

Disposal of composite boats and other marine composites

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Abstract: This chapter covers the disposal of marine composites which may arise from marine sports equipment, boats and ships, submarines, marine renewable energy systems or offshore oil exploration and exploitation industries. Consideration is given to the avoidance of waste by appropriate design, manufacturing, marketing and maintenance through life. A key issue addressed is the need to establish the ownership of abandoned vessels. Disposal routes are considered and some examples of differences in current practice are noted.

Key words: boats, composites, disposal, ships, marine, offshore, renewable energy, yachts.

18.1 Introduction

Fibre-reinforced monolithic composite materials and composite structures (angle-ply laminates and sandwich structures) find many uses in the marine environment. These applications include, but are not limited to, whole vessels and their components (e.g. hatch covers, masts, rudders, propellers, sailcloth):

- marine sports (surfing, windsurfing, canoes and kayaks, etc);
- dinghies and sailing yachts;
- ocean-racing monohulls, catamarans and trimarans;
- powerboats;
- work boats and passenger-carrying vessels;
- lifeboats;
- naval vessels, especially mine counter measures vessels (MCMVs) and stealth corvettes;
- submersibles and structures on submarines;
- marine renewable energy systems (e.g. wind turbines, wave power and tidal stream/barrage);
- offshore structures for oil exploration and exploitation (Babu *et al.*, 2008): composite grids/gratings, hand rails, ladder components, aqueous

pipings systems, water and fuel storage tanks and vessels, low pressure composite valves, sump caissons, pull tubes, spooled tubes, cable support systems, modular panelling for partition walls, high pressure accumulator bottles, flexible and floating risers, drill pipes, sub-sea structural components, boxes, housings and shelters, fire water and sea water lift pump-casings, tendons, offshore bridge connecting between platforms, and fire and blast protection.

Waste is not confined to end-of-life components but can take a variety of forms, including manufacturing waste (resin left in pipes and buckets and small fabric/prepreg pieces), trimmings and dust (from over-spray, mould-parting lines and machining), defective items, prototypes and trial runs. Further, the industry uses composites in order to create composites in the form of mould tools which may be of a similar size to the vessel being produced.

18.2 Market size

This commercial sector produces some of the largest composite structures as shown in Table 18.1. In addition to the vessels listed, offshore wind farms are employing ever larger turbine blades. Glass fibre composite blades, 36.8 m in length, generate up to 2 MW on each of the 20 turbines of the Middelgrunden wind farm off the coast of Denmark, while blades of 61.5 m in length have been installed on 5 MW turbines off the Scottish coast (LM Glasfiber, 2008).

A report published by the American Composites Manufacturing Association (2007) indicates that 4.01 billion pounds (1.82 million tonnes) of fibre-glass thermoset composites were 'shipped' in 2006. From that quantity, 20% was produced for the marine sector. In Europe, just over 1.1 million tonnes of glass fibre reinforced polymers were produced of which about 18% was for sport and leisure industries, which include boats, yachts, surfboards, etc. (Bültjer, 2007). The British Marine Federation (2008) estimates that there are about 463 000 privately and commercially owned craft under 24 m in the UK, and a further 17 000 personal water craft. They also estimate that 5530 boats over 2.5 m (8 feet) were manufactured in the UK in 2006. A substantial proportion of these boats will be made from or include composite components: glass fibre reinforced polyester is the main material for marine applications. A survey of large yachts (in the range 24–150 m (80–500 feet) long) published on Yacht Forums (2008) reports that in 2004, out of 572 yachts included in the global survey, 62% (357) had fibreglass hulls. The proportion for small craft (less than 24 m) is likely to be far higher.

There is limited data on the quantity of end-of-life marine composites arising annually. Annette Roux (2007) (President of the French

Table 18.1 Some characteristics of large marine composite structures

Vessel group	Displacement	Length	Width	Height
B&O Castorama Trimaran ocean-racing yacht	8.3 tonnes {13 tons}	23 m		30.6 m mast {57 m mast}
Maltese Falcon super-yacht (free-standing masts)	41 tonnes	17 m	5.9 m	
RNLI Severn class lifeboat	41 tonnes	35 m	14 m	
Cable & Wireless Adventure powerboat	45 tons	24.4 m (80 ft)	12.1 m (39.7 ft)	
US Navy M80 Stiletto	170 tonnes	31 m	9 m	
Australian Navy 'Bay' class catamaran inshore minehunters				
Swedish Navy Landsort class MCMV	360 tons	47.5 m	9.6 m	
HMS Wilton prototype MCMV	450 tons (132 tonne GRP)	46.6 m	8.5 m	6.1 m
Sandown/Racecourse class	450 tons	50 m		
Single Role Mine Hunter (SRMH)				
Christensen 186	>500 tons	57 m (186 ft)		
Belgian/French and Dutch navies	544 tons	47.1 m	8.9 m	
'Tripartite' class Minehunters/Sweepers				
Swedish Navy Visby stealth corvette	600 tons	73 m	10.4 m	
Italian Navy Gaeta class minehunters/sweepers	672 tonnes	51 m	9.6 m	
Hunt class	725 tons	60 m		
Mine Counter Measures Vessels (MCMV)				
Mirabella V super-yacht	740 tonnes	75.2 m		
United States Navy	851 tonnes	57 m		
MHC-51 class coastal minesweepers			10.6 m	

