END-OF-LIFE MANAGEMENT OF FIBRE REINFORCED PLASTIC VESSELS: ALTERNATIVES TO AT SEA DISPOSAL

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IMO INTERNATIONAL MARITIME ORGANIZATION

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Preface

In 2016, the London Convention and London Protocol (LC/LP) governing bodies, having reviewed the LC/LP Scientific Groups' discussion on the widespread nature of the problem of disposing of fibreglass vessels, particularly those that had been abandoned, instructed the Groups to propose recommendations regarding whether to develop advice on the disposal of fibreglass vessels.

In 2017, the governing bodies, noted the Scientific Groups' discussion on the disposal of fibreglass vessels, and that the issue seemed to be of direct relevance and concern not only to Small Island Developing States (SIDS), but also in other countries with large numbers of recreational craft. They subsequently instructed the LC/LP Secretariat to engage a consultant to collate information on the scale of the problem and to identify key knowledge gaps relating to impacts of fibre-reinforced plastic vessels dumped or placed in the marine environment.

IMO is one of the partners in the UN Environment-led Global Partnership for Marine Litter (GPML), and within the framework of this partnership, the LC/LP Secretariat was able to allocate GPML funding to commission a study on the end of life management of fibre-reinforced plastic (e.g. fibreglass) vessels, and on alternatives to disposal at sea. In January 2018, a consultant was contracted to carry out this study.

A draft report, prepared by the consultant was reviewed by the Scientific Groups in May 2018.

The main objective of the review was to provide an overview of the current state of knowledge regarding the end-of-life management of fibre-reinforced plastic (e.g. fibreglass) vessels, and on alternatives to disposal at sea and therefore provide the LC/LP governing bodies with a better understanding of the scale of the issue, the options for disposal and recycling, and the potential impacts of fibreglass in the marine environment enabling them to determine if any further guidance needed to be developed.

It should be noted that the purpose of the report is to inform discussions on the end of life management of fibre-reinforced plastic (e.g. fibreglass) vessels within the LC/LP. It does not claim to be a complete review of all aspects related to this issue, but will hopefully raise awareness and stimulate further discussions on this issue, both in relation to the LC/LP and within the wider global community.

Acknowledgements

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Executive summary

Fibre reinforced plastic (FRP) was created in the 1930s and generally commercially available for boat production from the 1950s. FRP vessels were given a life expectancy of 30-50 years, whilst in practice many older boats are still in service. This has resulted in a growing number of end-of-life vessels which, whilst no longer financially viable, have substantially intact hulls with limited options for their disposal bar landfill. It is evident that the difficulty of FRP boat disposal has been considered since the 1980s. Attention from industry, research and policy has increased with interest in potentially making boat owners / manufacturers financially responsible for end-of-life management of FRP boats.

The issue of end-of-life management of FRP vessels was raised by parties to the London Convention and London Protocol, specifically small island developing states (SIDS). This resulted in the International Maritime Organization (IMO) commissioning this study to review and summarise currently recognised options for the disposal and recycling of end-of-life FRP boats and to identify where guidance and further work may be required. Whilst the situation of disposal of end-of-life FRP boats was considered in general terms, this study was particularly focused on the practice of at sea disposal and the magnitude of the situation as affecting management in SIDS.

Review of available literature shows that numerous bodies (user groups, Government, industry) have undertaken studies to consider disposal options, with the impetus of finding a sustainable solution for FRP hull disposal. However, most reports and papers conclude that there is not currently a fully viable financial market for the material as the price for recycled fibreglass is too low to promote the industry.

The major current options are landfill, though some nations are now restricting the disposal of FRP materials in landfill space. Whilst financially viable options are currently limited, the market is being developed with crushed FRP material being used in, amongst others, concrete, tarmac and also as filler for other FRP items. The market is well intentioned, though as a cost model appears to have limited application, and importantly is more marginal in SIDS due to a lack of infrastructure to recycle. If this model is used on SIDS it will likely incur significant off-island transport costs for FRP material.

Research and trials are considering options that include pyrolysis where material is burned at temperatures to recover fibres for re-use (though resins are lost in combustion) and solvolysis where chemical replacement releases the resins and fibres for re-use; though these processes are expensive and not fully commercially viable at present, researcher and commercial groups are working towards financial feasibility. With regard to achieving financial sustainability to make end-of-life FRP boat disposal viable, instruments such as a levy on manufactures have been suggested and the option of charging users for end-of-life FRP disposal is potentially being trialled in France.

The environmental effects of current disposal options are discussed. Burning, previously practised on some SIDS, is known to release highly toxic compounds with a range of possible effects on biological organisms. Landfill options are largely related to the amount of space taken up, which in SIDS is a significant issue. FRP chemical breakdown and risk in landfill has been considered, though degradation is viewed as unlikely with FRP material, showing little change over time. At sea disposal is less well understood and whilst deliberate scuttling has been used as an option, FRP boats are often just left to decay on abandoned moorings. MARPOL makes it illegal to discharge plastic at sea, but FRP hulls are not covered as MARPOL is pertinent to shipborne garbage and the London Convention and London Protocol do not explicitly address FRP vessels.

There is limited research on at sea disposal though it is evident that dumped FRP vessels do not make suitable artificial reefs as they are likely to break up, and may be moved by currents and wave action potentially harming sensitive features (e.g. reefs, seagrass) and communities. In addition, FRP material will ultimately break up to potentially become microplastics with, as yet, poorly understood ecological pathways and direct biological effects, though its known plastics sorb organic and heavy metal pollutants potentially making them more bioavailable to organisms which may ingest plastics.

The problem of end-of-life FRP boat disposal and management has taken global proportions with an increasing number of vessels needing management. This is particularly pertinent to SIDS with space being a significant issue and disposal at sea having wider implications for the marine community on which people may be dependent and possible pathways to humans for plastics and associated pollutants. Some island nations are actively seeking options including pyrolysis and have halted at sea disposal with ongoing plans for FRP wreck management under the Nairobi International Convention on the Removal of Wrecks 2007 but as outlined, other legal instruments have poor applicability and the Nairobi Convention on wreck removal is targeted at vessels greater than 300 tonnes and to date has only been ratified by 41 states.

Research areas relating to management and disposal of end-of-life FRP hulls are numerous. Though current progress may be limited, further research into sustainable options is being addressed due to increasing interest and financial / policy drivers. The main aim is to achieve end-of-life management leading to either reuse (re-purposing) or recycling. With particular emphasis upon islands, these goals require appropriately targeted attention to avoid growing conflict with natural resources and unregulated disposal of FRP waste with potential environmental consequences.

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1. Introduction

1.1 Rationale

Following a request to AQASS Ltd by the International Maritime Organization (IMO), this report investigates the practice of disposal and recycling of fibre reinforced plastic / polymer (FRP) vessels and related environmental issues; N.B. for this report FRP is used but the material is also known as GRP (glass reinforced plastic) and fibreglass (a trading name), amongst others.

This subject is considered with particular reference to the problems of disposal at sea, and alternative approaches such as landfill, burning etc. Further to this, the report considers the current status of FRP recycling in recognition of the difficulties and opportunities presented and the implications for nations / regions attempting to deal with the situation.

A specific focus of the study is the issue of disposal of FRP vessels in island states which inherently suffer with problems with solid waste disposal. In such examples land is a limited resource which can lead to a drive to disposal at sea, or "*backyard burning*" rather than landfill or recycling options. Landfill capacity may be limited with (sometimes) outdated resources to serve a growing recycling and landfill industry (see: Kumar *et al*., 2011; Mohee *et al*., 2015). In addition, recycling facilities and local markets for recycled good may also be limited thus stifling incentive to develop a given sector.

The difficulty of disposal of FRP vessels has been noted for some time (e.g. Backman & Lidgren, 1986). Fundamentally whilst regulators and scientists seek a solution, the end users are in general faced with the practical problem. Articles in the boating press and chemicals industry highlight the issue for example Sponberg (1999) concludes that whilst some progress has been made, in general FRP vessels are still cut up and sent to landfill. From a commercial point of view this appears still the most financially viable option and a marine industry article from (Flannery, 2016) makes broadly the same conclusions as Sponberg (1999) highlighting apparent stilted progress in managing the issue cost effectively or practically in environmental terms. These articles note that there are drives to transfer responsibility of end-of-life disposal to potentially taxpayers, owners (possibly via registration or insurance (Flannery, 2016) and the boat production industry (Marsh, 2013; Flannery, 2016). In addition a lifecycle analysis approach has been considered and if future options continue to include landfill and at sea disposal, it is increasingly felt appropriate to take full economic cost (including ecosystem impacts etc.) into account when justifying a business case (Marsh, 2013).

Suggestions have been given that owners should be held responsible for disposal costs, however it is felt by some that this is likely to be impractical with ownership difficult to trace or owners not in a position to bear the outlay. Thus in the longer term, the costs of final disposal may rest with the original manufacturer in a similar fashion as the WEEE[1] initiative (e.g. see GOV.UK for the United Kingdom approach to WEEE). However, current implementation of such suggestions for global FRP vessel responsibility appear some way off and would not cover the wealth of older boats with no traceability (though see detail on "eco tax" in France, section 2.2.3). Thus the current disposal and management of end-of-life FRP vessels may require a more practical and immediate approach.

1 Waste Electrical and Electronic Equipment (WEEE) – a specialist part of the recycling industry (Health and Safety Executive).

1.2 Study objectives

In recognition of the issue and as an updated approach to disposal of FRP and the related environmental concerns and practicalities, "*the Scientific Groups under the London Convention and Protocol noted concerns regarding the disposal of fibreglass vessels*". Accordingly, this study has been promoted by the Parties to the London Convention and London Protocol (LC/LP) following concerns raised by Pacific Small Island States at LC/LP Scientific Group meetings and at a regional workshop on the implementation of the London Protocol held in Suva, Fiji in March 2016. Through this it was discussed whether guidance was needed with regard to management of fibreglass vessels and sea disposal and the LC/LP governing bodies agreed to engage a study considering the "*end-of-life management*" of FRP vessels in both current practical terms and realisms of what may be achieved in future.

The overall objective of this study is:

- A review to inform the "scale of the issue, options for disposal and recycling, and the potential impacts of fibreglass in the marine environment" [through] "an overview of the current state of knowledge regarding the end-of-life management of fibre-reinforced plastic (e.g. fibreglass) vessels, and on alternatives to disposal at sea".

This is to be achieved by:

- Collation of "*information* [where available] *on the scale of the problem associated with the end-of-life management of fibre-reinforced plastic (e.g. fibreglass) vessels, and on alternatives to disposal at sea, taking into account the different types of fibre-reinforced plastic*". ***N.B. currently this does not include detailed review of possible health implications for those undertaking the cutting up of FRP vessels****;*
- A literature review considering "*potential impacts of ocean disposal or placement of fibre-reinforced plastic vessels on the marine environment, including an evaluation of the impacts of the degradation or breaking apart of fibre-reinforced plastic vessels (e.g. microplastic components), taking into account the different types of fibre reinforced plastic and the influence of different environmental conditions*";
- Identification of "*knowledge gaps relating to impacts of fibre-reinforced plastic in the marine environment*"; and
- To "*identify where further guidance may be needed*".

