Mattress Solutions

Prepared by Jee Ltd. on behalf of Zero Waste Scotland and Decom North Sea

DNS 01 r01c
Decom North Sea

25 June 2015
Document Control

### Document History

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<td>C</td>
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<td>CA</td>
<td>Comparative assessment</td>
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<td>CAPEX</td>
<td>Capital expenditure</td>
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<td>CE</td>
<td>Circular Economy</td>
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<td>CFD</td>
<td>Computational fluid dynamics</td>
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<td>CNS</td>
<td>Central North Sea Area (Teeside to the Orkney Islands)</td>
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<td>CO₂</td>
<td>Carbon Dioxide</td>
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<td>Dynamic Positioning</td>
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<td>Dive Support Vessel</td>
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<td>Environmental Impact Assessment</td>
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<td>General Visual Inspection</td>
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<td>Hazard Identification</td>
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<td>Lifting Operations and Lifting Equipment Regulations, 1998</td>
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<td>NNS</td>
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<td>Polypropylene</td>
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<td>Public Relations</td>
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<td>Remotely Operated Vehicle</td>
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<td>Safe Working Load</td>
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Foreword

The following is a foreword provided by Zero Waste Scotland:

“Supporting Scotland to move away from throwaway culture and towards a circular economy is a key objective for Zero Waste Scotland. We want to stimulate innovation amongst Scottish businesses to help them to adopt more circular business practices, which treat all resources as assets – keeping them in use for as long as possible to extract the maximum value from them.

There’s huge potential for Scotland’s oil and gas sector to benefit from becoming more circular, and thereby play a key role in Scotland’s journey towards a circular economy. The decommissioning sector has already made commendable strides to increase recycling rates in recent years; a focus on re-use is the next worthwhile step in the journey – particularly so because re-use holds more financial gain for the industry, as well as being a better environmental option.

Taken alongside other engagement activities Zero Waste Scotland is undertaking in partnership with the industry, we hope to see doors beginning to open to support greater collaboration, innovation, and ultimately, more re-use of offshore equipment and resources.”

Iain Gulland
Chief Executive
Zero Waste Scotland

The following is a foreword provided by Decom North Sea:

“The UKCS Offshore Industry is facing significant change. The oil price has fallen, costs have been escalating and the Wood Review is being implemented by the new Oil & Gas Authority. Decommissioning activity is increasing and all evidence is pointing to increased costs.

Hence we are delighted to have worked with ZWS and Jee to commission and deliver this informative report that is both timely and necessary. Many of our members, drawn from operators, major contractors, service specialists and technology developers, have contributed to this report and we appreciate their valued contribution. The findings will benefit industry and our members, consolidate knowledge, bring new learning and demonstrate the benefits of a Circular Economy approach.

Decom North Sea is the only organisation focussed solely on the challenges of decommissioning in the oil and gas sector, working to enhance knowledge transfer and facilitate collaborative activities to achieve efficient solutions. With decommissioning expenditure in the North Sea set to increase from the current £1bn pa, DNS plays a vital role in solution development, cross-sector learning and building supply-chain capability. I commend this collaborative report for enabling an understanding of new methods and technologies to help reduce decommissioning costs and increase efficiency whilst maintaining the integrity of the long term environmental solution.”

Nigel Jenkins
Chief Executive
Decom North Sea
Executive Summary

Oil & Gas UK estimates that there are between 35,000 and 40,000 subsea mattresses installed throughout the North Sea to protect pipelines and other subsea infrastructure. This equates to at least 200,000 tonnes of concrete\(^1\). Under current regulations all mattresses installed must be removed at the end of field life unless it can be adequately proven that a recovery operation cannot be completed safely and efficiently. The decommissioning of subsea mattresses is therefore expected to be a significant challenge to the industry.

Subsea mattresses were not designed to be recovered, and therefore when it comes to decommissioning the operation can be a complex, timely and expensive one. The operation must also be carried out in such a way as to minimise risk to personnel and the environment. The complexity of operations is compounded by the variety of mattress styles and sizes that are installed and the fact that relatively few decommissioning projects have been carried out in relation to the overall total assets and therefore the industry has fairly limited experience in this field.

To date, the majority of mattress decommissioning has been facilitated through using subsea baskets or speed loaders (see section 4.2 for more details). Both methods are diver intensive and there has been a drive within the industry to move away from using divers to minimise unacceptable risk to personnel. Jee has identified a number of companies who can offer innovative removal technologies for mattress decommissioning, which seek to reduce diver involvement or can offer a totally diverless solution. The innovative technologies presented also offered the prospect of reduced operation costs either through facilitation of quicker removal or through reduced dependency on costly vessels (see section 4.3 for more details). It has become evident that to reduce the cost of mattress decommissioning there needs to be a drive towards the development of new technology. A number of recommendations have been identified which may assist in promoting the development of emerging technologies (see section 4.5.2).

The recoverability of a mattress is heavily influenced by its structural condition. Mattresses that have degraded are more difficult and dangerous to recover and have less scope for re-use once recovered. The various styles of mattress each have their own issues in respect to handling and recovery (see Table 5-1) and their structural condition can vary significantly due to a number of influential factors such as: region of the North Sea, length of time in service and to a lesser extent, installation history (see section 5). Mattresses installed in the shallower waters of the Southern North Sea suffer most degradation and tend to self-bury, while mattresses from the deeper waters of the Central North Sea and the Northern North Sea tend to remain structurally intact and burial is less common. This is due to differences in environmental conditions as characteristically, the Southern North Sea is shallow with strong tidal currents and a mobile sandy seabed, which reduces the shielding from UV light and surface

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\(^1\) Estimate based on all mattresses being flexible concrete mattresses with a weight in air of 5 Te.
hydrodynamic forces. As dive windows are reduced, visibility is poor and seabed excavation is often required any seabed work, including mattress removal, in the SNS is challenging.

As the Central and Northern North Sea is much deeper the seabed is more stable which both preserves the integrity of the mattress and makes recovery operations less onerous, however the CNS and NNS experience rougher sea states and poorer weather conditions which can impact operations.

If a survey indicates mattresses are in poor structural condition or are significantly buried there may be concerns that it might not be possible to recover mattresses both safely and efficiently. In this instance the Operator may enter into discussions with DECC around leaving the mattresses ‘in-situ’ as part of the Decommissioning Programme. ‘In-situ’ decommissioning involves leaving the mattress on the seabed at the approval of the regulating body; DECC. The default position of DECC in any mattress decommissioning programme is that everything must be removed, however under certain circumstances they may enter into discussions with Operators around leaving mattresses ‘in-situ’. This requires the Operator to present a fully evidenced and balanced argument of why the ‘leave in-situ’ option is the most appropriate in the form of a comparative assessment report. A comparative assessment report details all the decommissioning options available and an assessment of each option based on set criteria outlined in the DECC decommissioning guidance notes. Approval to leave mattresses ‘in-situ’ will come with conditions which will require the Operator to perform regular monitoring and trawl sweeps to demonstrate that they do not present any threat to other users of the sea. The Operator will also retain perpetual liability for anything left ‘in-situ’ at the site.