boatbuilding federation FIN and the main shareholder of Groupe Beneteau) has stated that the industry has worked hard on techniques to destroy old fibreglass hulls, instead of having owners abandon them. 'But so far we are having difficulty finding any: they are in good condition and sailors continue to use them,' she said.

Stevenson (undated) surveyed boat yards and marinas in the Southampton area to ascertain 'How often do you deal with abandoned boats?' The most common reply to the question was 'Not very often' with the maximum reported number being 25 per year. To the best of our knowledge there is no in-depth study yet reported and hence there is scope for further research to establish more accurate quantities of end-of-life hulls arising annually in the UK.

Since the Finnish marine industry association, Finnboat, started promoting the responsible disposal of end-of-life boats in 2005, approximately 500 have been collected and recycled. The boats handled reflect the overall composition of the Finnish boat market by type with the majority being less than 6 m in length. Of the 500 boats recycled to date, approximately 150 were of glass reinforced plastic (GRP) construction with the majority of the balance being acrylonitrile-butadiene-styrene (ABS), then a small number of metal boats. On average the weight of the boats disposed of has been about 200 kg and fewer than 10 have been more than 1 tonne. In terms of length, the largest boat destroyed was a GRP clad wooden fishing boat. No sailing boats have yet been recycled.

Composite waste, including marine composites, does not constitute a category of its own in the annual waste statistics. Production waste arisings would be included in Industrial and Commercial Waste data. The categories where it is likely to fall are 'Manufacture of motor vehicles, and other transport and equipment' in Industrial Waste, and 'Miscellaneous' under Commercial Waste. For the year 2002, statistics published by the Department for Environment, Food and Rural Affairs (Defra, 2006b, Table 5) the totals of these two categories reported were 1475 thousand tonnes and 1554 thousand tonnes, respectively, from a total of 67907 thousand tonnes. In other words, production waste in the marine sector is probably less than 4% of all commercial and industrial waste. End-of-life marine composites are most probably included in the municipal waste (not household) making up an unknown but potentially small proportion of the 5 million tonnes reported for 2002. Adding all these together, marine composites contributed less than 2.4% to the 335 million tonnes total waste arisings in 2002 (Defra, 2006b, Table 1).

The problem of disposal of waste marine composites appears to be relatively minor at present. However, if the marine leisure industry continues to grow at the current 8% per year (British Marine Federation, 2008), then, as new designs are produced and as the existing fleet ages, there will be

more end-of-life materials produced, both from worn-out vessels and obsolete mouldings. It is therefore important that economical methods of treatment are developed now.

18.3 The design phase

Searle and Summerscales (1998) have reviewed the durability of fibre-reinforced composites in the marine environment. The key considerations for the achievement of long life are (a) to avoid water soluble components in the laminate which can lead to osmosis and blistering, and (b) for carbon fibre reinforced composites, to avoid direct contact with light alloys in order to avoid the formation of a galvanic corrosion cell. Nevertheless, GRP is well known for its long life, which makes it still an attractive material for new designs.

Landamore *et al.* (2007a) reviewed the environmental impact of three different materials that might form the hull of a sustainable boat designed for use on the Norfolk Broads. These were wood-epoxy, GRP and steel. Their analysis was based on a 30 year life expectancy, and took account of the production, operation and disposal phases. They concluded that while a wood-epoxy hull would have the least environmental impact it would be more costly than GRP, and steel was too harmful in the production phase to be competitive. Furthermore, the boat-owners themselves ranked wood and GRP highly, and the durability of GRP hulls meant that it was more economical to maintain their old boats than to invest in new models (Landamore *et al.*, 2005). It was concluded that GRP could be made more sustainable if low-styrene polyester was used as the matrix, if resin-infusion production methods were adopted, and if the hulls were recycled at the end of their useful life, rather than land-filled (Landamore *et al.*, 2007b). Thus GRP proved to be a sensible choice for the hull of a boat designed with the effect on the environment in mind.

