The Royal Academy of Engineering

Engineering for Sustainable Development: Guiding Principles

‘Humanity has the ability to make development sustainable – to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs.’

From *Our Common Future* (The Brundtland Report) – Report of the 1987 World Commission on Environment and Development

Front cover picture credits:

WEEE man (top left)
The RSA WEEE man is an environmental awareness initiative developed by the RSA (Royal Society for the encouragement of Arts, Manufactures and Commerce) and Canon Europe – and is a visual reminder of the amount of waste electrical and electronic equipment (WEEE) one UK citizen will generate in a lifetime.

The WEEE man concept was developed by Mark Freemantle and Hugh Knowles – both RSA Fellows, it was designed by Paul Bonomini and built by Stage One.
For more information visit **www.WEEEman.org**

Mossley Mill (top right)
The 250 year old Mossley Mill site – eight miles from Belfast – was rescued from demolition when Newtonabbey Borough Council decided to save and renovate it. In 2000 the Council took over the Mill as its new Civic headquarters.
From being owned and operated by one of the district’s largest employers as a flax mill, the building now employs approximately 150 people and is an attractive location for residents and visitors.
© Newtownabbey Borough Council and University of Ulster

Motorway car picture (bottom right)
© Highways Agency.

Wind turbines (bottom left)
© National Wind Power

Engineering for Sustainable Development : Guiding Principles

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Engineering for Sustainable Development: Guiding Principles

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List of abbreviations used

AISE	International Association of Soaps, Detergents and Maintenance Products
BPEO	Best Practicable Environmental Option
CPD	Continuing Professional Development
CSR	Corporate Social Responsibility
DEFRA	Department of the Environment, Food and Rural Affairs
EA	Environment Agency
IPCC	Intergovernmental Panel on Climate Change
IPP	Integrated Product Policy
NGO	Non-Governmental Organisation, for example Greenpeace or Friends of the Earth
ODPM	Office of the Deputy Prime Minister
RAEng	The Royal Academy of Engineering
RoHS	Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment
SD	Sustainable Development
SME	small or medium-sized enterprise
UK-SPEC	UK Standard for Professional Engineering Competence (published by the Engineering Council UK)
WEEE	Waste Electrical and Electonic Equipment

Foreword

Sustainable development, especially since the 1992 United Nations Conference on Environment & Development at Rio de Janeiro, has become an increasingly important theme in local, national and world politics, and increasingly a central theme for the engineering professions around the world. The sustainable development concept requires of all of us – as engineers and citizens – to consider much more widely than before the impact of our own lives and of the infrastructure and products we produce, both geographically and temporally.

With infrastructure and engineering products and processes becoming increasingly complex, engineers need to integrate consideration of whole-life environmental and social impacts – positive as well as negative – with the mainstream and commercial aspects of their work. Wise use of natural resources, minimum adverse impact and maximum positive impact on people and the environment are the targets. As the Introduction to this Guide makes clear, time is not on our side to make the necessary changes in our way of life if we are to live within the limited carrying capacity of Planet Earth.

The practice of design has also concerned the Academy for many years. In keeping with its mission of encouraging excellence in the practice of engineering, The Royal Academy of Engineering has, since 1998, operated a scheme for the appointment of Visiting Professors in Engineering Design for Sustainable Development at universities in the UK, with a total of 26 appointments made so far. The principal aims of the Scheme are to assist – across all engineering teaching, not just design – in the generation of teaching materials for the undergraduate curriculum based on real-life case studies, and to enhance the understanding of sustainability and sustainable development amongst academic staff and students alike.

The result we seek is that graduates leave their courses inspired by, and with understanding of, both the concept of sustainable development and the place of their chosen engineering specialism in delivering it, and with relevant knowledge and skills to apply in the engineering profession.

One of the Scheme's objectives has therefore been to create a set of case studies from the practical experience of the Visiting Professors and to distil a set of general Guiding Principles that are encapsulated in or illustrated by the case studies. This Guide fulfils that objective and I hope that it inspires you to make a difference to the world through sustainable development based upon wise practice of engineering.

Photo: Royal Academy of Engineering

Lord Broers FREng FRS
President
Royal Academy of Engineering

Preface

This Guide is aimed primarily at:

- Academic Staff in University Engineering Schools and Departments, who need or are considering how to embed the essence of engineering for sustainable development into their courses and teaching

In addition, the following groups are also seen as important target readers and we hope they will also find the Guide useful:

- students on engineering undergraduate and post-graduate degree courses
- teachers in Universities in related disciplines, with which engineers have to work
- training managers in any engineering-related organisation, who will be able to use it to frame their company's Continuing Professional Development (CPD) in sustainable development and design
- individual practising engineers at all levels, who will be able to use it for their personal CPD
- those concerned with and running the professional development schemes and examinations of the engineering institutions
- those concerned with the procurement of engineered products from consumer products to utilities and infrastructure

The overall structure of the Guide is as follows.

- Section 1 provides an Introduction to the Guide and why it has been produced, plus some fundamental definitions, which – it is hoped – provide sufficient background to sustainability, sustainable development and their interactions with engineering, even for those new to the subject
- Section 2 provides an illustration of sustainability issues in engineering through summaries of seven examples selected mostly from case studies generated by the Academy's Visiting Professors Scheme
- Section 3 presents a set of 12 'Guiding Principles' of Engineering for Sustainable Development distilled from the Visiting Professors Scheme, together with a table of links between the Principles and the examples
- Section 4 provides advice on the application of the Guiding Principles in practice by relating them to five main stages in any engineering project or enterprise
- Section 5 indicates how to take the Guiding Principles into action – in university teaching and in engineering practice

The longer-term aim is for this Guide to be a key component of resources to assist, in particular, academic staff who are teaching on UK engineering degree courses.

This Guide can be seen as complementary to the existing Royal Academy of Engineering Guide *Educating Engineers in Design* (The Royal Academy of Engineering, 2005) and to the Academy's Report, *The Societal Aspects of Risk* and its companion documents (The Royal Academy of Engineering, 2003). It should assist in delivering the sustainable development competencies required by the UK Standard for Professional Engineering Competence. (Engineering Council UK, 2004).

The Guide is published both physically and electronically.

Acknowledgements

Our thanks are due to a wide range of people involved in the preparation of this Guide, and in teaching and practice of engineering for sustainable development. In particular, we thank Professor Jim McQuaid, Visiting Professor in the School of the Built Environment, University of Ulster, and Professor David Fisk, Department of Civil and Environmental Engineering, Imperial College, London, for their tireless work in developing early drafts as well as commenting on the later drafts of this Guide. We also give special thanks to Professor Roland Clift of the University of Surrey for his significant contribution to the Introduction. Each of the Visiting Professors who have contributed to the examples presented in Section 2 is indicated at the head of each example. In addition, we gratefully acknowledge the contributions of text and/or comments by members of the Academy's Sustainable Development Education Working Group, plus other members of The Academy and wider profession.

Further information on some of the case study material generated by The Academy's scheme can be found from the References, including the websites listed there.

Finally, we think it important to set the Guide into the current context of government and business policies. The new 2005 UK strategy on sustainable development, *Securing the future,* has been published and needs to be taken into account by those using this document in their work. In the strategy, the UK Government sets out the set of shared principles that it will use to achieve its sustainable development purpose, and demonstrates that it has been active in recent years developing approaches and principles for sustainable development in the UK. The latest strategy has been agreed by the UK Government, the Scottish Executive, the Welsh Assembly and the Northern Ireland Administration. They have brought together and built upon the various previously existing UK principles to set out an overarching approach, which is summarised in the figure below.

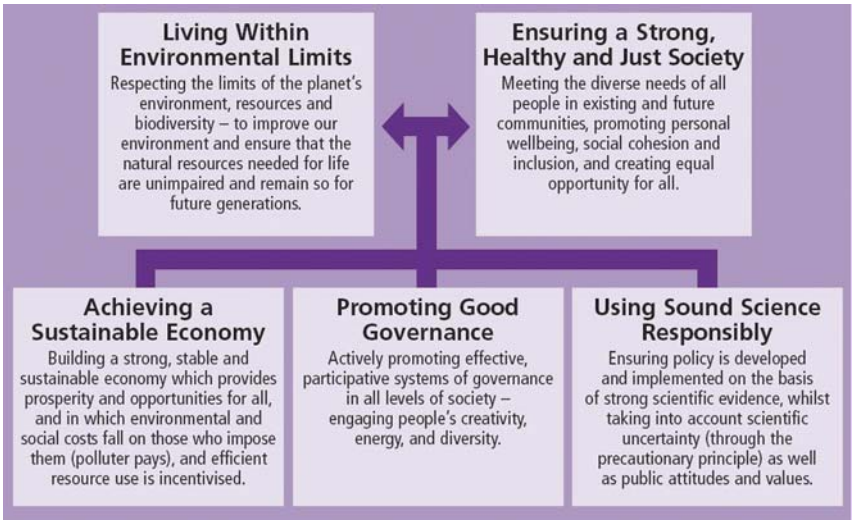

Figure 1: The principles of sustainable development in the 2005 UK strategy 'Securing the future'

In addition to this national policy picture, the development of action in these areas is also increasingly influenced by Corporate Social Responsibility (CSR) Policies in industrial and commercial organisations. Whilst this publication does not specifically address the CSR agenda, many of the Principles are equally compatible with a CSR approach as with one based on the concept of sustainable development. Whatever the basis for action, what is important is the direction and urgency of that action aimed at improved engineering practice.

Richard Dodds and Roger Venables, Editors

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1 Introduction

1.1 Why Engineering for Sustainable Development?

It is increasingly recognised, in public discussion and political discourse, that many of the practices and lifestyles of modern society – particularly but not exclusively industrialised society – simply cannot be sustained indefinitely. We are exceeding the capacity of the planet to provide many of the resources we use and to accommodate our emissions, while many of the planet's inhabitants cannot meet even their most basic needs.

This problem, of recognising the need to live within constraints and to ensure more fairness in access to limited resources, lies at the heart of the concepts of sustainability and sustainable development. It is something new in human history – the planet is full and we have no new geographical horizons to move to. This Guide is intended to provide an introduction to how sustainability and sustainable development affect the way in which engineering must in future be practised.

Sustainable development is the process of moving human activities to a pattern that can be sustained in perpetuity. It is an approach to environmental and development issues that seeks to reconcile human needs with the capacity of the planet to cope with the consequences of human activities. It is useful to represent the constraints that make sustainable development an imperative in the form of a simple Venn diagram (Figure 2).

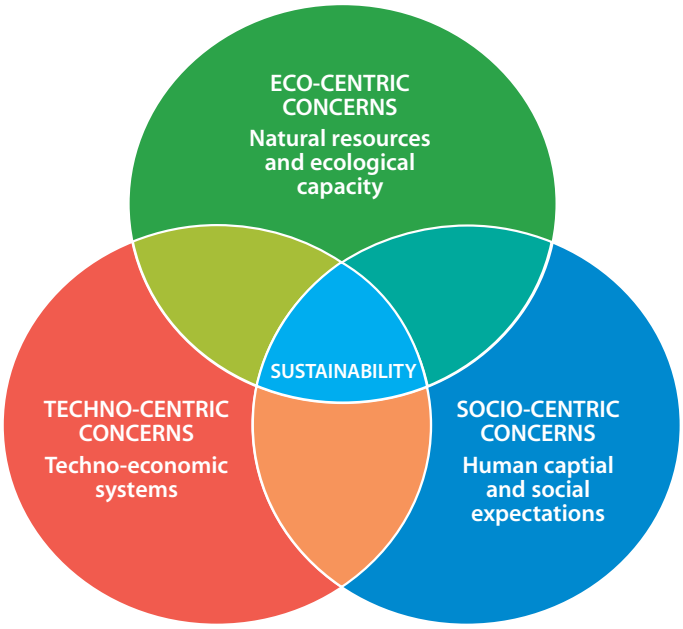


Diagram prepared by Crane Environmental Ltd after an original idea by Roland Clift

Figure 2a: Three dimensions of sustainability

'Techno-centric concerns', which encompass techno-economic systems, represent human skills and ingenuity – the skills that engineers must continue to deploy – and the economic system within which we deploy them. 'Eco-centric concerns' represent the ability of the planet to sustain us – both by providing material and energy resources

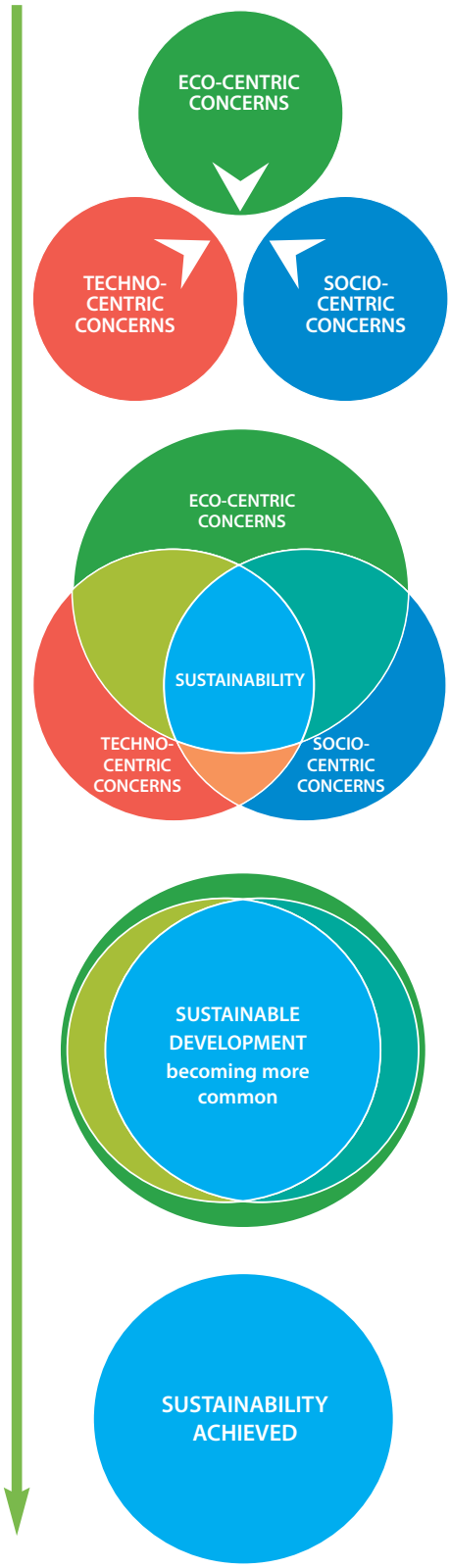


Figure 2b: Moving towards Sustainable Development

and by accommodating us and our emissions and wastes. 'Socio-centric concerns' represent human expectations and aspirations – the needs of human beings to live worthwhile lives, summed up by the phrase in the UK Government's interpretation of sustainable development as 'a better quality of life for everyone, now and in the future'.

