The Institution of Engineering and Technology

Sustainable manufacturing
Starting the journey

The destination

What will truly sustainable manufacturing look like in the future? Is sustainable manufacturing actually possible? Will it produce artefacts at the speed and volumes of today? Will its products be as complex, as exciting or last as long? The answers to these questions may be "yes and more so". What is certain, is the need for resource efficient manufacturing processes e.g. materials, energy and water. Failure to secure such efficiencies could result in resource depletion, scarcity and further environmental degradation. The ability to meet the needs of society in a sustainable way is key for manufacturing.

> "Sustainable manufacturing is defined as the creation of manufactured products that use processes that minimise negative environmental impacts, conserve energy and natural resources, are safe for employees, communities and consumers and are economically sound."
> US Department of Commerce 2013

Within post-industrialised nations over the last generation the air is cleaner, waters are clearer and quality of life is better. We have more 'stuff', which in principle is not a problem but globally environmental damage is ever worsening. Is it our problem or someone else's?

Globally, the population is expected to rise from 7 billion today to 9.3 billion in 2050 (UN). The impact of this rise will be compounded by further urbanisation and increasing affluence in developing and developed nations.

As a result, the rising ecological burden on the planet will reach an estimated 2.9 planets (WWF 2012) by 2050. Current plans for change stretch to 2050 and yet many children born today will still be alive in 100 years.

Design & Production

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Even if reserves of resources will last for the lifetimes of our very youngest in society, there is the challenge of whether it can be used; to keep within global warming targets we can only use a fraction of the known fossil fuel reserves (McKibben 2012). For adults 2050 may seem too distant to comprehend, but for the youngest in our societies this will be their middle age; around one-third of babies born in 2012 in the United Kingdom are expected to survive to celebrate their 100th birthday (UK Office for National Statistics).

There are behaviours and conditions in societies that are now considered unacceptable independently of the law. Child labour, unsafe conditions and smoking in public buildings are now not acceptable in the developed countries. Our legacy must ensure that future generations have waste, resource inefficiency and pollution high on their list of what is unacceptable.

Nationally, the demographics of sudden rises in population or proportion of the elderly in society are presenting challenges to the enhancement and maintenance of living standards. Many nations have challenges in sourcing and processing energy and water, either because of the security of supply or the reliability of supply.

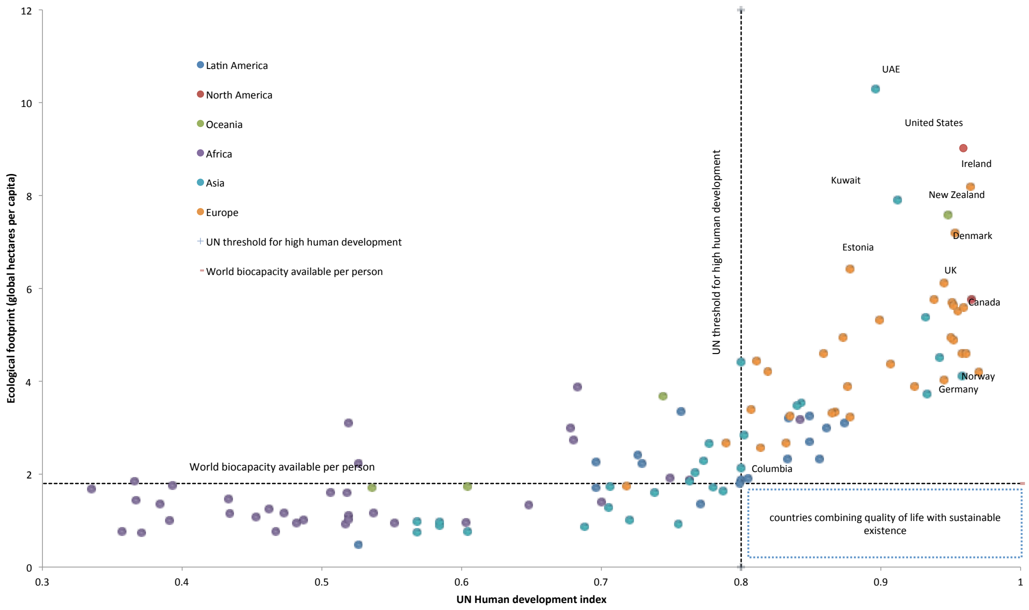
Where are we now?

If we consider the quality of life together with the ecological impact, there are now no sustainable nations. By considering the human development index (that combines life expectancy, education and GDP per capita) with the ecological footprint (that is dominated in developed nations by the carbon footprint), Columbia is one of the few nations that comes close to the UN's threshold high human development and one planet living (see graphic).

