Waste management is now a high priority, particularly in the European Union, and directives are restricting traditional disposal routes, such as landfill, and requiring recycling of other waste streams. For instance, the End-of-Life Vehicle Directive requires that by 2015 all vehicles disposed of must be 85% recyclable. Consequently, there is a need for recycling routes for composites to be established.

There are particular problems in trying to recycle composites. Thermosetting polymers are cross-linked and cannot be remoulded, unlike thermoplastics. Composites are by their very nature mixtures of different materials: polymer, fibre reinforcement and often fillers. There are few standard formulations and so compositions vary and composites are often manufactured integrally bonded with other materials such as foam cores or metal inserts.

Research and development of recycling techniques has been ongoing for some years and there are two fundamental categories of process for recycling thermoset composites, as shown in figure 1.

Mechanical recycling
Mechanical recycling techniques involve grinding techniques to reduce the size of scrap material into powder or fibrous recyclates that can be used as raw materials. The technique is to use a primary crushing process to reduce the scrap components into manageable sized pieces. Then, a hammer mill or other high-speed mill is used to grind the material to a finer product, with particles ranging from fibrous strands, up to 10mm in length, down to fine powders of less than 50 microns in size. All the constituents of the original composite are reduced in size and appear in the recyclates, which are thus a mixture of polymer, fibre and filler.

The recyclates can be used at limited substitution levels in the manufacture of new, short-fibre composite moulding compounds such as sheet moulding compound (SMC), mainly as partial substitutes for the filler. Some coarser grades of recyclate containing more fibre can be used as partial substitutes for reinforcement. But in all cases, the mechanical properties deteriorate at high recyclate substitution levels. Many other uses for recyclate have been investigated. For example, at Brunel University, a novel twin-screw extrusion process has been developed in which thermoset recyclate can be compounded with thermoplastics. And in Sweden,
IFP SICOMP have developed a glass fibre base reinforcement (Recycore) where the core contains recyclate with a high permeability to allow resin flow during impregnation. Coarse grades of recyclate have also been used as reinforcement in asphalt and in the manufacture of plastic lumber from thermoplastics, where the recyclate can be used as an alternative to wood fibre.

Thermal recycling
Thermal recycling techniques involve the use of heat to break down the composite. Thermosetting polymers have a calorific value similar to good quality coal and trials have shown the composites can successfully be burned for energy recovery, for example by mixing with municipal waste in an incinerator. Value can be recovered from the incombustible materials if the scrap is burned in a cement kiln, where glass fibres and mineral fillers can be used as raw materials for cement. The fibre reinforcement has potentially the most recoverable value in a composite and research at the University of Nottingham has developed a fluidised bed process to recover high-grade fibre, shown in figure 2. In this process, pieces of scrap composite are fed into a bed of sand fluidised with hot air operating temperatures between typically 450 and 550°C. At these temperatures, the thermosetting polymer volatilises and, once the polymer has been removed, the fibres and any mineral fillers are released and carried away in the gas stream. They are then separated out whilst the gases are fed to a high temperature combustion chamber for full oxidation and energy recovery. A high-quality fibre recyclate is produced which is clean, has good mechanical properties and has potential for reuse in applications requiring disperse short fibre such as short-fibre moulding compounds – both thermoset and thermoplastic – and non-woven fabrics. The advantage of the process is that it is tolerant of mixed and contaminated materials. For instance, high-grade glass fibres were recycled from a composite component comprising two painted GRP skins with a foam core. Even the metal inserts did not have to be removed and were recovered from the fluidised bed. Research is currently focusing on the recycling of more valuable carbon fibre composites and a new project has recently commenced in which the recycling of carbon fibre vessels used for the storage of hydrogen fuel in vehicles is being investigated and the process is being developed to recover chemical products rather than energy from the polymer. This is part of a European-funded research project (StorHy) which is developing hydrogen storage systems for vehicles.

Pyrolysis has also been investigated for recycling thermoset composites. In this process, the scrap composite is heated in the absence of air. The polymer decomposes to form lower molecular weight organic materials (liquids and gases) and a solid char product is also produced that is mixed with the recovered fibres. In a recent investigation at Leeds University, potentially valuable chemicals were among the organic products formed, but further refining would be needed to separate them. Despite the research effort, a commercially viable composite recycling operation has yet to be established. The Phoenix Fiberglass process in Canada ceased operation in 1996 and the ERCOM Company in Germany has yet to achieve commercially viable levels of operation. The key issue is that the costs of the recycling operations mean that recyclates are too expensive to give a clear market advantage over existing materials. Faced with the threat of legislation, the European Composite Industry Association (EuCIA) is developing a European Composites Recycling Concept (ECRC). Under this arrangement, a “green label” will be given to composites from manufacturers adopting the scheme and this will guarantee that components will be recycled at the end of their life in accordance with legislation. It is thus expected that, with the combination of waste management legislation and new recycling initiatives, commercial recycling activity will be stimulated in the near future.