WORLD ENGINEERS CONVENTION (WEC) 2019

Engineering for Humanity, Sustainability and the SDGs

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ABSTRACT

Engineering should serve the needs of humanity, in terms of providing sustainably for our present needs and those of future generations. These needs relate to such areas as housing, water supply, sanitation, transport, communications, infrastructure, industry, energy use, employment, health, education, to reduce poverty and enhance quality of life, with regard to responsible consumption, production and resource use, climate change reduction and equitability. These areas map closely to the 17 UN Sustainable Development Goals, and also to various areas of engineering. Engineering will be essential and vital to achieve the SDGs, and needs to be emphasised as such. Without such recognition, and the appropriate orientation and application of engineering, no SDGs will be achieved. Engineering, engineering education, professional practice and CPD also needs to recognise this. Unfortunately, engineering and technology are part of the problem of unsustainability and anthropogenic climate change - engineering and technology have enabled richer countries to over-consume, in terms of unsustainable resource use, with consumers showing little evidence of change. The selfish gene has become the selfish generation. We live on one planet but currently are using the resources of two. As David Attenborough noted at WEF2019 "Unless we sort ourselves out in the next decade or so, we are dooming our children and our grandchildren to an appalling future." This policy-oriented presentation will review this situation, the political economy of engineering, development and growth, lessons learnt from the UN MDGs and mapping of the SDGs and engineering. There will be particular reference to issues, challenges and prospects for change, success factors for engineering and sustainable development, the importance of indigenous, humanitarian and sustainable engineering, education and professional practice and the policies, pathways and actions required by the engineers of today and tomorrow.

MAIN TEXT

Engineering and technology has been vital in addressing human, social and economic development – just think of the Stone and other Ages, and the waves of innovation - from water to steam power to electricity, automobiles and space. Engineering underpins social and economic, sustainable and humanitarian development. Engineering is vital in innovation, infrastructure, industry, employment, sustainable production and consumption, climate change response, post-disaster and post-conflict response and reconstruction. Engineering for human, social and economic development has recently come to be known as humanitarian engineering, although this term has also been linked to engineering for 'humanitarian' emergency and disaster situations. In the wider sense of the word, humanitarian relates to improving the lives and well-being of people and the philosophy that it is our responsibility to promote human welfare and sustainability. This concept builds upon previous interest in appropriate technology (AT). Engineering is vital in promoting human welfare and sustainability, and will be vital in addressing the UN Sustainable Development Goals (SDGs). But engineering, and engineering education, needs to get better positioned if it is to respond effectively to addressing the SDGs.

The SDGs are similar to and build upon the UN Millennium Development Goals (MDGs) of the UN Millennium Summit, held in 2000, for the period 2000-2015. The MDGs were designed by an expert group, and agreed by all 191 nations, but with what has widely been observed as a limited sense of country ownership? There were 8 MDGs, together with 18 targets and 48 indicators of achievement. The MDGs focused on poverty, primary education, gender equality, child mortality, maternal health, combat diseases, environmental sustainability and partnership. Engineering and technology are vital in all these areas, and yet there was no specific mention of engineering in the MDGs, the closest being a reference in MDG8, target 18 to knowledge, S&T and ICTs. The MDGs were 'the most successful anti-poverty movement in history', although they were aspirational rather than actual, and achieved limited actual success, despite the spin. Only

3 targets achieved – halving poverty, halving no access to water, and a 66% increase ODA. This was mainly due to development in China and India, rather than MDGs per se, and ODA has since declined in many countries, including Australia.

And yet billions of people continue to live in poverty, despite the huge development and application of knowledge over the last century. Why is this? Why have these activities often achieved little and sometimes failed completely? This seems to be due to a mixture of factors. One relates to the focus on outcomes rather than process and policy (eg “halving poverty”). Another relates to the lack of focus on drivers of human, social and economic development – for example on engineering and technology. This relates more broadly to the political economy of engineering, technology and development. Engineering applications and technology depend on knowledge, resources, funding, and the application of engineering/technology in development depends on awareness of the role of engineering and technology in development, good policy and implementation (by policy makers and decision taker, information and advocacy for engineering in development. Engineering is often overlooked or under-represented in S&T policy, for various reasons – lack of political interest or will, bureaucracy, political economy knowledge and power, and poor understanding of engineering, S&T and development. The lessons learnt here is then need for continuous demonstration and advocacy of engineering for development. Some lessons from the MDGs were learnt in the development of the UN SDGs, not least in scope - with 17 SDGs, 169 targets, and 304 indicators of achievement.