2. Background and current baseline

2.1 Nature and scale of challenge

Broadly, FRP is a composite material consisting of fine strands of glass, carbon etc. (in various weave patterns) embedded in a resinous matrix to form a strong, but relatively flexible structure. The resins generally comprise "*polyester, vinylester, phenolic and epoxy compounds*"; the polyester (bisphenolic and ortho- or isophtalic resins "*make up circa 75% of the* [FRP] *matrix*" *(*López *et al.,* 2012*)* with isophtalic resins recommended for marine applications due to greater strength and less permeability (Du Plessis, 2010). However, isophtalic resins are more expensive and Du Plessis (2010) noted that the uptake of their use was slow and that some manufacturers rely on orthophtalic resins or a mix of the two.

Created in the late 1930s, and generally commercially available for boat production from the late 1950s (Norden, 2013), FRP is used in numerous applications including wind turbine blades and vessels, to small scale piping and roofing (for a comprehensive list of marine related applications see Singh *et al*. (2010)). FRP boats are given as having a life expectancy of 30-50 years (e.g. Norden, 2013), whilst in practice many older FRP boast are still in service. Thus, based on *suggested* lifetimes, it appears that an increasing number of hulls will reach end of service further emphasising the need for sustainable disposal or recycling options. However, allowing for growth in the recreational vessel sector, and that hulls are lasting longer than originally expected, the "glut" of older hulls may be an issue that has yet to reach its peak.

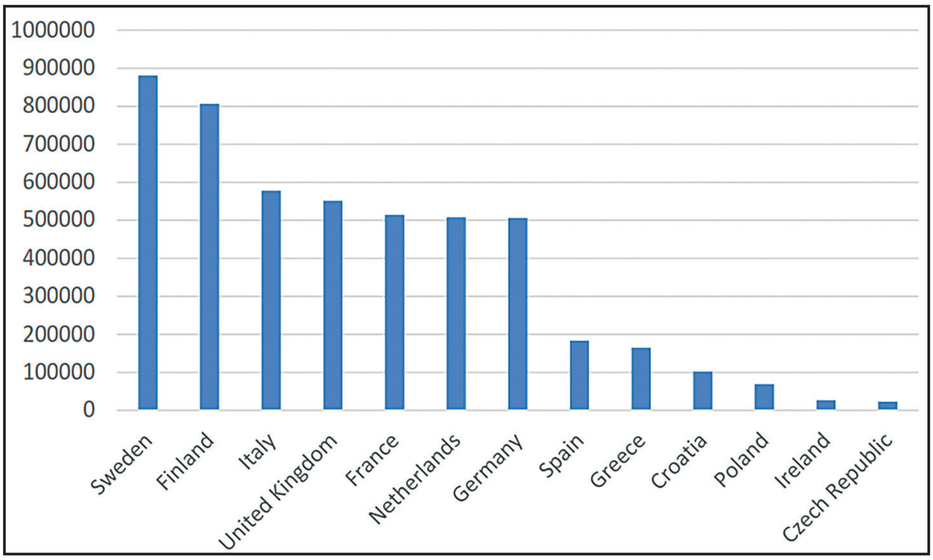

Figure 2.1: Total recreational vessel numbers in EU nations (2014)
(Source: Haines, 2016)

In noting that FRP has certain detrimental (irritating) effects on human skin and respiration (e.g. Kilburn, Powers and Warshaw, 1992), the IMO report LC/SG 40/2 (IMO, 2017) goes on to state that *circa* six million recreational vessels are present within the EU with some 140,000 due for scrapping each year. Data appear to have been collected from an EC Europa report which states that there are currently 6.3 million recreational vessels in the EU and some 16.5 million in the USA (Ventura Monsó., 2012). In addition, Haines (2016) gave a further breakdown of recreational boat ownership in the EU in 2014 (Figure 2.1), noting significant work on disposal of FRP boats in Nordic nations, especially in Sweden and Finland. However, Norden (2013) identified a "*lack of environmental care*" regarding the issue (Table 2.1).

Significantly in the context of this report, data considering the numbers of vessels and those disposed of in islands states were not readily available and this information may be an important element to guide future management and viable reuse / recycling options.

2.2 End-of-life disposal, current practice and aspirations

2.2.1 Current research

It is evident that there is increasing interest in recycling FRP vessels. Numerous bodies have made reports available on-line, though in general the end point acknowledgment is that whilst there is a drive to recycle FRP material from end-of-life boats, the reality is still problematic (as noted by the industry and end users). Table 2.1 below summarises potentially useful resources in understanding the wider issue and recent suggested solutions and actions.

Table 2.1: Example reports relevant to FRP disposal, collection and recycling

N.B. Publication data from developed nations may lead to conclusions not directly applicable to smaller nations or developing island states

Report	Author Body	Subject Area	Conclusion	Location
National Composites Network. Best Practice Guide, End-of-life Options for Composite Waste.	National Composites Network. Also see Ecocomp Conference for 2019 on composite recycling etc. (NCN, 2006).	Recycling and re-use of composite material.	Discusses that 70% of material (glass strands and inorganic filler) remains after pyrolysis. Suggests cement kiln firing is a better option (road and building use) and also discusses tax / recycling options.	Composites UK
Best Management Practices (BMP) for Abandoned Boats (2009).	National Association of State Boating Law Administrators (NASBLA, 2009).	View of 32 USA states included toward management of abandoned boats.	No specific guidance for FRP, but recognises the issue and makes provision for best practice, but landfill option evident.	Marine Debris (NOAA)
Recovery of Obsolete Vessels not used in the fishing trade (2011).	European Commission. DG Environment. (EC, 2011).	Section 7.5 onwards discusses non-metal ship recycling, and developing options (in 2011).	Notes that planned recycling centres in France did not develop due to lack of market for FRP. But notes (as others) that concrete etc. are options. Overall, shows nations encouraging FRP recycling, but as with other reports, problematic to show how this will be achieved.	European Commission
Boatcycle – guide on good scrapping and waste management practices for out-of-use boats (2012).	EU Life Project. (EU, 2012[a]).	Review of boat lifecycle, disposal options and promotion of good practice (from 2010-2012).	Makes specific reference to FRP. Concludes “*nothing convincing*” with regard to USA EPA approach to recycling. Suggests possible use of recycled composites in cement. Recommends EURECOMP study.	European Commission
EURECOMP. A new life for thermoset composite end-of-life components (2012)	European Union (EU, 2012[b]).	Identification of main sources of FRP waste. Investigation of chemical processes to recycle.	Solvolysis (substitution reaction using solvent), reactor created to investigate feasibility of FRP recycling / reclamation. Recovered fibres and polymer molecules.	See CORDIS for study summary. See also Oliveux, Dandy and Leeke (2015[a])

Report	Author Body	Subject Area	Conclusion	Location
Disposal of plastic end-of-life-boats (2013)	Nordic Council of Ministers. (Norden, 2013).	Discusses issue in Nordic nations, legislation, pollution and attitude	Concludes that no Nordic nation (in 2013) had a system in place. Highlighted lack of concern, and that burning and landfill were main accepted options. Concerns for this approach and lack of environmental care.	DiVA portal
Abandoned and Derelict Vessels: Where do we go from here? (2016)	Canadian Maritime Law Association. (CMIA, 2016).	Legal aspects of vessel disposal and possible funding routes.	Puts problem into Canadian legal terms, but also discusses funding sources (similar to those in place in USA). Largely aimed at commercial activities and discusses positive aspects of at sea disposal.	Canadian Maritime Law Association
Composite Recycling: Where are we now? (2016)	Composites UK (Job et al., 2016).	Overview of current and future challenges for composite recycling.	Overview of recovery processes, possible markets and legislation.	Composites UK
Recycling of fibreglass boats (unknown).	*University-National Oceanographic Laboratory System* (Benvenuto, Date unknown)	PowerPoint talk, recycling of composite boats – Rhode Island.	Useful summary of issues for small USA state. Recommends pyrolysis as the most cost effective route.	UNOLS

Of the reports listed above and of the many others available on-line, including those published by local / regional Governments, the general impetus is to find a sustainable solution to the issue. In the United States and Canada available reports show that policies have been put in place to collect and recycle old boats, however when it comes to the question of final management of FRP vessels, these tend to revert to the landfill option. For example, there are numerous discussions on the internet on the glut of damaged hulls after hurricanes. The owner of a boat recycling businesses in Texas had to landfill 200 hurricane-damaged hulls as he could not find a financially viable market for them. The comment was made that "*the market for recycled fiberglass is too small and fragmented, and the price for recycled fiberglass is too low to justify trying to recycle it*" (Flannery, 2016).

Wooden and steel vessels are readily recyclable with scrap yards being used (e.g. in Spain [see EU, 2012a]), however in the matter of FRP boats, in practical terms the situation has apparently not much changed since the issue began to be discussed more widely and its apparent that landfill is still the prevalent option with, for example, the United States still allowing landfill, but Germany and some other EU nations having "*largely banned*" this disposal route (Job *et al*., 2016).

Table 2.1 is by no means an exhaustive presentation of end-of-life vessel management research and reporting, but serves to give a readily available overview of the timeline of thought on the matter and reports published by trade and Government bodies. Notably, the main aspect is that end-of-life FRP vessels will generally be sent to landfill for disposal and that options for recycling are limited. This appears largely due to cost-benefit in that commercial operations cannot generate enough value from the recycling of FRP (currently) to make such actions economically viable though it is strongly commented that markets need to be developed (e.g. see Job *et al*., 2016) and infrastructure will be needed. In addition and unfortunately, many of the reports agree that the matter is a growing problem and from the geographical spread of information, this is unsurprisingly at the global level though the information here, due to availability, tends to focus on EU and North America.

2.2.2 Current management options

There is limited value in repeating too much of the strong body of research that has been undertaken with regard to the possibilities of FRP recycling or current general management and companies succeeding in commercial recycling of FRPs (e.g. see Job, 2013, 2014). However, an overview of options and references to pertinent material are provided for the sake of completeness. In respect of the potential for recycling, there is limited information on the possibility within such areas as island nations. However, whilst data on this aspect are in short supply for context, a discussion on this factor is given.

2.2.2.1 Disposal

Landfill

It is evident from papers, reports and personal communications, that the majority of FRP vessels (and related general waste), currently go to landfill, or, in particular where space is limited, they are burned or sunk (see section 4.3). Discussions with individuals in the research sector suggest that they view this as a growing issue which will, in due course, require legislation over and above existing. At the other end of the scale, persons operating boatyards left with derelict vessels and absent owners have to find potentially illegal methods of disposal (*Pers. comm*., 2017), not least to minimise their costs.

Asokan, Osmani & Price (2009) identified that not only is FRP waste from production processes an issue, but equally as seen here, so is end-of-life products. The authors show that at the time of research in the United Kingdom *circa* 55,000 tonnes of FRP waste were produced annually with the level expected to increase by 10% per year (Asokan, Osmani & Price, 2009). Further to this, the authors identified that *circa* 90% of FRP *waste* goes to landfill.

