact on student views of physical chemistry', *Chemistry Education Research and Practice,* vol 8, Issue 3, pp308-326.
[303] Evans, C. (2008) 'The effectiveness of m-learning in the form of podcast revision lectures in higher education', *Computers and Education,* vol 50, Issue 2, pp491-498.
[304] Cennamo, K.S. (1993) 'Factors influencing learners' preconceptions and invested mental effort', *Educational Technology Research and Development,* vol 41, no 3, Springer Boston.
[305] Shank, R.C. (1994) 'Active Learning through Multimedia', *IEEE Multimedia Magazine,* Spring, pp69-78.

Likelihood **[Survey: 3.6]**

The literature suggests that this option may be moderately likely, which is in accordance with the survey result of 3.6/5. Although engineering degrees are typically perceived to be quite 'full', a documentary DVD may be a good option for lecturers who feel that there is not enough time in the course for a module, nor sufficient time to prepare a lecture.

It was noted in several papers that a significant barrier to teaching engineering students sustainability principles can be a lack of knowledge of the field by the educators themselves.[306] "*It has been noted by several authors that engineering degrees typically are quite 'full'."*[307] As such, showing a DVD of a related documentary may provide a means for such engineering educators to give students the knowledge without having to themselves become an expert and may make this option more likely.

It may also be assumed that showing a DVD within an existing course would be a low cost method of teaching energy efficiency, which may entail minimal preparation by the lecturer.

[306] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.
[307] Abdul-Wahab, S.A., Abdulraheem, M.Y. and Hutchinson, M. (2003), 'The need for inclusion of environmental education in undergraduate engineering curricula', *International Journal of Sustainability in Higher Education,* vol 4, Issue 2, pp126-137; El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182.

14. Add Energy Efficiency Readings to the Required Reading List

Impact **[Survey: 2.2]**

The literature (through extrapolation) suggests that this option would have a low to moderate impact on the extent of energy efficiency content in the curriculum, depending on whether the readings formed part of subsequent assessment in the course, or were connected into the rest of the course. This is in general accord with the survey result of 2.2/5 – this low valuing of the option by the Australian engineering education community is perhaps also an indication of a low priority given to readings in engineering curriculum.

Minimal literature was found which discussed this option. Some speculation could be made, however, from an extrapolation of the literature found on slightly varied topics. It is assumed that be setting the reading list as 'required', the course explicitly refers to the required readings, and integrates the readings into the course. The impact would be improved further if assessment is aligned with the readings (as noted in *'Include assessment that aligns with the energy efficiency theme within the course'*). Many authors comment that engineering degrees are somewhat saturated with courses and information,[308] which may lead to a situation where not all students actually read the required readings, particularly where they are not (as has been assumed) integrated into other aspects of the course and the assessment items. On this note, there is evidence to suggest that assessment helps to align students with learning objects,[309] hence by implication it would seem that aspects of a course which are *not* included in the assessment items will be given a lower priority by students, if not potentially ignored altogether. As a final note, there is a significant wealth of literature to suggest that students learn best, and are best able to transfer learned knowledge, where the learning is interactive and requires reflection and participation, such as for example with problem based or project based learning.[310] It is assumed that a 'required reading' would be accompanied by assistance (e.g. through a tutorial or workshop) to help students process the information provided in the article.

Likelihood **[Survey: 3.1]**

Based on these inferences, it is assumed that this option is moderately likely, assuming that the reading options are made readily available to lecturers. This is in accord with the survey result of 3.1/5. It appears to be a potential way to address pressures to teach energy efficiency without significantly affecting lecturer time, as the students can complete the readings away from the classroom.

The addition of a required reading to the existing list does not require the lecturer themselves to have an in-depth knowledge of the topic, but does require integration of the reading into the course. The lecturers also need to be aware of where to find an appropriate reading, assuming that such a reading is available. It was noted by several authors that appropriate case studies can be difficult to find, and particularly ones which are relevant to engineering students. As

[308] Barger, M. and Hall, M.W. (1998) 'Sustainability in Environmental Engineering Education', *American Society for Engineering Education*, USA, Session 3551; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288; El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182; Theis, R. Wakins, P. and Beck, M.A. (2008) 'Pathways to learning: Orchestrating the role of sustainability in engineering education', *American Society for Engineering Education*, USA, AC 2008-968.

