2012-2013 Manufacturing Engineering Tripos Part IIA
Paper 6: Contemporary issues in Manufacturing **Dr Claire Barlow**

1 (a) Solar radiation passes through the atmosphere and warms the surface of the earth. The earth radiates energy in the form of electromagnetic radiation with a spectrum characteristic of its temperature; for the temperatures of the earth's surface; the radiation is in the Infra-red region. Some of this long-wavelength radiation is absorbed and reflected by components of the atmosphere (as well as by clouds); the rest escapes and allows cooling of the earth. A minute imbalance between energy in (received from the sun) and energy out (radiated by the earth and escaping) is enough to cause warming.
The components of the atmosphere responsible for absorbing and reflecting IR radiation are the greenhouse gases. Countries that have ratified the Kyoto Protocol have committed to cut emissions of not only carbon dioxide CO_2, but also certain other greenhouse gases: methane, hydrofluorocarbons (HFCs) used as refrigerants (and now largely banned), Perfluorocarbons (PFCs) and Sulphur hexafluoride (SF_6).
These molecules vary in their potency as greenhouse gases, and the effects are normalized to CO2e (CO_2 equivalent values). Methane is rated around 25 times more potent than CO2; HFCs may be as high as 11000.

Estimates are difficult because although climate change models linking greenhouse gas concentrations and global temperatures are now very sophisticated there are many uncertainties and the systems are hugely complex with feedbacks.
Water vapour is one factor which increases global warming in ways which can only be estimated. It is present naturally, is a potent greenhouse gas (no reliable estimates exist), and can account for 33-66% of greenhouse effect in a clear sky, 66-85% with clouds. It is very variable, by season and locality.
Another different sort of positive feedback comes from the melting of permafrost accompanied by release of methane as decay processes take place. This may lead to runaway effects, but is hard to model.
Other factors also contribute to global warming, such as particulates from diesel and other combustion processes, and models for these are not well developed.

The impact of global warming will be uneven: for an average warming of 4º, coastal regions will warm by 3º, poles will warm by 8º, and mid-latitudes (e.g. much of Northern Europe) by more than 5º.
Changes in weather patterns and an increase in extreme weather events will produce more severe impacts than the temperature rise alone
Changes in ocean currents are predicted. There are fears that the North Atlantic Transhaline Circulation, THC – better known as the Gulf Stream or North Atlantic Drift – might 'switch off' leading to abrupt and irreversible climate change.
Sea levels will rise, and will encroach on land areas which are heavily populated
In summary: a huge negative impact on a significant proportion of the global population is expected.

(b) I-PAT or I=PAT
Human influence on environment I: "Environmental impact" Includes land use; resource use; pollution
Population P (GDP/Person) A (Environmental Impact/Unit GDP) T

Population (P): exponential growth from present value P_0 over time *t* with rate constant R
$P=P_0 e^{Rt}$
Expected to increase from present 6.8 billion to 9.2 billion by 2050, and stabilise at 9 billion by 2100
Affluence (A): often measured as GDP per capita
There is a rough correlation between affluence (GDP) and power consumption (with notable exceptions).

Technology (T): resource intensity of living standards. It can be reduced by e.g. 'green' power, low carbon manufacturing, closed-loop manufacturing processes (zero waste), low energy transport, reduction in demand (e.g. for goods, services), and in general more efficient use of resources.

To make the biggest impact, look at the activities which have the biggest contributions.
Power usage:
Transport 35% Hot air 26% Hot water 8% Lighting 6%
Targeting energy production, note that proportions generated from different sources are as follows:
Oil 39%; Gas 24%; Coal 23%; Nuclear 7%; Hydro and other 7%.
And looking at energy consumption, the proportions are: Industry, including metals, chemicals and paper 35%; Transport 32%; Housing and commercial buildings 29%; Food 4%
By sector, energy usage is dominated by five materials, contributing 56% of the annual 9.9Gt CO_2:
Iron and steel 25% Cement 19% Plastics 5% Paper 4% Aluminium 3%
Restructuring the iron and steel industry in more and less radical ways would have a big impact: optimise efficient practices; re-use steel rather than re-melting.