ENGINEERING AND SUSTAINABILITY

Key elements of sustainability are identified in the UN Global Goals for Sustainable Development, “Transforming our world: the 2030 Agenda for Sustainable Development”, following the eight UN Millennium Development Goals 2000-2015. The Sustainable Development Goals (SDGs) consist of seventeen goals, 169 targets and 304 provisional indicators. The seventeen SDGs are for no poverty; end hunger; good health and well-being; quality education; gender equality; clean water and sanitation; affordable and clean energy; decent work and economic growth; industry, innovation and infrastructure; reduced inequalities; sustainable cities and communities; responsible production and consumption; climate action; life below water; life on land; peace and justice, strong institutions; and partnerships for the goals. The SDGs are illustrated in the figure below:

Figure 1: UN Global Goals for Sustainable Development

THE SDGS AND ENGINEERING

Engineering is of vital importance in sustainable development and a central factor in directly addressing most of the SDGs, as indicated below.

Poverty:
Engineering and technology are essential in the provision of basic services, infrastructure, income generation and humanitarian development

Hunger:
Sustainable agriculture, food production, processing depends on engineering

Health:
Health services, well-being and the quality of life depends increasingly on engineering and medical technology

Water and sanitation:
Engineering and technology are central in the provision of clean water and sanitation

Energy:
Affordable, sustainable energy, energy efficiency and renewable energy technologies are developed by engineers

Employment and economic growth:
Engineering and technology supports economic growth and employment

Industry, Innovation and infrastructure:
Engineering and engineers drive innovation, infrastructure, industry and economic growth

Sustainable cities and communities:
Sustainable cities and communities depend on engineering, construction and infrastructure

Responsible production and consumption:
Engineering and technology underpins sustainable production and consumption.

Climate action:
Climate change mitigation and adaptation, sustainable energy and reduced emissions depend on engineering and technology

Life below water; Life on land:
All life on Earth will depend increasing on the use of sustainable engineering and technology.

In addition, quality education will be essential if we are to enrol and train the next generation of sustainable engineers, and gender equality is important to ensure that a greater percentage of engineers are women, who also have a greater interest in sustainability. Engineering and technology are also vital in promoting global partnerships for sustainable development and in reducing global inequality. On the other hand, it is unfortunate that engineering is only mentioned specifically twice in the SDG document – in the context of scholarships to developing countries for engineering (SDG Goal 4b), and in relation to global partnerships for sustainable development (SDG Goal 17).

Lessons were learnt in the achievement, or rather otherwise, of the MDGs, and some results are already in regarding the achievement of the SDGs. Global hunger has risen for the third year in a row, according to the latest UN's world food security report (FAO, 2018), while fewer than five per cent of countries are on track to meet childhood obesity and tuberculosis targets, according to a study published in The Lancet in 2017 (Lancet, 2017). At the same time, global carbon emissions were rose by two per cent in 2018 to hit an all-time high, driven by rises in the use of coal, oil and gas (UEA, 2018). It therefore appears that there is no greater sense of ownership of the SDGs than the MDGs, by either politicians or public, as there is little mention of the SDGs by politicians in many countries, along with some dubious claims of how carbon emissions and climate change are being controlled, leaving the public to maintain their own awareness of the issues.