To highlight that this is a growing problem, a more recent use of FRP products is for wind turbine blades. Marsh (2017) notes that landfill for wind turbine blades (and by extension, end-of-life hulls), is "*hardly a viable long-term solution*". Further to this, Marsh (2017) commented that Germany has banned landfill disposal of blades and other FRP items and that use of landfill is increasingly expensive. For example United Kingdom landfill tax and transport fees put per tonne price of FRP disposal at £120-130 (Job *et al*., 2016). Furthermore, public perception of plastics management and disposal is increasingly an issue; this is particularly in relation to plastic related waste and marine / aquatic ecosystems (Law, 2017).

Acknowledging that the majority of FRP from production waste and end-of-life products (in particular boats) currently goes to landfill, there have been attempts, through research and commercial approaches, to create a use stream for FRP waste. However, currently from the overview undertaken here, it is evident from local Government, environmental management teams, research and commercial (trade) publications, that even if the aspiration is to achieve something other than landfill, on commercial and not environmental / altruistic grounds, the cost benefit model (e.g. López *et al*., 2012) still makes landfill the preferred option, but in island states limitations on this appear likely to lead to other approaches with their own concerns.. Where data allow, the potential impacts of FRP to landfill are discussed below (section 3.2).

Recycling: mechanical breakdown

An alternative to landfill is the mechanical breakdown of FRP for use in alternate markets through remanufacture. Oliveux, Dandy & Leeke (2015[b]) provide a useful research paper discussing recycling possibilities of FRPs, including economic cases and production issues. In this work an overview of the mechanical processes of breaking down FRP is given and a summary of some companies involved in this approach (for example see Filon Ltd). More recently Vladimorov & Bica (2017) give detail and an "*environmental evaluation*" of the process.

The bonded nature of FRP (fibre, resin and filler) means that the constituents "*cannot be depolymerised*" leading to them "*commonly ending up in landfill*" (López *et al*., 2012). Therefore methods to recycle have seen increasing attention though Vladimorov & Bica (2017) state that the commercial approach to mechanical recycling of FRPs actually began in the 1970s. An interesting observation here is that in the 2016 example of hurricane damaged boats in the United States given above, the fact that no financially viable alternate to landfill was found, suggests this market still needs development. However, some organisations are showing that they are making progress in this area with some even using FRP recycled products (e.g. United States Global Fibreglass Solution, Eco-Wolf Inc; Germany Fiberline Composites).

Waste FRP material is crushed into powders, flakes and "*fibres of various lengths*" and methods are improving to obtain different grades of recyclable material (Oliveux, Dandy & Leeke, 2015b). The most common uses for recycled FRPs are as fillers / reinforcement in a variety of applications such as concrete, tarmac, asphalt reinforcement etc. (see Vladimorov & Bica (2017)). However, the applications for using it as a filler for concrete / tarmac etc. are possibly limited (<10%) as the mechanical properties of the recycled compounds deteriorate and new fillers are relatively inexpensive (Oliveux, Dandy & Leeke, 2015[b]).

The research and practical studies show that there are numerous environmental benefits to the mechanical recycling of FRPs and that in comparison with other options it is a "*simpler process*" (Vladimorov & Bica, 2017). For concrete applications Vladimorov & Bica (2017) state that the use of GRP can lead to cost savings (over FRP waste handling, transport, storage and landfill) and FRPs used as aggregate can save *circa* "*15% of the aggregate cost*" (Asokan *et al*., 2009).

Overall Vladimorov & Bica (2017) found that recycling FRP to plastic foil followed by concrete reinforcement were the most viable uses, though it is unclear what the market may be. They advocate closed loop recycling (e.g. see Job *et al*., 2016) though on an island state this may not be feasible and equally is evidently proving somewhat problematic in larger nations.

It is not the role of the document to fully cover recycling options, however it is notable that the market has perhaps not yet fully developed despite positive comments on industry web sites from as long ago as 2010 (e.g. see Fiberline). On the basis of *some* research papers and yachting / trade magazine comments, it appears that this opportunity has not yet reached a level where it is financially sustainable, though others may challenge this view. This is with particular relevance to island communities where transport costs to recycling centres and probable lack of demand for materials, likely render the process marginal at best. It is seemingly unlikely to be currently viable in nations and states with no immediate access to recycling processes or market for products depending on operational / requirement scale. However, this would require research and possible opportunity mapping to clarify potential and alternate sustainable options on a region or country by country basis to achieve viable recycled products and a market for them.

Recycling: pyrolysis

Oliveux, Dandy & Leeke (2015[b]) discuss the opportunity and use of material broken down with pyrolysis (see also Oliveux, Dandy & Leeke, 2015[a]). This involves temperatures *circa* 450-700°C for the breakdown of FRPs and leads to recovery of "*fibres, fillers and inserts*" (Oliveux, Dandy & Leeke, 2015[b]). This does not lead to recovery of the resins which are volatised to gaseous states. In addition, López *et al* (2012) state that the glass fibres obtained through pyrolysis are somewhat physically degraded with two cited works in López *et al*. (2012) reporting a 35% and a 50% reduction in overall fibre strength. However, the recycled fibres have been successfully used in manufacturing of new composite material with "*some 25% of the original glass fibre*" being recycled (López *et al*., 2012).

FRPs can also be used for firing in concrete production at higher temperatures, but "*no more than 10% of the fuel input to a cement kiln could be substituted with polymer composites reinforced with glass fibre*" (Oliveux, Dandy & Leeke, 2015[b]). Thus kiln firing and incorporation of FRPs in concrete appears a potentially attractive solution providing demand and production infrastructure exists. Oliveux, Dandy & Leeke, (2015[b]) cite communication with the European Recycling Service Company who commented that they felt cement kiln to be the most sustainable option with regard to management of FRP. However, with particular pertinence to this report, it is commented that even the cement kiln / pyrolysis option is not as economical as landfill "*where landfill is an option*" (Oliveux, Dandy & Leeke, 2015b) though this situation may change with growing legislation.

Recycling: solvolysis

A methodology which, unlike pyrolysis, encompasses an aim to recover resinous materials in addition to filler and the fibre strands has been developed. Known as solvolysis (a replacement reaction between target molecules within a given substance and their replacement molecules), in the case of FRPs, a solvent is used to break the FRP resins into "*low molecular weight products, and ideally into the monomers initially used to manufacture the resin*" (Oliveux, Dandy & Leeke, 2015[a]).

The European Union EUROCOMP project (EU, 2012[b]) investigated the validity of solvolysis as a practicable method of FRP recycling with the aim of recovering independently, resins, fibres etc. The practice is recognised as potentially expensive as reactor vessels become more robust to withstand pressure and temperature and corrosion, due to solvent modification during the reaction (Oliveux, Dandy & Leeke, 2015[b]). Further to this, Vladimorov & Bica (2017) report that the EUROCOMP study found "*that solvolysis was not competitive with treatments like mechanical recycling or with incineration with energy recovery in terms of environmental impacts*", however Job *et al*. (2016) highlight that upscaling a chemical reprocessing trial at the University of Birmingham, "*will enable higher processing rate and lower specific energy demand*".

Accordingly it seems evident that the feasibility of chemical or combustion technologies may merit further consideration in specific cost – benefit models. The above is not to dismiss solvolysis as a potential viable future option in efforts to achieve sustainable recycling of the valuable materials and compounds within FRPs, which would not be an appropriate conclusion for this research. The method has obvious potential and may become more viable as financing routes and drives to achieve recycling of FRPs increase, but in specific context of this work, a comment was made that "*these processes* [pyrolysis and solvolysis] *are a long way from being scaled up to the capacities we need for boat hulls*" (Summerscales, *pers. comm*., 2018) thus consensus between differing views may be appropriate.

2.2.3 Aspirations

The drivers behind increasing interest and desire to find sustainable disposal or recycling routes for FRP vessel hulls will be numerous and in the context of island states, potentially site / nation specific. Largely they may relate to space, aspirations to achieve sustainability goals, public pressure (in particular with regard to plastics in the sea), declining landfill space, environmental aspirations of owners (e.g. see: Boat Digest though some links on website now defunct), and perhaps a realisation of FRPs financial potential, should recycling become more viable.

It is evident that interest in recycling plastics and the difficulties of disposing / managing end-of-life FRP hulls is gaining pace. Through this work, discussions with researchers in the field indicate increasing awareness of the issue and that some form of regulation and / or financial backing with FRP vessel disposal will be necessary in the relatively near future (Haines, 2016; Summerscales, *pers. comm*., 2018).

This review has not currently highlighted methods of recycling as the ones listed are the more commonly referred to. This has demonstrated, at least as anecdotes and reporting currently best show, that landfill is still the most commonly employed option on a global scale, though local variations do occur. As López *et al*. (2012) show "*recycling thermoset composites is a particular challenge since, once the thermoset matrix molecules are cross-linked, the resulting material can no longer be re-melted or remoulded*" though as demonstrated, research is ongoing into developing such options to make them increasingly viable.

For the future there have been suggestions that FRP hulls may have to be managed for disposal via a similar route as the WEEE Directive (European Directive on Waste Electrical and Electronic Equipment, (2, 002/96/EC)) and the European Directive on End-of Life Vehicles (1999/31/EC, 2000/53/EC) (López *et al*., 2012). Currently, as reported by Haines, (2016), there are no legal instruments in place requiring how end-of-life boats (ELB) should be disposed of. Further, Haines, (2016) reports that *circa* 1-2% of the 6-6.5 million recreational craft across the EU are recycled, with "*a large number of ELBs* [being] *abandoned, illegally landfilled* [presumably in unlicensed sites] *or sunk*". As this is the current suggested status of recycling across the EU, where active efforts have been made to address the issue, this presumably is somewhat the case across other major nations facing the same issue (e.g. United States as discussed above). Furthermore, if low recycling and illegal disposal is a problem in larger nations, it seems likely (though research to substantiate this is still needed) that in small island states as a percentage, the problem would be magnified particularly with regard to lack of storage space, sparse landfill capacity, lack of recycling facilities and possibly a limited demand for related recycled products (e.g. concrete etc.).

Haines, (2016) highlights the difficulties associated with ELB management (Figure 2.2), and suggests approaches towards the issue including owner registration, research funding and a management fund (Figure 2.3). Haines, (2016) comments that "*the limited scale of the ELB recycling and dismantling market reflects* [as previously demonstrated] *the unfavourable economics of the business*". The work goes on to discuss boat owner registration and its lack, as a barrier to potential future management options and that the deleterious impacts of FRP vessel disposal (legally or otherwise) are expected to increase on an EU basis and by extension, on a global scale.

