Doing More with Less through Factor Improvements: An Emerging Engineering Education Imperative

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Abstract: *Many are familiar with 'doing much more with much less' at a time in history when the human civilisation is putting unprecedented pressure on the planet's resources and ecosystems. Across government, business and the community, there is increasing demand for transformational rather than incremental improvements to energy, water and materials use. However, engineering education is still fundamentally grounded in knowledge and theory from an age of plenty. In this paper, the authors discuss the imperative for sustainable engineering across all disciplines, proposing that understanding the need for 80% improvements in resource productivity should be a core learning outcome for all engineering graduates within the next 5 years. The paper includes an overview of immediate opportunities for curriculum renewal with regard to knowledge and skill requirements for addressing the peaking and tailing of greenhouse gas emissions this century.*

An Emerging Imperative to do More with Less

Stabilising Greenhouse Gas Emissions

There is a growing understanding of the realities of stabilising carbon dioxide and other greenhouse gas concentrations in the atmosphere, to try to limit climate change this century. In 2006, UK economist Stern explored in detail the concept of '*stabilisation trajectories*', pointing out that there are two distinct 'phases' and a range of potential 'trajectories' to reduce and stabilise greenhouse gas concentrations, as shown in Figure 1. Firstly, global emissions need to stop growing, meaning that emission levels need to 'peak'. Secondly, there needs to be a sustained reduction of greenhouse gas emissions, across the entire global economy. This reduction is in the order of 3-5 percent per year, depending on the timing of the peak and our chosen endpoint for stabilised annual emissions.

Looking at Figure 1, each of the trajectories peak roughly between 2012 – 2025, with the IPCC calling for the peak by 2015 to '*limit global temperature rises to 2.0 to 2.4 Celsius over pre-industrial times*' (IPCC, 2007b), which is considered by many to be the point at which dangerous climate change will commence. According to Stern (2006), one of the leading drivers for change in the coming decades will be the threat of costs to economies around the world of *not* acting to decouple economic growth from environmental pressures.

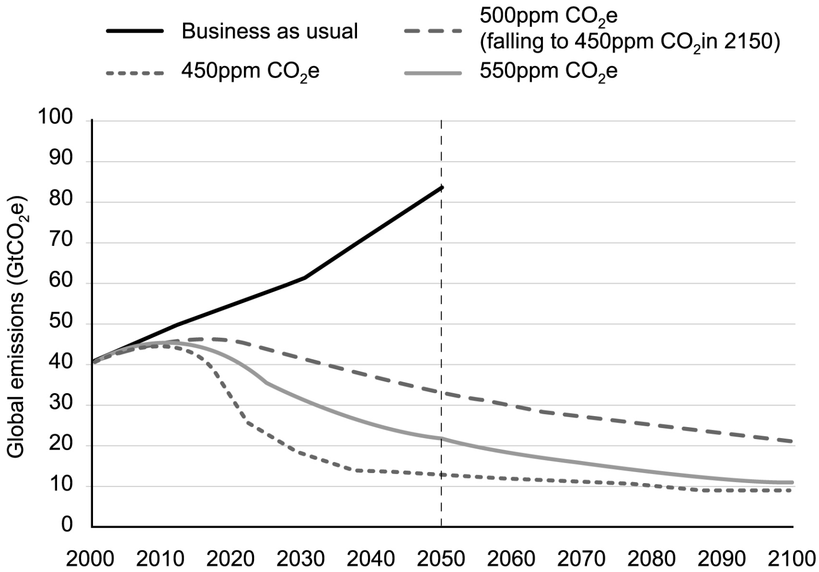

Figure 1: BAU emissions and stabilisation trajectories for the scenarios of 450 - 550ppm carbon dioxide equivalent (Stern, 2006)

Valuing the costs of *in*action is a complex task, including costs associated with a range of causes that engineers will be familiar with, such as (Smith and Hargroves, 2010):