Abdi *et al.* (2004) suggest that

risk management is required at all stages of the product life from concept to disposal. Composite structures must be addressed not only on a component basis but also as part of the overall system. For example, the disposal of a product when it has fulfilled its intended purpose may be governed by regulations. The use of some composites could result in the product being treated as hazardous waste (increasing disposal cost) or the substitution of an environmentally friendly composite for a metal component that requires a hazardous protective coating could reduce disposal cost.

Such areas of the product life cycle can benefit from a judicious combination of actual and virtual testing for risk management. Virtual testing software has been reported to contribute to risk reduction goals and could

reduce development and process costs (30–50%), time to market (10–25%) and product quality testing (30%).

Macdonough and Braungart (2002) have proposed that all components should be designed for dis-assembly.

One-design racing sailboats, where all competitors are expected to use identical boats, stifles innovation and hence these vessels tend to have a finite period of use before the sailors move to a new boat design, and the entire fleet rapidly becomes obsolete. Sectors such as the marine sports industry tend to be very 'fashion' oriented with new designs introduced in each new season for surfboards and especially wind-surfers. In consequence, there are probably many composite components lying unused in attics and garages, or simply sent to civic amenity sites. As noted above, no data are yet available for the quantities of such materials in existence.

18.4 The manufacture and marketing phase

The choice of manufacturing process can have a considerable effect on materials usage. For example, a woven cloth reinforced composite may have a maximum fibre volume fraction of 35% (contact moulding, including hand lamination or spray processes), 55% with one atmosphere of consolidation (out-of-autoclave (OOA) processes, including vacuum bagging and resin infusion), or 65% for higher pressure processes (autoclave consolidation or compression moulding). Assuming that the composite has a negligible void content, then the minimum resin volume fraction will be 65% for contact moulding, 45% for OOA processes or 35% with consolidation. However, the excess resin manifests itself as increased panel thickness and hence as greater panel stiffness. The linear change in panel weight with resin volume fraction has to be balanced against the thickness-cubed dependence of panel flexural stiffness. The reduced panel stiffness may be compensated by moving to a sandwich structure, but this does often introduce a third material into the system.

The amount of consumable material varies with the chosen manufacturing method. An important consideration in respect of waste from composite vessels is the elimination of unnecessary materials usage at the manufacturing stage. Tucker (2004) has reported that, according to Fox (2002), during 'low volume yacht manufacture, about 64 m³ of waste are produced for every tonne of finished boat' and that in surfboard manufacture 'about one-third of the raw materials used to make a board end up on the workshop floor as in-process scrap (Henty, 2002)'.

18.5 The use phase

It is unlikely all components of an entire vessel will fail simultaneously, and inevitably some items will need to be replaced during service, with the

failed component entering the waste stream. Landamore *et al.* (2007a) concluded that composite hulls (like the other materials, wood and steel) had very little environmental impact during the use phase. So over the life of a vessel it is expected that only small amounts of composite waste will be produced.

18.6 End of life

18.6.1 Legislation

The European Union aims to become the most sustainable community in the world. This has led to Directives aimed at minimising the environmental impact of discarded products. The key directives (see also Chapters 2 and 3) are:

- Waste Electrical and Electronic Equipment (WEEE) Directive (Commission Directive 2002/96/EC);
- End-of-Life Vehicle (ELV) Directive for the automotive sector (Commission Directive 2000/53/EC).

In the USA, the Aircraft Fleet Recycling Association (AFRA) (2008) is focused on the safe and economical return of aircraft to revenue service, of engines and parts to the world fleet and of reclaimed materials (composites, aluminium, electronics, etc) back into commercial manufacturing.

In the UK, concerns over the proposed deep-sea disposal in 1995 of the Brent Spar oil-storage platform and over proposals in 2003 by Able UK to import decommissioned US vessels for disposal led to government action. Defra published a consultation paper (Defra, 2006a) which aimed to develop a strategic approach to the recycling of UK-flagged vessels consistent with national and international sustainable development. Defra has also published a guidance document (Defra, 2007) but the strategy only applies to vessels of 500 gross tonnes and to commercial flagged vessels, which are generally constructed from steel. The strategy does not apply to recreational craft so, at present, there is no legislation that applies to the disposal of the major proportion of marine composites.