Sustainability can be thought of as the region in the centre of Figure 2a where all three sets of constraints are satisfied, while sustainable development is the process of moving to that region. Alternatively, sustainable development can be thought of as the process of moving the circles together so that they almost completely overlap but with the societal and techno-economic circles sitting within the environmental circle, at which point all human activity is sustainable – see Figure 2b.

Although Figure 2 is simplistic, it reminds us that sustainability means living within all three types of long-term constraint: technology cannot be deployed as though it has no environmental or societal implications. Engineers must therefore be key players in sustainable development, and have an obligation as citizens not just to act as isolated technical experts. Achieving sustainability through sustainable development will require some significant shifts in behaviour and consumption patterns. Often it will be – and should be – engineers who lead processes of making decisions about the use of material, energy and water resources, the development of infrastructure, the design of new products and so on. One implication is that engineers must recognise and exercise their responsibility to society as a whole, which may sometimes conflict with their responsibility to the immediate client or customer.

Engineers will still be called on to design and manage complex systems, or simple systems to meet complex sets of demands. However, sustainable development redefines the contexts within which these skills must be deployed. It is a new integrative principle, not a new set of tools, so that the concept cannot simply be regarded as an 'add-on' to existing engineering skills and educational programmes. This Guide is aimed at providing a set of Guiding Principles and understanding to help promote more-sustainable design and guide their application in the practice of engineering, illustrated through summaries of selected real-life examples.

1.2 Scope of the Guide

In preparing this Guide, we have taken a wide definition of engineering, so its scope consequently ranges more widely than only engineering design. We have taken an holistic view, recognising three main issues.

- Firstly, engineering and sustainable development are closely linked, with many aspects of sustainable development depending directly and significantly on appropriate and timely actions by engineers
- Secondly, engineering design is only a part, though a very important part, of the extended engineering process of analysis, synthesis, evaluation and execution, as summarised in *The Universe of Engineering – A UK Perspective*, (The Royal Academy of Engineering, 2000)
- Thirdly, engineering input to sustainable development solutions must be provided in partnership with many other interests. Such engineering input begins with participation in framing the issue of concern or how it is described in terms of the

actual needs or wants underlying the issue to be addressed. The input needed then proceeds through the development and detailing of the engineering dimension of options, to the implementation of the option that is judged as the most attractive by and to the variety of stakeholders. It is also vital that the engineering input includes consideration of all of the consequences of that implementation into the future

This holistic and whole-life view of engineering serves a dual purpose.

- For the audience of academic staff, students and engineers in practice, it provides the overall framework within which engineering design practice has to fit. It emphasises that, for sustainable development to be achieved, professional practice in engineering needs urgently to have a wider compass than the development of elegant solutions to narrowly specified technical problems
- For the wider audience of the Guide among the many people outside the profession, we trust it will help to demonstrate that engineers are addressing sustainable development issues in their work, and are taking steps to make a sustainability-orientated approach central to the way engineering decisions are taken

1.3 Definitions and undefinable principles

The literature is full of definitions of sustainable development, starting with *Our Common Future* (the 1987 Report of the UN World Commission on Environment and Development, commonly known as The Brundtland Report), which contained the statement:

> *'Humanity has the ability to make development sustainable – to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs'.*

One of the reasons for the plethora of definitions is that 'sustainability' and 'sustainable development' are very rich concepts. The philosopher Michael Banner (1999) has likened them to justice, which has been recognised as an important ethical principle since at least the time of the Athenian republic, but which has never been capable of one succinct definition. However, that does not mean we should ignore the concept. It is therefore very important for engineers to gain a feel for sustainable development so that, as with concepts like justice, they can recognise it as a guiding principle to be interpreted for each instance in which the principle is needed.

The goal is sustainable living – being able to live on Planet Earth for the indefinite future – but recognising our impact on other people inhabiting the planet both now and in the future, indeed many generations in the future. This is why some authors and politicians have referred to sustainable development in terms such as 'We don't own the earth; we hold it in trust for our children' (and, we should add, our grandchildren, and their children, and…). This is sometimes known as the principle of inter-generational equity.

It sits alongside the responsibility to ensure adequate quality of life for all the current inhabitants of the planet, which can sometimes seem more pressing and problematic, and which is sometimes known as the principle of intra-generational equity. However, considering intra-generational equity reminds us that both engineering and consumption have world-wide implications: engineering is an international profession, but international trade can 'export unsustainablity' so that 'meeting the (supposed) needs' of one group of people can have serious negative impacts on people in other countries.

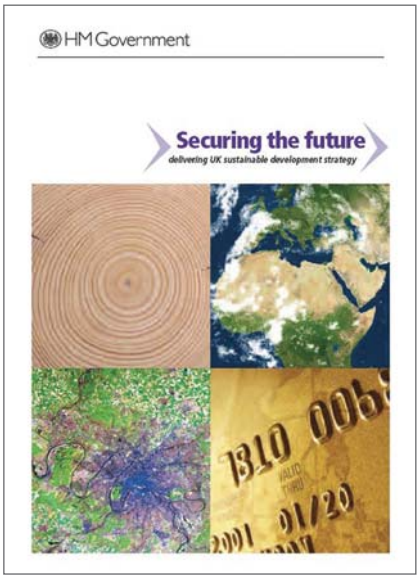
Figure 2 introduced the idea that sustainability has three pillars – environmental, social and techno-economic – and that, in addition to the constraints implied, building on these pillars provides major opportunities for engineers and engineering. Sustainable development is thus not simply a matter of trading off positive impacts in one area against negative impacts in another. A successful development builds on the three pillars and achieves economic success, social benefit and high environmental quality together. On the other hand, an activity that causes environmental damage or social disquiet, or that results in economic loss or waste of public funds, should be characterised as un-sustainable. Measuring success against all three factors at the same time is often referred to as the 'triple bottom line' approach.

An alternative to the three pillars approach is to consider sustainable development as seeking to preserve and enhance what are sometimes called 'the five capitals' and then 'living off the interest'. In this context 'enhance' often does not mean simply 'increase' but to improve matters, such as quality of life or quality of environment.

The five forms of capital that determine the options available to future generations are:

- human (the peoples of the world)
- environmental (the wider environment, flora, fauna and resources)
- social (our collective ability to govern ourselves and enhance human well-being)
- financial
- manufactured (all engineered products, built infrastructure and other physical assets)

Just like the three pillars, the extent to which the five forms of capital are inter-changeable or substitutable is limited. So, on this model, a sustainable development is one that utilises human, environmental and financial capital to enhance or increase human, social, environmental, financial and/or manufactured capital.



Meeting the requirements of the UK Sustainable Development Strategy is part of the challenge ahead

1.4 The challenge ahead

The Principles of engineering for sustainable development presented in this Guide, together with the guidance on its application in practice, should assist all involved in engineering to make their vital and urgent contribution to society to:

- drive down the adverse environmental and social aspects of engineered products, services and infrastructure
- dramatically improve their environmental performance
- improve the contribution of engineering products, services and infrastructure to a high quality of life
- help society to move towards a significantly more-sustainable lifestyle
- ensure products, services and infrastructure meeting these criteria are competitive in their marketplace and, ideally, the most competitive

This task is vital and urgent, and demands innovation, creativity and other traditional engineering skills, alongside an ability to work with the many other disciplines involved. It also requires a new view of the world, and a preparedness to adopt new ways of working and thinking about the impacts into the future – negative as well as positive – of engineered products, processes and infrastructure.

2 Examples of sustainability issues in engineering

Let us examine the concepts of sustainable development through summaries of projects, products and actions from across the engineering disciplines. Our aim is to demonstrate the crucial connections between sustainability, sustainable development and engineering, and the vital role of engineers and engineering in delivering sustainable development. Consider the following seven examples, most of which are based on case studies developed by Academy-sponsored Visiting Professors:

- Civil Engineering – Jubilee River
- Chemical & Manufacturing Engineering – laundry cleaning products
- Walking the talk: embedding sustainable development into an organisation – Glasgow University
- Product design in Electrical & Electronic Engineering – mobile phones
- Civil Engineering & Building – Mossley Mill regeneration in Northern Ireland
- Balancing positive and negative impacts – the case of catalytic converters
- The energy challenge

Where available, references to further detail on these examples are given in the References on page 46.

2.1 Civil Engineering – Jubilee River

Roger Venables, Visiting Professor in the Faculty of Engineering, Queen's University, Belfast

Too often in the past, flood alleviation channels have been constructed as hard-surfaced channels that added no or very limited amenity or wildlife value to the communities and landscapes into which they were introduced. However, Jubilee River, the name chosen following a local public competition for the £100 million Maidenhead, Windsor and Eton Flood Alleviation Scheme, represents a new way of constructing flood relief channels.

The UK's River Thames rises in Gloucestershire and flows eastwards to London and into the Thames Estuary and the southern North Sea. As with many major rivers, communities have grown up at strategic points such that, in times of sufficiently high flow for the river to overflow its normal channel banks, there is a significant risk of flooding properties close to the river.

A limited range of techniques is available to reduce this risk, primarily:

- upstream storage – the flooding of uninhabited land upstream of the vulnerable community, and the steady release of that excess water back into the river as capacity allows
- protective banks – permanent and/or temporary
- relief channels, traditionally trapezoidal in section and made of concrete

High flows in the Thames through Maidenhead, Windsor and Eton have caused, over the years, repeated and substantial flooding, and consequent damage and trauma for residents and businesses. After extensive studies, proposals were developed for a major 12 km long relief channel to alleviate flooding in these towns. What makes Jubilee River special in relation to the social and environmental aspects of sustainability is that it has been designed to have many of the environmental and amenity features of a natural river, including islands, reedbeds and shallow margins. The channel has an average width of 45 m and was designed to have a maximum capacity of 200 m^3/sec, and is similar in size and capacity to the River Thames channel in that location. A dry weather flow of 10 m^3/sec is passed down the channel to provide aeration and amenity value from the flowing water.

The creation of the Jubilee River significantly reduces the risk of flooding to approximately 5,500 homes and 12,500 people in Maidenhead, Windsor and Eton, in addition to reducing the risk of disruption to road and rail networks, communications and utilities. It flows from just upstream of Boulter's Weir in Maidenhead to just downstream of Eton.

Although the new channel is aimed at reducing flooding risk, the proposers of the scheme (the Environment Agency's predecessor body, the National Rivers Authority) recognised that there were potential implications for a much wider area beyond the locality of the scheme, including significant lengths of the River upstream and downstream of the Scheme. Indeed, the solution and route eventually implemented involved the placing of the Scheme on the north bank of the Thames, although the greatest flood risk benefit accrues to communities on the south bank. Planners had allowed development in the flood plain on the south bank, whereas the planners for the communities on the north bank had restricted such development. The scale of the scheme, and its implications for the landscape, was also a significant consideration in the design.

These wider considerations and the scheme's scale led to a new style of solution – of a flood channel designed and constructed not as a traditional concrete channel but to be mostly unlined to look like a natural river, with numerous wildlife and public amenity features. In summarising the findings of the Public Inquiry into the Scheme, the Inspector said: "I find the evidence

Flooding from the River Thames into Windsor in 1947

Image from an Environment Agency leaflet

The route of the Jubilee River flood relief channel. Maidenhead is on the upper left, Windsor and Eton at bottom right.

presented strongly suggests that the scheme would be a uniquely attractive addition to the landscape between Maidenhead and Eton."

The design resulted from collaboration between a wide range of professionals – civil engineers, planners, landscape architects and ecologists. Amongst many other objectives, they sought to create a scheme that replaced habitat that had been lost from the local Thames corridor as a result of past land drainage works and 'channel improvements'. At the same time, the team needed always to keep firmly in view the Scheme's prime purpose as a functional flood alleviation Scheme. This combination of features in the design was strongly supported by the funding body for the Scheme, the Regional Flood Defence Committee, and met a clear objective to create as sustainable a solution as possible.

In the development of the need, and the framing of the challenge to be addressed by the designers, extensive consultation was undertaken with residents and others likely to be affected by the Scheme, and of course the consultation process continued through the Public Inquiry. Aspects of the design were changed as a result of input from those consulted.

However, during the consultation, some people asked for features to be included, which, in the end, could not be accommodated. For example, many would have liked the channel to be as navigable as the main Thames channel in this area, but the funding for locks at each weir was not available, quite apart from the practical design considerations involved such as the varying depth of the new channel.

Once the Secretary of State for the Environment gave approval in 1995, the intensive planning of the previous few years could be brought to fruition. Features of interest in the plan included:

- the construction of most of the bridges over the new channel before it was excavated, which not only made the construction processes easier, but also enabled movement of excavated material along the line of the channel and out onto major roads, rather than create congestion, nuisance and environmental damage along minor roads crossing the Scheme
- an early use in construction of geographical positioning systems for the control of excavation machinery, both for position and depth of excavation, and thus minimisation of over-digging and waste
- the use of excavated material for landscaping, and the sale of the surplus extracted gravel as a construction material for beneficial use elsewhere

The approach adopted was to create a permanent, landscaped asset for local communities. There is no doubt that, at the time, the sustainability-driven approach was innovative and involved some additional risks.