- Damage to infrastructure from an increase in frequency and intensity of natural disasters, including storms, hailstorms, storm surges, flooding, and cyclones;
- Health related costs due to more frequent heat waves, flooding and the spread of communicable diseases, such as Dengue Fever and Ross River virus;
- Reduced agricultural production from increased temperature affecting crops along with more intense and less frequent rainfall;
- Reduced revenue from nature based tourism, such as coral reefs, forests and alpine regions;
- Costs related to relocation or protection from rising sea levels and enhanced storm surges;
- Reductions to the carrying capacity of grazing land for livestock due to higher temperatures and lower availability of water;
- Increases in peak electricity loading due to the use of air-conditioners in response to rising temperatures, along with more frequent 'heat waves';
- Increased losses from forest fires due to reduced water availability and higher average temperatures; and
- Increased risk of conflict over resources such as oil, water and timber, and declining food production - to name but a few.

In 2006, the *Stern Review*, after analysing a broad range of such costs of inaction, concluded that, '*the costs of action to the global economy would be roughly 1 percent of GDP, while the costs of inaction could be from 5-20 percent of GDP*' (Stern, 2006). In this context, a significant challenge for government and business is the fact that while GDP impacts are in the future, political attention and business strategy is most often focused on short term performance. Balancing this conflict between short and long term imperatives while delivering policy, infrastructure, products and services, will therefore be a considerable challenge for engineering professionals across the public and private sectors in the coming decades.

Transformational rather than Incremental Improvements

Nationally and internationally, political leaders are making it clear that transformational improvements in energy and materials efficiency will be at the forefront of development in the first half of the 21st Century. At the 2009 Group of 8 summit in Italy, Prime Minister Rudd acknowledged climate change as *'the great moral and economic challenge of our age'* (Wolf, 2009). Following his 2008 commitment to build a modern Australia, *'capable of meeting the challenges of the 21st Century'* Rudd acknowledged to the Australia 2020 Summit that, '*... we've seen extraordinary transformations* *in Australia and extraordinary transformations across the world these last 12 years. And we need therefore, now more than ever, to anticipate change ahead, or else we will be swamped by it.'* (Rudd, 2008). In 2009 as part of his election commitment, American President Obama announced his country would aim for 80 percent reductions of greenhouse gas emissions compared with 1990 levels by 2050, through significant economic innovations, including the introduction of a cap and trade system and a $50 million a year investment (over 10 years) in alternative energy (Cordell, 2009). Incoming Japanese Prime Minister Hatoyama has also committed to reducing emissions by 25% over 1990 levels by 2020 (Nikkei, 2009).

With such statements having implications that extend over the next 4 decades, there is a clear imperative for all sectors of society to begin implementing strategies that work towards these commitments. The good news is that there are significant precedents in achieving such transformational – or 'Factor' – improvements. More than a decade ago in 1995, *Factor 4: Doubling Wealth and Halving Resource Use* was published as a report to the Club of Rome, offering a comprehensive response to the problems outlined in the 1972 seminal publication *Limits to Growth*. *Factor 4* focused on transformational resource efficiency opportunities. The authors presented 50 examples of making 'Factor 4' improvements – that is, at least quadrupling resource productivity (i.e. achieving the same output with one quarter of the inputs, or doing for times as much with the same amount of inputs), across energy, materials (including water), and transport. According to the authors, '*The next wave of innovation comes from the laboratories, workbenches and production lines of skilled scientists and technologists, from the ingenuity of engineers, chemists and farmers, and from the intelligence of every person … The goal is using resources efficiently; doing more with less … It is the beginning of a new industrial revolution in which we shall achieve dramatic increases in resource productivity'* (von Weizäcker, 1997).

Capacity Building within Engineering Curriculum

Given that such precedents have been available for more than a decade and that national and international leadership is now evident at the highest levels, there is no more time for the higher education sector to continue to teach outdated content, related to the business-as-usual heat-beat-and-treat engineering practices. Indeed, the authors have identified a 'time lag dilemma' now facing engineering educators, where an engineering department's decision about the scale and pace of curriculum renewal in undergraduate curriculum may significantly affect their risk profile in a rapidly changing industry, regulatory, and accreditation environment. The observed dilemma is that, in contrast to the last 20 years, herein updating engineering curriculum using 'standard' (i.e. usual) methods, and the associated timelines of between 15–20 years (i.e. 3-4 program accreditation cycles), may expose the engineering department to potential risks with regard to student demand for the program/s, tightening accreditation requirements and ultimately, program viability. This is shown diagrammatically in Figure 1.