Ships generally reach their end of life because their operation is no longer profitable and there is no buyer on the second-hand market. They are generally sold for dismantling to extract the steel (and some equipment) for recycling. This operation is labour-intensive and has moved from European/OECD countries (includes Turkey) via China to South Asia (Bangladesh, India and Pakistan). Labourers in ship dismantling yards may earn US\$250/day in the Netherlands, US\$13/day in Bulgaria or US\$1–2/day in Bangladesh and India (EC Commission, 2007). These low labour cost

economies also tend to have less than optimal environmental and health-and-safety requirements. Facilities for dismantling large ships in Europe are concentrated in Belgium, Italy and the Netherlands with a combined capacity of ~230 kLDT per annum. The price paid for a vessel may be >US\$400/light displacement ton (LDT – ‘roughly equivalent to the steel weight of the ship’; Defra, 2006a) in Bangladesh where the scrap material supplies 80–90% of the national need. Chinese yards offer about half the previous figure and US operators offer about one-tenth (European Commission, 2007).

End-of-life ships destined for dismantling are considered waste under international (and Community) law, especially where they contain substantial quantities of hazardous substances (which may include remnants of cargo, oils and oil sludge, asbestos, heavy metals in paints and polychlorinated biphenyls (PCBs)). In the European Union, export of such vessels to a non-OECD country for dismantling is therefore prohibited (European Commission, 2006) until they have been decontaminated or processed so that they are no longer considered hazardous waste. The Basel Convention (United Nations Environmental Programme, 1989) requires prior authorisation from the destination country before waste can be moved. In 1995, the Basel Convention was amended (but not adopted by all countries) to ban exports of hazardous waste from OECD countries to non-OECD countries. The ultimate aim of the EU is to ensure that minimum environmental and health and safety standards are observed worldwide (not to maintain this business in the Community).

The European Union commissioned a Green Paper (Europa, 2007) to open consultation on ship dismantling and identify the most appropriate routes for environmentally and socially sustainable dismantling. The Green Paper limits comment on composites to ‘composites which are very difficult to separate and recycle’ (European Commission, 2007) and ‘some materials are hard to recycle (composite materials)’ (Europa, 2007).

The International Maritime Organisation (IMO) Marine Environment Protection Committee (MEPC) prepared a draft Convention on the Safe and Environmentally Sound Recycling of Ships (IMO, 2008a) which was approved at the London MEPC session in 2008 and adopted by IMO at the Hong Kong Convention in 2009. The Convention will not apply to vessels of less than ~400–500 gross tons, nor to warships, naval auxiliary or other vessels owned or operated by or on behalf of each government of the signatory countries. Consequently, there are almost no composite vessels currently afloat to which it will apply. The IMO have published a bibliography associated with this initiative (IMO, 2008b).

The Recreational Craft Directive (Commission Directive 94/25/EC) and the subsequent amendment (Commission Directive 2003/44/EC) do not

consider end-of-life vessels. Some national representative bodies have given extensive consideration to disposal routes. The French in particular have commissioned a number of studies (FIN, 2006; Wittamore, 2007a) finally concluding that the best disposal route is by means of existing infrastructure. A similar conclusion has been drawn by the Finnish marine industry federation (Wittamore, 2007b) and this overall route has also been endorsed by the International Council of Marine Industry Associations (ICOMIA) (Amble, 2007).

18.6.2 Ownership of abandoned vessels

A key issue in deciding whether a vessel becomes waste is the cost of renovation of older craft relative to the costs of acquiring a new vessel. For the owner of a vessel, the costs of storage can quickly exceed the resale value (negative equity). Abandoned vessels (an example is shown in Fig. 18.1) not only take up space in the marina but also reduce the capacity of the marina to generate revenue (Fig. 18.2). Further, they often do not have a significant scrap value especially if the hull is wooden (Figs 18.3 and 18.4). This figure also illustrates the social consequences of dumping vessels on the shoreline – loosely translated, the graffiti says that the beach is not a dustbin. The local authority then has to deal with the ‘waste’. Hulls abandoned below the high water mark become the responsibility of the local harbour master (Stevenson, undated) who generally only disposes of them if they become a safety hazard. Figures 18.5 and 18.6 illustrate just how much of a hazard abandoned vessels can be, with the local authority issuing stern warnings against boarding derelict vessels.



18.1 Abandoned GRP vessel (photograph by Ken Wittamore).



18.2 An abandoned vessel occupying a valuable mooring (photograph by Ken Wittamore).



18.3 Wooden-hulled boats left to rot on the French coast (photograph by Ken Wittamore).

In countries with boat registration, establishing ownership prior to disposal should be straightforward provided that (a) the owners actually register them, (b) the records are maintained and (c) the last owner has not deliberately removed the registration details from the boat. In the *Oakland Tribune*, Rosynsky (2006) makes it clear that, when faced with disposal costs greater than the value of the vessel, owners will go to considerable lengths to hide their identity, leaving the costs of disposal with the state. He estimates that between 1998 and 2006 the US Department of Boating and Waterways spent \$2.8 m in disposing of 427 abandoned boats.