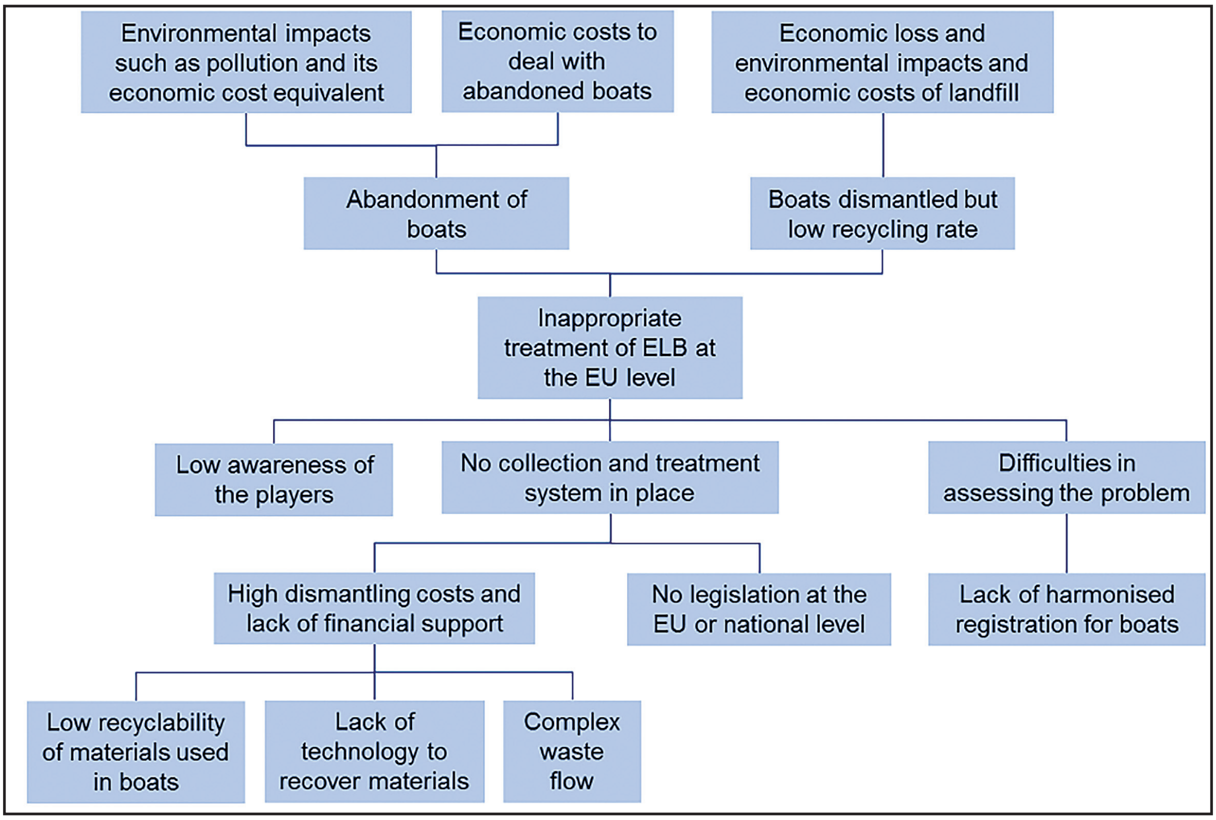

Figure 2.2: End-of-life boats management tree (to be read from bottom to top). Note, whilst an EU specific project, the drivers and problems are global
Source, Haines (2016)

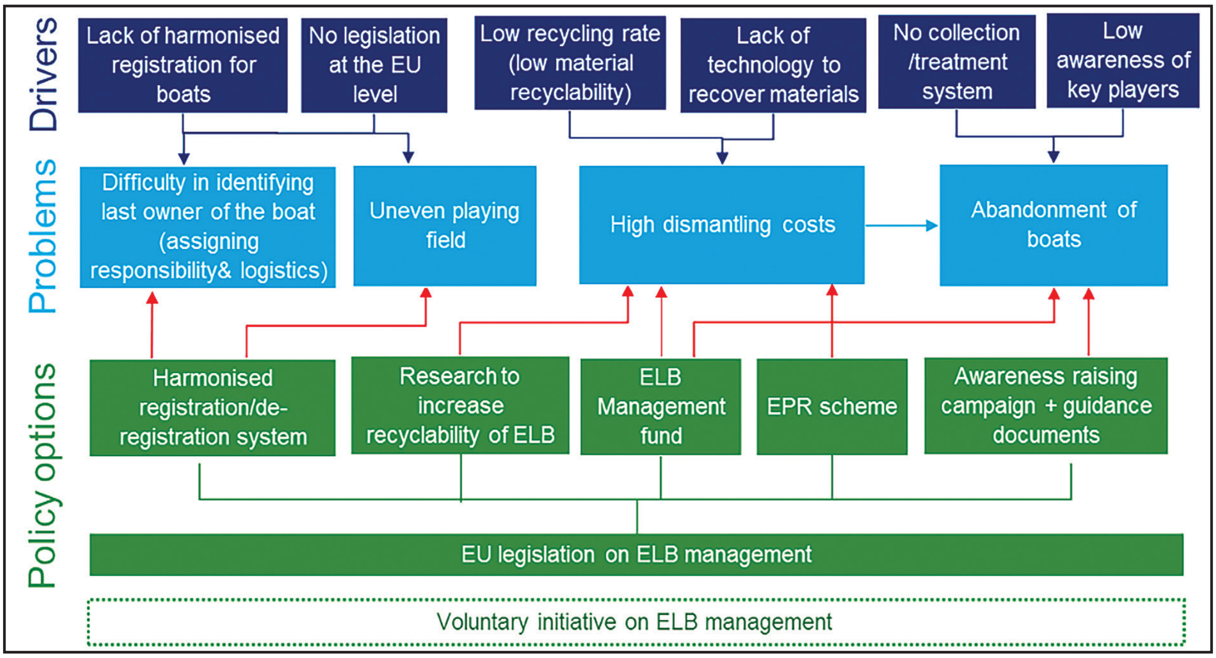

Figure 2.3: Mapping of the drivers, problems and policy options. "*Red arrows indicate the problem areas that the policy options directly address*".
Source, Haines (2016).

Further discussion by Haines, (2016) highlights possible voluntary and policy options with regard to future management of ELBs. These are suggested to both combat the current and potential growth in number of older and abandoned boats, and to develop further research towards more viable recycling options or enhancing current ones to industrial scale; this latter point has been made by those in the field during research for this work.

Whilst Haines, (2016) stated that "*it was concluded that no individual policy option could fully resolve all of the problems related to end-of-life recreational boats*" a set of policy options were put forward representing differing levels of legislative control (Table 2.2), though the applicability of these in developing nations would require research or trial.

Table 2.2: Options (modified) put forward by Haines (2016) for the improved management of end-of-life boats

Option	Outcome
A: Enhancing knowledge and awareness (this would include following sub options): • Registration system; • Awareness raising materials such as guidance and best practice documents.	The policy package addresses the main issues in to ELB management (identification of last owner, difficulty in assessing the situation and low awareness of the environmental impacts of ELB abandonment). It would involve minimal government intervention.
B: Direct support and non-legislative direction through establishment of ELB management fund and targeted research. In addition to registration system, option includes establishment of ELB management fund, financed by boat manufacturers and/or boat owners. The ELB fund would collect funds through a "disposal fee" that could be applied through existing fee systems e.g. port-service & boat registration fees, etc. and/or at the purchase of new boats.	The funds collected would help to pay for dismantling costs and fund targeted research on the recyclability potential of ELBs. For example, research on recycling processes / opportunities for polymer plastics and new materials to replace polymer plastics and life cycle analysis assessments (LCA) to address the relative merits and disadvantages of the various boat disposal options.
C: Additional legislative action. Would require the greatest amount of Government intervention.	As A and B above through additional legislation.

Whilst an EU based study which relates to future management of end-of-life vessels and in particular to this work on FRP boats, the major conclusions by Haines (2016) are generally applicable to the global issue with a degree of variance. Thus this is not to suggest a panacea as local situations would require relevant approaches to the matter. For example, since 2010 Florida has an "At-Risk Vessel Program" enforceable by local police in an effort to control boat decline and subsequent abandonment, though as discussed here, tracing owners can be a problem (Lydecker, 2011). To compliment this, Florida runs a Marine Debris Program dealing with derelict vessels considered to be an environmental risk (Marine Debris [NOAA]). However, Haines (2016) notes that "*a harmonised registration system across the EU* [and by extension other global areas] *would result in the following behavioural changes*":

- "*Abandoned boats could be retrieved more readily*" *(and presumably ownership traced);*
- "*Boat owners would be less likely to abandon their boats and the number of boats transferred to authorised facilities will increase, especially if the registration system is mandatory*".

Importantly, however, Haines (2016) goes on to note that the effect on owners' behaviour may be minimal because of "*lack of legislation requiring them to transfer ELBs to authorised dismantling facilities*". Nevertheless a fund at the centre of future FRP vessel management financed through vessel users and retailers or insurance, may prove a useful tool in future management of composite (and all construction materials) boats, equally (as seen with some other wastes) it may lead to a black market development and a physical shifting of the waste and the associated problems.

For interest, Haines (2016) goes on to calculate the potential costs of an end-of-life boat management fund. The figures have not been quoted here as they are EU specific, though an overall fund value of *circa* €80 million per annum is suggested with regard to EU boats; not just FRP recreational vessels, though they may be assumed as the majority and the most problematic to recycle. For further detail on the figures calculated, see section A7.7.2.1 (page 264) of the Haines (2016) report.

Finally, and notably, the French appear to be taking a lead in a national response to boat recycling, including promoting the repurposing of FRP hulls (possibly of interest in developing nations). A national organisation (APER) "*is a non-profit organization, created in 2009 by the French Nautical Industries Federation*". A presentation from 2014 explains their general rationale. Importantly for this study, and in direct relation to the work by Haines (2016), the President of APER, Pierre Barbleu gave a talk at the METS TRADE conference (November 2017) highlighting that the French Government are "*introducing an Eco Tax on all newly registered boats from January 2019, and adding some government financing to create a new fund*". It was stated that "*the APER network will be able to use this money to subsidise their work, and increase the number of boats it is able to dispose of from 600 a year currently to 6,000 a year from 2019*" (METS Trade, 2017). In addition, the METS TRADE (2017) article, through comments below it, points to a Dutch report highlighting that the problem of end-of-life boats may reach a peak, in the Netherlands, by 2025-2030 (WA Yachting Consultants, 2015). It is stated that the matter in The Netherlands, and by extension globally, needs concerted attention. In addition as discussed above, the issue with hurricane destruction of recreational craft (particularly in the Caribbean and Florida) is also recognised as a significant problem (METS TRADE, 2017).

3. Potential environmental impacts

Numerous FRP vessels can be observed in various stages of disrepair in boatyards and abandoned in waterways and onshore. This particularly highlights the difficultly with tracing responsible parties and / or the financial burden that boat ownership can place on individuals leading to general abandonment and thus problems of disposal for boatyards or local authorities / Government bodies.

The environmental implications of FRP hull disposal are problematic to qualify in detail as there appears to be a general lack of readily available research on the outcomes of some of the various disposal routes.

Where data allow, the impacts are discussed below.

3.1 Decomposition / disposal on land

Within this section the practice of burning is encompassed. This is not a recognised or recommended disposal route, however research for this report indicates it can be employed by members of the public / as a last resort.

On-land decomposition on the integrity of compound material is difficult to quantify as the nature of FRP hulls and research reviewed here suggests possible lifespans (with some degree of error) of 30-50 years, though this is presumed in the context of a water environment use. As López *et al*. (2012) and numerous other internet discussions and research papers show, the resin / spun glass wastes from FRP boat hulls are non-biodegradable and other factors (e.g. photo degradation, have limited effect), thus hull life may be considerably longer than the quoted time periods suggested.