If the SDGs are to be met, there is a need for transformational rather than incremental change. SciDevNet has observed that the SDGs are "failing to create transformational change", and that systemic thinking needed to create far-reaching changes, SDGs activities are often applied to work already being done, and that global hunger rising, with carbon emissions at an all-time high. Comments that the SDGs are often failing to produce the profound changes needed to achieve their ambitious objectives due to a lack of coordination across the 17 separate goals, were also heard at the 2018 annual meeting of the American Association for the

Advancement of Science (AAAS). Peter Gluckman from the University of Auckland noted that "The reality is that if they are just seen as aspirational goals what happens is - what is actually happening now - is that governments are just labelling what they are doing anyhow as being in the obligation of the SGDs". Nakao Ishii, chief executive of the Global Environment Facility, noted that in Japan, people would wear SDG badges at policy meetings, "It's almost an order if you go to those meetings you have to wear the SDG badge, but the question is to what extent they really do understand the need of transformation, which is not the incremental approach anymore" (AAAS, 2018). There are also contradictions and trade-offs between SDGs – diverting river flow for agriculture, for example, may impact on downstream aquatic life, ecosystems and biodiversity.

Achieving success in addressing the SDGs relates particularly to the engineering community – the main driver of engineering and technology for development. The engineering community needs to lead and advocate for engineering and the SDGs, in conjunction with associated communities in policy and planning, government and private sectors, local and international NGOs and IGOs such as WFEO and UNESCO. Engineering and development needs drive from engineering community to emphasise the importance of engineering in development, to put engineering on the development agenda. Success factors and lessons learned for what works in engineering and technology for development relate to the need for technologies to be appropriate to local social and economic needs and conditions, to have a human face (as Fritz Schumacher put it in "Small is Beautiful"), to complement and build upon local technologies, to be affordable, maintainable, rather than tec-fixes to perceived problems, for example water pumps, cooking stoves, biogas plants, solar PV. Projects in developing countries in particular need to engage and involve local community and engineers. As noted elsewhere, humanitarian and sustainable engineering also attracts young people to engineering.

In the Australian context, it is also important to emphasise the importance of indigenous engineering. With a heritage going back at least 60,000 years, aboriginal Australians developed knowledge systems, engineering skills and technologies that enabled them to construct the earliest farming systems and astronomical observatories in the world. The Budj Bim Cultural Landscape, located in South West Victoria, includes evidence of one of the world's largest and oldest aquaculture systems, dating back around 6600 years. Aboriginal people used the abundant local volcanic rock to construct fish traps, weirs and ponds to manage water flows from nearby Lake Condah to exploit short finned eels and other fish as a food source. The Budj Bim National Heritage Landscape is on Australia's National Heritage List and UNESCO World Heritage listing. The Wurdi Youang stone arrangement, near Little River in Victoria, marks the positions of the setting sun at the equinoxes and solstices, with an accuracy of within a few degrees. Wurdi Youang could be as old as 11,000 years, if not older, which would make it the oldest astronomical observatory in the world. This knowledge, engineering and technology should be recognised as an important contribution from our earliest engineers.

APPROPRIATE ENGINEERING AND TECHNOLOGY FOR HUMANITARIAN DEVELOPMENT

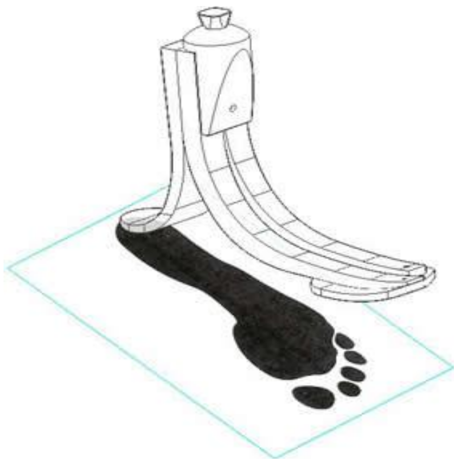
Engineering and technology are also of vital importance in addressing human and social progress and development, and humanitarian activity in the context of post-conflict and post-disaster response, and post crisis transition and development. The SDGs should more widely be considered global goals for sustainability and development, and many of the SDGs listed above relate particularly to social, economic and humanitarian development. These include almost all the seventeen SDGs. Engineering and technology are vital in the reduction of poverty and hunger, in promoting health in such areas as water supply and sanitation and the provision of affordable housing and energy. Engineering and technology also drive industry, innovation and infrastructure, employment and economic growth (Metcalfe, 1995; Stewart, 1977). Engineering and technology underpin sustainable production and consumption and will be an essential part of the solution of climate change mitigation and adaptation and the continuation of life on planet earth. It is also important to note that engineering applications and innovation are not just hi-tec, but also includes technology that is new to the user group, if not absolutely new, for example – the introduction of a new water pump for African farmers.