For mattresses that can be successfully removed and remain in good condition there are a range of applications in which they can be re-used, both onshore and offshore. Mattress re-use presents the most cost effective and environmentally friendly method of disposal and therefore it is recommended that mattress re-use is promoted to reduce the overall cost of mattress decommissioning. There are however, also a number of challenges that need to be addressed to maximise mattress re-use and circular economy opportunities.
Key Findings:
The following findings have been drawn from the work performed:

Mattress styles:
- Flexible concrete mattresses with polypropylene rope are the most widely used style of mattress in the North Sea. It is estimated that over 20,000 flexible concrete mattresses have been installed in the North Sea in the past 5 years alone, based on information provided to Jee by the leading supplier of stabilisation equipment to the North Sea market (Subsea Protection Systems Ltd.).
- Grout bags are also widely used throughout the North Sea for supporting spanning sections of pipeline or pipework.
- Fronded mattresses are used to a lesser extent; they tend to be deployed in the SNS where the seabed is more mobile.
- There are a small number of other mattress styles installed, although some of these styles have been discontinued and are no longer used within industry i.e. Armorflex, Bitumen and Link-lok mattresses.

Mattress decommissioning to date:
- Experience of mattress decommissioning in the North Sea is fairly limited with the number of mattresses removed to date standing at approximately 5% of the total number installed.
- The vast majority of mattress removal operations in the North Sea have been completed within the last five years.

Removal solutions:
- All existing removal solutions, with the exception of subsea grabs, are diver intensive. There are significant health and safety issues associated with diver based operations and they require DSV mobilisations, which are inherently expensive.
- Subsea grabs are an existing diverless solution and can be effective when there are small numbers of mattresses to be removed. However they are not an efficient solution when decommissioning large volumes of mattresses. They also eliminate the potential for re-use as the method of handling commonly damages the mattress.
- Speed loaders (see Figure 4-3:) have been perhaps the most successfully used mattress removal technology to date in the CNS and NNS. Average recovery times were quoted at approximately 45 minutes per mattress when the mattresses are in good condition. However speed loaders are not a suitable recovery method for all types of mattress. They have yet to be used for mattress recovery in the SNS and their suitability for use in this region is not certain.
- There are inefficiencies with current mattress removal practices, primarily centred on inefficient use of the lifting vessels’ time. Research has shown that during decommissioning programmes that involve recovery of large volumes of mattresses the heavy lift vessel is required to leave the field to offload recovered mattresses at the quayside before returning to the field to continue the recovery operation.
- Lack of mattress decommissioning experience in the North Sea has hindered technology development.
A number of emerging mattress removal technologies were presented to Jee which have good potential for reducing the overall cost of mattress decommissioning operations predominantly through facilitating quicker recovery operations or through utilising lower cost vessels. Some of the technologies presented also offer the advantage of diverless solutions. Knowledge to date is that none of these technologies have so far been piloted as part of a mattress removal operation.

Two of the technologies presented proposed the methodology of crushing or mulching mattresses in-situ and depositing the resultant concrete slurry on the seabed. Following a discussion with DECC it was confirmed that this would not be permitted. Subsea crushing of mattresses may be viable but the resultant debris would need to be transferred to a subsea container and removed to surface.

Mattress classification (condition and recoverability):

- Flexible concrete mattresses and Link-lok mattresses retain their structural integrity best and are the most readily recoverable.
- Armorflex and Bitumen style mattresses, as well as grout bags commonly lose their structural integrity and as a result have reduced recoverability.
- Fronded mattresses are typically more difficult to recover as they are designed to self-bury, this was demonstrated during decommissioning of the Camelot field.
- The condition of mattresses has been found to be best in the deeper waters of the Central and Northern North Sea where the water depth exceeds 50 m. Mattresses in the NNS and CNS also tend to experience less marine growth fouling due to the increased depth. The combination of these factors gives mattresses recovered from the CNS and NNS most scope for re-use following recovery.
- Mattresses in the Southern North Sea tend to be found in more advanced states of degradation on account of the shallower water depths, greater wave loading and faster currents. The seabed material in the SNS is also finer and heavily prone to scouring which will result in mattress burial, the suspended sediment combined with the current can also have erosive effects on the mattress materials harming their integrity during recovery. Marine growth fouling is also more common on mattresses removed from the SNS on account of the shallow water depths. These factors make recovery of mattresses from the SNS more difficult and mean that the scope for re-use may be limited.

‘In-situ’ decommissioning:

- Certain styles of mattress are likely to be more readily considered for leave ‘in-situ’ decommissioning on account of their susceptibility to structural degradation (e.g. Armorflex and Bitumen mattresses), design to self-bury (Fronded mattresses) and absence of sufficient lifting points (Grout bags).
- An application to leave mattresses ‘in-situ’ may be more readily considered if it can be shown that mattresses are buried to a minimum depth of 0.6 m (‘leave in-situ’ criteria for pipelines) and it is shown (through CFD or similar) that they are unlikely to de-bury significantly overtime.
- Justifying a leave ‘in-situ’ application for standard flexible concrete mattresses with polypropylene rope could be difficult as these mattresses retain their integrity well.
- DECC assess every leave in-situ application on a case by case basis and their default standpoint is always that the Operator will be expected to remove all mattresses. Therefore it should never be
assumed that approval will be granted to leave mattresses ‘in-situ’ even if the mattresses conform with the styles or burial depths outlined in the above bullet points. Any application to leave a mattress ‘in-situ’ must be backed up by a thorough, logically argued and evidenced case in the form of a comparative assessment (CA) report.

- When presenting a comparative assessment to DECC safety is of primary importance for an application to leave mattresses ‘in-situ’ with focus being on minimising risks in the long term to other users of the sea and in the short term to those involved in the decommissioning operation.
- When presenting a comparative assessment to DECC, the environmental case, although considered, would not be accepted on a standalone basis, this is because the leave in-situ option almost always carries the least environmental risk.
- To date, all decommissioning programmes in which mattresses have gained approval to be left ‘in-situ’ have been revised at a late stage. In these cases the original programmes submitted to DECC all specified that all mattresses would be removed.
- In light of the above point; there is an expectation on the Operator to apply ‘best endeavours’ in relation to mattress recovery. Therefore even if it is felt that mattress removal operations cannot be completed safely or efficiently then it may take a trial or test lift (pull test) to prove to DECC that a recovery operation is not the best option for mattress decommissioning and that they should be left in-situ.
- The Operator will retain liability for any mattresses that are granted approval to be left ‘in-situ’ and this will also come with the condition that periodic monitoring and trawl sweeps will be performed, at the Operators expense. The frequency of the survey and trawl sweeps will depend on the intensity of fishing activity in that area among other factors and will be determined by DECC with input from other stakeholders where appropriate. Therefore although the ‘leave in-situ’ option may be the cheapest option in the short-term, there are long-term cost implications associated with the conditional monitoring that will need to be performed.