[309] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education,* December 2001, vol 9, no 2, pp179-192.

[310] Lehmann, M., Christensen, P., Du, X. and Thrane, M. (2008) 'Problem-oriented and project-based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education', *European Journal of Engineering Education*, vol 33, no 3, pp283-295; de Eyto, A., Mc Mahon, M., Hadfield, M. and Hutchings, M. (2008) 'Strategies for developing sustainable design practice for students and SME professionals', *European Journal of Engineering Education*, vol 33, no 3, pp331-342.

required readings alone are unlikely to consume lecture or tutorial time, this option would not displace any existing aspects of the course, unless a reading is removed in order to include one on energy efficiency.

15. Show a DVD of a Keynote Lecture on Energy Efficiency

Impact **[Survey: 2.6]**

Based on the literature it is concluded that this option would have a low impact given that it is 1-2 hours within one course in a program. However, a targeted keynote on DVD may have an important role in inspiring the students with career opportunities in energy efficiency, which could have a positive impact on other options, increasing student appreciation of the concepts and knowledge being taught. This is in accordance with the survey result of 2.6/5.

The literature reviewed for the 'Show a DVD of a related documentary' is relevant, exploring whether DVDs are an effective teaching tool which provides deeper learning to students. This option can provide students with access to a keynote expert in the field, which may consequently be more influential than information relayed to them through their lecturer. However, DVDs of a keynote lecture - whether documentary or keynote in style – are a passive mode of learning which may be less engaging for students.

A recording of a lecture relies on the speaker, props and perhaps images on a screen to engage with the students, as opposed to a documentary which may include scenery, real life footage, computer animations to explain complex concepts etc. Students are unable to ask questions of the keynote lecturer themselves and the impact of this option may be limited by the ability of the course lecturer to respond to any such questions – this may be addressed by including a recorded question and answer session. However, a keynote lecture targeting a topic of high relevance to the course may have a higher impact than perhaps a more general documentary. Indeed, it may be a recording of an actual visit by an expert in a previous year.

Likelihood **[Survey: 3.0]**

From the literature it is concluded that the likelihood of lecturers using DVDs of recorded lectures (assuming they are readily available) is moderately likely. This is in accord with the survey result of 3.0/5.

It was noted in several papers that a significant barrier to teaching engineering students sustainability principles can be a lack of knowledge of the field by the educators themselves.[311] Where guest lecturers are not available to come to speak to a class, or where the cost of engaging one to do so would be prohibitive, providing a DVD of such a lecture can provide content to students where lecturers feel that they themselves are not sufficiently well versed on the topic to do so themselves. However, the likelihood may be less if lecturers feel that there is not enough time in the course to show an additional DVD, particularly given the perception noted by several authors that engineering degrees typically are quite 'full'.[312]

This option makes the assumption that such keynote lectures are available for lecturers to use, however, in reality this may be a barrier to this option that would make it less likely. Also, a lecturer must be aware that the recording of the keynote lecture exists, and its relevance to the course, which may be an issue if the lecturer does not have a grasp of the subject matter.

[311] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.
[312] Abdul-Wahab, S.A., Abdulraheem, M.Y. and Hutchinson, M. (2003), 'The need for inclusion of environmental education in undergraduate engineering curricula', *International Journal of Sustainability in Higher Education,* vol 4, Issue 2, pp126-137; El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182.

16. Include Elective Modules on Energy Efficiency Within the Course

Impact **[Survey: 3.3]**

The literature suggests that, given the limited scope of this option it would have a low to moderate impact on the extent of energy efficiency content in the curriculum. While it is recognised that student-led learning can lead to deeper learning, it may also be true that students may avoid topics such as energy efficiency through the program if they do not anticipate the relevance of the topic to their career, or see emphasis provided in assessment items. This finding is slightly less optimistic than the survey result of 3.3/5. This could be due to elective module-style learning perhaps being more popular in Australia where problem-based learning being more readily picked up.