In the event, whilst the amenity and environmental enhancements have been almost universally welcomed, some engineering problems have been encountered. Unlined gravel channels rely greatly on established vegetation for their stability and are susceptible to erosion. The first major flow – of about two-thirds' design capacity – flowed down the channel in January 2003, less than 18 months after it was completed and before

Photo: Crane Environmental Ltd.

Planting schemes along the new watercourse included trees, shrubs and marginal planting as well as extensive reedbeds.

the vegetation was firmly established, and some unexpected erosion occurred. The causes of these problems are still being investigated and include consideration of how the design was refined as the project progressed. However, the problems underline the clear need, when adopting a sustainable development approach, to remain focused on the need, as far as practicable, that the product or system functions as intended, whatever additional environmental and socially-driven features are included.

Finally, it is important to recognise that the Environment Agency as client of the Scheme tried to deliver what they try to persuade others to adopt. The EA has a statutory responsibility to promote sustainable development and its vision encompasses the following themes for the future:

- a better quality of life
- an enhanced environment for wildlife
- cleaner air for everyone
- improved and protected inland and coastal waters
- restored, protected land with healthier soils
- a 'greener' business world;
- wiser, sustainable use of natural resources
- limiting and adapting to climate change; and
- reducing flood risk.

It can be seen from the above brief description that, in creating the Jubilee River, the Environment Agency was seeking to practice its proclaimed vision for itself and others. Although the balance between economic, environmental and social performance is still being studied, it is judged that the Scheme is much more sustainable than an inaccessible, concrete trapezoidal channel would have been.

Photo: Crane Environmental Ltd.

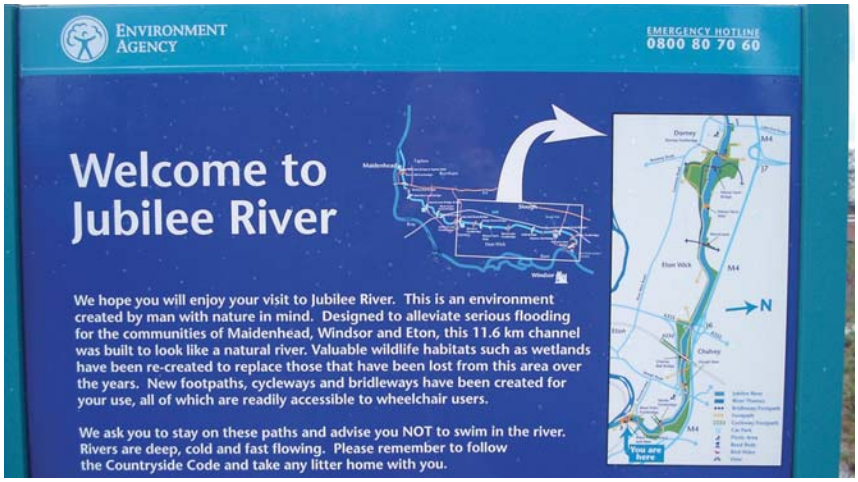


Photo: Crane Environmental Ltd.

Interpretation boards are provided along the bank and include information panels in braille.

2.2 Chemical and Manufacturing Engineering – laundry cleaning products

Richard Dodds, Visiting Professor in the Faculty of Engineering, University of Liverpool

The publicity surrounding sustainability is generally focused on global issues such as the ozone layer, or on products such as motor vehicles, where one can easily imagine significant environmental and social issues. However, manufacturers of many everyday products, purchased through supermarkets and which have a less obvious impact on the environment, also need to take sustainable development issues into account.

The market for laundry cleaning products is part of the fast-moving consumer goods (FMCG) market, and is surprisingly large and extremely competitive. The major international players are Proctor and Gamble, Unilever, Henkel and Colgate-Palmolive, together with strong own-brands from the large retailers.

The 'everyday' nature of the products and the fact that the major multinational players have been amongst the largest spenders on television advertising since the 1950s, when indeed the term 'soap opera' was coined, have placed them in the sights of consumer groups and various environmental and safety lobbies.

Over this period there has been a sequence of product changes – from soap powder to spray-dried synthetic detergents, the introduction of fluorescers, enzymes, and more-effective bleaches, the introduction of fabric washing liquids and,

by the 1990s, the move to concentrated products or 'compacts'.

Consumer concerns dealt with over the years have included:

- the foaming of rivers
- the use of fillers to 'bulk up' detergents
- the skin sensitivity aspects of enzymes
- the amount of packaging used
- the biodegradability (or otherwise) of packaging and the products themselves
- the use of live animals to safety-test new product components
- the contribution of detergents, together with fertilisers, to the addition of phosphates to our lakes, causing eutrophication

There have also been significant benefits. For example, bleach technology development, together with changes in consumer habits and washing machine design, has enabled the cleaning temperature to be progressively reduced in most cases to 40 and even 30º C, resulting in a major reduction in energy usage as well as reduction in damage to increasingly delicate coloured fabrics. All of these areas required considerable scientific and engineering innovation to identify and implement solutions.

The latest significant change in product form, from the late 1990s, has been the move to unit-dose formats of tablets for powder products, and capsules for liquid products. Both product forms had been attractive to consumers for many years, but adequate technology did not exist for their introduction. One challenge was to manufacture a tablet that was strong enough to withstand the high-speed factory packing line and yet be able to dissolve quickly in a washing machine at 40º C, or less – this was accomplished mainly by developing suitable binder chemicals holding the tablet particles together but which were fast-dissolving in the wash.

Another challenge was to prevent the tablet from lodging in the door of the washing machine or from becoming locked into a clothing item so that the tablet did not dissolve and release the cleaning components – this was overcome by some suppliers by the introduction of a net to hold the tablets, which required a change in consumer behaviour.

One major benefit to the environment of these new product forms is the avoidance of overdosing, thus reducing the usage of raw and packaging materials and reducing the impact on the environment of product wastes by many thousands of tonnes each year. It has been estimated that the switch to tablets alone has resulted in a reduction in materials used of over 250,000 tonnes each year.

Pictures courtesy of Richard Dodds

The introduction of compact washing powder tablets and liquitabs has led to a significant reduction in waste.

As a result of their previous experiences, the major manufacturers engage in life-cycle assessment processes for the introduction of any new products. The extent to which this has been communicated to the consumer is of interest because, in these markets, most consumers are unwilling, at the supermarket check-out, to compromise on price or quality for the benefit of the environment. In the event, manufacturers made the environmental impact information available through press releases and technical bulletins, but generally did not pursue this aspect in their advertising messages. This case is an example of the manufacturers being aware of the effects of the product on the environment through its total life-cycle and to some extent being ahead of consumers' concerns.

Inspection of detergent packs on the shelves currently will reveal the trademark Washright – see www.washright.com. The AISE (the International Association of Soaps, Detergents and Maintenance Products) has launched its Charter for Sustainable Cleaning, entitled *A common approach for all companies in the soaps, detergents and maintenance products industry in Europe*, aiming to promote and demonstrate continual improvement in the industry's sustainability profile. Currently, this focuses on using full loads, using the correct amount of cleaning product, using the lowest recommended temperatures and reducing packaging waste.

The industry has recognised the longer-term importance of sustainable sources of raw materials and of enabling consumers to carry out their laundry washing in their homes with the minimum impact on the environment, even if a significant emotional bridge between people's concerns over sustainability and their buying habits has yet to be built.

2.3 Walking the talk: embedding sustainable development into an organisation – Glasgow University

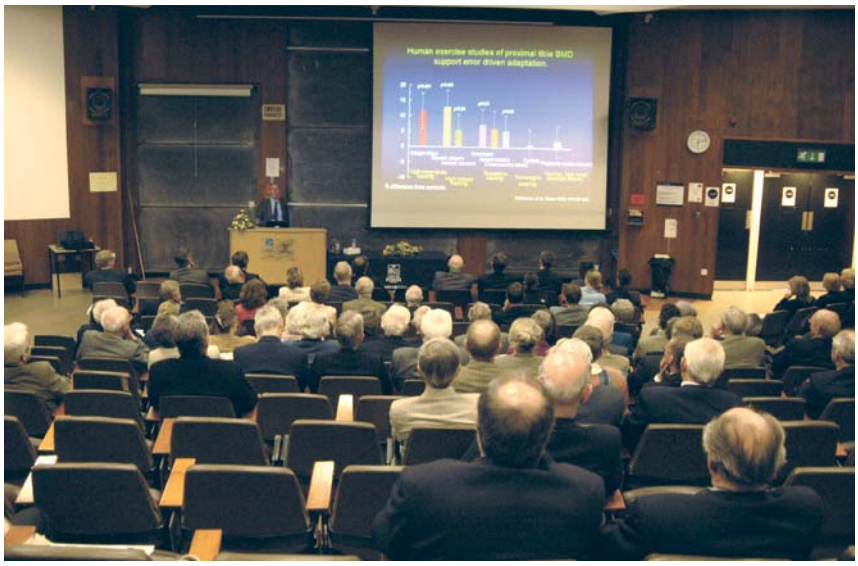
Barbara Carroll, Visiting Professor in the Faculty of Engineering, University of Glasgow

The sphere of influence of engineering design for sustainable development extends into all sectors of society, the activities of communities and to personal lifestyles. It thus applies to the running of all types of organisation, including universities. This section reviews work at Glasgow University, where the The Royal Academy of Engineering Visiting Professor and her colleagues have included in the scope of their activity the embedding of the concept of sustainable development in the running of the University and in the curriculum.

The work at Glasgow is one example of increasing attention within universities to the subject of sustainable development, and on how it affects the way they are run, what they teach and how. Another is the Talloires Declaration (see www.ulsf.org/programs_talloires.html). This is a ten-point action plan for incorporating sustainability and environmental literacy in teaching, research, operations and outreach at colleges and universities, to which Glasgow University is already a signatory, and to which the Board of Governors at Manchester University has very recently agreed to sign up.

The Glasgow team have set out the following aims for their work:

- development of a University-wide Sustainable Development Policy and Strategy
- embedding sustainable development into the curriculum through parallel top-down and bottom-up approaches
- development of cross-sector case studies for teaching students to encourage inter-departmental working
- raising awareness and capacity with academic staff
- raising awareness and capacity with senior management
- exploring the interconnectedness of engineering education and sustainable development with all stakeholders, including the city and its inhabitants
- exploring interactions with global issues through wider collaboration



Picture courtesy of University of Glasgow

All activities at Glasgow University are being addressed.

A small group of staff at Glasgow, including two engineers (civil and electrical), has lobbied senior management and prepared a Sustainable Development Strategy that demonstrates links with the Business Plan for the University. This has influenced policy for the University, but more work is needed to encourage implementation through this historic body that is the second largest employer in southwest Scotland.

A particular issue is that sustainable development tends to be equated with environmental matters such as waste minimisation. The Sustainable Development Strategy Group and the Sustainable Development Visiting Professor are continuing to promote sustainable development as an essential component of University management. Initiatives being used in this work include:

- targeted awareness-raising to university senior management to support the embedding of sustainable development into the curriculum
- identification and collaboration with sustainable development-aware staff in other departments, including the external business development group, to strengthen the sustainable development lobby and network
- initiatives to engage students in sustainable development in unusual ways, including:
  - carbon dioxide or transport-equivalent tree-planting,
  - waste minimisation or recycling at Freshers' Week, and
  - a Fair Trade Fortnight to raise

awareness of global interactions and responsibilities from local to global.

The work of embedding sustainable development into the curriculum includes:

- workshops with academic staff to raise awareness
- analysis of civil engineering courses to identify those that already include, and/or could readily incorporate, sustainable development principles and teachings
- identifying needs of academic teaching staff for sustainable development material
- identification of synergies and collaboration for sustainable development with other engineering departments
- an introductory sustainable development lecture for all first year civil engineering students

Development of cross-sector case studies has included the Clyde Waterfront Regeneration Case Study, which offers wider opportunities for engineering students to consider the interaction of their activities on communities and development. In addition, it offers ongoing opportunities for the academic staff for teaching and research, including collaborative projects with and links to other departments, universities and organisations, such as urban studies, economics, and social sciences.

Picture courtesy of University of Glasgow

Students and staff are actively involved.

Picture courtesy of University of Glasgow

Fair Trade Day at Glasgow University

Engineering students are exploring the interactions of their design and decision-making within a Sustainability Assessment Framework, including flood risk management, transport, remediation of contaminated land, cultural heritage, biodiversity, planning, governance, and the integration of new development with existing communities.

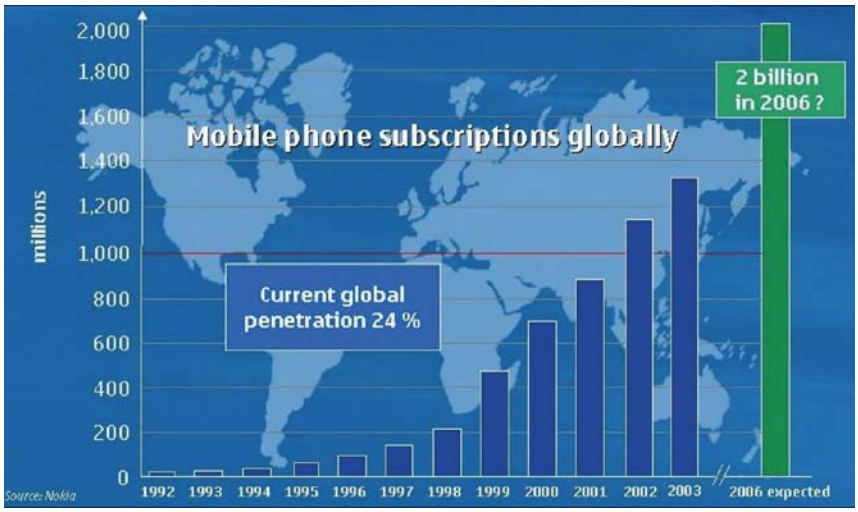
A key issue for the team at Glasgow is integration of the various strands into the day-to-day operation of the University. The role and value of a University-wide approach to promoting sustainable development and engineering education was explored during the Academy's Summer School in 2004. The experience from Glasgow was explored by participants (teaching staff at a range of universities) in role-play groups representing the key stakeholders for universities: students, senior management, academic staff and non-academic staff. The value of such an approach was endorsed and summarised as follows:

- Universities must lead by example and demonstrate relevance of sustainable development to everyday life
- Sustainable development is essential to keep universities relevant to business (employers), communities and the students
- Sustainable development must be embedded in the curriculum and the university management and operations
- Opportunities need to be optimised to build upon existing practice and links.
- All stakeholders need to be included, combining both bottom-up and top-down approaches
- Universities must develop and promote Strategy and Policy as a supportive Sustainable Development Framework, with appropriate monitoring and feedback mechanisms

2.4 Product design in Electronic & Electrical Engineering – mobile phones

Ken Snowden, Visiting Professor in the Wolfson School of Manufacturing & Mechanical Engineering, Loughborough University

Love them or hate them, you can't ignore them – mobile phones that is. The mobile phone – the iconic, electronic symbol of the 21st century – is the result of sophisticated engineering of electronic hardware and software. The number of global phone subscriptions is still growing fast and is expected to reach 2 billion in 2006 (see Figure 3). Over 470 million mobile phones were sold globally in 2003 and estimates for 2004 showed this figure rising to about 630 million.