3.1.1 Physical effects

The physical effects of abandonment or recycling on land include the obvious loss of space and visual impacts which should not be disregarded. Abandonment may be in areas of high natural beauty potentially important for tourism / the local economy. Thus the perception of local users may be negatively impacted by the "*eyesore*" (Helton, 2003). In areas of particular relevance here, visual aspects can be a significant driver for example on island nations where tourism perception may be important for local revenue, coupled with the drive for conservation of the very aspects tourists come to see (Lord-Boring, Zelo & Nixon, 2004; Roig *et al*., 2005).

Further to the above, disposal on land via recycling may benefit from further consideration with regard to human health and *possible* carcinogen, skin and respiratory issues plus water quality and longer term change associated with concentrated recycling effort

3.1.2 Chemical and biological effects

3.1.2.1 Weathering

There are limited data regarding the physical decomposition of FRP products when left on land. Potential effects relating to this are release of hydrocarbon compounds as material breaks down and the fibres contained within the resinous matrix, but with lifespans predicted to be 30-50 years, and in practicality somewhat longer, this may be why research in this field appears limited.

Blaga & Yamasaki (1973) and Bagherpour (2012) are two of the few readily available papers considering environmental weathering on FRP compounds. They report that FRP breaks down over time due to a variety of weather based factors, the most important of which were temperature and humidity leading to "*environmental stress cracking*". Other factors such as UV light associated with solar irradiation can also lead to break down of FRP materials through the release of free radicals (a highly reactive molecule or atom with an unpaired electron) in the resinous structure. No time scale elements are given, but it *may* be assumed that the period for weather / sunlight degradation is potentially longer than the suggested 30-50 years suggested by other workers in "normal" use scenarios.

As previously discussed, the release of fibres into the atmosphere or the degradation of hulls (or break up of them) with exposed fibres, can lead to respiratory tract and dermal irritation. While the U.S. Department of Health and Human Services issued a report in 1994 stating that fiberglass is "*reasonably anticipated to be a carcinogen," they issued a disclaimer that this did not apply to general consumer exposure. Conversely the* "*American Conference of Governmental Industrial Hygienists, the North American Insulation Manufacturers Association and other groups also underline the fact that conclusive research has not shown fiberglass to be a carcinogen in humans*" *(THOMAS, date unknown).* However, with the lack of research and clear examples, the open air weathering of FRP hulls (as opposed to cutting up) is possibly of limited concern when considered against other factors.

3.1.2.2 Burning

There is limited information of the general public or commercial practice of open burning of FRP being a *recognised* route of disposal. However, one document did refer to "backyard burning" of old boats. There are clear indications given that open air burning will be, in general unregulated and a process strongly recommended against. However, it evident that its an option undertaken to manage the issue at the private level when space becomes a problem (e.g. see this YouTube video). In research for this report, one Government officer did mention that some old FRP boats were burned onshore, but that this practice had now ceased whilst other options were sought.

Lemieux, Lutes & Santoianni (2004) explored toxic emissions from numerous open air burning sources (also see Lutes & Ryan, 1994). They report results from a United States EPA (Environmental Protection Agency) study into open air burning of fibreglass (FRP) where a comparison was made between burning emissions from FRP used for boats and that used in the building industry. Notably, emissions from FRP contained a greater variety of organic compounds, however building industry FRP pollutants were in general at higher levels (Table 3.1).

Emissions from FRP boat burning (accepting that there will not be a universal FRP in boat production (see section 2.1)) contain numerous organic compounds noted on the Hazardous Air Pollutants (HAP) list (EPA). Consideration of example compounds produced from FRP combustion emissions (found on EPA website) shows acute (short term) effects ranging from:

- Central nervous system dysfunction and narcosis e.g. toluene;
- Eye, skin and respiratory tract irritation (short term exposure) e.g. benzene;
- Eye, nose, throat irritation and gastrointestinal effects e.g. xylene compounds;
- Eye and skin irritation, toxic effects on liver, kidneys, central and peripheral nervous systems e.g. biphenyl;
- Haemolytic anaemia, liver and neurological damage e.g. naphthalene.

Note. Appropriate caution should be applied to assess air levels in relation to toxic effects.

Table 3.1: Organic compound emissions from open air fibreglass burning (mg/kg burned)
Modified from Lemieux, Lutes & Santoianni (2004)

Class	Compound	Boating industry	Building industry
VOCs	Chloromethane	435.9	420.8
	Vinylchloride	0.8	
	Bromomethane	1.7	772.6
	Chloroethane	0.8	
	1,1-Dichloroethene[a]	0.8	
	Acetone[a]	155.6	158.0
	trans-1,2-Dichloroethene[a]	0.3	
	1,1-Dichloroethane[a]	0.8	
	Chloroform	36.9	23.9
	1,1,1-Trichloroethane[a]	0.5	
	Carbon tetrachloride	0.6	
	Benzene	5921.3	10,472.7
	1,2-Dichloroethane[a]	0.7	
	Trichloroethene	0.8	
	1,2-Dichloropropane[a]	1.0	
	Bromodichloromethane[a]	0.7	
	cis-1,3-Dichloropropene	0.7	
	Toluene	3633.2	4723.7
	trans-1,3-Dichloropropene	7.6	
	1,1,2-Trichloroethane	0.8	
	Tetrachloroethene	0.9	
	Dibromochloroethane[a]	0.9	
	Chlorobenzene	2.0	
	Ethylbenzene	700.7	2686.0
	m,p-Xylene	468.0	1523.2
	o-Xylene	4.5	8.1
	Styrene		9931.6
	Bromoform	0.9	
	1,1,2,2-Tetrachloroethane	2.6	
	1,2-Dichlorobenzene[a]	1.5	
	1,4-Dichlorobenzene	1.8	
	1,3-Dichlorobenzene	1.1	
SVOCs	Acetophenone	77.0	286.0
	Benzoic acid[a]	1288.0	781.0
	Biphenyl	689.0	1936.0
	Cumene[a]		251.0
	Dibenzofuran	105.0	945.0
	n,n-Diethylaniline		353.0
	Di-*n*-butylphthalate		24.0
	Bis(2-ethylhexyl)phthalate		60.0
	2-Methylnaphthalene[a]	89.0	516.0
	2-Cresol	125.0	400.0
	3/4-Cresol		1731.0
	Phenol	328.0	6830.0
PAHs	Acenaphthene		
	Acenaphthylene	533.0	733.0
	Anthracene	353.0	202.0
	Benzo[*a*]anthracene	171.0	214.0
	Benzo[*a*]pyrene	86.0	72.0
	Benzo[*b*]fluoranthene	284.0	
	Benzo[*g,h,i*]perylene	33.0	
	Benzo[*k*]fluoranthene	48.0	
	Chrysene	323.0	458.0
	Dibenz[*a,h*]anthracene	16.0	
	Fluoranthene	314.0	694.0
	Fluorene	453.0	409.0
	Indeno[1,2,3-*cd*]pyrene	28.0	
	Naphthalene	1913.0	5915.0
	Phenanthrene	902.0	2156.0
	Pyrene		

Source. Ref. [26].
[a] Compound of interest not on HAP list.

Lemieux, Lutes & Santoianni (2004) commented that fibreglass produced "*fairly prodigious amounts of VOCs*" (volatile organic compounds) and data in their paper showed fibreglass burning being consistently in the top two for example toxic compound emissions.

3.2 Landfill disposal

3.2.1 Physical effects

As discussed above, landfilling is not felt to be a long term viable solution for waste treatment, let alone end-of-life FRP boat hulls. However, currently the majority of FRP products being scrapped go to landfill and FRP hulls and related wastes (e.g. wind turbine blades), despite growing research and methodologies, still follow this route based on financial reasoning. Unless considerably broken down into small pieces, hulls etc. are bulky and large and take up significant space within landfills.

An attempt to find concise information on the remainder status of landfill resources globally, or clear direction for nations (United Kingdom used as an example) proved contradictory with differing opinions on years of use left or to have low availability. In the United Kingdom there are claims that landfill space in England will cease in 6-7 years' time (United Kingdom Government, 2016). Conversely, some landfill companies feel there is capacity and opportunity (e.g. power generation) in landfill yet. However, overall the drive is to move away from landfill and aim to reduce and recycle more, particularly in relation to plastics.

In a Small Island Developing State (SID) context, Foolmaun, Chamilall & Munhurrun (2011) considered landfill space and resources available in Mauritius. It was shown that in the highly tourism dependent economy, landfill requirements had grown significantly in line with economic growth. It was also reported that, "*the island's fragile ecosystem is threatened with a host of environmental issues such as solid waste disposal, biodiversity loss, degradation of coastal zones, fresh water pollution, air pollution, hazardous wastes disposal, mainly resulting from unprecedented economic, social development, industrialization and unsustainable production and consumption patterns*".

A planned landfill site was receiving four times the waste expected and much material (*circa* 12%) was dumped in waterbodies and on open land. Thus, in context here, the physical impact of FRP hull disposal in landfill is a disproportionate take-up of space for a waste that will take a considerable period to decompose, if at all in likely anoxic landfill conditions.

3.2.2 Chemical and biological effects

The decomposition of FRP in landfill appears to be an understudied field. Despite numerous literature searches, no data or reports could be readily identified. This perhaps reflects the wider opinion and knowledge that FRP composites are inherently very stable and takes many years to decompose.

One of the earliest works obtained that researched the problems of FRP small boast disposal, commented on the possibility for FRP from boats adding to fire risk from spontaneous combustion in landfill (Backman & Lidgren, 1986). Interestingly, in landfill conditions one study (Adamcová & Vakerová, 2014) found that even degradable plastics showed little change over a 12 month period. Alternately, Yamamoto *et al*. (2001) reported that bisphenol A was found leaching from landfill sites in Japan at levels toxic to aquatic life. Bisphenol has been used in the production of FRP hulls (see section 2.1) and Yamamoto *et al*. (2001) comment that it is "*used as a monomer for polycarbonate or epoxy resin production*". However, personal communication with Summerscales (2018) led to the opinion that the source was more likely to be additives in plastics (e.g. see Guart *et al*., 2011) as the molecules in FRP resins are highly stable long chain and regularly used, for example in below ground piping.

3.3 Disposal at sea

This section does not deal with abandonment of vessels on the shore, rather the process of deliberate scuttling off or near shore. However, it is recognised that numerous recreational vessels (presumably mainly FRP), are abandoned by owners at shore side moorings, for example see Turner & Rees, (2016) who investigated United Kingdom abandoned boats on the east coast in estuarine environments.

Disposal at sea through scuttling etc. is a route taken by some boat owners when unsure of other options available, when finances restrict, or perhaps in the belief that smaller FRP vessels will be utilised as an artificial reef. It is referred to in papers and reports (e.g. Singh, Summerscales & Wittamore, 2010; Marsh, 2013) as a last resort action or deliberate, and perhaps irresponsible, approach. No figures are immediately available on the scale of the matter, but the issue is by no means limited to smaller nations (e.g. see IMO, 2017). Importantly for this context, the International Convention for the Prevention of Pollution from Ships (MARPOL), the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes, considers FRPs as plastic thus covered by MARPOL, which makes it illegal to dump plastic at sea. However, the disposal of FRP hulls at sea is not covered because MARPOL is applicable to "*shipboard-generated garbage*" only (Eric Green Associates, 2008).