It is assumed that a lecturer may provide between two and three modules from which students can select one, as more than this would entail too much preparation work for the lecturer. As such, it is assumed that between 30-50 percent of the students in the class will select the module for energy efficiency (this assumes the absence of other influencing factors which would make any of the modules significantly more attractive to students that the other). Given there is a choice of modules offered within the course, there may also be less lecturer focus on each of the models and potentially less related assessment, diminishing the potential of the content to develop the students' energy efficiency capabilities. Several authors have noted that students can view what they perceive as more qualitative, social science topics (such as sustainability or energy efficiency) as 'easy credit points' or less important than other, more technologically and quantitatively based topics.[313] Depending on whether the modules teach energy efficiency in a qualitative way, this may reduce the impact of this option.

In contrast, New Zealand Research Carol Boyle suggests that with the change required for full integration of sustainability subject matter into the curriculum, it would be more feasible to work towards educating only a portion of the 'sufficiently bright' students (for example through elective modules, in addition to specialised courses), or to offer a postgraduate course in which the necessary knowledge and skills could be learned.[314] While such a strategy would only reach a small portion of the engineering student population, Boyle suggests that this is at least a first step which would capacity build the profession, which could then be followed with full integration of sustainability into the curriculum. University of Queensland researcher Kevin Warburton[315] also suggests that the deep learning required to develop sustainability knowledge and skills is facilitated by mastery learning, and discovery learning, in which the student has a greater portion of control over their own learning. This option might assume that, as the students are studying their choice of elective module, a significant portion of their learning would be undertaken on their own. This may provide greater ownership over their learning and result in them pursing knowledge themselves – either with lecturer guidance and a certain level of control (mastery learning) or quite freely with the lecturer facilitating their discoveries (discovery learning). Deep learning is recognised throughout literature to result in a greater appreciation of complex notions, and is likely to have a higher impact than traditional learning.

[313] Madadnia, J., Koosha, H. and McKenzie, J. (2001) 'Development of a Learner-Focussed, Sustainable Engineering Subject', *Australasian Journal of Engineering Education,* December 2001, vol 9, no 2, pp179-192; El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182.
[314] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.
[315] Warburton, K. (2003) 'Deep learning and education for sustainability', *International Journal for Sustainability in Higher Education,* vol 4, Issue 1, p44.

Likelihood **[Survey: 2.4]**

As this option requires only moderate effort from lecturers related to scheduling and assessment, and as the content would not displace current materials, the literature suggests that lecturers would be likely to include energy efficiency as elective modules in existing courses, should this be an option. However, the survey result yielded a low likelihood of 2.4/5. From the comments received by the respondents via the phone poll and in written responses, it appears that this may be due to the practical constraints in making elective modules available to students, primarily in preparation and marking time.

Several authors have noted the time and financial constraints on engineering educators and how this limits the amount of materials they are able to develop for students.[316] A number of authors have also discussed a lack of knowledge among engineering educators of sustainability and related concepts (this is assumed to also apply to energy efficiency) as a key barrier to their being taught to students.[317] Such lecturers may feel more comfortable with this particular option, which minimises their role in actually teaching such topics while arguably still being able to satisfy department, student or other expectations of providing this material.

American researcher Quiong Zhang and his colleagues from Michigan Technical University, Yale and California Polytechnic University published a paper in 2008, discussing a collaboration to produce a textbook for an Introduction to Environmental Engineering.[318] From this textbook, the universities aim to develop 'drop-in modules', based on the chapters of the textbook, which can be added to any course to teach students relevant aspects of Environmental Engineering, such as the fundamentals of sustainability, environmental risk, green engineering, and wastewater treatment. A model such as this, in which the modules are developed alongside a textbook, may make it more likely that such modules are developed and offered to students. Further, the authors of this research project have published 30 lecturers on energy efficiency opportunities in Australia,[319] which are freely available online, in the form of downloadable pdf and word document files, with the intention of also publishing the lectures as a hard copy textbook. As the documents have just been published there is limited data on the nature and size of downloads from the website, but anecdotal evidence of Australian engineering educators using the materials in their classrooms is encouraging.