(c) Policy at national or international levels leads to guidance and legislation.
Direct regulation is the dominant method of environmental regulation in most countries, e.g. emissions targets, management of a common resource such as fisheries.
Legislation is commonly enforced using fiscal incentives (financial advantages and penalties - fines and taxes)
e.g. road pricing (London Congestion charge, and other city centre charges). e.g. a scheme in Durham involving a £2 charge to drive into the city resulted in an 85% reduction in traffic. Such fiscal incentives are recognised to be effective drivers of short-term change in behaviour (even though people immediately work out ways to get round the legislation – e.g. a whole industry has arisen around disguising number plates to avoid paying London Congestion Charge). Remove the charge, though, and people revert to their previous behaviour.
Taxation: e.g. Biffa tasked with using revenue from landfill tax to drive research to reduce the amount of waste going to landfill.
Moral Suasion: Aims to manipulate culture without exerting force. Providing information about environmental consequences of behaviour is a central mechanism. Popular with governments and corporations because they are seen to be encouraging people to do the morally correct thing, but avoid criticism of how this is being achieved.
e.g.

•Finance of campaigns to raise public awareness
•Product-labelling requirements
•Voluntary agreements by emissions sources on emissions targets
•Subsidising research and development for alternative technologies
•Finance of basic research

Legislation can be effective, and fines are generally regarded as the best way to enforce it. However, attitudes are slow to change, and it is commonly found that removal of the fines results in people reverting to their previous behaviour. More profound change of attitudes requires education, and the ‘moral suasion’ tactics can generatee long-term benefits.

2 (a) Write brief notes to explain the following.

(i) The difference between a cell, a tissue, and an organ.

(i) A cell is the smallest unit of life. Tissues are made up of cells plus nonliving extracellular matrix material (ECM). There are only four different types of tissue, nervous, epithelium, muscle, and connective tissue. Connective tissue is largely ECM, while the other three types are largely cellular. Organs are complicated structures made up of multiple different tissue types.

(ii) Cytotoxicity and biocompatibility.

(ii) Biocompatibility encompasses two things.

Biosafety: the exclusion of severe deleterious effects of a biomaterial on an organism. Includes cytotoxicity and mutagenicity/carcinogenity (ability to form cancerous tumors). Usually associated with a low-level immune response to the implant.

Biofunctionality: ability to perform with an appropriate host response in a specific application

Cytotoxicity, “cell toxicity” falls into 4 categories:

(i) Cell death
(ii) Cell damage
(iii) Cell population growth slowed (dead/damaged cells don’t proliferate)
(iv) Cell metabolism altered

(iii) The increase in medical device development in the 20th century.

(iii) Life expectancy has increased significantly since the early twentieth century, in part due to the knowledge about antibiotics and the decrease in deaths in early childhood. People who make it to adulthood also live longer. With increased life expectancy, however, comes increasing wear and tear on the tissues in the body, and an increasing need for “replacement parts” to perform various mechanical, electrical and chemical functions in the body. Thus, in the era after World War II, when biocompatibility of engineering materials was first established, implantable medical devices (medical implants whose main function is not pharmaceutical) started to be developed to help replace lost tissue/organ function.

(iv) The classification of medical devices according to risk.

Medical devices are classes according to risk, with class I being the lowest risk and class III being the highest risk, for long-term implantable devices. Class II or moderate risk devices are further divided into class IIa and class IIb devices in the European system, but not in the US system where there is a single class II. Low risk class I devices are relatively easy to get to market, but class II and III devices require increasing levels of scrutiny in terms of regulatory oversight at all stages of design and development.

(v) The principles of bioethics.

There are four principles of bioethics:
(i) Respect for patient autonomy (the patient is a participant in the medical process)
(ii) Justice (there is a fair distribution of scarce healthcare resources)
(iii) Beneficence (do good)
(iv) Non-maleficence (do no harm)

Ethical quandaries arise when two of the principles are in conflict, as in when doing good for a pregnant woman simultaneously involves doing harm to the fetus.

(vi) The premise of tissue engineering.