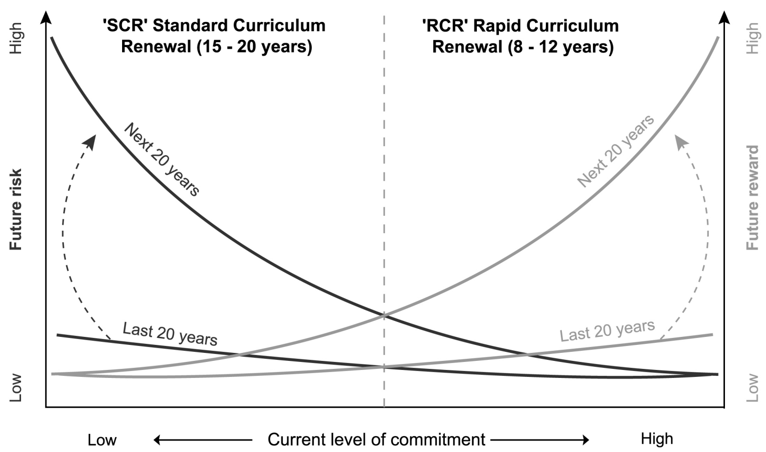

Figure 1: Risk and Reward Scenarios for Rapid Curriculum Renewal in the Higher Education Sector

Source: TNEP, 2009

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'* (Grear, 2008).

With a historical lack of progress in integrating sustainability content within engineering curriculum (Desha, Hargroves and Smith , 2009), it is logistically improbable 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. From the engineering curriculum literature the authors have distilled a number of emerging 'top down' and 'bottom up' factors that appear to be putting pressure on engineering departments to undertake such capacity building, including: tightened legislation and regulations; increased accreditation requirements; shifts in industry demands for graduates with sustainable development capabilities; and shifts in the demands of the students themselves (Desha, Hargroves and Smith, 2009). Faced with these emerging factors, engineering educators may well be asking themselves *'how far and how fast is my institution willing and able to proceed to make the transition to EESD?'*

Hence, the authors propose that in working towards the national and international commitments discussed above, there is a parallel imperative for the higher education sector to ensure that engineering education provides graduates across all disciplines with the knowledge and skills for achieving 80 percent improvements in resource productivity. Indeed, this should be a core learning outcome for all engineering graduates as soon as practicable within the next 5 years.

Knowledge and Skills Examples in Energy Productivity

Focusing on greenhouse gas stabilisation challenges, the authors now provide several recent examples of emerging knowledge and skills which graduates are increasingly being expected to understand and deliver on. Hence, there is a need to integrate such content within existing curriculum to enable graduates to contribute to addressing the peaking and tailing of greenhouse gas emissions this century.

Factor Improvements in the Buildings Sector

The residential and commercial building sector is responsible for close to 40 percent of global greenhouse gas emissions (OECD, 2003). Much can be done to cost effectively reduce energy consumption in this sector, as shown by the work of the German based Passive House Institute, led by Dr. Wolfgang Feist, in pioneering the design of ultra-efficient buildings that have achieved 80 percent improvements over contemporary German standards, and a 90 percent improvement over the average German building stock. Furthermore, when considering commercial buildings, a 2009 study by the US National Renewable Energy Laboratories found that if energy efficiency strategies along with, *'projected future technology and PV systems were applied to all buildings by 2025... new buildings in the commercial sector could, on average, consume 86% less than current stock'* (Griffith *et al*, 2009). The study also emphasised the need for a whole system approach to achieve these results, stating that, *'In the coming decades, commercial buildings can be dramatically reshaped by combining the results of research and product development in a variety of fields* – [including] *energy-efficient building shells; HVAC equipment; lighting; day-lighting; windows; passive and active solar; PV power systems; fuel cells; advanced sensors and controls; and combined heating, cooling, and power'*.