Boyle[320] points out that many engineering degrees are already overloaded with information and material. The addition of any extra material would consequently, in the opinion of many academics, result in a loss of fundamentals. This may provide a disincentive to educators who are reluctant to introduce more material, however it should be noted that this point would make this option more likely than those which require a complete overhaul, the introduction of a new course or other such actions.

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[316] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education,* vol 5, no 2, pp147-155; El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182.

[317] Robinson, M. and Sutterer, K. (2003) 'Integrating Sustainability into Civil Engineering Curricula', Proceedings of the 2003 American Society for Engineering Education Annual Conference and Exposition, American Society for Engineering Education, USA; Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155; El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182.

[318] Zhang, Q., Zimmerman, J., Mihelcic, J. and Vanasupa, L. (2008) 'Civil and environmental engineering education (CEEE) transformational change: Tools and strategies for sustainability integration and assessment in engineering education', *American Society for Engineering Education, AC 2008-1670.*

[319] Smith, M., Hargroves, K., Stasinopoulos, P., Stephens, R., Desha, C. and Hargroves, S. (2007) *Energy Transformed: Sustainable Energy Solutions for Climate Change Mitigation*, The Natural Edge Project (TNEP), Australia.

[320] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.

17. Offer a 'Major' Stream in the Engineering Degree on Energy Efficiency

Impact **[Survey: 4.2]**

The literature suggests that this option could have a significant impact. This is in accord with the survey result of 4.2/5. As a 'major stream' concentrates the teaching of energy efficiency in the later years of a degree (to perhaps five courses on energy efficiency in the last year to two years of study), students may have developed sufficiently to grasp the complex notions of energy efficiency and be more able to apply the principles. By taking several courses, these concepts are also likely to be reinforced and better transferred to other areas of learning and practice. This option also provides students with an understanding of mainstream engineering practice, potentially allowing for a wider application of the specialist knowledge gained through the major stream.

Canadian researcher Fiona Crofton in her 2000 paper remarked on the international consensus over the importance of undergraduate engineers having both specialised knowledge (for instance, in energy efficiency) and general knowledge of engineering concepts. This can provide students with a broad, interdisciplinary knowledge and skill base which can allow them to apply specialist principles, such as energy efficiency, to mainstream engineering settings.[321] This highlights the potential advantages of a major stream over a specialised degree program focused on energy efficiency.

Crofton also raises the issue of transferability, however, noting that some students can have trouble applying concepts learned in specialised courses (such as on sustainability or energy efficiency) to their more technical subjects and engineering design. Carol Boyle[322] furthered this argument in 2004, when she noted that traditional engineering education teaches students an 'end-of-pipe' approach to engineering, in which an apparent problem is resolved, as opposed to necessarily the underlying problem – a distinction of key importance in sustainability engineering, and also energy efficiency engineering. Students which undertake a major stream may hence learn this 'end-of-pipe' methodology in their traditional courses, and then be required to shift thinking and adopt a 'beginning-of-pipe' approach in the sustainability related majors. Boyle suggested that to have a true uptake of sustainability concepts, and a 'beginning-of-pipe' design paradigm, these concepts need to be integrated into all courses of an engineering degree – not solely as a major specialisation.

Boyle also commented on the maturity needed to comprehend and apply complex interdisciplinary concepts. Energy efficiency and sustainability require an interdisciplinary view, and an understanding of how to achieve a synergistic solution to problems which have diverse aspects and stakeholders. Boyle suggested that undergraduates which proceed directly from high school to university may have insufficient maturity. With this in mind, a major stream in which concepts of energy efficiency are taught in the latter years of an engineering degree may capture students at a stage of their education at which they are able to assimilate and comprehend these more complex notions.

[321] Crofton, F.S. (2000) 'Education for sustainability: opportunities in undergraduate engineering', *Journal of Cleaner Production*, vol 8, p397.
[322] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.