Circular Economy:

- Flexible concrete mattresses with polypropylene lattices have the biggest scope for re-use in the circular economy. Link-lok mattresses may also good scope for re-use.
- There does not appear to be much scope for re-using grout bags or Armorflex, bitumen and fronded mattresses.
- There are a range of onshore and offshore applications which can make use of reclaimed mattresses either in their entirety or in their constituent parts. There may be the greatest scope for re-use in offshore construction and renewables and onshore road building.
- The scope for re-use depends heavily on the condition the mattresses are found in during decommissioning. This is a key piece of information that onshore suppliers need to know in order to allow them to source an end user.
- Effective marine growth management is required to maximise re-use.
- Re-use is the most cost effective disposal option for reclaimed mattresses. Therefore by embracing circular economy principles and maximising mattress re-use the cost of onshore disposals can be significantly reduced thus contributing to reducing the overall costs of mattress decommissioning.
• Re-use and recycling of concrete mattresses can contribute to the reduction of CO₂ emissions by avoiding the manufacture of new concrete. The re-use option offers the greatest savings.

• Greater awareness of the availability of reclaimed concrete mattresses needs to be promoted across the various markets; they may serve a purpose for a company or individual that has not yet been realised. Communication and collaboration between the oil & gas industry and other industries (on and offshore) is key to developing the market.

• Recycling of concrete mattresses can also be carried out to produce concrete aggregate for the construction industry. There is little or no scope for recycling the other styles of mattress.

• Mattresses can be moved subsea from one location to another for re-use. If redeploying mattresses which have been recovered to deck then they would need to be redeployed using appropriately rated equipment such as speed loaders or subsea baskets. They cannot be redeployed for use subsea using the lifting lugs as these are not certified and subsequent lifts are considered as new lifting operations.

• Local markets are key to promoting the onshore re-use of reclaimed mattresses, this minimises transport and consequently the overall cost of re-use.
Recommendations

The following recommendations have arisen from the work performed:

Removal solutions:

- It is recommended that a detailed cost benefit analysis is performed by an impartial third party to compare the various emerging removal solutions against the existing removal solutions. A cost benefit analysis should consider like for like conditions for a mattress removal operation and also take account of influencing factors that may affect operation costs such as; ability to operate in harsher sea states etc. As many of the solutions considered are at the conceptual or development stage, it has not been possible to carry out a detailed cost comparison at this stage. As options develop, it is recommended that a full cost analysis be carried out in future industry studies.

- It would be useful if industry guidelines or best practice documents could be developed on mattress removal / decommissioning and classification, perhaps by DECC, or under the auspices of industry bodies such as Oil & Gas UK or Decom North Sea. However, the industry may first have to gain more experience before this is possible.

- A number of the technology solution providers have indicated that they are keen to work with industry to develop their mattress handling solutions (see section 4.3). It is recommended that contractors with practical experience of mattress decommissioning engage with innovative solution providers to provide input in this respect, and include consideration of the various styles of mattress.

- Others have indicated that they would like to complete offshore trials of their tools and are seeking vessel contractors and Operators who may be interested in mattress decommissioning and a collaborative approach to facilitate offshore trials of their solutions. Equipment providers who require investment to allow their technologies to be developed trialled or tested may have more success in attracting investment if they offer additional incentives such as lump-sum hire contracts for mattress removal campaigns. The ITF should also be engaged and the gap in the market defined, this may then lead to the launch of a JIP.

- Industry bodies such as Oil & Gas UK and the Oil & Gas Authority should negotiate with the Government for additional subsidies or tax relief for Operators who pilot new technologies as part of their decommissioning programmes.

‘In-situ’ mattress decommissioning:

- A ‘leave in-situ’ application may be considered by DECC (subject to appropriate surveys and comparative assessment) where Armorflex mattresses, Bitumen mattresses and large grout bags are installed. This is predominantly on account of the significant safety risks to personnel and inefficiencies of operation as a result of the susceptibility of these styles of mattress to lose structural integrity.

- A ‘leave in-situ’ application may also be considered where mattresses are shown to be buried to a minimum depth of 0.6 m. Fronded mattresses typically self-bury – however surveys, comparative assessments and local condition studies must provide evidence that this is likely to remain the case in future.
• Emerging mattress removal technologies should be taken into consideration before proceeding with an application to leave non-recoverable mattresses in-situ. Although mattresses may not be considered recoverable using market ready removal technologies there may be developing technologies (such as those outlined in section 4.3) which can more readily facilitate removal.

• Where the leave ‘in-situ’ option has been selected as most appropriate, it is recommended that Operators enter into discussions early with DECC and the area fishing federation, to identify a solution which is acceptable to all parties. In every case, minimum monitoring conditions will be agreed if the mattresses are permitted to remain ‘in-situ’ and other measures determined to minimise the snagging risk to trawlers.

• When considering an application to leave mattresses ‘in-situ’ a cost comparison should be performed between the estimated cost of a recovery operation against the cumulative costs of continual monitoring and overtrawling trials.

Circular Economy:

• Setting re-use target rates for Operators to meet as part of future decommissioning programmes would help to stimulate mattress re-use.

• The industry should work to better inform onshore waste management contractors of the dimensions and expected structural condition of mattresses being returned to shore. Sharing of key information like as-built drawings and visual survey results of the mattress inventory being decommissioned would assist the sourcing of an end user.

• Creation of central storage locations throughout the country will be required to allow reclaimed concrete mattresses to be supplied and re-used to the larger markets. It may be useful to consider sites around the UK that are close to oil & gas ports such as Wick, Invergordon, Peterhead, Teesside, Hull, Great Yarmouth and others. Storing recovered mattresses at several locations around the UK would help to reduce the onshore transport and assist in serving the local markets.

• It appears that there may be significant scope to re-use mattresses whole for laying road and highway foundations. It is recommended that discussions are entered into with civil engineering / construction companies to determine the feasibility and identify any potential issues.

• There may also be significant scope for mattresses to be re-used in the offshore renewables market. It is recommended that discussions are entered into with renewable energy operators to determine whether there may be demand for reclaimed mattresses and identify any potential issues.
1. Project Brief

1.1. Introduction

Jee was commissioned by Decom North Sea, in partnership with Zero Waste Scotland, to conduct a project to investigate current practices for the decommissioning of subsea concrete mattresses and to recommend new approaches to minimise removal volumes, costs and maximise re-use.

There is an industry need for a safe, quick and cost efficient solution to facilitate mattress recovery. At the outset of the offshore industry, mattresses were never designed to be recovered and over time may have structurally degraded underwater. As a result removal can be dangerous and time consuming. In light of this there are certain circumstances in which there is a logical case for submitting an application to DECC for leaving mattresses ‘in-situ’, however this option requires approval from DECC. This report is prepared in response to industry requirements and addresses the current and conceptual removal methods within the field and considers the factors which underpin an application to leave mattresses ‘in-situ’.