Numerous governments, including the USA, UK, France, Australia and Germany, are investing in and providing incentives for more efficient building design and retrofits. Some governments are also setting strong energy efficiency targets for this sector. For instance, the UK government has set the target that all new homes built in the United Kingdom after 2016 will be 'zero-carbon' homes (Communities and Local Government, 2008); French President Sarkozy has committed all new buildings by 2020 to be self-sufficient in energy (Bremner, 2007); and local councils like Freiburg, Germany (Clinton Climate Initiative, 2008) are mandating ultra-efficient home design. China too has increased the energy efficiency requirements for its new buildings, introducing a new building construction statute in 2006 that included clauses on a mandatory energy efficiency standard for buildings. The Standard requires energy efficient building materials and energy-saving technology in heating, air-conditioning, ventilation and lighting systems in civil buildings. Building construction energy efficiency is also included in China's 11th 5-Year National Development Programme (2006–2010), which aims for a 50 percent reduction in energy use (compared with the current level) and a 65 percent decrease for municipalities such as Beijing, Shanghai, Tianjin and Chongqing as well as other major cities in the northern parts of the country (IPCC, 2007a).

Factor Improvements in the Heavy Industry Sector

According to the IPCC, by 2004 industry's share of global primary energy use was 37 percent (IPCC, 2007a). Two of the most energy and water intensive industries are the steel and cement industries and they are currently rapidly growing in developing and emerging economies as their products underpin much of the world's growth. Since 1970, the global annual production of these industries has grown swiftly with the steel industry increasing production by 84 percent (USGS, 2005), and cement by 271 percent (IPCC, 2007a). Hence, as countries like China and India rapidly develop, it is imperative that the design of new plants and in the retrofitting of existing plants greenhouse gas emissions and resource consumption levels are significantly reduced. Significant advances of up to 92 percent energy productivity improvements can be made in the steel industry by switching to state-of-the-art electric arc furnace systems that process recycled steel, by adopting leading practices such as Net Shape Casting, and by implementing options such as energy monitoring, management systems for energy recovery and distribution between processes, and preventative maintenance. The cement industry can also become significantly more energy productive, and even eliminate greenhouse gas emissions, through the use of geopolymers, which are now well proven in practice.

Factor Improvements in the Transportation Sector

Transportation accounts for 22 percent of global energy use (InterAcademy Council, 2007), and 23 percent of world energy-related CO_2 emissions (IPCC, 2007a). Also the rate of growth of energy usage and greenhouse gas emissions in this sector is among the highest of all the energy end-user sectors, and although advances in energy productivity have been made, these advances, particularly in cars and aeroplanes (Davidson, 2005), are not keeping pace with the exponential growth of these modes. There are a range of options for reducing fossil fuel consumption in this sector, namely:

1. The improved design of the major passenger and freight transportation vehicles (including cars, trucks, rail, shipping, and aeroplanes).
2. A significant shift to lower energy consuming modes of transportation for both passenger and freight transport (such as shifting from long-haul trucking to rail or coastal shipping).
3. A shift in transportation fuels over time to source higher percentages of energy for transportation from renewable energy sources (including electricity and alternative combustion fuels).

Researchers and designers around the world are now showing that a combination of these efforts can lead to up to 80 percent reductions in fossil fuel consumption, particularly the pioneering work of Rocky Mountain Institute (Lovins and Datta et al, 2004). Also a focus on these three strategies will create multiple benefits including reducing urban air pollution (Van Vuuren and den Elzen et al, 2006), reducing congestion costs (EU Business, 2007), improving staff health and performance (WHO, 2000), reducing transportation costs (Newman and Kenworthy, 1999), and stimulating the economy (Newman, 1998).

Conclusion

In such urgent and challenging times, incremental efficiency improvements are not an option if the world is to meet its greenhouse gas emission targets. In parallel with a global effort across private and public sectors, higher education needs to embed the concept of factor improvements across energy, water and materials within engineering education. There exists plenty of precedent with regard to significant and rigorous examples of such improvements in practice. Hence, the authors propose that this knowledge and skill should be integrated as soon as possible within the next 5 years, so that graduates will soon emerge with the skills required to address the discussed challenges and the goals that our leaders have set.