Likelihood **[Survey: 2.2]**

Experience from universities both in Australia and abroad suggest that this option is a sizeable undertaking, which may rely on wider restructuring of engineering departments to make it more feasible, hence it is considered unlikely to occur for most universities. This is in accord with the survey result of 2.2/5. However, this option does sidestep many of the barriers identified in the literature which can make implementing changes more difficult and may provide niche opportunities for engineering departments looking to provide a highly marketable point of differentiation.

Paul Bryce, Stephen Johnston and Keiko Yasukawa reviewed the University of Technology in Sydney's overhaul of their engineering program in 2004, and noted that by combining their engineering degrees, they were more easily able to introduce new major streams or degrees. Indeed, they comment that UTS saw this as a principle reason for combining the previous engineering degrees into one, as it would simplify the processes of adding new majors as needed.[323] Given that the financial impetus which led to this restructure is one experienced by many universities, it could be the case that a similar restructuring will be seen in many engineering departments and thus this option would be more likely as a result.

Several authors from both North America and Europe have commented on the time and financial constraints which restrict overhauling courses and degrees.[324] As this option requires only a set of five courses to be developed, it may be more likely than the introduction of a new degree. However, it may for the same reasons, be less likely than many of the options on this list which relate to only a single course, or component of a course. This option may additionally sidestep some barriers which were experienced by Dirk-Jan Peet and his colleagues in the Netherlands in their efforts to integrate sustainability into engineering degrees at Delft University. These include lecturers being unwilling to change their own course (for time or financial reasons, or out of a belief it isn't relevant, believing it is in fact already being taught adequately, lack of knowledge of the field, resistance to 'top down' demands),[325] as the new courses run alongside existing ones, and would presumably be created and taught by lecturers with a strong interest and belief in the field.

[323] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.
[324] Crofton, F.S. (2000) 'Education for sustainability: opportunities in undergraduate engineering', *Journal of Cleaner Production*, vol 8, p397; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education*, vol 5, no 3, pp278-288.
[325] Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.

18. Include Several Workshops on Energy Efficiency in the Course (i.e. including laboratory-style experiments)

Impact **[Survey: 3.6]**

The literature documents how workshops can increase the effectiveness of an energy efficiency course by encouraging students to apply knowledge to a contextual situation, and to develop relevant skills such as problem solving, collaboration, communication and project management. To the extent which workshops can be classed as 'problem based learning', it is considered that this option will have a moderate to high impact on the extent of energy efficiency content in the curriculum. This is in accord with the survey result of 3.6/5.

[Refer also to Option 9: 'Include One Workshop on Energy Efficiency in the Course (i.e. laboratory-style experiments)']

The Aalborg Model, developed at the Aalborg University in Denmark, has shown that problem based learning (PBL) is an effective method of teaching as it develops students' process based skills, such as problem solving, applying technical knowledge, collaboration, communication and project management. It also helps to provide, and then reinforce, linkages between various 'elements' of a system, assuming that a real world problem will be more complex than a theoretical problem, which may focus on one issue at a time.[326] While the scope of such PBL at Aalborg University extends beyond just workshops, many of the learning principles (eg 'learning by doing') are applicable. Martin Lehmann and his fellow researchers from Aalborg University have found that this learning is, '*interdisciplinary, contextualised, student-centred, and based on a complex understanding of technological knowledge',*[327] all of which are highly relevant to learning and applying complex concepts like energy efficiency. Hence, strategically including a series of workshops and laboratory-style experiments in an energy efficiency course (rather than a once-off workshop) can further encourage students to apply knowledge and problem solve, and enhance the impact of the overall course.

Likelihood **[Survey: 2.0]**

According to the literature, introducing workshops into a course on energy efficiency would be in line with current national and international trends and research into teaching, which suggests that hands-on, problem based learning is effective at producing a deeper understanding of complex, multi-disciplinary concepts such as energy efficiency. However, the reality of implementation is low, due to time constraints within a course making it difficult to include new components, and a lack of finances limiting the ability of the course lecturer to purchase materials with which to run workshops and experiments. This is in accord with the survey result of 2.0/5.