The report will also explore the ‘circular economy’ principles with respect to concrete mattresses. A circular economy approach ensures that materials are retained within productive use, in a high value state, for as long as possible. Familiar examples in the offshore oil and gas market are equipment rental businesses where items are hired out, returned, serviced, refurbished as required and re-rented – thus keeping the rental items in a ‘high value state’ for as long as possible and maximising its productive life. The aim of this report is to maximise decommissioning sector benefits through the implementation of the re-use and circular economy principles in relation to concrete mattresses. Financial returns have been demonstrated in sectors such as food, retail and manufacturing. There is significant opportunity to make decommissioning more efficient and cost effective through embracing circular economy principles.

Based on the aforementioned, this report addresses three key issues:

1. Mattress recovery techniques – current and emerging
2. Leaving mattresses ‘in-situ’ – what factors underpin a successful application
3. Mattress disposal / re-use – the benefits of re-use and potential applications
1.2. Background

The recovery, disposal and application to ‘leave in-situ’ of subsea mattresses present a significant obstacle and financial cost for operators and contractors when decommissioning subsea infrastructure. There are estimated to be approximately 35,000 to 40,000 concrete mattresses installed around oil and gas subsea infrastructure in the North Sea[^1]. This equates to approximately 200,000 tonnes of concrete and therefore represents a significant challenge to the North Sea oil and gas market during field decommissioning. Consequently there is a need for an affordable, fast and safe solution for the removal, re-use and decommissioning of concrete mattresses.

Decom North Sea, funded by Zero Waste Scotland, selected Jee to investigate the following:

- Current practices for subsea mattress removal and emerging removal technologies
- Defining the classification of used mattresses to determine their recoverability and potential for re-use
- Potential solutions for leaving mattresses ‘in-situ’
- Re-use options for subsea mattresses

1.3. Objectives

The objectives of this study are:

- To identify innovative solutions for mattress removal, particularly without diver interventions during mattress lifting (to avoid potential health & safety issues)
- Provide a basis for economic and environmental assessment of mattress condition and options – potential to ‘leave in-situ’ / removal / re-use
- Identify options and requirements to leave mattresses ‘in-situ’
- Identify opportunities for re-use of mattresses (in oil and gas or other industries)
- Increase industry awareness of Circular Economy principles
1.4. Information Sources

Two industry workshops were held to determine industry experience of mattress decommissioning to date, and provide industry input to the deliverables of this study. Present at these workshops were a variety of Operators and Contractors that have performed mattress decommissioning works. Also present were equipment suppliers and waste management / recycling contractors. Subsequent meetings were held with workshops attendees and other stakeholders not present at the workshops.

Sources of information include:
- Input from workshops held on 17th and 18th of February 2015
- Publicly available decommissioning programmes
- Experience of ZWS, DNS, DNS members and Jee engineers
- Research carried out into current and proposed mattress removal methods
- A series of subsequent meetings and correspondence with the following:
  - Manufacturers who specialise in producing mattresses and stabilisation equipment
  - Waste disposal contractors
  - Landfill and recycling centres
  - Environmental specialists with experience in oil & gas decommissioning
  - Department for Energy and Climate Change
  - Decommissioning programme statutory consultees
  - Survey contractors
  - SEPA
  - Marine Scotland

1.5. Regulations

DECC provides the legal framework for decommissioning activities conducted by operators in the UK sector of the North Sea. DECC Guidance provides the following clause which outlines their stance on the removal of mattresses and grout bags:

10.9 “Any mattresses or grout bags which have been installed to protect pipelines during their operational life should be removed for disposal onshore. If the condition of the mattresses or grout bags is such that they cannot be removed safely or efficiently then any proposal to leave them in place must be supported by an appropriate comparative assessment of the options. The Department would however be willing to consider a proposal to leave any mattresses or grout bags in place if they are under the pipeline and it can be demonstrated that this would not cause a snagging protrusion above the pipeline.” [2]
2. **Mattress Styles**

There are a range of mattress styles which have been commonly used in the North Sea to date; these are described in the following sections.

2.1.1. **Flexible Concrete Mattresses**

These mattresses are predominantly used to provide pipeline stabilisation and impact protection from dropped objects. They are used extensively for protection of pipelines, spoolpieces and umbilicals; particularly within platform 500 m zones where there is a higher risk of dropped objects. They consist of cast articulated concrete blocks which are linked by a polypropylene rope lattice. Standard sized mattresses are 6 m x 3 m and can be supplied with blocks of 150 mm, 300 mm and 450 mm thickness. The concrete can be supplied in a range of densities from standard (2400 kg/m³) to high (3900 kg/m³). Most mattress suppliers can manufacture mattresses bespoke to the client’s needs. The articulated nature of the concrete blocks allows the mattress to ‘flex’ over a 3D profile which permits the mattress to follow the contours of the seabed and the pipeline. They can also be supplied in barred concrete segments which can accommodate a 2D profile. The bar style mattress commonly have reinforced concrete to provide additional strength and rigidity. For additional stability, flexible mattresses can be supplied with tapered shaped blocks on the outer edges of the mattress to provide a more hydrodynamic profile. This style of mattress has a typical weight in air of between 5 – 20 tonnes.

This style of mattress was introduced into the market in the 1980’s and is the most widely used in industry today. A discussion with Subsea Protection Systems Ltd. (the UK’s largest supplier of concrete mattresses) revealed that they have provided around 3,500 flexible concrete mattresses, to be placed in the North Sea, each year for the past 5 years. SPS provide 80% of the mattress requirements in the North Sea with the additional 20% made up by their competitors. This equates to an estimated 21,000 flexible concrete mattresses being placed in the North Sea in the last 5 years.

![Flexible concrete mattresses](image)
2.1.2. Link-lok Mattresses

Link-lok mattresses are similar to the flexible concrete mattresses described above. In the same way as flexible concrete mattresses, they are used for stabilisation and impact protection. They are made up of articulated blocks which are constructed by casting concrete into hard plastic shells (sometimes honeycomb shaped), with polypropylene rope or nylon rope used to link the blocks together. Like the flexible concrete mattresses they can also accommodate 3D profiles. The concrete density can also be varied to achieve a heavier or lighter mattress, as required. This style of mattress has a typical weight in air of between 5 – 20 tonnes.

This style of mattress has not been commonly used since the 1990’s as they were deemed too expensive.

![Recovered ‘honeycomb’ Link-lok mattresses](image)

2.1.3. Armorflex Mattresses

Armorflex mattresses are also similar to flexible concrete mattresses and are made up of articulated pre-cast concrete blocks. The difference with the Armorflex mattresses is that the lattice which holds the concrete together is constructed from steel wire. This style of mattress, again, is used for stabilisation and protection of pipelines and umbilicals. They can accommodate 3D profiles and come in a range of sizes and densities similar to the flexible and Link-lok mattresses. They have a typical weight in air of between 5 – 20 tonnes.