18.4 Public reaction to a vessel abandoned on a French beach (photograph by Ken Wittamore).



18.5 A warning of the safety hazard caused by a derelict steel ship (photograph by Ken Wittamore).

In Finland, any boat that is believed to have been abandoned and is of unknown ownership is first advertised in the local press. If no owner is forthcoming, the boat is auctioned or sent for disposal.

18.6.3 End-of-life strategies

Conroy *et al.* (2004, 2006) and Halliwell (2006) have reviewed the end-of-life options for composites waste using the waste hierarchy:

Waste reduction > reuse > recovery > disposal



18.6 Boarding an end-of-life wooden-hulled boat is prohibited (photographs by Ken Wittamore).

Rathje and Murphy (1992) have divided recycling into four categories:

- primary: reprocessing waste to obtain product comparable to the original version;
- secondary: recovery of waste material with lower performance when compared to virgin materials;
- tertiary: decomposition of materials to recover monomers, feedstock materials or fuels;
- quaternary: recovery of the embedded energy in the materials.

Reuse as a vessel

At the end of its useful life a vessel may be assigned to a lower duty cycle or enter the second-hand market for whole vessels. As long as a vessel remains seaworthy it may have multiple owners. For example, HMS *Wilton* (M1116) was built to the same basic design as the Coniston-class minehunter (often simply referred to as the Ton class minesweeper) using glass reinforced polyester resin composite in place of the normal wood construction for these vessels. She was built at Vosper Thornycroft in Southampton, launched in February 1970 and commissioned in July 1973. At the time of her construction she was the largest plastic ship in the world (and probably the largest composite structure) at 450 tons displacement and was unofficially known as HMS *Tupperware* or HMS *Indestructible*. The design and use of this vessel informed the design of the subsequent Hunt-class MCMVs and the Racecourse-/Sandown-class Single Role Mine Hunters. In 1991, as the sole remaining Ton-class vessel, her weapons systems became obsolete. She was modified and adopted as a navigation training ship at Dartmouth

Britannia Royal Naval College. She was retired from Royal Navy service in July 1994 and paid off at Portsmouth. She was then bought by a private individual, moved to Southampton for repair then to Lowestoft. The Essex Yacht Club acquired her in 2001 for conversion into a floating Headquarters Ship and she has been based at Leigh-on-Sea since 2004.

Reuse of components

Standardised components enable a market for second-hand parts to be established. There is scope for smaller composite components such as hatch-covers or rudders to be limited in their range of designs making them available for reuse at the end of a vessel's life.

Reuse of the materials

Steve Pickering (2006) has reviewed the technologies for recycling thermoset composite materials with particular emphasis on mechanical and thermal processing. It may be difficult to recycle thermosetting composites, but there is greater potential for the reuse of the materials in a thermoplastic composite. In both cases it is impractical to de-ply laminated composites to reuse the layers (given the current state-of-the-art). It is thus necessary to reduce the waste composite to usable dimensions which may involve sawing, crushing to produce parts of perhaps a few square metres followed by grinding or hammer-milling to increase the density of the waste for transport to recycling facilities. All of these options require significant energy inputs and consideration should be given to the balance of benefits gained against gross environmental impact. A related issue is the material toughness: by design, the inclusion of reinforcement fibres significantly increases the toughness of the material. That toughness will result in significant energy consumption during comminution of the structure. Further, in general the thermoplastics have higher toughness than the thermosetting resins and hence will require yet more energy at this stage. The machinery required is relatively expensive and hence the process may not be economically viable on a small scale. For further information on machining of composites, see the review papers by Abrate and Walton (1992a,b) and Gordon and Hillery (2003). (See also Chapter 9 on mechanical methods.)

For thermoplastic composites, there is the possibility of granulating the material for processing by extrusion and/or injection moulding. Both of these processes will cause attrition of the fibre length and hence the material will need to be used at lower duty (i.e. reduced stresses). Thermoplastic hulls (albeit un-reinforced) have been produced by rotational moulding of thermoplastics at LDC Racing Sailboats (<http://www.rssailing.com/>), Performance Sailcraft (Dart/Laser) and Topper

International (<http://www.toppersailboats.com/>), and by unspecified methods at Bic Sport Boats (<http://www.bicsportboats.com/>).