Research by Martin Lehmann and his colleagues[328] has found that an increasing number of universities worldwide are moving towards using problem based learning to teach engineers the kinds of skills that are expected of them today. They comment that this gives students sustainable and transferrable skills which will assist them in understanding the complexity of the

[326] Lehmann, M., Christensen, P., Du, X. and Thrane, M. (2008) 'Problem-oriented and project-based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education', *European Journal of Engineering Education*, vol 33, no 3, pp283-295; de Eyto, A., Mc Mahon, M., Hadfield, M. and Hutchings, M. (2008) 'Strategies for developing sustainable design practice for students and SME professionals', *European Journal of Engineering Education*, vol 33, no 3, pp331-342.
[327] Lehmann, M., Christensen, P., Du, X. and Thrane, M. (2008) 'Problem-oriented and project-based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education', *European Journal of Engineering Education*, vol 33, no 3, p285.
[328] Lehmann, M., Christensen, P., Du, X. and Thrane, M. (2008) 'Problem-oriented and project-based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education', *European Journal of Engineering Education*, vol 33, no 3, pp283-295.

issues facing engineers, and the world today. Although these authors aren't referring specifically to workshops, it may still provide evidence for a trend towards this type of teaching and learning. Similarly, in the USA, Kathryn Hollar and Beena Sukumaran introduced a hands-on style learning experience for second year engineering students at the Rowan University Department of Civil and Environmental Engineering (New Jersey).[329] Their experiences led them to conclude that their approach can be 'easily adapted' to core courses.

There were several authors in the literature who remarked that engineering courses are already quite 'full', and that there is minimal room for introducing new material or classes,[330] which may make this option less likely in some instances. Additionally, this option may require the purchase of laboratory equipment, which may be difficult given funding constraints within many courses and degrees. [331]

[329] Hollar, K.A. and Sukumaran, B. (2002) 'Teaching Students Sustainability: An Interdisciplinary Design Project for Sophomore Engineering Student', Proceedings of the 2002 American Society for Engineering Education Zone I Conference United States Military Academy, West Point, New York, USA.
[330] Barger, M. and Hall, M.W. (1998) 'Sustainability in Environmental Engineering Education', *American Society for Engineering Education*, USA, Session 3551; Abdul-Wahab, S.A., Abdulraheem, M.Y. and Hutchinson, M. (2003), 'The need for inclusion of environmental education in undergraduate engineering curricula', *International Journal of Sustainability in Higher Education,* vol 4, Issue 2, pp126-137; El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education*, vol 9, Issue 2, pp170-182.
[331] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155; Peet, D.J., Mulder, K.F. and Bijma, A. (2004) 'Integrating SD into engineering courses at the Delft University of Technology', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp278-288.

19. Develop a New Degree Program on Energy Efficiency (e.g. Bachelor of Energy Engineering)

Impact **[Survey: 4.1]**

The literature suggests that the development of a degree program focused on energy efficiency would have a high impact, producing engineers with highly specialised skills and a deep understanding of the complex relationships which can lead to energy efficiency in society. This is in accord with the survey result of 4.1. The integration of energy efficiency throughout all components of the degree would enable students to perceive energy efficiency as relevant to all aspects of their practice. The focus of energy efficiency education into a separate program may, however, miss the opportunity to educate all engineers about energy efficiency, and therefore the wider impact of this option on engineering practice would depend upon the engineering profession and society valuing the skills these graduates would have and employ their services.

New Zealand based researcher Carol Boyle suggests that the creation of a dedicated degree, particularly at a masters level, can be an effective means of introducing change into engineering education and as a consequence, engineering as a profession, particularly when those changes are complex and require a certain level of maturity.[332] Similarly, in the United Kingdom, the Sustainable Development Education (SDE) panel concluded that sustainable development was best taught through specialised courses to produce engineers which have finely honed skills and appreciate the complex nature of sustainability.[333] A specialised degree program would allow energy efficiency to run as a consistent thread throughout all courses, highlighting its relevance to all aspects of engineering practice. Researchers from Canada,[334] the Netherlands,[335] and Sydney, Australia[336] have all remarked on the importance of helping students to create linkages between sustainability and various aspects of engineering, as did Doanh Van in the United States, whose study of teaching 'energy sustainability' to engineering students found that energy sustainability is a key thread which underpins not only engineering and its applications, but society, the economy and the environment. [337]