Armorflex mattresses were commonly used on older installations but are no longer used on new projects.
2.1.4. **Bitumen Mattresses**

Bitumen mattresses are canvas style bags filled with bitumen impregnated with grout or gravel. They are used to provide stabilisation to pipelines and umbilicals. These were prohibited from the early 1990’s due to re-introducing hydrocarbon based materials into the environment [4]. During installation the bag was either lowered on a lifting frame (as shown) or the empty bag was placed in the desired location and the bitumen filler then pumped in to set.

Bitumen has a nominal density of 2.2 tonnes/m$^3$.

![Figure 2-3: Bitumen mattress deployed on lifting frame](image)

2.1.5. **Grout Bags**

Grout bags are a smaller style grout filled canvas bag. They are can be small in size; around 25kg, and suitable for manual handling by divers, or they can be of a larger size; typically 1 Te consisting of 40 x 25 kg bags contained within a larger canvas bag, which are unsuitable for manual handling. Older larger style grout bags may have been filled with grout once in position on the seabed. The smaller sized bags are used widely to support spanning sections of pipework, such as at the base of a riser or at swan necks tying into manifolds. The larger style bags can be used for stabilisation purposes and for rectifying pipeline free spans due to seabed scouring. Depending on the style, they may have lifting strops like the ones shown below.

Small grout bags typically have a weight in air of <25 kg, to make them suitable for manual handling. Large grout bags typically have a weight in air of 1 Te but can be several tonnes in weight.

![Figure 2-4: Grout bag with lifting lugs](image)
2.1.6. Fronded Mattresses

Fronded mattresses are used to a lesser extent but are more commonly deployed in areas with mobile seabed which is prone to scouring (such as the Southern North Sea). They work using polypropylene ‘fronds’ which act like an artificial seaweed and trap sediment suspended and carried in the water column. The intention is that the fronds gather silt and sediment to build up a natural bank and help prevent scouring. The design of the mattress causes it to ‘self-bury’ and fronded mattresses are incredibly effective at this under the right conditions. There are two types of these mattresses; concrete blocks with fronds cast into them or a fronded sheet that is pegged over a standard concrete mattress.

![Fronded mattress prior to deployment](image)

2.2. Mattress Styles Summary

2.2.1. Key Findings

The following key findings arise from the investigation into North Sea mattress styles:

- Flexible concrete mattresses with polypropylene rope are the most widely used style of mattress in the North Sea. It is estimated that over 20,000 flexible concrete mattresses have been installed in the North Sea in the past 5 years alone, based on information provided to Jee by the leading supplier of stabilisation equipment to the North Sea market (Subsea Protection Systems Ltd.).

- Grout bags are also widely used throughout the North Sea for supporting spanning sections of pipeline or pipework.

- Fronded mattresses are used to a lesser extent; they tend to be deployed in the SNS where the seabed is more mobile.

- There are a small number of other mattress styles installed, although some of these styles have been discontinued and are no longer used within industry i.e. Armorflex, Bitumen and Link-lok mattresses. There are various difficulties when it comes to removing the older styles of mattress, specifically the Armorflex and Bitumen styles, these are discussed in section 5.2.
3. **Mattress Decommissioning to Date**

Publically available decommissioning programme close out reports were reviewed to determine the level of industry experience in subsea mattress decommissioning and removal to date. From available close-out reports it appears that mattress removal is limited to around 10 key projects within the last decade, with Frigg (Total) in 2004 being the earliest available reference. However, of this the vast majority of mattress removal has been completed within the last five years. A timeline illustrating the decommissioning programmes that have been completed to date and involved mattress removal is shown in Figure 3-1, with details of the field and number of mattresses recovered. For more information see Appendix A which includes details of all publically available approved decommissioning programmes which involve mattress removal.

Based on the information below, the total number of mattresses recovered to date stands at approximately 2000. This equates to around 5% of the total number of mattresses installed throughout the North Sea (against the Oil & Gas UK estimate of 35,000 to 40,000). Therefore, it can be deduced that experience within the industry of mattress decommissioning is fairly limited.

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Figure 3-1: **Timeline of mattress removal in UKCS**

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Excluding Renee Rubie which has not yet been completed but is due to commence in the summer of 2015
3.1. Mattress Decommissioning to Date Summary

3.1.1. Key Findings

The following key findings arise from the investigation into North Sea experience of mattress decommissioning to date:

- Experience of mattress decommissioning in the North Sea is fairly limited with the number of mattresses removed to date standing at approximately 5% of the total number installed.
- The vast majority of mattress removal operations in the North Sea have been completed within the last five years.
4. Removal Solutions

This section outlines the various mattress removal solutions that are currently available to the market, as well as identifying some of the emerging technologies which are either new to the market or are still in the development or conceptual phases.

4.1. Disclaimer from DECC

DECC’s default position is that everything must be removed from the seabed with the following recommendations (discussed further in section 6):

- If a mattress can be located and moved both safely and efficiently then it must be recovered to the surface
- Every case should be discussed fully with DECC before any technology selection is carried out
- A full comparative assessment of all decommissioning options should be undertaken

4.2. Existing Removal Technologies

There are several established options for mattress removal currently available to the market:

- Reverse installation by 16-point lift of an individual mattress; ii
- Utilising speed loaders to stack 3-5 mattresses subsea and recover to surface in one lift;
- Lifting mattresses into half height skips subsea and recovering the skip to the surface;
- Lifting mattresses into steel cargo nets, bundling up and recovering to the surface;
- 6 or 8 ‘finger’ mechanical grappling grab arrangement to recover the mattress to surface;

The above methods have all been utilised and are suitable for recovery of mattresses in different scenarios. Engagement with the North Sea decommissioning community appears to indicate that the use of speed loaders is the most widely deployed removal method for concrete mattresses due to safety, speed and simplicity.

The following sections discuss each of the above recovery options.

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ii Note this method would not usually be considered to recover mattresses fully to the surface but is generally used for moving or arranging the mattresses subsea (such as into speed loaders or subsea baskets (see section 4.2.1))
4.2.1. **Reverse Installation**

The process of reverse installation makes use of the mattress’ installation hoops as detailed in Figure 4-1 below.

![Concrete mattress with visible installation hoops](image1)

**Figure 4-1:** Concrete mattress with visible installation hoops

The process normally involves a diver connecting the installation hoops to a spreader bar or handling frame by Karabiner style clips or bolt loops along two sides of the mattress. The mattress is then lifted off the seabed using the vessel crane in a predictable level cradled profile and repositioned in the desired location. Figure 4-2 shows a mattress being lifted using a spreader bar.