Having said this, it is also worth noting that humanity, especially in the richer countries, are currently consuming resources at an unsustainable rate that would require two planets to fulfil sustainably. Unfortunately there is little evidence of reduced consumption by consumers in richer countries, and increased consumption elsewhere, for example in terms of cars, energy and natural resources, and compound effects in the need for more roads, power and resource consumption. The selfish gene has lead to a selfish generation. There is clearly a role for humanitarianism, and for humanitarian engineering. This role has been addressed, for example, by the development of Engineers Without Borders and similar groups in many countries.

Engineering and technology play a special role in post-conflict and post-disaster response and reconstruction, in all the areas of social and humanitarian development noted above. Engineers are usually the most immediate post-crisis responders in terms of rescue and making safe, and engineers are at the forefront of reconstruction activities. In Colombia the peace process follows 50 years of armed conflict and engineering will be vital in post crisis transition and development. East Timor became independent after 25 years of Indonesian occupation, with severely damaged infrastructure and no experience of the understanding, planning, organisation and management of development activities, particularly in rural areas, that had taken place over the same period in similar countries – such as those of the Pacific islands. Engineers with insight into and experience of technology, innovation and social and humanitarian development, and associated institutions, policies, programmes and initiatives, are vital in such situations. Examples of such humanitarian development activities include improved affordable housing building upon local skills and materials. Household water supply using roof-water catchment or slow sand filters and locally made ferro-cement or galvanised rainwater tanks. Improved pit and pour-flush sanitation. Solar PV household energy systems and improved cooking stoves. Food production and processing for household and small business development. Small scale technologies are the basis for many other small business and employment development initiatives, including chicken and livestock raising, bakeries, trades-based and workshop businesses.

The Daimler-UNESCO Mondialogo Engineering Award was an example of an international initiative promoting cooperation between engineering students to address issues of humanitarian development in developing countries, with a particular focus on quality of life improvement and sustainable development. The Mondialogo Engineering Award ran in three series, each concluding with a Symposium and award ceremony, from 2003-2010, organised by Daimler and UNESCO, and involved over 10,000 young engineers from over 100 countries. Students formed international partnerships to cooperate on problem-based, problem-solving project design exercises in humanitarian development. Projects included impressive design solutions to a diversity of humanitarian issues such as affordable water supply and sanitation systems, improved housing and household lighting systems and cooking stoves, low-cost bridges, food production and processing, telemedicine and prosthetic limbs, some of which were successfully commercialised, although this was not a condition of the competition. The Mondialogo Engineering Award was itself a multi award-winning initiative, that unfortunately concluded with the Global Financial Crisis and impact on Daimler's luxury car and truck business (UNESCO, 2010). The Mondialogo Engineering Award helped inspire similar activities, such as the EWB Challenge, that began in 2007.

Low cost bridge building – Rwanda-Germany team



Prosthetic foot – Colombia-USA team

ENGINEERING AND ENGINEERING EDUCATION

Engineering and engineering education are as they are today due to a mixture of technical, cognitive-educational and socio-professional factors – previous engineering and technological innovation and change, previous approaches to engineering education, and the changing role of engineering and engineers in society.