Boyle suggests that the task of overhauling every engineering degree, while arguably necessary, is unlikely in the near term and hence creating a specialised degree may be an effective interim measure. Boyle warned that this strategy potentially excludes the bulk of engineering students and the impact is reliant upon society and the engineering profession in valuing the unique knowledge and skills of the graduates from such a degree. However, Canadian researcher Fiona Crofton found that some courses which were developed for a particular department or faculty were later offered to students from a range of disciplines, as did William Gaughran and his colleagues in Ireland (University of Limerick), expanding the influence of this option.[338]

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[332] Boyle, C. (2004) 'Considerations on educating engineers in sustainability', *International Journal of Sustainability in Higher Education*, vol 5, no 2, pp147-155.
[333] Perdan, S., Azapagic, A. and Clift, R. (2000) 'Teaching sustainable development to engineering students', *International Journal of Sustainability in Higher Education*, vol 1, no 3, pp267-279.
[334] Crofton, F.S. (2000) 'Education for sustainability: opportunities in undergraduate engineering', *Journal of Cleaner Production*, vol 8, p397.
[335] Crofton, F.S.(2000) 'Education for sustainability: opportunities in undergraduate engineering', *Journal of Cleaner Production*, vol 8, p397
[336] El-Zein, A., Airey, D., Bowden, P. and Clarkeburn, H. (2008) 'Sustainability and ethics as decision-making paradigms in engineering curricula', *International Journal of Sustainability in Higher Education,* vol 9, Issue 2, pp170-182.
[337] Van, D. (2003) 'Teaching Design for Energy Sustainability', Proceeding of the 2003 American Society for Engineering Education Annual Conference and Exposition, American Society for Engineering Education, USA.
[338] Crofton, F.S. (2000) 'Education for sustainability: opportunities in undergraduate engineering', *Journal of Cleaner Production*, vol 8, p397; Gaughran, W., Burke, S. and Quinn, S. (2007) 'Environmental Sustainability in Undergraduate Engineering Education', *American Society for Engineering Education,* USA, AC 2007-2020.

Likelihood **[Survey: 1.1]**

Given the presumed costs, time and inertia (in terms of entrenched beliefs and systems) involved, the literature suggests that this option is very unlikely to be taken up, which is in accord with the survey result of 1.1. It is not inconceivable, however, as evidenced by similarly large changes to engineering programs in Australian and other international universities.

American researcher Peter Bosscher and his colleagues noted in their 2005 paper that many universities and engineering colleges in the US and abroad have developed new degree programs with specialised courses teaching environmental and sustainable technologies.[339] Similarly in Sydney, UTS overhauled its engineering program in 1998 to combine three separate engineering streams into one unified structure. This has enabled them to incorporate sustainability as an underlying theme for all engineering degrees, and simplified the introduction of a new engineering degree program.[340] Both of these studies acknowledged the importance of accreditation boards in inciting these changes, as well as shifting industry and societal expectations of engineers. Indeed, the current international concern surrounding greenhouse gas emissions from energy production[341] and peak oil[342] may make it increasingly likely that accreditation boards include requirements for engineers to have an understanding of energy efficiency, which in turn may make this option more likely.

[339] Bosscher, P.J., Russell, J.S. and Stouffer, W.B. (2005) 'The Sustainable Classroom: Teaching Sustainability to Tomorrow's Engineers', American Society for Engineering Education Annual Conference and Exposition, American Society for Engineering Education, USA.
[340] Bryce, P., Johnston, S. and Yasukawa, K. (2004) 'Implementing a program in sustainability for engineers at University of Technology, Sydney – a story of intersecting agendas', *International Journal of Sustainability in Higher Education,* vol 5, no 3, pp267-277.
[341] IPCC (2007) *Climate Change 2007: Synthesis Report,* Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge.
[342] Holmes, J. (2006) 'Peak Oil?', *Four Corners*, Australian Broadcasting Commission, 10 July 2006.