![Concrete mattress being lifted with a spreader bar](image2)

**Figure 4-2:** Concrete mattress being lifted with a spreader bar

This process is generally only used for moving and arranging the mattresses subsea, for example for loading into speed loaders or subsea baskets. IMCA D 42, which provides guidance on diver and ROV based mattress decommissioning, does not recommend that this method is used for recovery to surface without careful investigation and risk assessment. The reason for this is because the lifting loops are no longer certified for lifting following installation. Facilitating a lift to surface using reverse installation has the potential for a serious incident to occur as the linking material (whether polypropylene rope or steel cable) will have high forces applied during break out of the splash zone and in air, where buoyancy forces are removed. Failure of the linkage material during handling would therefore result in the mattress breaking up or being dropped which exposes both divers and personnel on deck to the risk of serious injury. If used to recover mattresses to surface this method inevitably makes for a labour intensive removal process, particularly if a significant number of mattresses are planned for decommissioning, due to the requirement for a greater number of vessel crane lifts.
4.2.2. Speed Loaders

From engaging with the industry, it has become apparent that speed loaders are the most utilised removal method for the decommissioning of concrete mattresses. Speed loaders were used to recover mattresses during field decommissioning of Kittiwake SAL, North West Hutton, IVRR and FFFA.

Figure 4-3: Subsea Protection Systems speed loader [5]

The equipment consists of two structural steel beams with high capacity steel cable netting connected between them, to form the base frame of the speed loader. The speed loader is deployed subsea for divers or ROV's to load. Mattresses are then stacked on top of the speed loader using a separate handling frame to manoeuvre them into position. Once the speed loader has reached its stacking and weight capacity, the lifting slings rigged to the speed loader structural beams are hooked to the vessel crane and the whole load is recovered to the surface.

Subsea Protection Systems (SPS) are the primary supplier of speed loaders in the UK. Their speed loaders have a capacity of 25 Te SWL which translates to a load of approx. 3 x 300mm THK mats or 5 x 150mm THK mats on one speed loader [6]. The high capacity cable rigged between the structural beams of the speed loader can be specified and sized to suit the dimensions of the mattresses installed.

By utilising several speed loaders, a vessel can substantially reduce the average removal time per mattress. One workshop participant [7] quoted an average removal time of 45 minutes for the first mattress and 25-30 minutes for the subsequent mattresses, which is comparable with the average installation time. This was achieved through careful project planning on a recent decommissioning programme.

The speed loader arrangement also helps to maintain an organised and predictable load on the back of a vessel, compared to grappling grabs or cargo nets, which do not produce an organised arrangement. This helps to improve the packing factor allowing more mattresses to be packed onto the deck.
Key benefits of the speed loader are that they are simple and are the most tried and tested method for mattress recovery in the North Sea. The ability to lift several mattresses at the same time on a single vessel lift cuts down the number of lifts to surface that are required, this is especially pertinent when operating in deeper waters.

There are some limitations associated with this technique. Speed loaders are generally only suitable for recovering standard sized mattresses and the workshop gleaned examples of mattresses found to be too large for the speed loaders on site, rendering them ineffective for the scope of work (North West Hutton decommissioning programme). As a result it was necessary to trim the mattresses down to a size that could fit the speed loader. Taking DSV vessel day rates into account, this can be a costly scenario.

SPS have upgraded their speed loaders which can now be adjusted to accommodate various sizes of mattress. It is the intention that this will address the problem of mattresses being too large for the speed loader, such as in the case previously mentioned. The decommissioning contractor specifies what sized rigging is required based on the mattress inventory and the speed loader can be adjusted to fit various standard sized mattresses by changing out the rigging. The new generation of speed loader can also be used for wet storage which enables the decommissioning contractor to lay the speed loaders on the seabed in preparation for the decommissioning programme. Alternatively, the loading of the speed loaders could be completed as a separate operation to recovery; in which case the DSV would be mobilised to allow divers to load the mattresses into multiple speed loaders and then leave them on the seabed for recovery to surface at a later date. This would maximise DSV time as the vessel would not have to leave the field to discharge the retrieved mattresses. Once all mattresses have been loaded in the speed loaders, a lower cost vessel, or a vessel with greater deck space, could be mobilised to perform the recovery operation, perhaps utilising ROV’s to hook the speed loader rigging up to the vessel crane.

4.2.3. Subsea Containers/Baskets

Subsea half height containers and baskets have also been used for mattress recovery. Specifically these were used during the decommissioning of Frigg, Kittiwake KLB\(^iv\), Linnhe, Tristan NW and Shelley\(^v\).

The containers are deployed subsea by the vessel crane and then divers or ROVs manoeuvre mattresses and mattress debris into them using a handling frame or lifting slings. For recovery of standard sized mattresses, 20 ft. or 23 ft. standard sized containers would be required. The internal dimensions mean that it may not be possible to lay whole mattresses out flat; this has implications on achieving an evenly distributed load. The weight capacity of the standard containers is likely to limit them to two or three mattresses per skip. During the decommissioning of the Shelley field, Premier Oil had a number of bespoke subsea frames designed and manufactured by Technip for recovery of their mattresses.

Once full the containers can be recovered to the surface by rigging lifting slings between the container and the vessel crane. Once on deck the containers can either be stacked on top of one another (if the load allows for it) or the mattresses could be deposited on deck and the container re-deployed subsea.

\(^iv\) Subsea baskets were used in conjunction with subsea grabs during the decommissioning of Kittiwake KLB.

\(^v\) Mattresses from the Shelley field were recovered using bespoke frames designed and manufactured by Technip specifically for this project.
4.2.4. Steel Cargo Nets

Steel cargo nets can be used for mattress recovery. The steel net is laid out on the seabed and the mattress is either rolled or lifted onto the net, the sides are then pulled up over the mattresses and secured at the top. The full cargo net is then rigged to the vessel crane for recovery to surface. Once on deck the load can be released from the net into a container or can be left inside the net for offloading at quayside. Again the packing factor is reduced when using cargo nets, as the load is not evenly distributed. Cargo nets are more suited for recovering large pieces of debris or grout bags.
4.2.5. **Subsea Grabs**

Subsea grabs have been used during the Kittiwake KLB and Camelot decommissioning programmes. Subsea grabs can be supplied in a number of arrangements. Primarily there are two styles of grabs; those which have multiple ‘fingers’ orientated in a circular direction (‘orange peel’ grab) to secure around all sides of an object or they have two set of parallel fingers which close together to pick an object up from two opposing sides.

The main advantage subsea grabs offer is that they can be used to recover mattresses without the need for divers. An eyeball ROV is commonly deployed alongside so the grab operator has visibility. They have been successful for recovery of a small number of mattresses but can be inefficient when there are a large numbers of mattresses to recover.

Disadvantages are that the grab lifts a mattress in a way it was never designed to be handled and the mattresses are usually in an unpredictable tangled state when recovered to deck. The grab can also damage the mattress causing debris to fall off; this then has to be recovered separately. Seabed material is quite often brought back to the surface by the grab; this then also has to be treated as waste and cannot be re-deposited to the seabed. There is also the possibility of lifting the pipeline / umbilical or other object being protected by the mattress. Because of the high likelihood of damage to the mattress during the lift and during offloading at quayside, this can be a more risky operation for personnel. The use of a grab also eliminates the potential for re-using a mattress; the end product is likely to be only fit for recycling or for landfill.