Engineering has developed through the successive waves of technological innovation, from the first wave technological change in the Industrial Revolution of 1785-1845 – 60 years of development, particularly of iron, water power and mechanization. The second wave of technological innovation from 1845-1900 saw the rise of steel, steam power and the railways, over around 55 years. The third wave of technological innovation from 1900-1950 witnessed the development of electricity, chemicals and the oil industry, heavy engineering and the internal combustion engine over a period of 50 years. The fourth wave of technological innovation from 1950-1985 saw the development of automobiles, petrochemicals, electronics and aerospace over 35 years. The fifth wave of technological innovation from 1985-2005 saw the growth of computers, ICT, information societies and economies over around 20 years – in increasingly shorter periods, from what was a lifetime to less than a generation. The sixth wave of technological innovation (2005-25?) is seeing the further development of new knowledge and applications in the areas of ICTs, biotechnology, nanotechnology, materials technology, robotics and sustainability. The increasing emphasis on sustainable development, climate change mitigation and adaptation will continue into a seventh wave of cleaner/greener engineering and technology, albeit against some populist feelings of climate change and knowledge skepticism. These Kondratiev waves of technological innovation and revolution have seen new modes of knowledge generation, dissemination and application in increasingly knowledge- and information-based societies and economies. These changes have primarily been from "Mode 1" disciplinary knowledge systems to "Mode 2" interdisciplinary knowledge systems (Gibbons et al, 1994; Nowotny et al, 2001). New areas of knowledge such as ICTs and biotec are typified by innovation and interdisciplinary cross-fertilisation and fusion, with the rise of new areas and decline of old disciplines. Kondratiev waves of innovation are presented below (Von Weizsäcker et al, 2009).

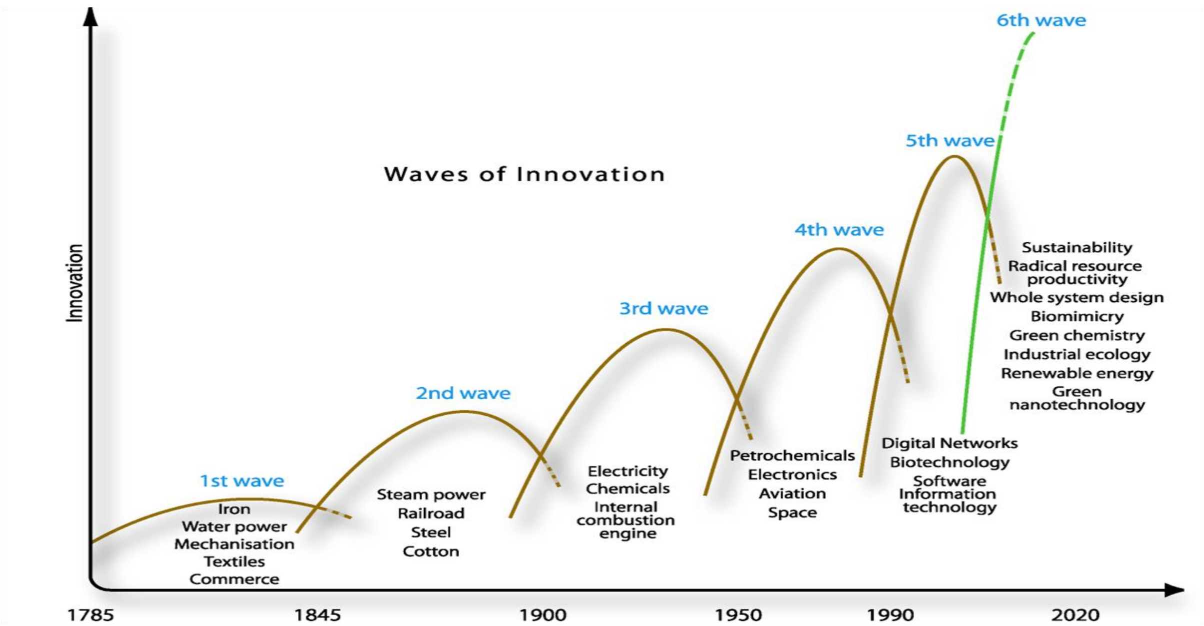


Figure 2: Waves of innovation - Kondratiev waves

ENGINEERING EDUCATION

New modes of knowledge production and application see new needs and new modes of learning (Beanland and Hadgraft, 2014). Engineering education has itself evolved from craft-based learning in the early industrial revolution, with an activity-based, hands-on learning approach, following a Pre-Renaissance separation of knowledge/science and practice/technology. This was succeeded into the second wave of industrial innovation and change by more formal apprenticeships, trade and skills-based, again with an activity-based, hands-on learning approach, coupled with the development of analysis and theory in the post-Renaissance growth of classical science and increasing science-base to engineering. This development continued with the growth of formal schools, colleges and universities, following the establishment of the University of Berlin, the 'Mother of modern universities' by Wilhelm von Humboldt in 1810, creating the "Humboldt model" of engineering education based on theory and practice. As schools, colleges and universities of engineering and technology developed into the 20th Century, so did 'engineering science' and the development of professionalization and disciplinary formation within engineering and of engineering education and accreditation, with an increasingly science-based, theoretical and a hands-off learning approach – with the decline of the practical element of the Humboldt model. The development of 21st century, post-industrial science and engineering has seen the further erosion of separation between science and engineering, with the growth of interdisciplinary cooperation, integration, networking, systems approach and fusion of science and engineering, with an increasing focus on synthesis, applications and problem-solving.