The Building Research Establishment (BRE) has carried out development and evaluation trials for products incorporating ground GRP. GRP/plastic lumber has similar properties (density, elastic modulus and modulus of rupture) to some other wood plastic composites and is more durable in the marine environment than natural timber. It is claimed to offer 'an alternative to tropical hardwoods or treated softwood for some types of lightly-loaded marine piles such as groynes, fender boards, light bridge foundations, jetties, boardwalk posts and similar applications' (Conroy *et al.*, 2006).

A specific issue for disposal of composite structures used in the marine industry is size (the overall dimensions – not surface treatments on the fibres). A small boat is typically of similar dimensions to a large car. This introduces a range of problems specific to this and related (e.g. wind turbine blade) sectors including transport and size reduction to permit feeding to crushing equipment. In Finland, recreational boats at the end of their useful life are recycled using commercial car crushing plants having first been broken up using mechanical methods (Fig. 18.7).

A particular issue for the recycling company in this case is the contamination of the recovered composite materials. By the end of its life the exterior of a vessel will have received many coats of paint of various types, including anti-fouling. Internally, the composite is likely to be contaminated with oils, paints and embedded core materials such as cork and 'Nomex'. The experience of the Finns indicates that composite cladding of old hulls creates recycling difficulties and as a result of this and the relatively small volumes involved, all composite materials go to landfill.



18.7 Kuusokoski scrap plant where end-of-life vessels are crushed (photograph by Ken Wittamore).

Recovery of fibres and feedstock materials

It is possible to recover the reinforcement fibres and degradation products of the polymer matrix system. In practice, this will be more practicable where a known consistent source of material is available (i.e. from manufacturing, but not post-use, waste) rather than a mixture of different resin systems as optimal processing is then possible.

The options for fibre and feedstock recovery include the following:

- Incineration (see Chapter 4): this destroys the resin, but at 450–500°C usable clean glass fibres remain, while at 450–550°C usable clean carbon fibres can be recovered albeit with a reduction in the fibre mechanical properties. The lower temperatures are used for polyester resins and the higher temperatures for epoxy matrix systems. Milled Carbon (Birmingham UK), Karborek (Puglia, Italy) and ENEA (Ente per le Nuove tecnologie, l'Energia e l'Ambiente – the Italian national agency for new technologies, energy and the environment) are to build a composite recycling facility in Puglia to process an average of 1000 tonnes (1102 tons) of composite scrap annually (NetComposites, 2008).
- Pyrolysis (see Chapter 5): heated to temperatures of typically 400–600°C in an oxygen-free atmosphere.
- Catalytic transformation (see Chapter 6).
- Acid digestion.
- Solvolytic/solvothermal processes: these include hydrolysis and glycolysis.
- Sub-, near- and super-critical fluids: this normally includes water (at 300–500°C) or carbon dioxide. Piñero-Hernanz *et al.* (2008) used a batch-reactor in the temperature range 250–400°C with pressures from 4 to 27 MPa and residence times up to 30 minutes. Iwaya *et al.* (2008) have depolymerised glass fibre/polyester composites to separate the fibre, filler and polymer using sub-critical diethyleneglycol monomethylether (DGMM) or benzyl alcohol (BZA) in a batch reactor at 190–350°C for 1–8 hours.

George and Carberry (2007) have identified potential investment areas for the optimisation of carbon fibre recycling (Table 18.2) which will be equally applicable to other fibre reinforced polymer matrix composites.

Composting

Natural-fibre and bio-based resins may find use in dry applications for composite materials and structures, but their use in moist/wet environments raises issues with respect to durability. Hence, it is unlikely (in the short term at least) that this disposal route will be appropriate for waste composites from marine applications.

Table 18.2 Potential investment areas for optimizing carbon fibre recycling (George and Carberry, 2007)

Material tracking and identification
Product specific dissection maps (end of airframe life)
Joint de-integration (pre- and post-dissection)
Pre-CF recovery contamination removal
Optimized pre-CF recovery material size
Reclaim resin chemical value
Post-CF recovery contamination removal (possibly integrated with other fibre value added processes)
Fibre length adjustment and sorting
Fibre de-bulking for transport
Aligned fibre material forms

Incineration (preferably with energy recover energy)

Considerable energy is used in the production of polymers (embodied energy of plastics in general is given as 90 MJ/kg; Lawson, 1996), but as in many other systems that energy is not lost and can be recovered at a later stage. Halliwell (2006) quotes a figure of 36 MJ/kg as the energy value for ground composite. During recovery of the energy content of the materials, it will be necessary to comply with the Waste Incineration Directive (WID, agreed by the European Parliament and the Council of the European Union on 4 December 2000). The Commission Directive 2000/76/EC aims to 'prevent or limit, as far as practicable, negative effects on the environment, in particular pollution by emissions into air, soil, surface and groundwater, and the resulting risks to human health, from the incineration and co-incineration of waste'. It sets and seeks to maintain stringent operational conditions and emission limit values for (co-)incineration plants throughout the European Community (Defra, 2008).