> "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"
>
> World Commission on Environment and Development (WCED), 1987

CO_2 emissions and life expectancy correlate for third world and developing nations bringing increased quality of life with increased consumption. But only up to a point. The relatively excessive CO_2 emissions of developed nations does not increase the life expectancy of their citizens; whilst the USA emits 10 times and the UK five times the carbon of Costa Rica, life expectancy is the same (Wilkinson & Pickett 2010). Hence it can be argued that a threshold level of CO_2 emissions brings high life

Figure 1: Ecological footprint against Human Development Index (HDI) (2006 data)



Sources: UN Development Programme 2009, Global Footprint Network 2010

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expectancy, further CO2 emissions can increase quality of life, albeit in a very expensive way.

Attitudes are changing, behaviours are changing, regulation is increasing, expectations are changing and what is and is not acceptable is changing. Examples are numerous and repositories of practices are developing. There are a number of actions that align to the waste hierarchy that gives highest preference to reuse and lowest to disposal. These can also be mapped to the lifecycle of materials (see industrial cycle graphic). Ideally, once materials have been extracted from the ecosphere, they should remain in the technical system, circulating by the shortest loops. The impact of any materials lost from the technical system back into the natural environment should be minimised.

Reuse: reuse is not a new phenomenon and some parts of developed nations are re-learning this discipline. The car market is an obvious example of reuse but others include books and even the humble bicycle. Industrial examples include the re-use of heat from one process by another, from within a company to across municipalities. Kalundborg (Denmark) is one such municipality in which heat and other wastes from companies are used as valuable inputs to other companies to establish a symbiotic relationship akin to natural systems.

Repair/Remanufacture/refurbishment: common in volume markets where origin of product does not override the (perceived) value available from a product, e.g. truck tyre re-moulds and photocopier market.

Recycling: whilst it does not retain the value of the above approaches it does retain some; industry and public accept the value of the activity from household waste to production scrap to end of vehicle life initiatives. Care needs to be exercised to ensure that the material can genuinely be re-cycled through a system rather than be down-cycled as a poor quality material for lesser uses, for example using glass for road infill.

Recovery: where the material value cannot be economically recovered in the current form then recovery is an option. Recovering heat from waste by burning is not an efficient use of resources but can be the best compromise in the absence of better recycling technology and disposal avoidance. There is a danger that the ‘zero waste to landfill’ targets motivate poor quality recovery at the expense of earlier strategies. It could be the case that landfill is an appropriate option whilst waiting for technology to better exploit the spent resource.

Disposal: this is the least favourite option as it returns no value to the industrial system and has most impact on the environment. Landfill is the obvious example here but extends to other areas such as discharge of treated water into rivers downstream of the water intake or venting valuable heat to atmosphere.

> “It may be a sobering thought to consider the number of decades over which companies globally have been working on the lean manufacturing philosophy from a starting point in which we knew most of the answers.”

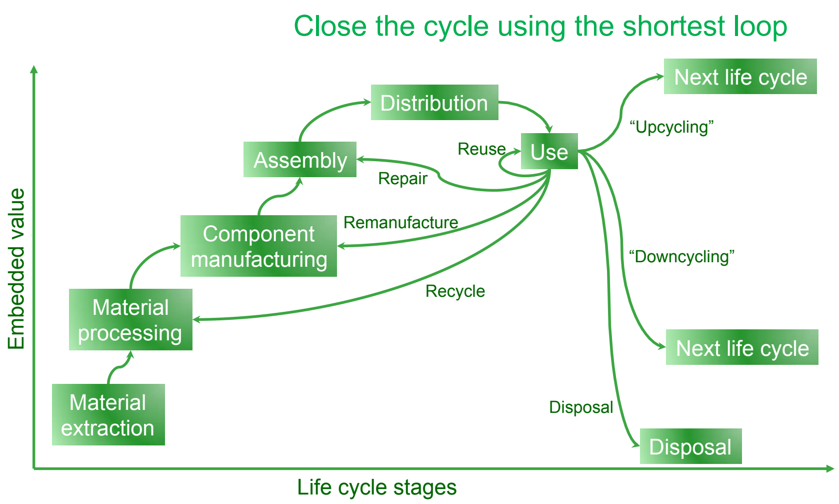

Figure 2: Retaining the value of material by keeping it in the industrial cycle (based on Despeisse et al 2012)

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Some of the activities are being delivered through the application of lean tools (that reduce waste) whilst some companies are developing their own focused eco-efficient, green improvement methods. These activities are a great starting point for improving resource efficiency by focussing on today's downstream industrial activities and reducing our current demand. However there are a number of challenges. We must understand how to extract resources more effectively from the part of the industrial cycle where the environmental impact is first felt and produces huge volumes of waste, whether minerals or agriculture. Additionally, new design and production thinking in the medium to long term is needed on material selection, material processing and product configuration.