This has created the need for new educational approaches for the present and next generation of engineers, of education for real world practice and application, based on real world issues and challenges such as climate change, sustainable development, poverty reduction and enhancing the quality of life in developing countries. New educational approaches overturning the traditional teacher-centred approach based on student centred learning combining theory and practice, blended learning, teamwork, continued and lifelong learning. Many focus on problem-solving through project and problem-based learning, following such exemplars as the Aalborg model of PBL, the Conceive Design Implement Operate (CDIO) approach and, most recently, flipped classrooms - reversing traditional learning with online instruction and classroom exercises (not unlike aspects of PBL).

APPROPRIATE ENGINEERING EDUCATION – PROBLEM-BASED LEARNING

Core principles of problem-based learning are based around problem orientation, project organisation, integration of theory and practice, participant direction, team-based approach, cooperation and feedback, and can be summarised as follows:

- Problem orientation
  - Guided problem analysis/solving - basis for learning
- Project organisation
  - Projects guide problem analysis to reach educational objectives
- Integration of theory and practice
  - Students see link between theory and practical knowledge
- Participant direction
  - Students define problem and make decisions on project work
- Team-based approach
  - Most problem/project work is in groups of 3 or more students
- Cooperation and feedback
  - Peer and supervisor feedback and reflection important in PBL

Problem-Based Leaning is a learning approach that is essentially student-centred, as opposed to teacher-centred in traditional pedagogy, focusing on student learning needs in terms of maintaining the balance and link between theory and practice of the Humboldt model, based on real-life problems. PBL is also project-organised education, with project work supported by lectures and courses, in the context of group or team work in groups of 4-6 students, with staff playing a mentoring supervisory role. PBL may also combine interdisciplinary studies, further integrating theory and practice and a focus on learning to learn and methodological skills, and may be a faculty or university-wide model (as is the case at Aalborg, with faculty variations).

The theoretical background to PBL is that PBL focuses on learning rather than teaching, active learning rather than passive, which is fun, as opposed to traditional teaching, which involves listening and memorising, which is not fun, assessed on the ability to produce and use knowledge. Knowledge development takes place in collaborative student groups, with staff support, and focuses on learning to develop knowledge. Interest in PBL began in the 1960s-70s, with the development of new universities in around the world and interest in new ways of learning (Kolmos, Krogh and Fink, 2004; de Graaf and Kolmos, 2007; Du, de Graaf and Kolmos, 2009; Barge, 2010).

ENGINEERING ACCREDITATION - PROFESSIONAL ATTRIBUTES AND COMPETENCES

A focus of interest in engineering education and accreditation has moved away from engineering curricula to professional attributes and competencies. This is reflected in the work of the International Engineering Alliance – a global group from 30 developed countries with agreements covering the recognition of engineering educational qualifications and professional competence. The IEA includes the Washington

Accord - an international accreditation agreement between national accreditation bodies. Interest includes the need for new educational approaches for the present and next generation of engineers - what engineers do we need, will we need? This in turn includes the need for cleaner and greener engineers with background attributes and competencies to deal with problems of climate change mitigation and adaptation and broader issues of sustainable development, new areas of engineering and technology such as robotics and the fact that change has become a constant rather than an exception. In this context there is a need for engineers, and engineering education to respond to rapid change in knowledge, learning how to learn for lifelong and distance learning, continued professional development in a cognitive, knowledge-based approach, which will require adaptability, flexibility and intercultural interdisciplinarity for multiple career paths, requiring experience and competence in terms of understanding, insight, awareness, analysis, synthesis, ethics and social responsibility for practical applications and problem-solving.