Scuttle (sink deliberately)

Climate change and sea level rise pose significant challenges. A redundant vessel might then serve as a substrate for coastal defences or for the growth of coral reefs or as a feature for divers. However, disposal of marine composite wastes at sea would require rigorously controlled conditions. In each of the above cases:

- considerable attention should be paid to anchoring the feature;
- an appropriate life-cycle assessment should justify the post-use management of the structure; and
- care must be taken to offer this methodology as creating a positive benefit rather than simply justifying disposal to the marine environment.

In 2002, the European Union (EU) adopted a recommendation on implementing Integrated Coastal Zone Management (ICZM) which prompted improved integration of marine spatial planning. The UK Government passed the Planning and Compulsory Purchase Act in May 2004 with sustainable development as an explicit objective at Section 39(1). The Act requires the preparation of Regional Spatial Strategies (RSS) or a Spatial Development Strategy (SDS for London) and Local Development Documents (LDD) to include Integrated Coastal Management (ICM) where appropriate.

The UK has made a commitment to establish a network of marine protected areas (MPAs) to conserve marine ecosystems and marine biodiversity and in turn to respond to international commitments and European obligations. The 1992 OSPAR (Oslo-Paris) Convention is the current instrument guiding international cooperation on the protection of the marine environment of the North-East Atlantic: it combines and updates the 1972 Oslo Convention on dumping waste at sea and the 1974 Paris Convention on land-based sources of marine pollution. As a signatory of OSPAR, the UK is committed to establishing an ecologically coherent network of well-managed MPAs and under the Habitats Directive (Commission Directive 92/43/EEC) there is a requirement to establish and maintain a network of Natura 2000 protective areas. (Natura 2000 is the Europe-wide network of sites tasked with the preservation of natural heritage as a testament to the importance that EU citizens attach to biodiversity.)

The responsible bodies for nature conservation and shoreline management are the Environment Agency (EA) and the local authorities (LA) (being the Coast Protection Authorities (CPA) and Maritime District Councils (MDC)) respectively although they have no regulatory powers. The statutory control of marine works in the UK, formerly the responsibility of the Marine Consents and Environment Unit (MCEU within Defra), has been integrated into the Marine Fisheries Agency (MFA) since April 2007. The merger means that MFA now has service delivery functions covering the control of coastal and marine developments (including coast defences, wind farms, wave and tidal power; the disposal of marine dredgings at sea; contingency planning for oil spills and other marine pollution, and marine aggregate extraction). The first generation of Shoreline Management Plans (SMPs – high level documents that form an important element of the strategy for flood and coastal erosion risk management) which cover the 6000 kilometres of coast in England and Wales are now in place. All second generation SMP2s should be completed by March 2010.

In April 2008, the UK Government published a draft Marine Bill (HM Government, 2008) for consultation. It intends to set up a new Marine Management Organisation (MMO) as a centre of marine expertise to

provide a consistent and unified approach, deliver improved coordination of information and data and reduce administrative burdens. The Bill will enable implementation of the EU Marine Strategy Directive in a coherent and systematic way and support delivery of UK commitments under the EU Water Framework Directive (Commission Directive 2000/60/EC) and EU Habitats Directive (Commission Directive 92/43/EEC), amongst others. Further, the Marine Bill makes a commitment to make progress towards a network of Marine Conservation Zones (MCZs) for the conservation and promotion of the recovery of a wider range of habitats and species.

A New Zealand-based marine consultancy (ASRL) claims to lead the world in coastal protection, artificial surfing reefs (ASR), inland surfing pools and numerical modelling (ASRL, 2008). ASRL was honoured with the ANZ Bank 'Waikato Export Innovator of the Year' Award for the design and construction of 'multi-purpose artificial reefs' – coastal structures which reduce beach erosion while at the same time enhancing the quality of breaking waves and creating a new recreational facility in the form of a surfing break.

The creation of a reef using a (normally steel) frigate is a well-proven system with vessels placed on the seabed in Canada, Australia and New Zealand. In the UK, the National Marine Aquarium (NMA) selected HMS *Scylla*, a steel Leander Class Frigate, as an artificial reef which would be colonised by anemones, sea squirts and other marine life, so that fish and other mobile animals would be attracted to the developing reef. *Scylla* is intended to be 'an exciting destination for divers' (Leece, 2006).