Additionally, the London Convention and London Protocol (LC/LP), the international treaties which protect the marine environment from pollution caused by the dumping of wastes at sea, have produced Revised Specific Guidelines for the Assessment of Vessels (IMO, 2016). These guidelines set out the factors to be addressed when considering disposal of vessels at sea, with particular emphasis on the need to evaluate alternatives. However, it is explicitly stated in these guidelines that they do not address the specific concerns with the disposal of FRP vessels.

As previously discussed, landfill space is an issue in island states which in some instances leads to unregulated disposal of waste on land and in water (Foolmaun, Chamilall & Munhurrun, 2011; also see Mohee *et al*., 2015). The issue of nearshore / offshore abandoned FRP vessels has perhaps more significance in relation to ecosystem services dependency (e.g. fishing and eco-tourism).

Furthermore, to highlight a possible misconception, Eric Green Associates, (2008) discusses that FRP vessels were no longer (at that time) accepted by New Jersey and New York reef programs (echoed by the United States EPA) as "*wave action and currents broke up and moved the vessels about. Thus, fiberglass wrecks did not provide the stable environment necessary for an artificial reef and fiberglass debris ended up on the beaches*". In this respect, work by Summerscales, Singh & Wittamore, (2015) discusses that in the United States FRP hulls sunk to depths of >75 m "*are likely to remain there, and that fish will inhabit them for at least 30-40 years*" [but that] "*hulls sunk to 100 feet (35 m) or less are likely to be disturbed by storms, even when segments are cabled together*". Thus there is potential for damage to benthic features e.g. reefs, seagrass (Lord-Boring, Zelo & Nixon, 2004, see section 3.1.1) onshore stranding of debris, or breakup into microplastic with possible ecological and bioaccumulation implications (Van Cauwenberghe *et al*., 2015).

3.3.1 Physical effects

There is limited general information on physical habitat damage from abandoned boats of FRP or other construction. However, usefully there is one paper that discusses the issue in some detail with particular reference to Pacific and Caribbean islands. As representatives of island states were significant in providing the impetus for this studies' attention to this issue, this paper (Lord-Boring, Zelo & Nixon, 2004) is pertinent and widely referred to here.

The work (Lord-Boring, Zelo & Nixon, 2004) discusses the physical and chemical aspects of abandoned vessels on marine benthic systems and general implications for ecology and function of these communities. The pollution from plastic elements is discussed below, as are related aspects of antifoul and other contaminants possibly still pertinent to abandoned hulls, though in less detail than the FRP element itself.

The authors noted that physical damage from abandoned vessels to seagrass, coral and mangrove habitats could be observed. This can occur not only at the time of sinking, but also in subsequent storm activity which can move wrecks, particularly in shallower waters, to sensitive areas or cause more damage from repeated physical impact.

Effects recorded by Lord-Boring, Zelo & Nixon (2004) include:

- Initial grounding scars which can exacerbate erosion, particularly in seagrass areas (important ecosystem services from seagrass as nutrient / detritus supply for wider marine food webs and passive coastal protection plus numerous other benefits particularly pertinent to island communities) (see: Salomidi *et al.,* 2012);
- In seagrass areas, apart from initial grounding effects, scour (due to meso / microscale current alteration) ranging from 1 to 30 m were recorded, also noted was shoot height and seagrass density increasing with distance from sunken vessels and debris, though current changes were mainly related to larger vessels and debris more commonly associated with smaller (e.g. recreational) boats;
- Coral reef impacts including: "*damage from the initial vessel grounding; damage from vessel or resulting debris and coral rubble moved by wave action, particularly during storms; crushing of benthic organisms and displacement of resident biota; filling in gaps; and reduction of*" reef complexity which can lead to loss of biodiversity and further impact ecosystem services such as tourism, food supply and passive coastal protection (Graham & Nash, 2013). Lord-Boring, Zelo & Nixon (2004) recorded "*extensive debris fields*" associated with sunken boats, with recreational vessel (FRP) debris traveling over wide areas;
- For mangrove communities in both Caribbean and Pacific island areas, initial grounding damage was recorded plus impacts from debris distribution to roots etc. Mangroves are important for e.g. coastal protection / wave attenuation and fish and shellfish nurseries (e.g. Koch *et al*., 2009).

Whilst the damage to mangrove, seagrass and coral habitats from abandoned vessels may be on a relatively localised basis, the cumulative effect from the practice may increase unless the matter is managed proactively as disposal of end-of-life FRP (and other) vessels is predicted to increase. Prevention of at sea disposal in terms of negative physical effects should be a future consideration and driver of planned policy and possible funding routes.

3.3.2 Chemical and biological effects

The chemical and biological effects of FRP vessel disposal at sea are less easy to clarify in terms of the plastic element. There is a generally studied chemical and thus biological relationship from other substances associated with abandoned vessels in benthic / pelagic ecosystems. These include hydrocarbon products (e.g. engine oils) and antifoul paints. The latter in particular can lead to lower diversity and a "halo" effect of relatively depauperate communities impacted by the long term toxicity of antifoul (Haynes *et al*;., 2002; Marshall & Edgar, 2003; Dafforn, Lewis & Johnston, 2011).

In terms of plastic pollution, effects from the physical breakdown of FRP boats on ecosystems and bioaccumulation through food webs is less well understood. It is widely studied and increasingly recognised that plastics in the marine environment break down finally to microplastic (see GESAMP, 2015 for review), and some plastics break down more readily than others (Cooper & Corcoran, 2010), but precise data on the breakdown of FRPs was not available. For example, the GESAMP (2015) document considers plastics at a global scale, but makes one reference to boats and associated production material. This is not a criticism, rather a reflection that data are not readily available on the chemical / biological fate of FRP particles.

As with other plastics it may be reasonably assumed that FRP breaks down to microplastics, though FRP is a very strong compound thus this may be a lengthy process (Summerscales, *pers. comm*., 2018) without physical impact. Plastic particles are known to be assimilated into the food chain by zooplankton (e.g. Desforges, Galbraith & Ross, 2015), filter feeders (e.g. Van Cauwenberghe *et al*., 2015) by which they may bioaccumulate and biomagnify to and in higher organisms (Wright, Thompson & Galloway, 2013), or pass directly to higher planktonic feeding organisms such as basking shark and whales (Fossi *et al*., 2014).

Not only do the plastics themselves accumulate in the gut of receiving organisms, but they also have the ability to "*absorb persistent organic pollutants such as PAHs*[2]*, PCBs*[3] *and DDT*[4]" [and heavy metals (Rochman, 2015), and can reach] "*concentrations up to 10× higher than their concentrations on natural sediments*" (Van Cauwenberghe *et al*., 2015). However, the role of larger FRP fragments, or resultant microplastic particles, in the marine environment for uptake by organisms or accumulation of pollutants is not clear and would require clarification.

In theory FRP particles are potentially not so widely spread as many other plastics and their specific gravity (>1.35) (GESAMP, 2015) will mean they sink relatively quickly even when broken up. Again in theory, as FRP fragments will tend to be concentrated nearshore or shallow subtidal where vessels are abandoned, disposed of or wrecked, it may be assumed that the majority of FRP particles will remain in the general area of origin, though GESAMP (2015) notes that plastics can be re-suspended through the growth of a biofilm.

Finally, whilst it is acknowledged that FRPs consist of strongly bound molecules which, as recycling methods and hull life show, do not readily break down, emissions from these plastics as they decompose in aquatic conditions may have other issues. Rochman (2015) shows that "*according to United Nations and European Union frameworks, >50% of the plastics that are produced are hazardous based upon their constituent monomers, additives and byproducts*". In addition, Rochman (2015) goes on to say that whilst the long chain molecules may be "*chemically inert*" many of the monomers to which they break down are known to be toxic. For example bisphenol can be an endocrine disruptor as can styrene (though a direct endocrine effect for styrene in marine / aquatic systems needs to be clarified (e.g. see Gelbke *et al*., 2015) which is also associated with "*carcinogenic and / or mutagenic responses and are listed as toxic substances by the USEPA, ATSDR* [Agency for Toxic Substances and Disease Registry] *and OSPAR*" (Rochman, 2015).

2 Polycyclic aromatic hydrocarbons
3 Polychlorinated biphenyls
4 Dichlorodiphenyltrichloroethane

4. Scale of the issue

Through research leading to this review, it is evident that the problem of FRP boats and their management at end-of-life is growing in quantity and presumably spatially thus presented here is an overview of the issue in a geographical context. This does not reflect any geographical bias rather that data are relatively available for some regions. For example: North America, where efforts to manage the issue appear to be growing; Europe where France may be taking a legislation lead and Nordic countries which appear to face a significant issue based on the number of FRP vessels. Whilst data for island states and developing nations are limited, they are brought into focus here to further highlight the particular problems with this issue in spatially restricted areas.

4.1 North America

North America comprises Canada and the United States and, with significant crenulations, Canada has the longest coastline of any nation with some of the most remote locations for abandoned boats to become lost / hidden in. The United States coastline is less geomorphologically variable, however, recreational (largely FRP) boat ownership is the largest in the world by nation.

For both Canada and the United States the problems with end-of-life boats are receiving attention from local authorities and central Government recognising that many are reaching end-of-life (not just FRP) and that they constitute cumulative environmental risk. Whilst specific guidance on the future management of FRP boats is still problematic, both nations have put in place programs to recover recreational vessels, for example NABSLA, (2009) (United States) gave guidance on management of end-of-life boats, and at the state / regional level, there are several reports of means by which derelict vessels are removed and the reasons for doing so (e.g. San Juan County, Washington state, Portland, Oregon. Abandoned, or hurricane damaged FRP vessels have been identified as a specific problem for Florida, and in general southern United States, and highlights the difficulty of FRP disposal (see section 2.2.1).

To highlight the growing awareness of the issue, in October 2017 the Canadian Transport Minister announced Canada's formalisation and emplacement of the 2007 Nairobi Convention (see section 5) (Parliament of Canada, 2017). This deals with wrecks / abandoned vessels >300 gross tonnage and shows an increasing drive towards managing the overall issue. In addition, Canada is already running the Small Craft Harbours Abandoned and Wrecked Vessels Removal Program to address "*legacy vessels of concern*" (see Fisheries and Oceans Canada). However, again when reported in the press, TheStar.com (2017), highlights the difficulty of tracing vessels with lack of owner details. This further strengthens calls for compulsory registration and ownership detail transfer to allow financed future management of FRP (and all) recreational vessels not covered by the Nairobi Convention, as well as those that are covered.

4.2 Europe

In strong comparison to Canada, Norway's geomorphologically complex coast makes it the second longest in the world. Perhaps unsurprisingly, even back in 1986 Norway had the highest level of recreational boat ownership with Finland and Sweden close behind. The work that cites this also highlights that at that time in Europe the issue of FRP vessels and end-of-life disposal was beginning to be considered (Backman & Lidgren, 1986). As has been noted elsewhere in this report, several efforts have been made to highlight and manage the issue of end-of-life boats, including European Union backed research into FRP recycling and re-use and projects to specifically consider and drive boat recycling (e.g. the BoatCycle project [see Table 2.1]).