These needs and qualities are reflected in the twelve key graduate attributes and professional competencies identified by the Washington Accord (Washington Accord):

1 Engineering knowledge
2 Problem analysis
3 Design and development of solutions
4 Investigation
5 Modern tool usage
6 The engineer and society
7 Environment and society
8 Ethics
9 Individual and team member
10 Communications
11 Project management and finance
12 Life-long learning

As is evident, less than half of these criteria relate to the "old" engineering curricula, with the majority relating to contemporary and emerging needs of professional practice. All are ideally suited to problem- and project-based learning, as originally outlined by Wilhelm von Humboldt, combining theory and practice.

TRANSFORMING ENGINEERING FOR HUMANITY AND THE SDGS

Particular challenges for engineering include the repositioning of engineering and engineering education to address the SDGs, and the decline of interest and enrolment of young people, especially women, in engineering. The latter is mainly due to negative perceptions that engineering is boring, nerdy and uncool, that university courses are difficult, hard work and boring, that engineering jobs are not well paid and that engineering has a negative environmental impact and image. There is also evidence that young people turn away from science at age 10-12, that good science education at primary/secondary level is vital and that teachers can turn young people on/off science. There is an overall need to emphasise engineering as the driver of social/economic development to get engineering on the development agenda, to develop public and policy awareness of engineering, develop information on engineering, highlighting the need for better statistics and indicators on engineering, to promote change in engineering education, curricula and teaching to emphasise relevance and problem-solving, more effectively apply engineering to global issues such as poverty reduction, sustainability and climate change and to develop greener/sustainable engineering and technology and the next wave of innovation. There is a particular need to address negative perceptions that engineering is boring, that engineering education is hard work, that engineering jobs are not well paid and that engineering has negative environmental impact and image. These negative perceptions can be addressed by promoting the public understanding and awareness of engineering, making engineering education more interesting and relevant for problem-solving (eg through problem-based learning), better understand and control the supply and demand for engineers and encouraging small engineering business development and the promotion of engineering as a part of the solution, rather than part of the problem to sustainable development, climate change reduction and mitigation.

Many of these issues, challenges and opportunities are linked in terms of providing positive solutions. When young people, the public and policy-makers see that engineering is a major part of the solution to global issues, their attention and interest is raised and they are attracted to engineering and the relevance of engineering in address global issues humanitarian engineering. There is therefore a need to provide examples of engineering relevance in development and promote transformation and innovation in engineering education – to combine theory and practice as in the original Humboldt model, linking fun and fundamentals and demonstrating that engineering can be cool. Promoting public interest and understanding of engineering will also promote the relevance of engineering to address global issues such as poverty, sustainability and climate change. Promoting the relevance of engineering and humanitarian engineering in addressing such issues has been demonstrated in such initiatives as the Daimler-UNESCO Mondialogo Engineering Award and the many Engineers Without Borders groups around the world that are very attractive to students (Mondialogo, 2010).

Transformation and innovation in engineering education is important in updating engineering curricula and pedagogy to be less theory and formulae driven, involving more activity, project and problem-based learning, in more just-in-time, hands-on approaches, such as the Aalborg PBL model and related approaches. Other professions have moved in this direction – for example, medical education has moved toward more "patient based" learning. It is beyond time for engineering to do the same. The transformation of engineering education needs to address the need to respond to rapid change in knowledge, learning how to learn in a cognitive, knowledge-based approach with relevance to pressing global issues and challenges

Engineers are innovators and need to innovate in engineering education, based on problem and project-based learning for a problem-solving profession (UNESCO, 2010), linked to issues of relevance such as sustainability and humanitarian engineering and technology. In response to changing knowledge production and application, lifelong learning and continued professional development, there is a need for the increased use of ICT resources for student-centred learning, with limited lectures, where staff act as learning facilitators and mentors. There needs to be greater focus on the development and assessment of graduate attributes and the provision of learning and work space to facilitate student interaction. Transformative actions are required in the areas of knowledge systems in engineering, science, technology, relating to the social context and ethical issues in engineering and technology, improved data and information on engineering, the development of the engineering profession and organisations, engineering education and educators. The development of engineering policy, planning and decision making is also required, and the promotion of engineering as a separate but related aspect of 'STI' – SETI would be a more accurate descriptor.