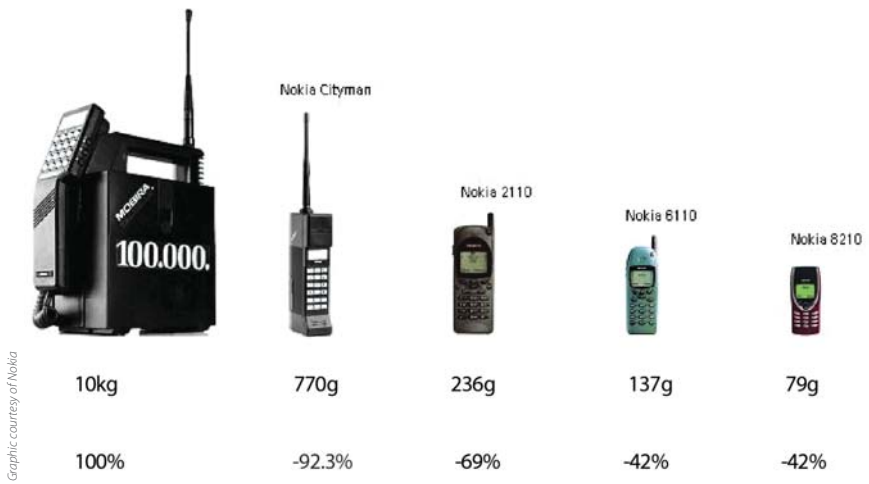
Graphic courtesy of Nokia

Figure 3: Global market growth of mobile phones

However, as mass-produced electronic consumer items, mobile phones have recently come under scrutiny regarding their sustainability and their potential effects on the environment. Originally, potential human health risks took centre stage, and leading companies were investigating their life-cycle impacts. With the arrival of two European Directives – on Waste Electrical and Electronic Equipment (WEEE) and on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS) – the whole life-cycle of mobile phones is under more scrutiny. This is an example of an EU intervention that is pushing the responsibility for improvement in practice back onto manufacturers and retailers.

Nokia, a leading mobile phone producer, has been evaluating the life-cycle impacts of its products since the mid-nineties. It has recently completed an in-depth study looking at this topic (Singhal Pranshu, 2005a) initiated as part of the European Commission's Integrated Product Policy (IPP). The IPP approach is to 'reduce the environmental impacts from products throughout their life cycle, harnessing, where possible, a market-driven approach, within which competitiveness concerns are integrated'. The work has been carried out in co-operation with a range of stakeholders, to assess the life-cycle impacts of mobile phones.

It is easy to forget that a mobile phone is a small, personal two-way radio, which sends and receives radio signals carrying voice and data in personal communications with other mobile phones and telephones. The great strides that electronic engineering has made in reducing the demands on the Earth's resources in mobile phone manufacture can be seen in Figure 4. Early models weighed as much as 10 kg; by 2005, technological advances in electronic



Graphic courtesy of Nokia

Figure 4: Development of mobile phones and their substantial reduction in weight within 20 years

component integration and battery production have reduced this to around 80 g, a reduction of over 99%.

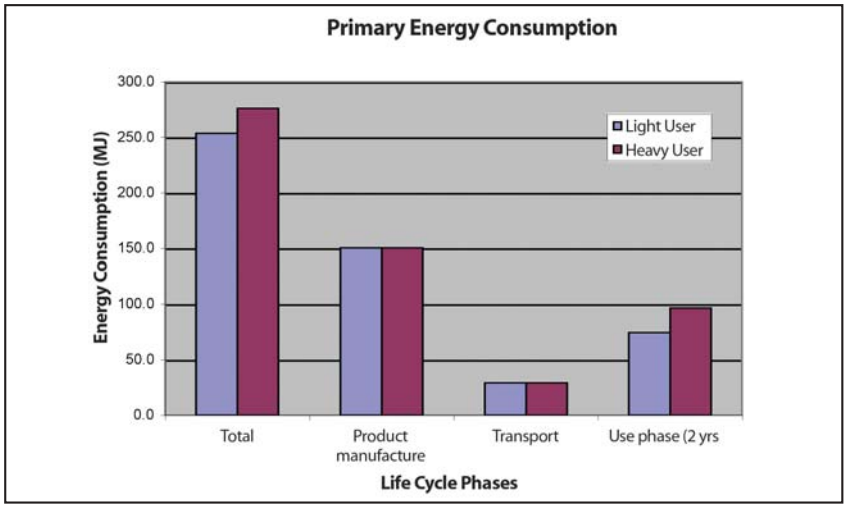
Mobile phones have a very complicated structure and material composition. A typical mobile phone, like many electronic products, consists of 500–1000 components. Most of these components are made up of a large variety of materials and substances. The commercial sources of these components could be situated anywhere in the world, making supply management a key issue in attempting to control environmental impacts.

The examination in the study of the different phases of the life cycle of a mobile phone showed the complexity of its components and the large number of stakeholders involved in its life. The main phases are extraction and processing of raw materials, components manufacture, transport of components to the phone assembly plant, phone assembly, transport of the phones to the distribution network, use and, finally, end-of-life.

The following eight points were the main findings of the Nokia study.

- The use phase and component manufacture phase are the biggest contributors to life-cycle environmental impacts (see Figure 5)
- In the use phase, the stand-by power of the charger – assuming it is left plugged in and not switched off – accounts for the majority of the environmental impacts. Recent advances in reducing the stand-by consumption of the charger have greatly reduced the impacts
- In the component manufacturing phase, the energy consumption of the manufacturing processes account for the major portion of environmental impacts
- The most important environmental issue for a mobile phone, in all the life cycle phases, is energy consumption
- The Printed Circuit Board, Integrated Circuits and Liquid Crystal Display are the components with the highest environmental impacts
- In the transportation phase, air freight accounts for almost all of the environmental impacts
- The collection and proper management of the mobile phones (and accessories) at the end of their life is critical to prevent any material and substance dispersions to the environment. Positive environmental impacts are achieved by the recovery of metals, especially precious ones such as gold and platinum
- From the perspective of a mobile system (which consists of mobile phones, a radio network with radio base stations and radio network control equipment, and a core network with switches, routers, servers and workstations), the energy consumption of radio base stations during the use phase is the most significant contributor to environmental impacts

The total CO_2 emissions, which are closely linked to total energy consumption, from



Graphic courtesy of Nokia

Figure 5: Primary Engergy Consumption in the life-cycle of mobile phones

Graphic courtesy of Nokia

The mobile phone has now evolved and can send e-mail, take photographs, play music...

the life cycle of a 3G mobile phone (including the use of the mobile phone but excluding the system and infrastructure emissions) are equivalent to the emissions from driving a car for only 65 to 95 km or to using 4–6 litres of petrol. Even the CO_2 emissions per subscriber for one year's usage of a 3G system (all the infrastructure but not the phone itself) are equivalent to driving a car for only 250 to 380 km, or using 19–21 litres of petrol.

A mobile phone contains small amounts of some materials that could be considered hazardous. These substances do not present any environmental or human health hazard when the phone is in ordinary use. However, they might be released into the environment from landfills, incinerators and recycling facilities if the end-of-life processes are not properly managed.

To reduce adverse environmental impacts throughout the mobile phone's life, Nokia's environmental activities are focused on sound management of its own operations, systematic supplier network management, integration of the concept of 'Design for the Environment' into product and technology development, and sound end-of-life practices.

The second stage of the Integrated Product Policy project then sought to identify and document the improvement options that Nokia and the participating stakeholders could take to enhance the environmental performance of the phones. In the IPP Stage II draft report (Singhal, Pranshu, 2005b), the improvements options were identified under eight themes: improvements in mobile phones; optimisation of life-span; reduction in energy consumption and environmentally relevant chemicals used during component manufacture; influencing the buying, usage and disposal patterns of consumers; end-of-life management of disposed mobile phones; reduction of energy consumption of network infrastructure; development of suitable environmental assessment methods; and development of a conducive policy environment.

2.5 Civil Engineering & Building – Mossley Mill regeneration in Northern Ireland

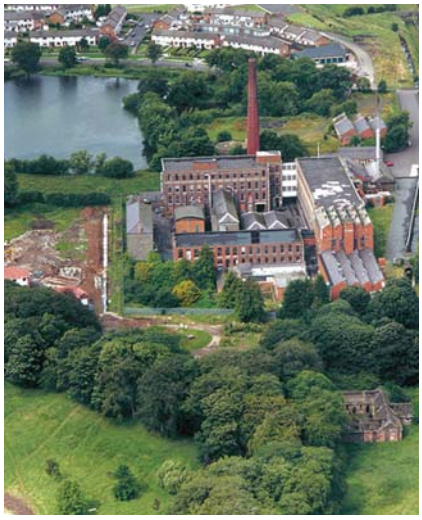
W Alan Strong, Senior Lecturer, and Jim McQuaid, Visiting Professor, School of the Built Environment, University of Ulster

The use and re-use of buildings and their grounds is central to sustainable development and is important to several professions associated with the built environment. The case study, *Mossley Mill – Regenerated to last?*, was developed at the University of Ulster, and addresses the concept of sustainable development through a detailed appraisal of the context, redevelopment and operation of the new Civic Headquarters of Newtownabbey Borough Council in Northern Ireland.

The Council's need for a centralised headquarters led to a review of several potential new-build locations and, following a comprehensive decision-making process, a disused mill building was selected as the preferred site option.

The processes of designing, (re)constructing and facilitating the mill regeneration were carried out by a team of consultants, experts and contractor, who embraced sustainable development (SD) principles.

The case study team fully evaluated the elements of the Mossley Mill building and grounds against indicators and benchmarks, to develop a picture of its overall SD performance. Reference to a range of protocols, directives, strategies and standards from International, European, UK and Northern Ireland sources set the detailed evaluation within a legislative framework, while links to the Council's strategic documents set its local context.



Mossley Mill before refurbishment

Local communities retain an idealistic view of their old buildings, in contrast to the planners, local administrators, financiers and politicians who may see the benefit in meeting local needs in an efficient yet high profile manner. Against this backdrop, this study involved several investigations across a range of disciplines in order to build up a full picture of the decisions and outputs. Investigations, outputs and key issues included:

- Mossley Mill historical timeline – to set the cultural and business context of the original building and its extended community, covering 1750–2000
- Planning and development process timeline – to track the determination of the Council to relocate its staff and functions from five dispersed offices into a central location, leading to the selection of the disused mill building, having investigated 38 potential site options between 1982 and 1990
- the resourcing of several expert reports in areas such as biodiversity, transport, energy, procurement and water, as well as accessing internal Council documents such as the Council Mission Statement and Strategies
- Mossley Mill fact sheets – describing 20 key sustainability aspects of the functions and physical attributes of the Mill
- Sustainability auditing evaluation – leading to the selection of the Forum of the Future 'Five Capitals' and '12 Features' as the preferred auditing mechanisms

A sustainability case study addresses issues and drivers in order to secure a balance that both informs the readers about the constituent parts of the project and points towards improvements that will guide future developments. This study moved the analysis further forward, towards a comprehensive appraisal of several inherent sustainability features. While the 'triple bottom line' SD approach was helpful, the Five Capitals' audit approach facilitated assessment of both the actual and potential performance, the latter being referred to as ASARP: As Sustainable As Reasonably Practicable. Key findings were also assessed against the triple bottom line of economic, environmental and social issues for the Mill

The new Civic Headquarters of Newtownabbey Borough Council

redevelopment, highlighting recommendations for further action and concluding with a general SD statement on the project.

Those key findings were categorised into three main areas:

- ***Environmental matters*** included protected species preservation, natural habitat disruption, biodiversity levels, pond water quality, contaminated land removal, employee journeys linked to gas emissions, demolition waste salvage, green space usage and energy consumption
- ***Social matters*** included public transport access, centralised services access, disabled persons accessibility, Council performance, and community ownership of and participation in the redevelopment process
- ***Economic matters*** included catering facilities, revenue return from sale or disposal of the Council's former facilities, use of local and/or durable building materials, operational savings from energy-efficient devices, redevelopment and greenfield costs, and open plan office issues

The specific findings were developed into a set of 'deferred outcomes' or recommendations, by identifying high-level areas for possible integration and for further attention. These covered matters such as water usage, energy reduction and management, environmental awareness and education, biodiversity planning, transport integration, community facilities and liaison, procurement policies, and future building developments.

Evaluation of this study involved both product and process. The product output concerns the Mill redevelopment and is encapsulated by the statement "The regeneration of Mossley Mill has proved to be a valuable and illuminating example of how the principles of sustainable development can be delivered, with even further room for progress". This should be seen in light of the desire for the deferred outcomes to be further addressed by the Council.

The process of delivering the case study into academia is a much longer but equally demanding task. Involvement of subject staff in using the case study is vital, but requires commitment and a desire to encourage students to embrace

the principles of sustainable development. This study has provided material for students taking modules in construction, building surveying, planning and civil & environmental engineering courses. It has also provided a valuable statement and exemplar of how sustainable development can be addressed and delivered at a project level that has strong links to society, this latter area frequently being seen as foreign to the built environment professions. The study has also provided a basis for mini case studies to evolve in which students consider an aspect of the Mill Redevelopment and derive SD solutions, within a seminar environment.