Experience in the United States (GASMFC, 2004) suggests that GRP hulls for artificial reefs sunk to depths of more than 250 feet (75m) are likely to remain there, and that fish will inhabit them for at least 30–40 years. However, hulls sunk to 100 feet (35m) or less are likely to be disturbed by storms, even when segments are cabled together. This may result in debris floating to the surface or being washed ashore. Furthermore, it was observed that marine life did not establish themselves within 3 years on the fibreglass surface.

It will be important to bear in mind the precautionary principle should such a route be selected for the disposal of large composite marine structures (for example naval mine counter measures vessels). The primary concern will be to consider appropriate routes for the removal and disposal of the toxic compounds (especially cuprous oxide and tri-butyl tin) found in commercial anti-fouling coatings. However, where the reused composites may be subject to abrasion and scour by sand and/or pebbles, they will be degraded. There is growing concern about polymer microparticles entering the marine environment and subsequently marine animals (Thompson *et al.*, 2004, 2005, 2009; Browne *et al.*, 2007). It has been shown (Teuten *et al.*, 2007) that tiny plastic particles may act as agents to carry hydrophobic

contaminants such as phenanthrene from the surface of the sea to the sediment where they may be ingested by animals such as lugworms that form part of the food chain. Moreover, there is evidence that microparticles of plastic ingested by mussels can pass into their circulatory system rather than simply being excreted although their toxicological effects are yet to be established (Browne *et al.*, 2008).

Landfill as a last resort

The Landfill Directive (Commission Directive 1999/31/EC; COM, 2005) provides operational and technical requirements for waste and landfills. These measures seek to prevent or reduce negative effects on the local environment (especially the pollution of surface water, groundwater, soil and air) and on the global environment (including the greenhouse effect and risk to human health) during the whole life cycle of the landfill. The Directive defines four different categories of waste (i) municipal waste, (ii) hazardous waste, (iii) non-hazardous waste and (iv) inert waste. According to Halliwell (2006) 'composite waste is currently classed as non-hazardous under the banner heading of "Biodegradable wastes and other non-special waste which can give rise to organic or other contamination" according to the UK Waste Classification Scheme'. Figure 18.8 illustrates typical composites waste derived from crushing GRP end-of-life vessels and bound for landfill.

The Environmental Code of Practice 'A Green Blue Initiative' supported by the British Marine Federation, the RYA and the Environment Agency (ECOP, 2008) recommends that boat and marina owners adopt the waste



18.8 Fragments of scrap GRP retrieved from a crushing plant (photograph by Ken Wittamore).

hierarchy noted above: reduce, reuse, recycle (materials), recover (energy), landfill or incinerate. They state that when disposing of end-of-life hulls, scuttling or incineration should be avoided at all costs, and that if incineration is carried out, then it must be done in a controlled fashion and with permission of the relevant authorities. Landfill is the least favourable option, and with the rates of landfill tax increasing by £3 per tonne for the past three years, and by £8 per tonne in 2008 compared with 2007 to the current rate of £32 per tonne (HM Revenue and Customs, 2008) it is becoming ever more expensive. As technologies advance it may become more advantageous economically to recycle.

18.7 *Vive la différence?*

In respect of current practice, the disposal of end-of-life hulls is proving to be controversial (Wittamore, 2007a). The French have invested in a number of theoretical studies whilst the Finns just send them to the local car crushing plant – the French are saying that this is not the most environmentally responsible method of disposal whilst the Finns shrug and say it is available now and immensely practical. In the UK the position declared by ICOMIA is the formal disposal route for recreational boat hulls although the industry awaits clear evidence that there is a problem to be tackled.

18.8 Conclusions

This chapter has considered the disposal of marine composites which may arise from marine sports equipment, boats and ships, submarines, marine renewable energy systems or offshore oil exploration and exploitation industries. The total quantity of marine composites waste arising in the UK is comparatively small – too small to warrant a separate category of its own. The guiding principle for waste disposal is to follow the waste hierarchy: reduce > reuse > recover (materials and energy) > landfill (or scuttle).

Consideration has been given to the avoidance of waste by appropriate design, manufacturing, marketing and maintenance through life. Vessels and their composite components can be salvaged for reuse and the second-hand market for boats of all sizes is flourishing. A key issue is the need to establish the ownership of abandoned vessels, but the number of these found each year in the UK has yet to be fully documented. A way forward is likely to be through registration of a wider range of vessel types: while there is discussion on legislation on the recycling of ships, the disposal of small craft is currently unregulated.

Recovery of the energy embedded in polymer composite matrix materials by incineration is still a field for further development. The costs of separation and cleaning end-of-life composite components are still prohibitive