Transformation and change does not come easy, however, and barriers may be encountered from people and institutions that do not see the need or rationale for change. Barriers to change in engineering educators and universities relate to the traditional focus on research rather than education that does not reward effective educators, a culture of lecturing rather than learning, space designed for lecturing, conservative attitudes resistant to change and leaders who rarely see the need for transformation. The traditional rhetoric of the need to maintain educational 'quality' is undermined by overloaded academics, declining standards and funding, increasing bureaucracy and focus on revenue, 'efficiency' and university profile, especially university ranking and KPIs (Hill, 2012). Accreditation authorities may also be conservative, slow to change from a traditional approach to one of graduate attributes and professional competencies, but – who can be progressive and drive change, for example the American Accreditation Board for Engineering and Technology (ABET) and the international Washington Accord. The failure to transform engineering education, to address the challenges noted above, will result in insufficient engineers, technologists and technicians around the world, insufficient engineering educators, consequent impact on developing countries and continued brain drain from poorer developing countries - who can ill afford to lose engineers, effectively subsidising richer developed countries, creating borders without engineers!

CONCLUDING REMARKS

As for the prospects for change, and associated issues and challenges, in many countries there is limited support of SDGs, sustainability, climate change – in Australia, for example, the Coalition government makes little mention climate change or the SDGs, and appears to remain in thrall to the coal industry. This is partly due to: powerful unseen lobby of coal and oil interests, as in many countries, and the fact that the future is beyond the horizon of many politicians, where short term issues such as jobs and growth and re-election take priority. There is also some interest in possible technological, magic bullet "solutions", for example geoengineering (solar radiation management and CO2 capture) on a planetary scale, with equally possible mega ecological impacts, which may become the ultimate technological fix. There is clearly a need for an informed approach to issues, challenges and opportunities, and a transition to a culture of sustainability, cleaner and greener engineering and technology.

There is clearly also a need for real solutions, rather than quick fixes, based on real policies, pathways and actions. Engineering knowledge development and application is vital for sustainable social and economic development, climate change mitigation and adaptation, and engineering needs to be at the centre of the sustainable development and climate change debate and policy agenda, with sustainable development at the centre of the engineering agenda. This was at the heart of the engineering, technology and innovation considerations in the "limits to growth" debate in the 1970s regarding population growth and resource use. Increased efficiency of technology in resource productivity has later been emphasized in the ongoing Factor Four (1997) and Factor Five (2009) debate regarding improvements in resource productivity of up to 80% (Factor Four, Factor Five).

Actions that are needed for the engineers of today and tomorrow focus on the need for tools to achieve sustainable resource use and reduce global warming in line with the 2015 Paris Agreement aims on CO2 emissions (despite recent reports by IPCC that this will be almost impossible). We need political will, but, acknowledging the poor prospects of this, we need action by engineers in terms of policies, pathways, lobbying and education. Policies and pathways are required to support the transition to sustainability through green engineering. Advocacy and lobbying are required that use the techniques of the established lobbies, but using real not fake information. Engineering education needs to develop curricula, learning approaches and appropriate accreditation – for example based on the Washington Accord graduate attributes and professional competences. We do not have long – we are 5 minutes before midnight on geological clock, and there could be adverse tipping points. Hopefully we can look back in 50 years time and see how easy this was, synergistically. Otherwise we will have the opposite – dysergy and climate and human disaster.

In conclusion, it is important to re-emphasise that engineering will be vital in achieving the SDGs. There is therefore a great need to promote engineering as part of the solution, especially with respect to climate action, SDG Goal 13 - without this, no other SDGs will be achieved. Engineers need to articulate policies and pathways to address the SDGs and need to present actions and roadmaps for engineering and each SDG. There is also a need to prepare engineers of today and tomorrow – through engineering education and CPD in terms of cleaner and greener engineering, and especially enhanced resource productivity. Finally, there is a need for advocacy and lobbying of government, and intergovernmental organisations, and a need for champions in terms of people, institutions, companies and countries.

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BIOGRAPHY

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