Finally, it became clear that the learning and teaching of sustainable development is more complex, but less complicated, than the delivery of traditional engineering material. Hence this study has been set within a continuum of earlier sustainable development awareness teaching and later design studies. Creation and testing of relevant pedagogical material, such as presentations, reading lists, assignment briefs and feedback mechanisms have been essential to ensure that the study has contributed to knowledge of the wider sustainability issues and to appropriate learning in specific subject modules.

Photographs have been provided courtesy of W Alan Strong (Sustainable Development Group, University of Ulster), along with Newtownabbey Borough Council and Ostick & Williams (Architects).

2.6 Balancing positive and negative impacts – the case of catalytic converters

Charles Duff, Visiting Professor in the School of Chemical Engineering and Advanced Materials, University of Newcastle upon Tyne

Policies and practice designed to deliver sustainability need to take account of all the elements of sustainable development: environmental, economic and social factors. This example illustrates the interaction between these elements in the case of one well-identified and pervasive problem: energy usage and local air quality.

The effect on local air quality of the emissions from burning fossil fuels, and in turn the impact of poor air quality on human health, has been recognised since medieval times. Increasing urbanisation and industrialisation made progressively greater impacts, until the climactic Great London Smog of December 1952, a prolonged smog that was estimated by the Ministry of Health to have led directly to over 4,500 premature deaths in the Greater London area.

The Government accepted a responsibility to deal with the situation through the introduction of the Clean Air Act of 1956, which forbade (with exceptions) the burning of coal in open fires. This legislation won general public acceptance. It was rapidly followed by a number of market-driven technological developments, such as the introduction of improved varieties of smokeless fuels, more-efficient fuel-using devices for heating water, and more-effective approaches to home insulation. However, while smokeless fuels improved matters at their point of use, the plants where they were produced were sources of extreme pollution – an example where solving one problem gave rise to another.

In the 1960s, a combination of economic instruments (for example tax differentials on different fuels), technical developments and market mechanisms had led to the near-universal adoption of gas-fired central heating systems. The average sulphur dioxide concentration in London in 2000 was less than 50 mg/cc compared with 400 mg/cc in 1950, while the total amount of energy supplied annually in London rose by 50% in the same 50 years.

Nonetheless, there is still a formidable cost to the National Health Service (and

Photo courtesy of The Highways Agency

to people's quality of life) arising from admissions to hospital due to cardiac and respiratory conditions associated with poor air quality (as analysed by the Committee on the Medical Effects of Air Pollution – Department of Health, 2002). The source of the problem in recent decades has clearly been road traffic. The number of vehicle miles travelled in the UK has risen 15-fold since 1950, and much of this is attributable to short-distance trips in urban areas.

The environmental effects of a rapidly increasing car population were first identified in the Los Angeles Bay area of California, where a combination of the local geography and climatic conditions was leading to the production of

'photochemical smogs', of which eye- and lung-irritant ozone was an important component. The Californian authorities developed close technical communications with the auto and chemical engineering industries. As the dialogue proceeded, an end-of-pipe solution emerged: the catalytic converter. These then became mandatory, initially, in the 1970s, for all cars sold in California. Since then, there has been a progressive ratcheting-up of the regulations, to match the industry's confidence that its technical improvements can deliver improved performance. The present position is that, in spite of the 15-fold increase in traffic in the UK since 1950, emissions of the harmful exhaust gases (CO, hydrocarbons and NO_x) have actually fallen.

But, are catalytic converters, for all their effectiveness at their point of use, a sustainable solution? The catalysts concerned (and specified by authorities regulating some 80% of the world's new cars) are Platinum Group Metals (platinum, palladium and rhodium). About 3 grams of a mixture of these have to be applied to each converter. However, these precious metals are extremely sparsely distributed around the world, and are predominantly found in Siberia and South Africa (with smaller deposits in Zimbabwe and North America). Further concentration in ore bodies is measured in a few parts per million (a few grams per tonne). The environmental impact of extracting the ores, and the energy required for their electrochemical refining, are formidable.

As a result of the above issues and factors, crucial questions are faced by policy makers and engineers of all disciplines, and need to be actively addressed if the adverse impact of energy consumption on air quality is to be further reduced. Here are some of those questions.

- Can public awareness be raised such that there will be a voluntary restriction in road traffic? The benefits would be improved public health and reduced congestion
- Should policy makers factor in the savings to the National Health Service in planning new public transport systems and road networks?
- Should more funding be allocated to the further development of alternatives to fossil-fuel-based motive systems, such as fuel cells?
- As with any industry dependent on the extraction of scarce and finite resources, in the long term the mining of Platinum Group Metals cannot be sustainable. Can systems and technologies be developed for an efficient system for the collection and recycling of used converters?
- What provision can be made for any damage to the economic and social welfare of those involved in the mining industries of the less developed countries in which the catalytic materials are extracted?
- Can systems and technologies be developed to do the work of catalytic converters in a sustainable manner?

2.7 The energy challenge

Roger Booth, Visiting Professor in the Department of Engineering Science, University of Oxford

Meeting the increasing global demand for energy is one of the key challenges for sustainable development.

Teaching materials on this subject introduced at the University of Oxford have provided a rich means of interaction with students. The subject is topical and the material used confirms that the current global supply and use of energy fails to meet the criteria for sustainable development on the grounds of social equity, use of non-renewable resources and environmental impact, and particularly its contribution to climate change. Here are five of the main points in the argument.

- Current global commercial energy use – about 9,700 million tonnes of oil equivalent per year – is dominated by fossil fuels (see Figure 6)
- Demand, particularly in China and India, is increasing
- The pattern of use is far from equitable, with per capita consumption in the developed nations being many times higher than in the developing world
- The Intergovernmental Panel on Climate Change has concluded that mankind is having a discernable impact on global climate. The UK Royal Commission on Environmental Pollution recommended that emissions of carbon dioxide need to be cut by 60% by 2050 if the atmospheric concentration is to be stabilised in this century at what they deemed to be an acceptable level, that is double the pre-industrial level.
- There is increasing evidence that both oil and gas global extraction rates could peak in the near future. Although there are very large resources of other fossil fuels, notably coal, they all emit more carbon dioxide per unit of delivered energy service
- Although nuclear power generation is low-carbon, the social, political and technical issues of how to dispose effectively of high-level waste have not yet been resolved

Fossil fuels are part of the natural capital of the planet and we need to assess whether we could live off the interest, the renewable sources of energy. The largest renewable energy source is direct from the sun, with the total energy reaching the surface of the Earth in a day being equivalent to about 30 years of current global commercial energy use. Many technologies to convert the diffuse solar energy are technically proven, including hydro (both large and small-scale), wind, solar thermal, photovoltaics and biomass (either wastes from forestry and agriculture or from sustainably grown crops). Smaller amounts of renewable energy are available from geothermal and tidal sources. All sources can be used for power generation; however, biomass is also a potential source of renewable transport fuels and fuels for heat.

In total, the renewable sources of energy have the technical potential to meet a greatly increased global demand for energy with significantly reduced environmental impact, particularly atmospheric pollution. No single conversion technology will be sufficient to meet demand and all the technologies would have to make a contribution. With the exception of large-scale hydro, the renewable technologies currently meet only about 2% of global commercial energy supply and their direct costs are higher than the established fossil alternatives. The costs of all the conversion technologies are falling, but a number of problems, such as integration and intermittency, need to be overcome.

The evolution from a primarily fossil-based global energy system to a primarily renewable system will take many decades and a wide range of other technical innovations will be required in the interim. Energy is used to meet human needs for heating, lighting, cooking, transportation and communication.

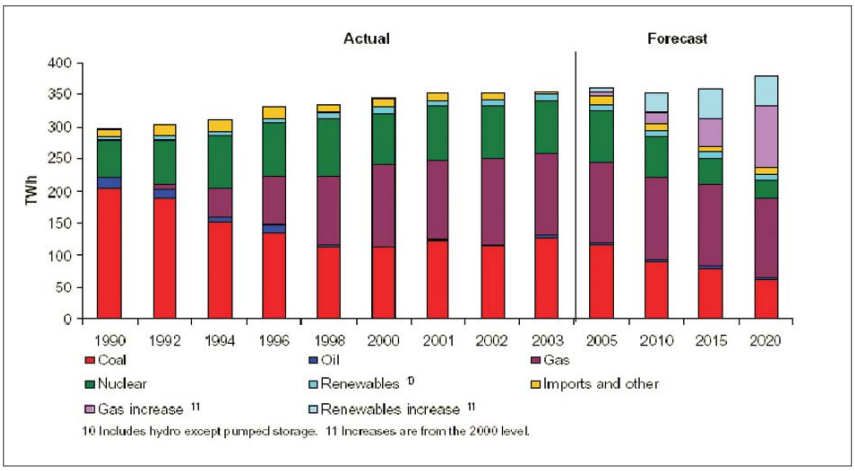


Diagram courtesy of Oxford University

Figure 6: Generation mix projection

Energy efficiency measures in, for example, buildings, domestic appliances and cars, offer the scope to reduce energy use, possibly by as much as half, without any adverse impact on quality of life or standard of living.

A good example is in the design and performance of cars. The current design concept has basically not changed since the late 19th century and results in only about 10% of the potential energy of the fuel being delivered at the wheels in urban driving conditions. The series hybrid concept, whether fuel cell or combustion engine powered, coupled with improved vehicle design for, amongst other things, reduced mass, offers the potential to improve efficiency at least fourfold.

Picture courtesy of HR Wallingford

Other engineering solutions being developed include carbon capture and storage techniques to enable fossil resources to be used in the transformation stage but with reduced carbon emissions. Hydrogen is a possible future energy vector for heat, power and transport applications. If produced from renewable energy sources or fossil resources with carbon capture and storage it could be near to a 'zero carbon' fuel, but the laws of thermodynamics need to be taken into account over the full energy cycle.

Life Cycle Assessment and Scenario Analysis are powerful tools to compare alternative energy strategies and futures. Many published scenarios confirm that there are a number of paths to stabilising global carbon dioxide emissions by 2050, without creating an unacceptable burden on national economies. All stakeholders – including governments, multi-national energy companies, NGOs and individual consumers – will only achieve this goal with appropriate co-ordinated actions and policies. The key question is whether the political will can be found to take the necessary action.

3 Guiding Principles of Engineering for Sustainable Development

3.1 The Principles

Involvement in the seven examples reviewed in Section 2, together with other case studies, has enabled the Visiting Professors to consider the engineering aspects of sustainable development in the context of the many principles of sustainability and sustainable development appearing in the literature. This has led to the identification of a set of 12 Guiding Principles of Engineering for Sustainable Development. The 12 Principles are listed below without embellishment. In Section 3.2, each is explained in turn, and all are related back to the examples as appropriate in Section 3.3.

The 12 Principles of Engineering for Sustainable Development are:

1. Look beyond your own locality and the immediate future
2. Innovate and be creative
3. Seek a balanced solution
4. Seek engagement from all stakeholders
5. Make sure you know the needs and wants
6. Plan and manage effectively
7. Give sustainability the benefit of any doubt
8. If polluters must pollute… then they must pay as well
9. Adopt a holistic, 'cradle-to-grave' approach
10. Do things right, having decided on the right thing to do
11. Beware cost reductions that masquerade as value engineering
12. Practice what you preach.

3.2 The Principles explained

Principle 1 – Look beyond your own locality and the immediate future

In considering the effects of our decisions on the wider world, we need to:

- identify the potential positive and negative impacts of our proposed actions, not only locally and soon but also outside our immediate local environment, organisation and context, and into the future
- seek to minimise the negative, while maximising the positive, both locally and more widely, and into the future

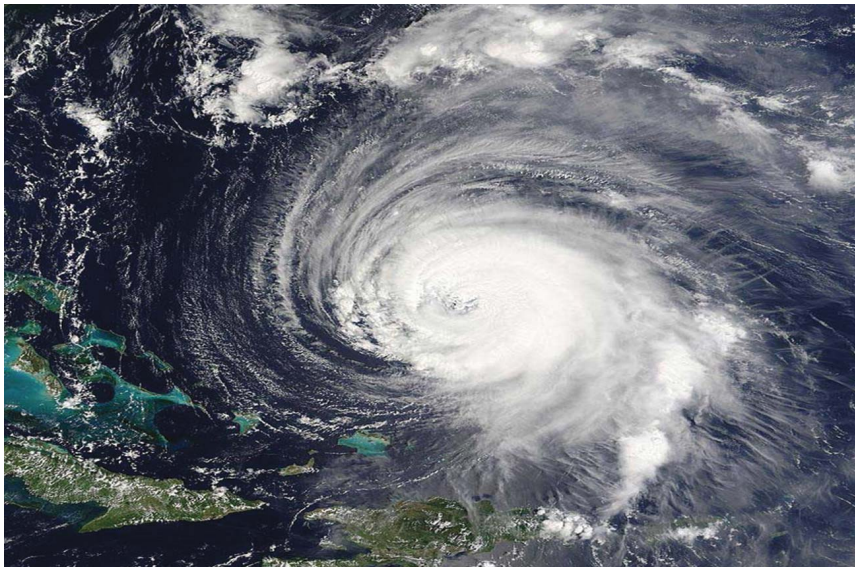
Examples where these considerations may apply include the environmental and social effects of raw material extraction, which may arise a very long way from a product manufacturing plant or other point of use such as construction, and in the environmental effects of operating a product, which may also arise far from its point of manufacture.

Un-sustainable development or product manufacture can result from an action that, while based on trying to act sustainably in a local context, creates more severe development problems or social and environmental effects in a broader context, either immediately or in the future.