In relation to reports on the matter, the majority of attention to end-of-life FRP boats seems to be focussed on Nordic nations, although this may just be an impression from readily available literature or an actual reflection of the level of boat ownership in these nations. In addition it has already been shown that France is making legislative efforts leading to financing of end-of-life boat recycling (see section 2.2.3). As elsewhere, disposal of FRP boats causes significant public confusion, for example see public queries on the subject from 2012 in Yachts & Yachting. Further, the United Kingdom's Royal Yachting Association (RYA) who identify financing the main barrier to boat dismantling and FRP recycling (RYA, date unknown) and also highlights a previous EU funded project, BoatDigest. The final BoatDigest conference was in 2015 (European Boating Industry, 2016); this perhaps explains why some of the resources on the website are now out of date.

Overall the Nordic nations may be facing the greatest issue related to the number in use boats and the Netherlands is also driving research. The French in particular appear as taking a legislation lead, though its acknowledged other nations may be active though data less available. The outcome of the French approach will require observation and possible emulation by other European nations.

4.3 Island States

It's clear from this review that through financial pressure, space and logistics, island states are potentially facing the greatest challenge from end-of-life FRP boats. Whilst they may not have the highest numbers of FRP vessels overall, in terms of dependency on the sea the concentration of boats, and available space for landfill, opportunities for recycling, and practices of disposal, island state Governments face a significant problem in managing the issue logistically and financially. This is all the more important as these nations are, in the main, highly dependent on the marine environment and at sea vessel disposal (Lord-Boring, Zelo & Nixon, 2004) or leaving old FRP boats on shore can harm the industries (including tourism) and ecosystem services that island nations may rely on.

As previously discussed, landfill is an option for island states (Foolmaun *et al*., 2011; Kumar *et al*., 2011; Mohee *et al*., 2015), but limited land availability, lack of landfill capacity and resultant illegal dumping leave authorities considering options with how to manage all waste. As Mohee *et al*. (2015) commented for the island states studied "*waste disposal via landfilling, illegal dumping and backyard burning were favoured most of the time at the expense of sustainable waste treatment technologies such as composting, anaerobic digestion and recycling*".

Pertinent to this review, a study undertaken by Stoter (2017) discussed the options for FRP / end-of-life boat recycling in Fiji. The work considers options for recycling of FRP, and concludes that the option of firing FRP boats / products in cement kilns to both create the cement and augment the material itself (Asokan *et al*., 2009; Oliveux, Dandy & Leeke, 2015b; Vladimorov & Bica, 2017) is the most effective. Based on research, the use of FRPs in cement production is the most commonly recommended option (see section 2.2.1), however the sustainability and / or feasibility in an island context is questionable. In practice, long-term success of this disposal option will require a sufficiently large market for cement and considerable private sector investment. Whilst this may be an option for some island states, for those with minimal infrastructure or financial backing to create the necessary industry, this may not be a sustainable option. Despite the constraints to disposal of FRP by landfilling within island states, this appears currently to be one of the few practical, economically feasible and environmentally-responsible options. However, the long-term occupational health impacts of those involved in the breakdown of the hulls prior to landfilling requires further investigation. Conversely also based on the cement firing model, this possibly leaves the potential for FRP vessels etc. to be collected and shipped away for subsequent recycling in areas where the infrastructure permits and creates a market. However, as already demonstrated by others, financially the value of recycled FRP is low leading some boat recyclers to send them to landfill on a best business case. Whether a boat registration system (such as the upcoming French model) conferring responsibility on current and past owners for recycling would improve the likelihood of responsible disposal is again open to discussion, and of course the possibility of creating a fund from levy on manufacturers and / or through insurance may be feasible. However, the fund would need to cover shipping costs from island states to make it feasible.

Pyrolisis has been shown as a possible method of FRP recycling (see section 2.2.1), though there is resultant waste material which will require management (likely landfill). From this method, recovered fibres can be recycled though again markets would need to be established on island states. Pyrolisis plants have been used for power production and waste disposal (including tyres) in some island states (e.g. Papua New Guinea (PNG), Fiji and Mauritius [Mohee *et al*., 2015]) thus it may be that this method has already been used for FRP boat disposal or this option may benefit from further discussion.

Much of the above is conjecture and would require detailed discussion and clarification with representatives from islands states specifically managing the issue and regulators and industry with influence over finance and future options. This may lead to informed decisions on taking the matter forward, particularly as interest in management of disposal of all plastics at sea is gaining pace and backing. To this end, a flow chart of possible options for FRP end-of-life boat disposal with particular reference to island states is given below (Figure 4.1).

Finally, for this study, relevant representatives of island states in the Pacific region were contacted to assist in identification of the practices they currently undertake for FRP vessel disposal or the activities they have observed by boat owners. Responses were limited, but gave useful backup to comments made by researchers in that:

- PNG: Vessel owners can approach the National Marine Safety Authority (Papua New Guinea) and propose how they want to dispose of a boat (FRP and other construction). If approved, usually leads to deep sea disposal away from navigation passages and with all contaminants removed;
- PNG: Some dumped by locals to create man-made reefs (possibly not FRP vessels);
- PNG: Some used as fuel barges for logging camps (likely not small FRP but larger vessels) (Poiya, *pers. comm,* 2018);
- Palau: Sunk at owner's request, some lying around with unknown future. Some sold to recycling companies (possibly steel vessels);
- Palau: For FRP vessels, in the past, and burnt and sunk, but now stripped of metal and disposed of on land; and
- Palau: Future plan to manage some shore based wrecks under Nairobi Convention (Moses, *pers. comm.*, 2018).

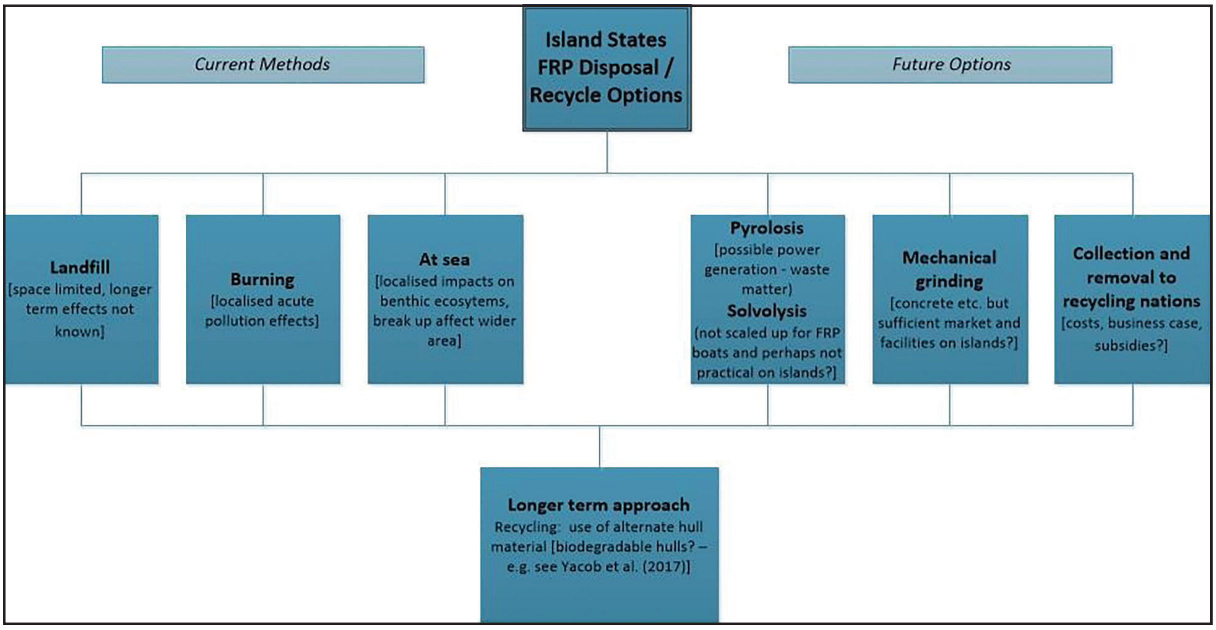

Figure 4.1: Conceptualised consideration of current and potential longer term options to FRP vessel management and future use in island states

5. Legal framework

The legislation background to the management of end-of-life boats is currently lacking with regard to FRP / recreational vessels below certain size / weight limits. In this regard however, there are signs that legislation and / or taxes are rising to meet the issue.

Previously mentioned in this regard was that suggestions are made here and by other authors (López *et al.,* 2012; Summerscales, Singh & Wittamore, 2015) that the basis of the European Union WEEE Directive (European Directive on Waste Electrical and Electronic Equipment, (2, 002/96/EC)) and the European Directive on End-of Life Vehicles (1999/31/EC, 2000/53/EC) demonstrate impetus towards the responsibility of manufacturers and thus may be applicable to related end-of-life legislation for FRP boats. In particular, Summerscales, Singh & Wittamore, (2015) commented that the French and Finnish had undertaken a number of studies towards best approaches for end-of-life boat disposal. This pro-active approach from France may be the driver towards the new "eco tax" outlined in section 2.2.3. However, whilst this tax is outlined by METS TRADE (2017) as being put in place in 2019, another website (Ritchie, 2017) states the tax comes into force 1st January, 2018; clarifying detail could not be readily identified though organisations note the tax approach and recommend similar be undertaken in other nations.

Whilst not strictly applicable to smaller / lighter FRP boats, in terms of legislation showing the growth of recognised responsibility for waste management and disposal of end-of-life vessels, the international / EU legislation time line broadly encompasses:

- **The Basel Convention (1989)**

  Adopted on March 22nd 1989 (United Nations Environmental Programme) the Basel Convention provides a framework for minimisation and safe management of environmentally hazardous waste material. Under the Convention, Technical Guidelines for the Identification and Environmentally Sound Management of Plastic Wastes and for their Disposal (UNEP/CHW.6/21) were developed.

  Pertinently the convention outlines the common types and sources of plastics and details the "*sound and safe handling, compaction, transport, storage and shipping of plastic waste, as well as possible second life applications for plastic materials*" (IMO, 2017). But, the guidelines do not provide direction for wastes relating specifically to end-of-life FRP, but importantly in the context of this review they "*contain information that could be of value in the context of the development of further guidance*" [on end-of-life FRP management] "*in particular with respect to factors influencing the disposal and recycling options*" (IMO, 2017).

- **The Nairobi International Convention on the Removal of Wrecks (Adoption, 18th May 2007, entry into force 14th April, 2015)**

  The Nairobi Convention (signed in Kenya, 2007) set in place a legal basis for states to remove wrecks which "*may constitute a hazard to navigation, potentially endangering other vessels and their crews*" [and] "*potential for a wreck to cause substantial damage to the marine and coastal environments*" (IMO, 2018). Through consultation in this study, whilst the Nairobi Convention has been identified as a possible instrument in which wrecks on an island state may be removed, it is important to note that the Convention only applies to vessels of 300 gross tonnage and above and has only been ratified by 41 states to date.

- **The Sound Recycling of Ships (Hong Kong) Convention, 2009. (Adoption 15th May 2009, entry into force 24 months after ratification by 15 States, representing 40 per cent of world merchant shipping by gross tonnage, combined maximum annual ship recycling volume not less than 3 per cent of their combined tonnage.)**

  With specific reference to end-of-life vessel recycling, the Hong Kong Convention is intended to ensure that boats to be recycled do not pose an unreasonable risk to human health, safety and the environment. The Convention is applicable only to vessels >500 gross tonnage and only applies to ships over 500 GT operating in international waters, and it does not contain any specific reference to fibreglass vessels (IMO, 2017). However, as with the basis of the Basel and Nairobi Conventions, the Hong Kong Convention will perhaps provide useful guidelines into developing statutory instruments and guidance for the safe management and disposal of smaller FRP vessels and future methods by which this may be financed.