When using grabs it would be preferable to mobilise a barge alongside the lift vessel. The grab would then deposit the recovered mattresses onto the barge, which maximises deck space and utilises the more expensive crane vessel as efficiently as possible.

Grabs are a more appropriate method for recovering buried mattresses or mattresses that have been damaged or broken up on the seabed.

4.2.6. **De-burial**

Mattresses can often self-bury over time, and certain styles of mattress (e.g. fronded mattresses) are designed to self-bury. This is especially common in the southern sector of the North Sea where the seabed is more mobile. Recovery of buried mattresses would require a de-burial operation prior to carrying out any lifting. Mass flow excavators can be used to perform this operation. Mass flow excavators work using rotating propellers to create a high speed, low pressure column of water to fluidise the seabed material for de-burial operations. ROV mounted water jetting pumps or dredging pumps are the most common forms of mass flow excavators.

A substantial amount of seabed material would require to be excavated prior to mattress removal if they are not buried to a depth of 0.6m for possible left in-situ decommissioning. For an average size of mattress with dimensions of 6m x 3m x 0.5m burial, it would require approximately $9m^3$ of material to be moved. Disturbing this amount of seabed and re-suspending the sediment will create another period of non-stabilisation of the environment, destroying the new equilibrium created after installation and potentially smothering the adjacent fauna. Visibility for the operation will also be greatly reduced and may require a period of downtime before it is safe to recommence operations. Depending on the number of mattresses requiring de-burial, there could be the requirement for hundreds of tonnes of seabed material
to be removed and a large area of the seabed affected. The environmental aspect of seabed disturbance is further discussed in section 6.4.2.

4.3. Emerging Technologies

There is a drive within the industry to move away from diver intensive recovery techniques, primarily from a health & safety perspective. There is also a need to identify recovery techniques which can facilitate lower costs operation. There are several solutions currently being considered for development within the industry. These range from small innovations on existing concepts to a radical re-thinking of the mattress decommissioning philosophy.

The key issue with developing a universal mattress decommissioning solution is that every case is different. There are a wide number of mattress types and sizes laid in differing configurations and the structural condition of the mattresses can vary significantly depending on a number of factors as detailed in section 5. As a result, a recovery method that works for one mattress style may not work for another.

Innovative concepts were shared with the authors during the course of researching for this paper; these are outlined in the following sections.

4.3.1. Ecosse Subsea Systems Ambient Lifting

Ecosse Subsea Systems (ESS) Ambient Lifting System allows loads to be lifted and moved subsea without the use of heavy lift vessels, offering potential savings on decommissioning activities by negating or reducing the requirement for heavy lift apparatus and support vessels.

The technology is scalable to over 1000 Te and can be implemented with smaller and more readily available vessels so has the potential to offer a versatile and cost effective solution. The system works by controlling buoyancy and ballast in pressurised receptacles. The pressurised receptacles are water and gas tight coiled tubing (similar to HDPE water pipe) contained within an external frame. The external frame is connected to the structure that is being lifted. By pumping ballast liquid or buoyant gas into a pressurised receptacle any structure can be lifted or floated through the water column.

It is envisaged that the most efficient method for implementation of this technology for the removal of mattresses from the seabed would utilise two Ambient Lifting units. A smaller unit for individual mattress lifts which would be positioned and controlled by an ROV, removing mattresses from the seabed and depositing them in a large subsea container/basket (which in turn can be recovered by a larger Ambient Lifting unit). This Ambient Lifting unit would be in an elongated cylindrical configuration allowing for the use of a spreader beam for stable lifting and manoeuvring of mattresses in a controlled and safe manner. See Figure 4-6.

Figure 4-6: Ecosse Subsea Ambient Lifting
Once all required mattresses have been removed and deposited in the container, a larger unit with a large lift capacity, attached to the vessel via tow wires, would then dock with the container. The larger unit would lift the container and allow for it to be towed back to port for a quayside lift back onto land.

The height of the load from the seabed can be altered during transfer back to shore (to account for changes in the seabed bathymetry) by increasing the buoyancy of the pressure receptacle achieved by pumping in more gas.

Once at shore a quayside crane could be used to recover from the water. The system can be used to lift in excess of 1000 Te through scaling the technology (approximately 200 x 5 Te mattresses).

The main advantage offered by this technology is that it eliminates the requirement for Heavy Lift Vessels and thus is not dependent upon their availability or subject to their rates. Also, because the load can be submerged towed, this allows the technology to be operated in a wider range of sea states as the effects of sea swell and surface weather are reduced.

For more information contact Ecosse Subsea Systems Ltd (see Appendix B).
4.3.2. Fisher Offshore Mattress Crusher

Fisher Offshore presented a concept at one of the workshops which adopts a different approach to mattress decommissioning. Rather than recovering the mattresses and disposing of them onshore, their concept would process the mattresses on the seabed where the resultant crushed concrete material would be deposited\(^vi\). Alternatively, the concept could also be used on the back of the vessel to facilitate more efficient storing for disposal onshore.

![Fisher Offshore Mattress Crusher Concept](image)

**Figure 4-7:** Fisher Offshore Mattress Crusher Concept

Subsea concept

The concept that was presented is essentially a marinised quarry crusher driven by closed loop hydraulic motors; this would be integrated with Fisher Offshore’s existing centrifugal pump dredging system (see Figure 4-7). It is a diver operated system which would be deployed subsea and would then involve loading mattresses into the crusher via a subsea lift using a spreader bar or similar. The resultant crushed material then drops into a discharge point below the crusher which is then dredged out to the seabed through the centrifugal pump dredging system.

Fisher Offshore’s aim is that only the crushed concrete material would be left on the seabed. Other material such as steel rebar and polypropylene rope would be separated and recovered to deck. For separating any steel rebar they have proposed fitting an electromagnet to the discharge point to retain

\(^vi\) However, during the course of this study subsequent discussions with DECC around this concept confirmed that it would not be acceptable to deposit crushed concrete on the seabed.
any metallic material. The polypropylene rope debris may require some form of filtration system to be developed, divers could also work to manually pick up any stray PP material; however capturing all PP debris may be difficult.

The advantage associated with this concept is that the snagging hazard is removed without having to recover the mattresses to surface. Performing the mattress processing subsea could improve decommissioning times as the requirement to perform multiple lifts to surface is removed. It is possible that a smaller vessel could also be mobilised to complete the operation as deck space for storing recovered mattresses is no longer required.