Tissue engineering is trying to rebuild broken body parts by seeding a porous biomaterial scaffold with living biological cells, where necessary utilizing additional growth factors or other agents to try and encourage cell growth and development. The cell source is a key consideration: the cells can be autologous (from the person themselves), allogenic (from a donor) or xenogenic (from a donor of another species, although in practice this is rarely implemented). Cells can be from mature differentiated sources, from adult stem cells or from embryonic stem cells. Scaffolds can be made from materials that are synthetic, hybrid or natural.

(b) Resorbable (erodible) polymers are commonly used in biomedical applications.

(i) Describe hydrolysis.

Hydrolysis is the reverse reaction to condensation polymerization. For example,
$R—O—R' + H_2O \rightarrow R—OH + HO—R'$

It occurs when
1. water enters the polymer
2. there's a chemical reaction associated with bonds breaking
3. the pore size of the material increases, allowing more water to get in, such that further hydrolysis occurs by a chain reaction

ALL polymers undergo some hydrolysis, but the rate can be very different depending on the polymer's specific chemistry/covalent backbone.

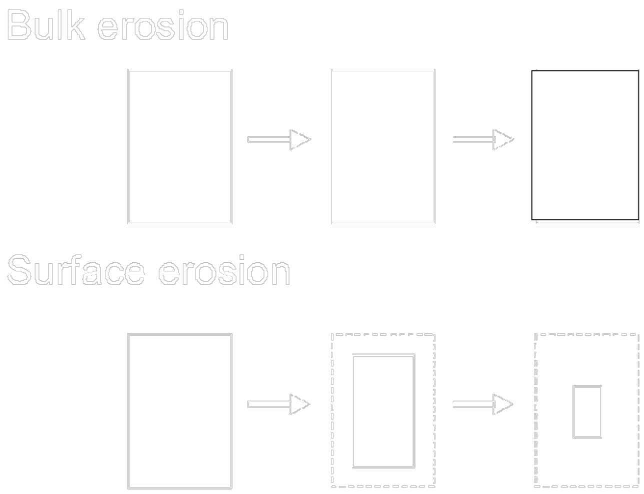
(ii) List the factors that influence a material's hydrolysis rate.

Factors affecting the hydrolysis reaction rate:
1. basic chemistry—which backbone (choice of polymer class) ** most important
2. side chains that are hydrophobic (slower) or hydrophilic (faster)
3. crystallinity: hydrolysis is slower in a crystalline structure as the water has less access to the hydrolysable bonds
4. geometry of the implant/material: surface area to volume ratio, implant or coating thickness. Again controls the motion of water into the material; determines surface versus bulk erosion.
5. porosity—again due to water access
6. glassy versus rubbery state of the polymer—rubbery state, faster reaction

Aside from 1 (backbone) the others (2-6) all have to do with water access to the hydrolyzable bonds.

(iii) Explain the difference between bulk and surface erosion. What determines which form of hydrolysis will occur?

Bulk erosion is when water enters a polymer uniformly and erosion occurs throughout the sample. The properties of the sample degrade uniformly with time. Surface erosion is when water can only gain access to a limited depth of the implant, and the erosion only takes place along this limited (fixed width) front. The properties of the core material do not change. This is illustrated below:



The trade-off between the two erosion mechanisms has to do with the competition between the diffusion time for water into the polymer, which is related to the diffusivity (diffusion constant) of water in the polymer, and the erosion time of the implant, which is related to the hydrolysis reaction rate constant. If the water can diffuse into the polymer faster than the hydrolysis can occur, the bulk erosion mechanism occurs. If the hydrolysis reaction is much faster than the diffusion of water into the polymer, then surface erosion will occur. NB for most polymers the diffusivity of water in the polymer is about the same, and the tunable parameter for device design is via choice of polymer with different hydrolysis reaction rate constants.

(iv) What are the key factors in the utilisation of erodible polymers in drug delivery devices? How are surface and bulk eroding materials used for drug delivery?

For use of erodible polymers in drug delivery, we have the two tunable parameters as in the comparison between bulk and surface erosion above, the diffusion time constant for water in the polymer and the hydrolysis reaction time. But now we have a third additional critical parameter, the diffusivity of the drug in the polymer. For a bulk eroding polymer, the drug is released via the increase in porosity in the material as it degrades. For a surface eroding polymer, the drug is released from the surface of the implant as the material is removed.

3.

