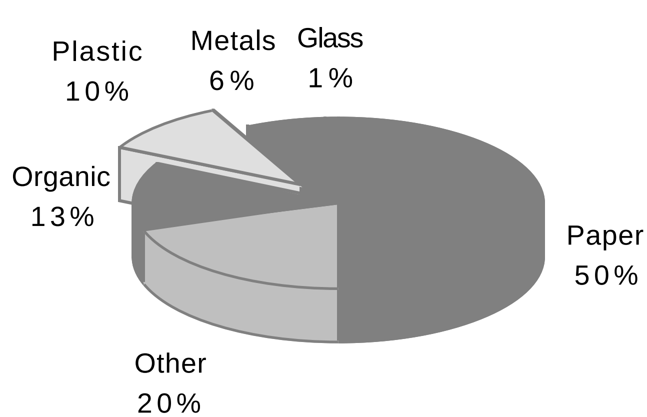
An Engineering Design Problem: Plastics for a Sustainable Environment

Plastic production represents a very large component of the US manufacturing industry, with output exceeding 88 MM lbs in 1996 [C&EN, June 13, 1997]. All but about 2 to 3 MM lbs of this production are derived from petroleum-based feedstocks. Current estimates place the peak worldwide production of oil to occur within the next decade, followed by a steady decline in production over the subsequent 50 years as fields are depleted and cheap sources of crude oil dwindle [Sci. Am., Mar 1998]. Plastics are generally chosen for different applications due to their attractive mechanical properties, durability and ease of processability. Of course, a large part of these plastics eventually find their way into waste streams and often end up in the environment (see figure below), where the very properties that make them desireable in use become a detriment as waste materials. Numerous solutions are employed to reduce this waste stream. For example, we are all familiar with recycling programs for glass, metal and paper which involve collection, identification, classification, separation and reprocessing of reusable materials. Some plastics are also candidates for recycling. In most cases today, the plastics considered for recycling are conventional polymers that have a long track record of good performance. Technological innovations are then required to identify, separate and reprocess them into pristine (or near pristine) form for reuse, at a cost which is competitive with the price of the original polymer. Polyethylene, polypropylene, polyvinylchloride and polyethylene terephthalate are a few examples.

What's in our Solid Waste



Source: “Once and Future Landfills”, *National Geographic*, May 1991

Another alternative is to redesign the polymers themselves so that they do not remain in the environment as waste for any appreciable time. In this case, the innovations required are in design of composition (the chemical constituents of the polymer) and morphology (its microscopic structure) to achieve a combination of reasonable in-use lifetime and rapid post-use degradation, without harmful byproducts. Environmentally degradable polymers usually fall into one of two categories: photodegradable or biodegradable. Cellulose (e.g. wood pulp) and starch (e.g. amylose from potatoes) are examples of complex natural polymers which biodegrade enzymatically. Other, simpler polymers such as the poly(hydroxy-alkanoates), which may be produced by biological production or synthetically in the laboratory, are also degradable by enzymatic or, more commonly, hydrolytic decomposition.

A third alternative to developing plastics for a sustainable environment entails the production of plastics from renewable, non-petroleum sources. This approach is geared less towards the reduction of waste as towards the reduction of dependence on limited petroleum supplies. Nevertheless, most of these plastics from renewable sources are themselves natural and susceptible to biodegradation to an extent which depends in large part on the degree of modification of the original material, e.g. polysaccharides or fatty acids. The attractiveness of this approach lies in the low cost and ready availability of raw materials other than petroleum, on which to base families of new plastics with attractive properties. The question in this case becomes what chemical modifications are possible and desireable.

One can easily imagine many constitutional variations involving either the number of carbons between hydrolyzable links (e.g. poly(ε-caprolactone) vs poly(glycolic acid)), the number of carbons in the side chain (e.g. poly(hydroxyvalerate) vs poly(hydroxybutryate)) or even polymers with two or more side chains, depending on the length of the repeat unit backbone. Due to the presence of *chiral centers* in many polymers, further refinement of properties can be accomplished simply by variations of the tacticity of a given polymer composition. One can also envision copolymers and blends of various homopolymers to get different polymer properties. Of course, these selections, in combination with carefully selected processing conditions, will also influence the final morphology of the product material.

For the final project in this case study, you are asked to evaluate one of several strategies or parameters which are likely to affect the viability of engineered polyesters for environmental sustainability. You should use your knowledge of chemical engineering principles, along with things you have learned in this class regarding the relationship between structure and properties for polymers and methods for estimating the properties of polymers, to evaluate the impacts, trends, sensitivities or efficiencies, of one design strategy on the environmentally benign use of polyesters.

Some potential design variations to consider are the following:

a) hydrophobicity vs hydrophilicity
b) copolymers
c) blends
d) chain flexibility
e) crosslinking
f) intermolecular associations
g) source of monomer
h) side chains

In your analysis, you should explain those features which make the polymer desireable as an element of an overall strategy for environmental sustainability. You should evaluate different polymer architectures in order to expose the relationships between the design variation being explored and the characteristics which are likely to affect the utility of the polymer. You should indicate whether or not characteristics important to the ultimate use of the polymer are sensitive to the design variation, and how these sensitivities should be used in selecting a candidate for synthesis and further testing. If you can make a recommendation of a candidate polymer, you should do so, explaining your reasons clearly and succinctly. You may find it helpful to think about the properties and uses of common, currently-available polymers, and how these might be emulated. You might also find it useful to consider conditions under which the polymer might be used, such as temperature, exposure to moisture or sunlight, or length of use.

You will work in teams of two. Each team should produce a short report of its results. The report should contain a brief abstract summarizing the main points of the study, followed by sections which (i) introduce the reader to the objective of the study, (ii) describe the materials and methods used, (iii) summarize the important results and discuss these results as necessary to justify (iv) the conclusions and recommendations of the report. Details of calculations should be provided in appendices.

Oral reports will be scheduled in class for Tuesday and Wednesday, May 11 and 12. Final written reports are due by 5pm Wednesday, May 12. A late penalty of 25 points (out of 100) will be deducted for each 24 hour period (or increment thereof) that the report is late.