Closing the gap

The gap between our current trajectory and that of the acceptable trajectory to ensure the current population does not compromise the living standards of future populations cannot be met with point solutions alone. New technology, new methods, new disciplines and new values each in isolation will be insufficient and possibly ineffective. For example, designing products that use less energy may give room for us to use those products more (the rebound effect). Solutions need to be holistic.

The notion of cradle-to-cradle (McDonough & Braungart 2002) in which we understand how to design products, use them and ensure that at the end of their life they have minimal impact on the environment is well established. As a concept this is 'easy' to understand but how to popularise and replicate this across the entire industrial system it challenging. Design for X methods that include design for lower energy use, design for disassembly and design for through-life exist but rules, principles, tools, software, skills and disciplines need to be developed and communicated. Critically, the dissemination speed must be more rapid than at any other period of recent industrial change. To meet the challenge of sustainability we need to train and educate vast numbers of operators, technicians and engineers to be able to implement solutions using new techniques and technologies.

Where do we need to be?

A vast majority of manufacturing companies now have targets for improvement. Metrics may include CO2 reduction, water reduction, percentage sustainable material content. Some of these may be in the production stage, others in the use phase. Some of these targets are ambitious and necessarily so. A minority of companies are now publishing these targets as it is taken as a given; they, as well as the rest of industry, must at the very least meet these targets. Well-known companies have pledged to halve their greenhouse gas, waste and water impact within the next 10 years. Corporate websites show both the targets and the progress towards those targets and companies are open about shortfalls. Inspirational leadership from industry leaders capture the long term perspective of the change required (see Ray Anderson quote) and what we think might be good now will not be considered so in the future.

Dramatic reductions in use of resources have obvious immediate impacts in purchasing cost and CO2 output. However, there are less obvious but other significant benefits that should not be overlooked. The reduction in resource use leads to greater resilience at times of scarcity, either directly from market supply and demand or more subtle effects such as periods in which utility companies may restrict demand for high use category customers and the ability for a business output to grow when land, water supply, power supply and the like are constrained by local conditions. Additionally, the management of waste either during the production phase or at the end-of-life phase will be improved to reduce total waste and increase the quality of waste for reuse elsewhere. In the production stage this could include heat, water, product materials or consumables. It is interesting, that in the current era, visitors to companies are fascinated by the forward production but are less interested and rarely see the significant facilities handling waste material, heat and returned products. From an engineering perspective, this is now the harder and potentially more interesting problem.

Governments use a mix of incentives and banning (or "carrot and stick") to change behaviours. Correction to the lack of information through public advertising and standardisation of the way information is presented, such as product labelling, exist on one side of a spectrum of government strategy.

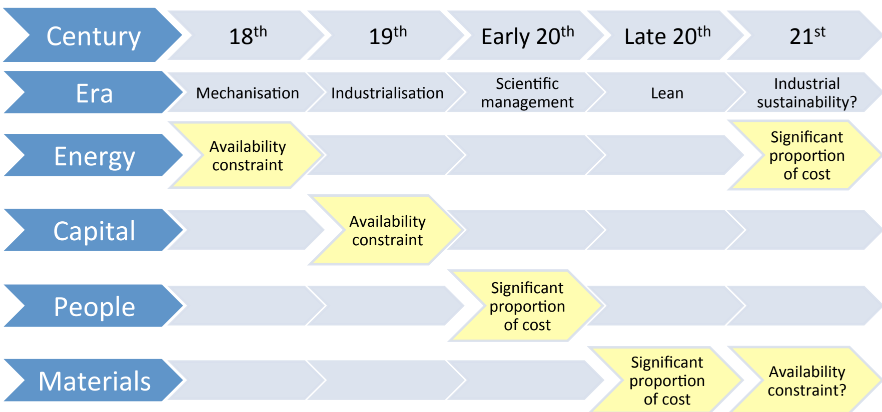
Regulatory reform, subsidy removal and tax occupy the middle ground of offering incentives. Finally the other end of the spectrum brings in standards and at the extreme, bans. Over the decades government legislation has moved from command and control immediate results orientation to market instruments to correct dysfunctional structure to hybrid approaches that foster more responsible, participative roles (Graedel et al 2003). Given the challenges, whilst rates of change may vary globally, it is a certainty that legislation will become tougher and more punitive. It is likely that more materials will be banned in the future and activities limited either in the producer country or the consumer country. For example, limiting the energy consumption of a product or its material composition.