Principle 2 – Innovate and be creative

A sustainable development approach is creative, innovative and broad, and thus does not mean following a specific set of rules. It requires an approach to decision-making that strikes a balance between environmental, social and economic factors.
This means that:

- we are not seeking a 'holy grail' of a single 'correct' solution
- alternative solutions can be identified that fit with the sustainable development approach
- it is very difficult to predict with certainty how these alternatives will work into the future, so we need to provide options and flexibility for change and other action in the future
- there are no guarantees that our solutions will be truly sustainable – we therefore must do our best with the skills, knowledge and resources we have at our disposal now



Picture courtesy of Oxford University

It is now scientifically acknowledged that atmospheric carbon dioxide concentration is having an effect on global climate, including the frequency of extreme weather.

Principle 3 – Seek a balanced solution

Approaches like the 'three pillars' and the 'five capitals' explained in Section 1 seek to deliver economic, social and environmental success all at the same time, and so seek to avoid any product, process or project that yields an unbalanced solution. This could be one that generates significant environmental harm, that generates social disquiet or that generates economic loss or spends public funds inefficiently, because each of these should be characterised as un-sustainable.

Thus, in considering options and in our decision-making, we need to:

- not just seek to balance the adverse and positive impacts on economic, social and environmental factors in the challenge we are addressing but seek gains in all three

- ensure, as far as practicable, that renewable or recyclable resources are used preferentially before non-renewable, non-recyclable ones
- ensure non-renewable resources are used, wherever possible, only for the creation of permanent new assets
- focus on the future at least as much as the present
- aim for durability, flexibility and low impact products and infrastructure
- live off the 'interest' rather than depleting nature's capital assets – recognise that the environment is an ecological system, and assess the carrying capacity of the environment and nature's capacity for regeneration
- avoid irrecoverable changes to already-refined materials
- recognise that, even though enhancement of social capital may be difficult to quantify, it is a very important aspect of sustainable development
- recognise that sustainable solutions that are competitive will be promoted and propagated by the market

Principle 4 – Seek engagement from all stakeholders

Society will ultimately say what is needed or wanted for any development, sustainable or otherwise. So reaching decisions in this area requires:

- engagement of stakeholders to bring their different views, perceptions, knowledge and skills to bear on the challenge being addressed
- professional engineers to participate actively in the decision-making as citizens as well as in their professional roles

Principle 5 – Make sure you know the needs and wants

Effective decision-making in engineering for sustainable development is only possible when we know what is needed or wanted – the framework of the problem, issue or challenge to be tackled. This should be identified as clearly as possible, including identifying any legal requirements and constraints. We should use teamwork and assistance of immediate colleagues to improve problem definition.

It is important to recognise that many engineering challenges are driven by what people want to have – such as even better motor cars – rather than just what they need – a means of transport. In addition, 'wants' are often characterised as 'needs' when they are in fact just perceived needs, and a more modest solution may ultimately be acceptable. As a result, we need to:

- engage with stakeholders in identifying the problem, issue or challenge to be tackled ahead of the engineering problems to be solved
- ensure clarity of the considerations, criteria and values that different stakeholders wish to have reflected in the framing of whatever is being tackled
- identify the legal requirements and constraints upon the problem, issue or challenge to be tackled and ensure they are reflected in the framing
- recognise the distinctions between a need and a want, and between an actual and a perceived need
- then identify the 'wants' as well as the 'needs', so that the full spectrum of problems, issues and challenges is known

- identify interdependences between economic, social and environmental factors in these needs and wants
- decide on the system boundary, which should be sufficiently large to comfortably encompass the foreseeable influences on sustainability, but not so large that the detail of the current challenge is lost
- communicate the engineering opportunities and constraints to the team and stakeholders, and explain any value judgements about engineering aspects that are included in the framing
- use an appropriate template for your approach from those available – such as the three pillars or five capitals, and consider time as well as space – to ensure that a broad scope and range of options is considered initially, avoiding the trap of narrowing down to one technological solution too quickly
- recognise the legacy issues of the project to future users and future generations;
- however regrettable it may be, accept that an even better solution may have to await the creation of the next plant or piece of infrastructure

Principle 6 – Plan and manage effectively

In planning our engineering projects, we need to:

- express our aims in sufficiently open-ended terms so as not to preclude the potential for innovative solutions as the project develops
- assemble and critically review historical evidence and forward projections, and weigh the evidence for relevance and importance to the plan
- encourage creative 'out-of-the-box' thinking
- define the desired outcome in terms of an appropriate balance between the economic, environmental and social factors identified earlier
- recognise that ideas that may not be immediately practicable can stimulate research for the next project, but also that they need to be properly recorded if they are to be acted upon
- seek to improve on, or at least maintain, the sustainability of existing practices;
- ensure that the effort and resources devoted to avoiding un-sustainable development remains in proportion to the anticipated effect – don't use a sledgehammer to crack a nut
- keep the plan straightforward, so others can understand it
- pick the 'low-hanging fruit' (the easiest, readily-available gains), but not in a way that constrains further improvements and/or hinders the next generation in meeting their needs.

Principle 7 – Give sustainability the benefit of any doubt

This encapsulates the 'precautionary principle' and, to be implemented, forces us to address the future impacts of today's decisions. So we need to:

- demonstrate that improved sustainability will result from the actions proposed
- act with caution where we consider that the effects of our decisions may be permanent and/or if we do not have a full scientific understanding of the issue or challenge being considered

- only discount the disadvantages and benefits of future events or impacts when they are very uncertain
- recognise that sustainable development depends on investing for jam tomorrow and for bread and butter today.

Principle 8 – If polluters must pollute… then they must pay as well

The environment belongs to us all and its free use for absorption of our wastes or its unfettered exploitation are not sustainable. The adverse, polluting effects of any decision should, in some way, be paid for or compensated for by the proponent of an engineering project, scheme or development; they should not be transferred to others without fair compensation. In addition, it may be necessary to anticipate future pollution prevention legislation if a long-term project is to be sustainable.

The challenge that this Principle thus presents is how to define the 'cost' or compensation that is appropriate. To determine how much should be paid, or how much compensatory work should be done, we need to work with costs that fully reflect the social and environmental implications of a decision, and tools to undertake such calculations are now available and being developed. Current legislation partially achieves this by taxation (such as the landfill tax) or by imposing direct costs of prevention (for example on prevention of groundwater contamination).

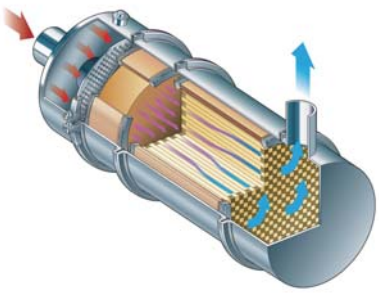
However, no pollution that is not allowed for by law should be considered for inclusion in the problem, issue or challenge to be tackled. For example, the controlled gaseous and solid-waste emissions from fuel-burning power generation is controlled yet allowed in many environmental legal regimes, but discharges of significant quantities of oils and chemicals into water courses are not. The WEEE and RoHS Directives (see section 2.4 above) will also control disposal of many industrial products at the end of their useful life. We thus need to:

- avoid incurring the costs in the first place by eliminating or minimising adverse environmental effects
- practice a responsible attitude to the environment
- broaden our perspective beyond current legislative requirements
- scan the horizon for emerging measures and plan accordingly
- fulfil any Corporate Social Responsibility Policies that apply, and promote their development if they do not exist
- bring social and environmental implications into options appraisal so that a balanced decision can be made
- remember the potential indirect costs of lax environmental stewardship on, for example, reputation and market share

Principle 9 – Adopt a holistic, 'cradle-to-grave' approach

To deliver this approach, the effects on sustainability throughout the whole life-cycle of a product or infrastructure scheme should be systematically evaluated. We need to:

- use whole-life-cycle tools to improve our decision-making: whole-life-cycle environmental assessment, whole-life-cycle costing, and assessment of the social impacts over the whole life time of the engineering challenge we are addressing –



Copyright: Johnson Matthey Plc 2005

The fitting of catalytic converters to passenger cars is a way of polluters paying to reduce the pollution level, but the example in section 2.6 illustrates the challenge of striking the right balance between reduced environmental effects at point of use and the environmental impacts of extraction and refining of the catalytic materials.

sometimes called assessment of inter-generational equity – where the impacts of our decisions on future generations are considered alongside the present

- handle uncertainty by keeping open as many future options as practicable
- ensure that the design is maintainable and that the materials are adaptable for re-use or recycling
- think in the fourth dimension and ensure that the design life is appropriate to the product or project and its context
- use high embodied energy only when it is justified by a long design life
- explicitly address the end-of-life options, and avoid wherever possible leaving to our successors any problems of disposal
- ensure non-renewable resources are used, wherever possible, only for the creation of permanent new assets

Principle 10 – Do things right, having decided on the right thing to do

Adhering to the Principles explained so far should ensure that right decisions from a sustainability point of view have been made in relation to the circumstances that apply. The implementation of these right decisions must then pay full regard to doing things right, again from a sustainability point of view. To deliver this Principle, we need to:

- retain the sustainability focus on the intended outcome right through the implementation of the solution
- recognise that the intermediate processes of construction, manufacture, production and transport can be resource-intensive and need to be managed with an active sustainability orientation
- ensure (as far as practicable) that the legal requirements and constraints on the problem, issue or challenge to be tackled are complied with
- aim to critically appraise current 'good practice' and be inherently sceptical of unsupported judgements, in order to decide on appropriate actions to be taken
- keep abreast of technical and market developments, to check the assumptions and predictions embedded in the design.

Principle 11 – Beware cost cutting that masquerades as value engineering

We are unlikely to arrive at our best decisions first time every time. So we need to challenge ourselves and refine those decisions, whilst remaining focused on the intended outcome. We therefore need to:

- avoid sacrificing the sustainability desires incorporated in a design when seeking cost reductions
- include any adverse effects on sustainability in the 'value equation' and value engineering
- be self-critical of our own fundamental assumptions and values
- be prepared to challenge our and others' existing assumptions
- re-examine first preferences and submit them to re-appraisal

- use intelligence from the marketplace to monitor assumptions on user behaviour included in the design
- check that the achievement of sustainable development objectives is not being subverted by unintended consequences of design changes and/or user behaviour
- however regrettable it may be, accept that an even better solution may have to await the creation of the next plant or piece of infrastructure

Finally, if satisfied with the balance struck between the economic, environmental and social impacts of the proposed solution, congratulate yourself. If not… change it.

Principle 12 – Practice what you preach

One's own everyday practices should not be at variance with what is being asked of others – you must not expect more of others than you do of yourself. Be prepared to be accountable for your design and engineering, and uphold by example the beliefs it reflects. Change yourself before you seek to change others.

Picture courtesy of University of Glasgow

A university-wide sustainable development policy has been agreed at Glasgow University, influencing not only the engineering courses but all activities at and management of the University.

3.3 The Principles related to the examples summarised in Section 2

In order to demonstrate the relevance of these Principles to the engineering profession, the following Table shows the Principles related to the seven examples of sustainability issues in engineering covered in Section 2 of this Guide.

Section 4, after the table, provides guidance on how the Principles can be applied to engineering projects and operations, through the main stages through which engineering projects pass.

Case Study: Principle:	Jubilee River (Maidenhead, Windsor & Eton Flood Alleviation Scheme)	Introduction of unit-dosed laundry cleaning products	Glasgow University Sustainable Development Policy and Practice
1 Look beyond your own locality and the immediate future	The potential effects of the scheme on upstream and downstream communities and habitats were studied alongside those in the areas to be protected from flooding and along the route of the scheme.	Consumers and consumer groups are concerned about the long-term supply of raw materials and the final destination of product chemicals and packaging. The industry takes these and other factors into account for any new product, generally through published life-cycle assessments.	Initiatives at Glasgow University to engage students and staff in SD from local to global include: ecological footprinting, waste minimisation & recycling at Freshers' Week, and Fair Trade Fortnight.
2 Innovate and be creative	Many alternatives were considered.It is accepted that there is no certainty that the scheme will be 'sustainable', it is clear that it is much less-un-sustainable than an inaccessible, concrete trapezoidal channel would have been. The wetland area includes an area specifically designed for use in teaching ecology and nature conservation	The range of products available means that there are always significant design choices: powder vs liquid vs tablet vs capsule, plus choice and functionality of formulation and packaging. Long-term effects of design choices (such as phosphate vs zeolite) can never be predicted with certainty, being dependent on developing scientific assessments as we learn about ecosystems, and also on availability of infrastructures to enable recycling to be carried out.	Embedding SD into a university and its curricula requires integration of a range of approaches, including top-down policy and strategy, and bottom-up awareness-raising and implementation. A University-wide SD Policy and Strategy has been agreed at Glasgow, but it is difficult to promote implementation with so many demands on the teaching staff for research and the general assumption amongst many staff that SD equates to environmental sustainability.
3 Seek a balanced solution	Significant environmental and financial capital was used, but significant environmental capital was also created, as well as enhanced human well-being and a significant reduction in risks of financial loss achieved. However, the new channel was not made navigable by powered craftbecause of the adverse effect on the environment and the ecological features in the project, and because of the desire to create a haven for wildlife and quiet recreation.	The balance in this industry is supplying an environmentally-responsible product that consumers are willing to pay for. Consumers are becoming more environmentally aware but rarely is this used as an advertising platform. In this case, the main environmental benefit is lower material use.	Environmental Sustainability is generally well-understood and, for example, Glasgow has won awards for its energy savings. Economic development remains the main driver, and focuses the staff on seeking major research funding rather than teaching. Social Sustainability is more difficult to engage, especially with technical subjects. The University's role in Sustainable Communities needs to be better understood and encouraged. Glasgow has sought SD links with different departments and the wider community to try to engage the social agenda of SD.