  More information on the history and guidelines associated with the Hong Kong Convention is available.

6. Discussion

6.1 Current situation

In relation to the project goals, concern of how to manage and recycle end-of-life FRP hulls has been raised in particular by marine / environmental managers and island state representatives. Noted by the IMO Scientific Groups of the London Convention and Protocol, this study has been undertaken to promote debate and development of practical and financially viable management options for end-of-life FRP hulls, not just for island states, but globally. However, in specific recognition of the pressing issue for island communities, the issues of limited landfill space, illegal dumping and burning has placed the matter into stark relief.

From research for this review, it is evident that the spatial scale of the problem is growing. With FRP in general use for boat hulls since the 1950's and with some ambiguity of hull life duration, the number of hulls is expected to increase; for example a possible density of end-of-life hulls maxima was given for The Netherlands of 2030 (WA Yachting Consultants, 2015). In relation to this, the attention to burgeoning end-of-life hull numbers and what to do with them has grown, though perhaps the progress hasn't been so closely related. In terms of time scale, as work has been found expressing concern from as long ago as 1986 (Backman & Lidgren, 1986), and further comments from for example, 1999 until today, the issue has as yet not achieved a satisfactory management option. This is not to suggest that researchers and policy makers are not making efforts, but rather that a fully viable / sustainable option has yet to be clarified and in this context, one that encompasses the particular difficulties that island states face. For example, there is a growing boat recycling industry and for the previously identified Houston Company, which purchased over 200 hurricane damaged FRP vessels, despite aspirations the most financially effective decision was to send the stripped hulls to landfill. Whilst this may also be the most financially viable option for small islands states, the lack of landfill and increasing desire to find alternates make the issue more pressing where land is lacking and alternate "solutions" have potential for environmental damage and cascading effect to humans (Graham & Nash, 2013).

Foolmaun, Chamilall & Munhurrun (2011) showed that a planned landfill site in Mauritius was receiving four times the waste expected and much material (*circa* 12%) was dumped in waterbodies and open land. The authors rightly note that Mauritius is "*famously recognized as a worldwide high tourist destination*" and that landfill, or lack of, is a drive towards other methods of managing the waste stream. Taking Mauritius as a broad analogue for other SIDs, it is apparent that decreasing landfill space and related environmental impacts are a clear issue. Thus as island states seek to develop routes to manage redundant and abandoned FRP hulls, a more sustainable solution and assistance is required, perhaps through a central funding route making collection of redundant hulls for recycling, at least cost neutral and promoting alternate material for boat hulls in locations where disposal is problematic.

As mentioned here and elsewhere in this review, the case for FRP recycling is clear on environmental terms, however the economics less so, even in large societies where public pressure in particular towards care of the marine environment is gathering pace, thus aspirations and industrial recognition are increasing. However, in areas such as small island states, whilst the case for FRP recycling is seemingly yet more enhanced due to high dependency on boats, but much more of a pressure amid less availability of landfill space, and the potential for impact to ecosystems and related services from unregulated disposal (or lack of options), the case is heightened and far more problematic.

Landfill is recognised as the major option for FRP in spatially larger nations and on some islands, though for some this is a limited option and for some FRP hulls are "*left on land as dry wrecks*" (Talouli, *pers. comm*. 2018), possibly burnt (unclear if this practice still occurs) or disposed of at sea. Considerable research work has been undertaken to establish recycling paths for FRP material, though the major recognised option still appears to be to break FRP up and use it in concrete and other related products. However, it's not clear how viable this will be for an island state economy in terms of market for material and facilities to perform the conversions. It appears that even within larger nations, this is still a marginal option. As Talouli (*pers. comm*. 2018) notes, there are very low margins for recycled FRP material and "*geographical isolation*" and high shipping costs for islands states make aspirational recycling options questionable.

Of other possible management / disposal techniques, solvolysis has been well researched for its potential value of recovering fibres and resinous compounds from FRP products. However, it's not clear if this is being scaled up to industrial potential and a comment was made that this process is some way from being able to deal with material the size of boat hulls, although such waste can be mechanically reduced prior to placement in a reaction vessel. However, whilst this *may* be a potentially viable option for large industrialised nations, whether such reaction vessels are feasible in smaller nations / island states and an industry / market to make this viable as a cost model seems questionable. In terms of pyrolysis, this process has been used for energy generation and disposal of problematic wastes (e.g. tyres) on islands; in addition it has also been used for straightforward "green" power generation on some islands states (Mohee *et al*., 2015). Nevertheless, whether it presents a viable disposal path for FRP materials (and the subsequent fibre waste material and atmospheric release) may be open to further research and trials.

Perhaps dependent on population size, levels of infrastructure and aspirations to grow these or to limit to possibly *sustainable* levels, markets for products developed from the mechanical or chemical recycling of FRP may be marginal. As noted, if a market were developed in larger geographical areas which support / require FRP to provide a need it has been noted that collection and transport of material is an expensive process which can make the landfill option preferable. This being the case in e.g. mainland United States, the isolation of island states and related collection and shipping costs make these options less viable based on current cost / value likelihood.

In terms of scale, it is evident that management of FRP from boats and other sources is a growing and global issue which has yet to reach a peak in relation to hull lives being perhaps longer than predicted. FRP is an extremely tough and long lived material and its breakdown time line, unless facilitated by mechanical processes, is not clear. Landfilling is the prevalent option currently practiced though some nations (e.g. Germany, [Marsh, 2017]) are or have banned the landfill of FRP which should promote investigation into viable alternative solutions. In island nations burning and disposal at sea have been practiced though it's not clear if this is still practiced in any states, and it's evident that environmental teams have been managing and reducing these practices. The breakup of FRP and resultant damaging debris fields has been reported (Lord-Boring, Zelo & Nixon, 2004), but the longer term breakdown and possible pollutant release of FRP is less clear. However, even if related chemicals are "locked" in FRP particles for considerable periods, authors such as Cooper & Corcoran, (2010) comment that "*further evaluation of plastic degradation in the natural environment may lead to a shift away from the production and use of plastic materials with longer residence times*".

Currently global legislation is based around larger vessels and does not appear to provide a ready route towards targeting smaller (generally FRP) boats. Localised or country based legislation may be based on waste management aspects and / or an approach towards compulsory owner registration. Talouli (*pers. comm*. 2018) comments that circa 40% of Pacific island states have adopted solid waste legislation. But, in a region where waste management is an increasing and perhaps more pressing issue, and options for its management decreasing (Mohee *et al*., 2015) there perhaps needs to be consensus on how to deal with large inorganic waste such as FRP with a solid financial resource to achieve this. Talouli (*pers. comm*. 2018) brings into focus that financial options are being considered at the scale of nation responsibility perhaps in a similar fashion to the system being put in place by France. Talouli notes that "*many Pacific islands have identified or adopted policy mechanisms to finance improved waste management systems and equitably distribute the costs of managing end-of-life materials*". This approach perhaps echoes ideals to be more widely adopted through owner registration schemes and central financing via possible levy routes on manufacturing.

6.2 Knowledge gaps and future options

Whilst much of the information presented shows clear outcome for the continued unsustainable use of FRP hulls, some gaps in information have arisen comprising:

- The overall life expectancy of FRP hulls and when the peak of production versus disposal may be reached geographically and temporally;
- Health impacts associated with natural degradation of hulls and occupational and environmental (ecological) exposure during break-up of hulls for either landfilling or recycling;
- Limitations on landfill and possible life expectancies in space limited locations (i.e. when will decisions need to be made by);
- The longer term outcome of break-up of FRP vessels sunk in nearshore marine systems and potential contaminant release and effects and pathways;
- Lack of data for many nations with most available for EU and North America;
- Total numbers of FRP vessels being disposed of and how;
- Approaches to management on islands, for example, is pyrolysis an option, or can finance systems be set up to facilitate collection and shipping;
- Non-destructive re-use options for hulls such as housing; and
- Longer term alternate closed loop and degradable hull materials.

Of possible future options in an island context, alternative approaches to landfill require firm consideration. Perhaps pyrolysis leading to energy / gas generation may be a viable approach allowing for the generated fibrous waste material. Though whether such plants can be financed are technically feasible and would be welcomed against public opinion in sensitive areas would need consideration and consultation.

Fundamentally the major issue with the recycling of FRP hulls and material is financial cost / benefit related. There are methods available, but early on in this review it was apparent that even if the will was there to push towards recycling (with facilities available), financially landfill was by far the cheapest option. Accordingly work is needed to look at nations / regions where financial models are being put in place to drive recycling. As suggested by Haines (2016) and being put in place in France, levies on vessel ownership, production and solid owner registration systems would benefit this approach and may lead to a "war chest" of funding at national / multi-national levels which can drive the sustainable recycling and disposal of end-of-life hulls (e.g. Global Fibreglass Solutions) and perhaps augment funding for nations where such systems are more difficult to put in place.

Whilst not a primary driver of this review, literature used here has led this work toward consideration of alternate construction materials for boat hulls which *may* be a future option and seem to be receiving recent consideration, though there are issues to be resolved over mechanical strength (Yang, Hamid & Abdullah, 2018). Particularly pertinent to island states where space limitation may, in the longer run, require approaches that significantly reduce waste and create alternate approaches to practical problems, perhaps consideration of more biodegradable or readily disposable boat hull material will be advantageous to the future (see Georgios, Silva & Furtado; Yaacob *et al*., 2017; Yang, Hamid & Abdullah, 2018).

7. Conclusions

- The issue of recycling and disposal of end-of-life FRP hulls has received attention for a considerable period, but recently this has grown in relation to concern over marine disposed plastics, lack of landfill space and difficultly of recycling FRP;
- For island states the problem is acute with declining landfill, some unregulated marine disposal and burning;
- FRP waste management is also significantly problematic for larger nations with various recycling options considered and some commercial groups working on making FRP reuse financially viable, though evidently this is still marginal;
- Physical impacts of disposal for land and sea options include space take up, lack of biodegradation and, in the marine environment, impacts from hull break-up on sensitive systems such as seagrass and coral (particularly pertinent to some island states);
- The chemical effects of at sea disposal of FRPs and the breakdown of the long chain molecules and related contaminants appears understudied, though this may be related to the knowledge that the material is highly stable over long periods;
- Recycling methods need consideration for their applicability and validity in island states for waste and possible energy generation, plus costs models for waste to be removed;
- Legislation will be the driver of change. The most feasible routes towards funding future recycling appear to be levy systems on new boat sales and on ownership registration leading to centralised funds to back up vessel recycling programs;
- In an island context where a finite resource is space, subject to enhanced research, alternate solutions in the longer term may be viable such as “green” biodegradable materials used in construction of boat hulls, though it is acknowledged that many end of life FRP boats left on islands may be associated with “off islanders”;
- Close liaison with key representatives from island states is recommended to provide better understanding of the issue from their point of view, leading to target approaches and legislation; and
- Further detailed liaison with industry and researchers is recommended to provide better understanding of what may be feasible, not least in the island state context.

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