For companies, drivers for change towards sustainability come from many quarters. It may be the values of the CEO or champions within the organisation, though more often the motivation is external. The motivation could be directly related to business activities such as cost pressures, resource scarcity, customer preference or the ability to grow with the same or less environmental impact. Calculation of embedded carbon in raw materials and finished goods as well as the introduction of extended producer responsibility will have a direct impact on behaviour. In addition, there are many well known cases where societies, in particular campaign groups, have changed company behaviours and values.

The advances in manufacturing over the centuries have been impressive, especially so over the last three decades. We can now make things faster, in higher volume and with higher functionality than ever before. Manufacturing has developed over the centuries (see graphic) to harness energy, organise people and transform materials. The new post-lean era heralds new constraints, particularly around materials and energy resulting from economic and legislative drivers. Companies, governments and societies value growth and value efficiency as do engineers! Within a generation, industries within developed nations have dramatically increased production and yet will have dramatically reduced the number of people employed. In the UK over the last 20 years, manufacturing output has remained approximately the same whilst employment has nearly halved (UK Commission for Employment and Skills). So is our obsession with, and understanding of, "efficiency" counter-productive? As we have developed and become more "efficient" we have employed fewer members of society, consumed more from the environment and produced ever more waste than we can expect the environment to somehow absorb.

> "Someday people like me will go to jail"
> Ray Anderson, founder and chairman of InterfaceFLOR

Figure 3: Eras in manufacturing and concerns



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Why it's our problem?

So what is the responsibility of a manufacturer? Is it to produce a product with less impact? Should that impact be measured only up to the point of consumption or throughout the entire use phase? At the end of life, is resource that is returned for recycling a problem or an opportunity? Perhaps we should measure how much of a product is returned after use. Indeed, changing our thinking from 'manufacturers' being those that transform materials to being custodians of materials could ensure that the value of the material is retained. There are many companies that operate in the space of 'product service systems' in which the product is sold as a service rather than as hardware and therefore reuse and refurbishment are priorities. The copier market is an obvious example.

Engineers are members of society, employed to design, manage and improve industrial systems. Engineers are fascinated by how things work and how they can use their ingenuity and problem solving skills to tackle difficult challenges. Our industrial systems exist within our societies, which exist within the environment. Industry must draw resource from the environment to serve societies and in turn find a way to continuously reuse the resource in a closed loop cycle or safely dispose of the resulting wastes in the environment. The challenge for engineers is creating innovation in the industrial system to produce great new things as well as innovating industrial systems without detriment to the environment for our activities for decades, centuries and millennia to come. Targets for 2020 and 2050 have been set but the configurations of industrial systems and our journey to get to them, need to be mapped out in detail.

Specialists are required to address technical and social aspects of resource use in the cycle of design, source, make, deliver, use, return, waste and disposal. Specialists are also required to understand this cycle in the context of the technical and eco systems to maximise value to society whilst minimising net impact on the environment.

The challenge

The challenge we have is in clearer understanding how to separate the industrial system from the environment. We need better methods and technology and disciplines to ensure that what is removed from the environment and brought into the technical system can either be kept in the within it or returned safely to the environment. This has to be achieved without long term detriment. Manufacturers need to continue to provide goods and services to maintain the health and wellbeing of the population whilst reducing consumption of the planet's resources or returning wastes to the environment more slowly than the regeneration rate. Companies will need to focus on the 'hot spots' in the overall value chain to reduce impact from raw material extraction, manufacturing, use and end-of-life. This challenge is beyond production operations. We must rethink product design, process design and the overall value chain for the creation, use and end of life of products to start the journey towards sustainable manufacturing.

You can get involved by contributing your views on the Design and Production Sector community at

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Useful resources

Carbon Trust, www.carbontrust.co.uk

ES-KTN (Environmental Sustainability Knowledge Transfer Network) https://connect.innovateuk.org/web/sustainabilityktn/overview

IEMA (The Institute of Environmental Management and Assessment) is the largest professional body for environmental practitioners in the United Kingdom and Worldwide approaching 15,000 members.

Centre for Industrial Sustainability, www.industrial-sustainability.org