Sustainable Product Design – Mobile Phones	Regeneration of Mossley Mill, Newtownabbey, Co. Antrim	Catalytic Converters	The Energy Challenge
The electronics business is a global industry. The numerous components are sourced from around the world. Looking only locally at SD issues is not an option in mobile phone design, production, use and disposal.	----	Autocats (automobile catalytic converters) improve local air quality, but the impacts of mining, refining and transporting catalytic materials from source to the autocat manufacturer need to be considered against these benefits.	Current global energy supply involves the extraction of raw materials in areas remote from final consumption and has an adverse impact on the global environment.
Mobile phones are only one means of mass communications. New electronic devices appear regularly in different hardware and software formats. Technology will invariably drive increased functionality, miniaturisation etc. New recycling schemes will become more viable as eco-legislation bites, especially in Europe and Japan.	A comprehensive site selection process ensured the most appropriate site was chosen in accordance with HM Treasury guidelines. As sustainability was not the overall goal, this process returned a greenfield site as the preferred option, overturned only when the present site came onto the market. The Mill out-scored the alternative option but, if it had not, the less-sustainable option would have been selected due to bureaucratic local government regulations.	Autocat manufacture depletes scarce and finite natural resources and consumes energy. But the processes create and preserve jobs in producer countries and protect human health in traffic-congested areas. This prompts consideration of alternative technologies or policy approaches to unconstrained personal mobility.	The evolution to the sustainable supply and use of energy will require the development and deployment of many different technologies – future supply of energy will be even more technically diverse.
Equipment manufacturers are increasingly being made aware of their SD and eco-responsibilities through legislation, action by competitors and supply chain pressures. Increasingly electronic and electrical equipment is scrutinised for its SD potential.	Newtownabbey Borough Council had to balance the Mossley Mill site in terms of the biodiversity value of the pond and established habitats with the need to redevelop a decaying structure into a cost-effective civic building. This required careful consideration of the financial implications of preservation and conservation, as well as regard for the environmental and social consequences of demolishing a significant example of local heritage.	We cannot ban all urban traffic without balancing that decision with acceptable alternative methods of mass transport. We should prioritise the needs, and direct technical development to these, e.g. non-fossil-fuelled power for taxis and urban delivery vehicles. Tax measures can then be adjusted to promote market mechanisms and consumer buy-in.	A sustainable energy future based largely on renewable sources of energy is a prime example of 'living off the interest' rather than capital.

Case Study: Principle:	Jubilee River (Maidenhead, Windsor & Eton Flood Alleviation Scheme)	Introduction of unit-dosed laundry cleaning products	Glasgow University Sustainable Development Policy and Practice
4 Seek engagement from all stakeholders	Extensive consultation took place to arrive at the solution and during construction, when the local community was fully engaged and the contractors offered visits to the site to local residents and the general public.	In the 1950s, the retail mantra was "pile 'em high, sell 'em cheap". Now, manufacturers, retailers and advertisers all need to be comfortable that regulations are met and high standards set. Adverse consumer or consumer-group reaction can damage a brand severely and quickly.	SD is essential to keep universities relevant to all stakeholders: staff, senior management, students, local communities and employers. It is important to engage the local community and the non-teaching staff who all have an interest in a university that has vitality and promotes SD.
5 Make sure you know the needs and wants	Much effort was expended on this issue, although not all 'wants' could be provided for. Navigation of the channel was a want, not a need, and was available close by in the main River Thames channel. See also comment against Principle 3.	Considerable effort expended here in developing the market position of a new product was constrained by financial, economic, regulatory and environmental issues, with particular emphasis on consumer attitudes to the product and its effects.	The needs of the students and staff have taken priority so far but within the context of an understanding of the needs of senior management. A strategy for meeting teaching staff's and students' needs is being developed in a phased approach.
6 Plan and manage effectively	Detailed planning was under-taken, including to minimise disruption to neighbours and local traffic by adopting a construction sequence that built the bridges first so as to enable the muckshift to take place along the channel route, not on local roads.	Sustainability concerns are not driving the introduction of laundry tablets and capsules, but significant improvements have been made by their introduction, even if this is not made explicit to the consumer in advertisements.	SD is being woven into the curriculum for those courses and lectures that already lend themselves to demonstrating SD guidelines.

Sustainable Product Design – Mobile Phones	Regeneration of Mossley Mill, Newtownabbey, Co. Antrim	Catalytic Converters	The Energy Challenge
Many and varied stakeholders were incorporated into this study. They ranged from authorities at the European level, telecommunications service providers, manufacturers, users, component suppliers, plus NGOs such as the WWF.	The design team appointed to undertake the Mossley Mill regeneration included expertise from a wide range of professions all of whom bought into the need for a high quality product. While the Council obtained an efficient and effective centre, the local community has been integrated into the final product through the building and its site being opened to public use, creating a sense of public ownership.	Most households have cars. Collectively we can curb emissions by sharing journeys, e.g. for commuting and the school run. Car makers and oil firms can work together on engine management systems and fuel types and formulations to reduce consumption and emissions. Local authorities and public transport operators can combine to offer more-attractive alternatives to use of private cars.	Multi-national corporations, governments, NGOs and individual consumers, plus future generations, are all stakeholders in energy supply and use.
Extensive efforts were made to strike a balance between user needs and wants, marketability and the SD and eco-aspects of the mobile phone and its supporting infrastructure.	The delicate nature of the on-site biodiversity in terms of its value as a habitat for protected bat species necessitated specialist management. As bat roosts cannot be disturbed, consultants drew up a Habitat Management Plan, including legislative compliance as well as clauses on safeguards during construction. This provided clarity to the situation and ensured that the correct solutions were incorporated into the design.	National policy aims to improve public health, to improve quality of life and curb NHS healthcare costs while minimising any infringement on personal mobility. The national needs are thus to improve energy efficiency to counter increasing reliance on imported fossil fuels and to increase public awareness of the issues and develop and promote appropriate products and services.	Energy is essential for economic and social development. The challenge is to achieve these goals using renewable resources and without risking irreversible damage to the environment.
Sustainability issues are increasingly being felt by the whole electrical & electronics industry worldwide. Initially, legislation was the main driver but latterly 'green' products are seen to give a commercial advantage in some sectors.	Recommendations were drawn up to identify the issues that the client could address to help increase their sustainability profile. Considered to be 'As Sustainable As Reasonably Practicable', these were therefore presented as issues that could be addressed without significant financial or operational hardship.	Applying more catalytic coating material may improve converter performance, but at increased cost. We should make sure other emissions-reducing processes and procedures play their part.	An example of 'out-of-the-box thinking' is shown by the need to change both the design of vehicles, and the source of fuel to sustainably-grown crops, in order to achieve sustainable transport.

Case Study: Principle:	Jubilee River (Maidenhead, Windsor & Eton Flood Alleviation Scheme)	Introduction of unit-dosed laundry cleaning products	Glasgow University Sustainable Development Policy and Practice
7 Give sustainability the benefit of any doubt	The sustainability approach led to risks being taken whether an unconventional, but more – sustainable, solution would work.	Cautious approaches must be taken on the key issues, even if the benefits cannot be quantified exactly. Manufacturers have bought into the www.washright.com campaign.	Raising awareness of SD and giving SD the benefit of the doubt is difficult to present to senior management, who tend to respond mainly to economic drivers.
8 If polluters must pollute … then they must pay as well	----	Consumer groups are aware of the pressures they can put on manufacturers to minimise pollution through the design of their products (e.g. packaging). However, consumers expect these aspects to be handled within current prices.	----
9 Adopt a holistic, 'cradle-to-grave' approach	The approach was definitely to create a permanent asset. No 'disposal' to hand on to future generations, only an asset. In addition, a substantial area of contaminated land was cleaned up, by creation of a containment cell, and brought back into beneficial use.	Life-Cycle Assessments are an essential component of this industry now.	----
10 Do things right, having decided on the right thing to do	Much was done well, but there have been structural failures of a weir and some banks. This illustrates that it is very important to get the engineering right alongside the environmental and amenity enhancement. The containment cell for material from contaminated land was created successfully and incorporated into the landscaping of the project.	The technical challenges of launching tablets were considerable and, unless the quality was consistent and the delivery mechanism in the machine adequate, then the product would have failed.	It takes time to promote and implement an SD Strategy throughout a University, and experience at Glasgow indicates that to 'do things right' needs persistent and patient persuasion, with demonstration of the necessity to embed SD.

Sustainable Product Design – Mobile Phones	Regeneration of Mossley Mill, Newtownabbey, Co. Antrim	Catalytic Converters	The Energy Challenge
SD issues should be assessed in the design process alongside price, performance, appearance etc.	----	We need to invest now in technologies and systems to recover and recycle scarce autocat materials. We also need to invest in alternatives to this end-of-pipe solution to exhaust emissions, giving proper weight to social and economic considerations.	In the current absence of absolute scientific certainty regarding the contribution of fossil fuel use to climate change, the application of the precautionary principle would be a wise approach.
Users of mobile phones are generally unaware of the wider SD picture. Primary concerns over human health and base station radiation have taken centre stage so far.	----	We need to prepare for future regulations requiring fuller internalisation of environmental costs, e.g. healthcare costs attributable to harmful exhaust emissions. Landfill tax and other levies can be minimised through investigating strategies for waste minimisation and disposal options, plus use of the waste hierarchy approach.	The external costs of the environmental and health impacts of fossil fuel use are not currently internalised in the end price to the consumer. If they were, renewable energy sources would have an increased market.
Life-cycle thinking now percolates the whole design process in the telecommunications business.	Design decisions that reflect longevity include maintenance-free and long-life materials; flexible open-plan design; lightweight partitioning; room for expansion in a second Mill; and possibility of re-using hydroelectric and water abstraction facilities on site.	We need, with customers and suppliers, to develop strategies for design for de-manufacture, take-back schemes and packaging options. Integrated Pollution Prevention and Control requirements (mandatory in autocat manufacture) need to be met, and the Environment Agency's BPEO Reference Notes, which provide a checklist of aspects to consider in a cradle-to-grave assessment, need to be followed.	Life Cycle Assessment is shown to be an essential tool for the comparison of energy technology options.
Customer requirements of lightness, functionality etc have produced coincidental eco-benefits of less material usage, more energy efficiency and recyclability.	From when the Mill was first constructed c.1750, it has always displayed a sustainability profile. Redevelopment of the Mill thus offered the client an opportunity to continue this legacy, with the building awards showing evidence that this has been achieved.	Design to go 'beyond compliance' e.g. on product life should be considered seriously. Engaging supply chain partners with the joint effort to seek more-sustainable solutions should pay off. The scope for participating in land restitution schemes in catalyst mining areas, and participating in 'green driving' public awareness schemes should be considered.	The application of emerging technologies for carbon capture and storage show how fossil fuels could be used with a reduced impact on atmospheric carbon dioxide during the short to medium term.

Case Study: Principle:	Jubilee River (Maidenhead, Windsor & Eton Flood Alleviation Scheme)	Introduction of unit-dosed laundry cleaning products	Glasgow University Sustainable Development Policy and Practice
11 Beware cost cutting that masquerades as value engineering	The wider implications of design changes made during construction may not always be easy to spot.	The competitive consumer goods market will quickly identify flaws in a product. The alert manufacturer can then refine the product e.g. not selling nets, which last months, in every pack of tablets.	----
12 Practice what you preach	The Environment Agency, as client, has responsibility for promoting sustainable development. With this project it tried to 'practice what it preaches'. Many believe that, despite the engineering difficulties, the Jubilee River experience means that more concrete trapezoidal flood channels are very unlikely.	The sustainability standards in the industry are generally running ahead of general consumer concerns. Manufacturers wish their brands to be seen as responsible and safe.	The essence of the ethos and approach at Glasgow is to try to find ways of practising what we preach, particularly by emphasising that SD progression is dependent on changing lifestyles.
Disciplines covered:			
Civil, infrastructure and built environment	✓		✓
Chemical		✓	✓
Electrical	✓		✓
Mechanical	✓	✓	✓
Aeronautical			✓

Sustainable Product Design – Mobile Phones	Regeneration of Mossley Mill, Newtownabbey, Co. Antrim	Catalytic Converters	The Energy Challenge
The mobile phone market is highly competitive and innovative. However, confusion sometimes arises when the technology – for example 3G – promises more than it actually delivers or takes longer than expected.	Despite regeneration of the Mill not being aimed at sustainability objectives, some progress was made incorporating them into the design. But the danger is that the Council fails to push further sustainability-inspired objectives. Challenges remain in integrated transport planning, consideration of non-commercial uses for Block II, closer community liaison, and green procurement.	There is a need to work with car assemblers, engine management systems engineers and fuel engineers to develop solutions that comply with standards, but require less resources in manufacture, use and disposal.	Some renewable energy technologies are significantly more expensive than the market prices for traditional supply. New materials and products are being developed with the potential for very significant cost reductions.
SD and eco-awareness in the industry are generally ahead of societal requirements at this stage.	----	We need to engage in supply chain dialogue, provide training programmers for SME suppliers and support subsidised public transport schemes for staff.	We are all users of energy and should put energy efficiency at the top of our buying criteria.
	Construction, transport, environmental health & engineering, building surveying & property	Traffic management, road planning	✓
✓		Catalyst operation and manufacture	✓
✓		Sensors to analyse exhaust composition and feed back e.g. to fuel injection systems	✓
✓		Appropriate location and fixing of autocats in the vehicle	✓
			✓

4 Application of the Principles in practice

4.1 Introduction

Decision-making in engineering, whether in the design of a process or product, in the provision of infrastructure, or in the management of an engineering enterprise, takes place throughout the life-cycle of that process, product, infrastructure or enterprise. There is a range of models for the study of such a life-cycle of decision-making. The one chosen to be used here is divided into five main stages:

- ***Framing the requirements*** – often completed in a Feasibility Study
- ***Scoping the decision*** – often made in a Project Definition Study
- ***Planning and Design*** – decisions made in the detailed design stage
- ***Implementation, Delivery and Operations***
- ***End of usable life***

The following sections provide guidance on how sustainability considerations and a sustainable development approach to engineering must influence decision-making at each stage.

The approach suitable for 'framing' and 'scoping' tends to be participative and qualitative, and that for 'planning and design' tends to be strategic and analytic, whereas that for 'implementation, delivery and operations' is managerial and quantitative. Contact must never be lost with the requirements of users (whether they be needs, wants or a combination) nor with other stakeholders throughout the processes.