References

Bremner, C. (2007). ‘The Next French Revolution: Nicolas Sarkozy Sets Out his Plans for a Green Future Target’, *The Times*, 24 October.
Clinton Climate Initiative (2008). C40 Cities: Buildings, Freiburg, Germany. Accessed at http://www.c40cities.org/bestpractices/buildings/freiburg_housing.jsp on 8 January 2009.
Communities and Local Government (2008). ‘New Proposals to Make the 2016 Zero Carbon Homes Target a Reality’, *COI News Distribution Service News Release*, 17 December.
Cordell, M. (2009). ‘Obama's CGI commitments’, *UN Dispatch*, 25 Sept. Accessed at http://www.undispatch.com/archives/2008/09/obamas_cgi_comm.php on 12 July 2009.
Davidson, S. (2005). Air transport impacts take off. *ECOS: Towards A Sustainable Future*, Issue 123, CSIRO.
Desha, C., Hargroves, K. & Smith, M. (2009). Addressing the Time Lag Dilemma in Curriculum Renewal towards Engineering Education for Sustainable Development. *International Journal of Sustainability in Higher Education*, *10*(2), 184-199.
EU Business (2007). ‘Road Congestion Costs EU Nations 1 percent of GDP’, *EU Business*, 31 May.
Grear, B. (2008). Personal Communications with the authors, 29 August.
Griffith, B., Long, N., Torcellini, P. & Judkoff, R. (2009). *Assessment of the Technical Potential for Achieving Net Zero-Energy Buildings in the Commercial Sector.* National Renewable Energy Laboratory.
InterAcademy Council (2007). *Lighting the Way: Toward a Sustainable Energy*. InterAcademy Council, see 2.5 ‘Transportation Energy Efficiency’.
IPCC (2007a). *Climate Change 2007: Mitigation of Climate Change*. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press, see ‘Policies, Instruments and Co-operative Arrangements’.
IPCC (2007b). *Climate Change 2007: Synthesis Report* (p104). Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.
Lovins, A. & Datta, E.K. et al. (2004). *Winning The Oil Endgame: Innovation for Profits, Jobs, and Security: Executive Summary.* Rocky Mountain Institute, London: Earthscan.
Newman, P. (1998). ‘Transport’, Interview transcript from *Radio National Earthbeat*, 12 October.
Newman, P. & Kenworthy, J. (1999). *Sustainability and Cities*. Washington, DC: Island Press.
Nikkie (2009) Hatoyama Promises Action On Host Of Challenges In U.N. Speech, Nikkei Press, 25 September, 2009
OECD (2003). *Environmentally Sustainable Buildings: Challenges and Policies*. Paris: OECD.
Rudd, K. (2008). Opening Address to the 2020 Summit, 19 April.
Smith, M. & Hargroves, K. (2010). *Cents and Sustainability: Decoupling Economic Growth from Environmental Pressures*. London: Earthscan.
Stern, N. (2006). *The Stern Review* (p10). Cambridge: Cambridge University Press.
USGS (2005). *Minerals Yearbook 2004*. VA, USA: US Geological Survey Reston.
Van Vuuren, D.P. & den Elzen, M.J.E. et al (2006). Exploring the Ancillary Benefits of the Kyoto Protocol for Air Pollution in Europe. *Energy Policy*, 34, 444-60. Cited in OECD (2008). *OECD Environmental Outlook to 2030*. Paris: OECD.
von Weizäcker, E., Lovins, A.B. & Lovins, L.H. (1997). *Factor 4: Doubling Wealth, Halving Resource Use*. London: Earthscan.
Wolf, R. (2009). ‘Obama, Australian leader announce climate institute’, *USA Today*, 9 July. Accessed at http://www.usatoday.com/news/world/2009-07-09-g8-thursday_N.htm on 25 Sept 2009.
World Health Organisation (WHO) (2000). *Transport, Environment and Health*. Copenhagen: Regional Office for Europa.

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