The themes that were investigated during the MET industrial visits were:

- Industry-level context
- Company level context
- Materials, production processes and technology
- Industrial Engineering
- Operations Management
- Design Management
- Human Resources
- CSR, H&S, Environment & Sustainability

Good responses will describe each of the themes to a certain degree of detail.

(b) As part of the industrial visits programme, all students visited Jaguar Land Rover, Solihull in the automotive sector, and two companies – Rolls Royce and Marshall Aerospace in the aerospace sector. The following table was produced from the visit debrief presentations. The overall learning is that lean manufacturing principles are highly valued in both the automotive as well as the aerospace sectors. One of the major difference between the two is the focus on services – RR receives majority of their revenue from services.

Good candidates however, would elaborate on these aspects and supplement them with material gleaned from additional reading.

Automotive	Aerospace
Operations Management • Operations centre around the key bottleneck – the press shop. This governs cycle time, task times, etc.	**Operations Management** • Factory layout according to the parts made, e.g., main shafts follow a production line- each process is completed in a separate cell then

• Continuous flow type process • In order to maintain a constant flow the bottlenecks are situated at end of line. Capacity decreases very slightly at each station around the line (7.5% over capacity at start of line compared to end of line) • Buffers in stock are used to cope with short delays but not used for long delays. • Multiple on-line inspections - • Dimensional checks are performed along the line. • Lean manufacturing principles widely in use • Increasing amounts of automation, which improves efficiency, lowers costs, and also has some health and safety benefits	moved to the next stage rather than a continuous line • Components are inspected at each stage of the manufacturing process. • Rolls Royce receives 47% revenue from equipment, 53% from services (i.e. constant demand) • R&D is focussed on how to make the products lighter and cheaper and easier to manufacture • Theoretically, they use lean principles to reduce wastes. However, a lot of WIP was visible. • There has been investment in faster machine tools to allow lead time to be reduced.
Environment and Sustainability • There was a plastic recycling competition widely advertised, and lorries had posters advertising commitment to sustainability. • JLR participate in a carbon offset programme to fun the construction of forests. • Solar panels are fitted on most buildings which contribute a lot to the overall energy source. • Each factory had their own environmental targets they had to meet, and a scrap bill to stick to, so only 2-3 cars a year are scrapped. • Sheets are reused if the product is not up to standard to reduce wastage. • There were recycling bins throughout. • New technology is being brought in to reduce emissions in response to customer demand, for example, aluminium bodies are being brought in to reduce fuel consumption. • Large components are made in	**Environment and Sustainability** • Local community work: there is a community liaison project on which employees on the graduate scheme are sent in to help paint a school • Company supports local charities • To help sustain the morale of employees, there is a large range of social events • During 2011, the Group's total contributions (including money, employee time and gifts in kind) were £7.1 million • -Waste reduction is a key aim. Waste occurs in the form of scrap parts and production inefficiencies • -They are attempting to make a 10% reduction in greenhouse gas emissions. A graph showing the emissions in the past couple of years, and the desired reduction in emissions showed that they seemed to be on track in completing this goal. • Environmental strategy: o maintain drive to reduce the environmental impact of business activities

Solihull, whilst smaller ones are made elsewhere to reduce the fuel consumption. • JLR is also involved in community work, it has an assigned environmental lead to work with local companies to increase sustainability.	o further reduce the environmental impact of their products o develop entirely new low0emission and renewable energy products o 70% of research and development goes into making engines lighter and to burn less fuel. This has the additional benefit that customers spend less money on fuel • About 80% of scrap metal is reused if the fault is to do with machining. Otherwise, if the material itself is incorrect, it is destroyed

(c) The answer to this part of the question should focus on the major challenges the companies face today (as shown in table below):

Automotive	Aerospace
• Uncertainty about customer demand effecting business and management operations • Matching supply and demand • Minimising WIP of cars between different manufacturing departments in plant- average 2-3 days. • Capacity management: Maximum capacity in Solihull is approx 325000 units per year, currently the plant produces 168000 per year.	• Machining operations dictate work time, causing a lot of idling for operators. • Non-lean processes leave a lot of stock in progress (£9 million worth). Major cause of defects. • Design for new products is always late, causing new products to be late. Established products generally on time. •