Actual impacts on future development (compared to predicted impacts) occur once the Implementation, Delivery and Operational Stage is entered. It is crucial to the successful delivery of sustainable development to realise that this and subsequent stages always benefit from a rigorous consideration of sustainable development issues at earlier stages. It is, however, also crucial to recognise that, from the Implementation, Delivery and Operational Stage onwards, earlier sustainable approaches are extremely vulnerable to being overturned through short-sighted responses to unforeseen difficulties and resource constraints. The principles of sustainable development therefore have to be applied at every stage in an engineering decision and its implementation.

The relationship between the Principles and the five stages is presented in a table at the end of this section.

Example from the Visiting Professors' case studies of the need for an SD approach at the Framing Stage:

The failure of legislators, who required the introduction of catalytic converters, to draw the boundary of their decision and analysis around the whole life cycle. This resulted in a concentration on the in-use beneficial effects, with little or no consideration of the upstream effects and impacts of mining the Platinum Group Metals.

4.2 Framing the requirements

Framing the requirements involves defining the need or desired outcome. Marketers call this the 'needs and wants' for a new product or service, and the framing is done by describing the issue, problem or challenge to be tackled in its general context and – very important – agreeing the boundaries to the decision-making. Often, such work and outcomes are undertaken and determined through a Feasibility Study but, at the

other end of the scale of engineering projects, they may simply be done in the early stages of an otherwise seamless design process.

Increasingly, there is also a need to consider carefully what it is acceptable to build or manufacture. This may also lead to a recognition that the client or customer for the engineering design may not be able to accommodate a substantial leap in design thinking to accept a full sustainable development approach. Some aspects of such an approach may, from a pragmatic standpoint, therefore need to be included in 'the plant (or product) after next'. There is a danger here, however, that insufficient urgency will be engendered for the need for change.

4.3 Project Definition – Scoping the decision

At this stage, significant effort will be required to agree on carefully constructed descriptions of the problem(s) to be solved or challenge(s) to be met, and thus to agree on the aims and objectives for the project and for the engineering decisions to be made. These outcomes may be achieved through a formal Project Definition Study or simply be conclusions drawn from the early stages of the seamless design process already alluded to.

It is *crucial* to the successful delivery of sustainable development to realise that this is the stage where rigorous consideration of sustainable development issues – and in particular a cradle-to-grave approach (see section 4.5 below) – will generate the greatest benefit. The more design decisions are made at this stage without consideration of sustainable development, the fewer sustainability benefits will accrue, however great the consideration of sustainable development issues later in the process.

Example from the Visiting Professors' case studies of an SD approach at the Project Definition Stage:

In the creation of laundry tablets, care was taken to ensure that the strong environmental case for this new product format was recognised and developed in parallel with the normal product development tasks. Relevant information was made available to the retail trade and consumers on the resource efficiency aspects.

4.4 Planning and Detailed Design

Planning can usefully be characterised as the analytic process that precedes taking action, which includes appraisal of the options available, creating the objectives that would indicate success and a means of meeting them.

Detailed design then involves the creation of solutions, product or process designs, or infrastructure designs that meet all the diverse but connected requirements – fitness for purpose, safety, quality, value for money, aesthetics, constructability, ease of use and material efficiency. It does so alongside the minimisation of adverse environmental and social impacts, the enhancement of the environment where possible, and the enhancement of quality of life for consumers, workers and neighbours alike. This is a substantial challenge for engineering designers but one that can – with careful thought, creativity, innovation and determination – be delivered for society's benefit.

Even though there is a separate stage of 'End of usable life' to consider (see section 4.5 below), it is vital that, at this Planning and Design Stage, active consideration of these issues is included. One prime example of such consideration is the importance of design for disassembly, to allow for the maximum re-use and recycling of the resources embedded in the product or infrastructure.

Example from the Visiting Professors' case studies of an SD approach at the Planning and Detailed Design Stage

In the Jubilee River project, the landscaping brief for the wetlands included a requirement early in the project to collect seeds and seedlings of local plants, and cultivate them off-site, so that sufficient local-provenance plants were available for the wetland planting schemes when the project reached that stage.

Example from the Visiting Professors' case studies of an SD approach at the Implementation, Delivery and Operations Stage:

At Glasgow University where, because it takes time to promote and implement an SD Strategy throughout an organisation, implementation is needing persistent and patient persuasion, with demonstration of the necessity to embed sustainable development in University practices. Without such persistence and persuasion, earlier decisions in principle may not be realised in practice.

4.5 Implementation, Delivery and Operations

Implementation, Delivery and Operations involves the practical realisation of the design into, for example, a real physical product, creation of new infrastructure or implementation of a new process in chemical engineering.

It bears repeating that it is crucial to recognise that earlier sustainable approaches are extremely vulnerable at this stage to being overturned through short-sighted responses to unforeseen difficulties and resource constraints, such as cost reduction measures masquerading as 'value engineering'. The principles of sustainable development therefore have to be applied at every stage in an engineering decision and its implementation.

4.6 End of usable life

All engineered products, processes and infrastructure will have a designed and actual design life, after which sustainability and a sustainable development approach demand continued application of the thinking already discussed. The returning of resources for further use, or for re-absorption into the environment, through re-use, recycling or disposal, is a crucial element of sustainable development, for which the term 'remanation' has been suggested.

The waste hierarchy *must* be applied:

- think first of opportunities for re-use;
- if that is not practicable, then maximise the practical opportunities for recycling
- only after maximising practical recycling should destructive disposal be considered
- even then, recovery of the energy embodied in the material to be disposed of should be sought, with disposal to landfill being considered only as the last resort, not the first resort as is so often the case at present

Example from the Visiting Professors' case studies of an SD approach at the End of usable life Stage:

The increasingly important emphasis on seeking to recover redundant mobile phones and subsequently to recover valuable materials through careful recycling.

4.7 Linking the Stages to the Guiding Principles

The Table below suggests a relationship between the Stages and the Guiding Principles of Engineering for Sustainable Development, using a simple 5-star rating system that aims to indicate the importance of each Principle at each stage along the following lines:

- no stars = no connection, with the Principle unlikely to be applicable at this stage;
- one star = a definite connection between stage and Principle, but of low priority;
- three stars = Principle not the highest priority, but nevertheless important for the successful delivery of the stage in question;
- five stars = the Guiding Principle is vital for successful delivery of the stage in question.

Stage: / Guiding Principle:	Framing the requirements	Scoping the decision	Planning and detailed design (incl. end-of-life considerations)	Implementation, Delivery and Operations	End of usable life
1 *Look beyond your own locality and the immediate future*	★★★★★	★★★★★	★★★	★	★★★★★
2 *Innovate and be creative*	★★★★★	★★★★★	★★★	★★★	★★★★★
3 *Seek a balanced solution*	★★★	★★★★★	★★★		★★★★★
4 *Seek to engage all stakeholders*	★★★	★★★★★	★★★	★★★	★★★★★
5 *Make sure you know the needs and wants*	★★★★★	★★★★★	★★★	★★★★★	★★★★★
6 *Plan and manage effectively*		★★★	★★★★★	★★★★★	★★★
7 *Give sustainability the benefit of any doubt*	★★★★★	★★★★★	★★★		★★★★★
8 *If polluters must pollute… then they must pay as well*	★★★	★★★★★	★★★	★★★	★★★★★
9 *Adopt a holistic, 'cradle-to-grave' approach*	★★★★★	★★★★★	★★★		★★★★★
10 *Do things right, having decided on the right thing to do*		★	★★★★★	★★★★★	★★★★★
11 *Beware cost cutting that masquerades as value engineering*			★★★	★★★★★	
12 *Practice what you preach*	★★★★★	★★★★★	★★★	★★★	★★★

Picture courtesy of University of Glasgow

5 Developing approaches in teaching, training and CPD

The original aim of the Visiting Professors Scheme was to embed the topic of Engineering for Sustainable Development into engineering courses, and not to create a separate subject. The range of options for teaching the subject is therefore very wide, and there is no prescribed approach. The experience of introducing the topic into the Engineering Department at Cambridge University has been published and contains useful lessons (Fenner, 2004).

Sustainable Development is a still-new subject being introduced into engineering curricula at a time when new approaches to teaching are being debated. Increasing the importance of the 'know-how' approach in addition to the established 'know-what' approach has been argued strongly (Hills, 2005). This is one reason why the Academy asked its Sustainable Development Visiting Professors to concentrate on case studies, so that students could benefit from the real experiences of practitioners in this area.

The Engineering Institutions have recognised the importance of an awareness of the subject. The Engineering Council has introduced the following requirement in its *UK Standard for Professional Engineering Competence* (EC UK, 2004) accreditation criteria:

> *"Undertake engineering activities in a way that contributes to sustainable development. This could include an ability to:*
>
> - *operate and act responsibly, taking account of the need to progress environmental, social and economic outcomes simultaneously*
> - *use imagination, creativity and innovation to provide products and services which maintain and enhance the quality of the environment and community, and meet financial objectives*
> - *understand and encourage stakeholder involvement"*

In addition, other bodies are taking action, for example the Joint Board of Moderators for degrees in civil and structural engineering, which has issued Sustainability Guidelines for inclusion of the subject in BEng and MEng courses. They indicate that:

> *"The key capabilities for an engineer graduating from an accredited engineering course are:*
>
> - *the capability to frame a product, or process, in a sustainable development context;*
> - *understanding the long-term implications of continuing to exploit the product or system for ever; and*
> - *to be able to identify and know how to implement any design changes to counteract the negative impacts."*

The following four steps are suggested as one way of generating the required capability.

First is demonstration that the student is aware of and understands the concept of sustainable development – for example through an essay: 'Explain the likely consequences of the carbon tax on the building industry' or 'Explain how sustainability principles ought to be applied to the design of infrastructure or of a product'. This might make a very suitable task in a first-year communications module.

Secondly, an analysis could be sought of the life-cycle 'cradle-to-grave' aspects of a product, industry or process, with a qualitative or simple quantitative life-cycle analysis to identify the key positive and negative impacts, and then this could be extended to identify areas for improvement. This task can be facilitated by the increasing number of case studies available and enlivened by role-playing as the various stakeholders.

Thirdly, all teaching modules – and particularly for design teaching and projects – could be reviewed for their content on or relationship to the concept and practice of sustainable development. This may lead to a wide range of amendments, from very modest yet important additions, for example the inclusion of sourcing of materials, to more major revision, such as the addition of resource efficiency and waste minimisation to a module that does not currently cover these matters explicitly.

Fourthly, these issues could be brought together in the significant projects – whether undertaken in teams or individually – carried out during the final years of under-graduate degree courses. Alongside the in-depth technology work of the project, the resulting product, process or system should be framed in a sustainable development context. This might, for example, then gain up to 5% of their marks in a 300-hour task, or rather more if sustainable development is the prime focus of the project.

In training and CPD, an increasingly wide range of courses is becoming available, both public and in-house, and the professional engineering institutions are increasingly including coverage of sustainable development in their learned society activities. Training managers and individual practising engineers will need to study the implications for them of the sustainable development requirements of the *UK Standard for Professional Engineering Competence* (Engineering Council UK, 2004) given above, and take steps to ensure that the subject is adequately covered in their professional development programme.

Finally, whatever the method of teaching, or the career stage of the students, the Principles set out here can be used to assist in the delivery of effective learning about the contribution of engineering to meeting the challenges of sustainable development.

Picture: Crane Environmental Ltd

A possible student project - How do hybrid cars measure up to the Principles of Engineering for Sustainable Development?

In summary:

- Engineering for Sustainable Development will not happen of its own volition – it needs action by everyone involved
- universities in particular, and training managers as well, have a responsibility to deliver to the world graduates and qualified engineers who understand sustainable development and can deliver significantly more-sustainable solutions for society
- individual practising engineers have a duty to become and remain competent to deliver the concept and practice of sustainable development in their day-to-day work, and may need actively to seek out courses and other development support to achieve this objective
- this Guide and the Principles it contains provide assistance and support to learning about engineering and sustainable development, whatever the method of teaching
- above all, courses and teaching need to inspire every student and participant to make a difference to the world through sustainable development based upon wise practice of engineering

References and further reading

References to further details of the case-study-based examples

Jubilee River – For some additional detail, visit www.environment-agency.gov.uk and search the site for Jubilee River. For links to material at Queen's Univerisity, go to www.qub.ac.uk/feng/ then click on the sustainable development button.

Laundry Cleaning Products – Further information on these issues and challenges is available from: www.pgperspectives.com; www.henkel.com; www.scienceinthebox.com/en_UK/sustainability/lifecycleassessment_en.html; www.unilever.com/Images/tablets_amended_tcm3-4583_tcm13-5327.pdf; www.unilever.com/Images/capsules_tcm3-4586_tcm13-5319.pdf; and www.unilever.com/Images/dishwash_tcm3-4574_tcm13-5318.pdf

Mobile phones – Further details available in, and figures taken from, Integrated Product Policy Pilot Project Stage I Report: Life Cycle Environmental Issues of Mobile Phones, by Pranshu Singhal of Nokia, which can be found at http://europa.eu.int/comm/environment/ipp/pdf/nokia_mobile_05_04.pdf.

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(UNESCO Portal for Sustainable Development)

www.arup.com/sustainability/skill.cfm?pageid=4929
(SPeAR™, Sustainable Project Appraisal Routine, a project appraisal methodology, to be used as a tool for rapid review of the sustainability of projects, plans, products and organisations)

www.bedzed.org.uk (Beddington Zero Energy Development)

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www.johannesburgsummit.org

www.naturalstep.org.uk/uk_homepage.htm (The Natural Step provides a visionary blueprint for a sustainable world. As an international advisory and research organisation, the Natural Step work with some of the largest resource users on the planet to create solutions, models and tools designed to accelerate global sustainability)

www.projectsigma.com (Project Sigma aims to provide clear, practical advice to organisations to help them to manage the social, environmental and wider economic impacts of their organisations' activities and make a meaningful contribution to sustainable development)

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www.worldenergy.org/wec-geis (the World Energy Council promotes the sustainable supply and use of energy)

www7.caret.cam.ac.uk/index.htm (the route through to available material from the Visiting Professors Scheme)

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