Limitations noted are that the concept could be useful for certain styles of mattress; i.e. standard flexible concrete mattresses but not for others; i.e. plasticised Link-lok mattresses, bitumen mattresses, fronded mattresses and grout bags are unlikely to be appropriate as a result of their constituent materials. Divers are still required to operate the system and load the mattresses and there are likely to be safety concerns around having divers working in close proximity to an open top crusher. The potential for mattress re-use is also eliminated with this method of mattress decommissioning and we lose the value of the embodied material.

**Deck concept**

Fisher Offshore also stated that the system could alternatively be used on the deck of a vessel. This would involve recovering the mattresses to deck where they would be loaded into the macerator which would then crush them to a size that will allow the concrete to be stored more efficiently, allowing vessels to recover more mattresses per trip. The machine would cut and separate PP rope via a filter or steel reinforcement using an electromagnet. The crushed concrete/steel would then be taken into offshore containers using a system of conveyor belts.

Utilising the crusher on the deck does not eliminate the requirement for divers and the recovery operation is still likely to be diver intensive.

The potential for mattress re-use is eliminated with this method of mattress decommissioning and we lose the value of the embodied material. However, this approach does allow for a degree of material recycling as the crushed aggregate may be sold on and used for civil engineering projects onshore.

A test case would be useful to determine how the system performs in the field. Fisher Offshore stated that they could build a prototype system in collaboration with an interested sponsor.

For more information contact Fisher Offshore (see Appendix B).
4.3.3. IHC Engineering Business Subsea Multi-Tool

There are a range of different mattress types in the North Sea and their condition can vary significantly due to a range of influencing factors (discussed in Section 5). As such a removal technique that works for one mattress may not work as well for another. To accommodate this IHC has developed a multi-tool subsea vehicle (Hi-Traq) which can be equipped with a range of tooling to perform multiple subsea operations in one go. This would ideally enable the contractor to approach a project knowing that they have the equipment on board the vehicle to cope with the variety of situations that could be encountered during the decommissioning operation. The vehicle is controlled remotely from the vessel, making mattress recovery a potentially diver less operation. IHC are currently in the process of building the vehicle and aim to have it available to the industry by Q2 2016.

![Hi-Traq Subsea Vehicle](image)

Their Hi-Traq vehicle is a four track system with a linkage arm which is equipped with various tooling to suit the specific application (see Figure 4-8). The Hi-Traq was originally developed for trenching applications in the offshore renewables sector (note that trenching is not permitted during oil & gas decommissioning) and as such it has been developed to withstand high current and wave action as well as undulating terrain, making it a very robust platform to equip with subsea tooling. ROV and diver operations will be limited by sea states and current speeds; however a large heavy subsea vehicle like the Hi-Traq increases the scope to work in more challenging conditions and thus decreases operation downtime.

Typical tools that can be fitted to the linkage arm include dredging and jetting equipment, grabs, pulverisers, road headers and cutters. Having a range of tooling available enables handling of most mattress types. IHC are keen to work with the industry to determine what types of tooling would be most suitable for mattress decommissioning.
The following are some brief examples of the various situations in which the Hi-Traq system could be deployed and the advantages that such a system offers:

- If the mattresses to be recovered have good integrity then it may be suitable to use the subsea grab to lift the mattresses into subsea baskets, the basket could then be recovered to deck for unloading while subsequent baskets are loaded ready for recovery. The ability to load a basket with multiple mattresses or apply multiple subsea baskets reduces the dependency on vessel crane operations which offers a distinct advantage in overall recovery times.

- If the mattresses are found to be buried under a layer of silt or sand then dredging or jetting equipment would be connected to the tool to de-bury the mattresses prior to removal. Once the mattresses have been uncovered then the best method of removal or disposal can be assessed. Mattress de-burial is particularly pertinent to mattresses being recovered from the SNS, in particular fronded mattresses. Usually recovery of buried mattresses would require two separate operations; dredging/jetting and recovery; however the Hi-Traq system offers the capability to perform these simultaneously. Again there are recovery time advantages to be yielded from this.

- In situations where very large mattresses are being decommissioned then it may be necessary to use a cutting tool to trim the mattresses down to a size that the subsea lift basket can accommodate. The Hi-Traq can be equipped with cutting tools to facilitate this without the need to deploy divers or ROV’s.

- If the mattress integrity is found to be poor then the vehicle can be equipped with the grab tool to lift the elements that can be removed easily. Once all easily recoverable parts have been recovered then it may be helpful to fit a pulveriser or mulcher tool to the linkage arm to crush the concrete up to a size that is suitable to be left on the seabed and just recover the polypropylene mesh. Approval to pulverise the concrete and ‘leave in-situ’ will be dependent on approval by DECC\textsuperscript{vii}.

The size of the vehicle does have implications with regards to the type and size of vessel from which it can be deployed. Ideally the vehicle would be launched from a vessel with a 45+ tonne A-Frame. Failing this it could be crane deployed, however this would reduce the opportunity for operating in wider sea states. For an idea of required deck space: an ideal system would involve mobilising the vehicle on a single grillage, the vehicle is on a lift umbilical for quick deployment and recovery, this would require an umbilical lift winch a power container (20 foot), control container (20 foot) and a spare workshop container (20 foot). The mobilisation of the vehicle and the spread on the vessel would initially be quite costly and therefore this technique would be better suited to a large scale project. This would require an initial CAPEX cost; however this could be offset against OPEX savings.

To justify the initial CAPEX it may be useful to consider using the Hi-Traq to undertake a variety of operations as part of a wider decommissioning scope. With this single vehicle it would be possible to do mattress removal up to the jacket structure, significant large scale excavation activities to enable jacket removal, and for pipeline decommissioning, it could perform pipeline de-burial for inspection and then re-burial using reverse excavation techniques.

For more information contact IHC Engineering Business Ltd. (see Appendix B).

\textsuperscript{vii} During the course of this study subsequent discussions with DECC confirmed that it would not be acceptable to deposit crushed concrete material on the seabed.
4.3.4. Imenco – Conceptual Solutions

Imenco UK Ltd. has made us aware of its concept to utilise a subsea plough style vehicle. The concept would involve the vehicle travelling along the line of mattresses with the aim of driving a wedge under the edge of the mattress which will then travel up a ramp into a half height skip or similar recoverable container. Once the container has been filled it can then be recovered to deck and replaced with an empty container for continued recovery along the pipeline. This is still at the conceptual phase and Imenco proposes that the vehicle would be manufactured / adapted for purpose by a third party.

Imenco has a second concept which involves a subsea ‘JCB’ which would be fitted with a spreader beam and two off three finger jaw assemblies. This would feed a secondary unit holding recoverable baskets which would be recovered to surface once filled. The baskets/half heights would then be offloaded from the operations vessel to a barge/supply vessel to avoid the operations vessel having to leave the field to discharge the recovered mattresses and speed up the overall recovery time. Again this is still at the conceptual phase and Imenco proposes that the vehicle would be manufactured / adapted for purpose by a third party.

For more information please contact Imenco UK Ltd (see Appendix B).
4.3.5. SDS Subsea Skip

Subsea Deployment Systems Ltd (SDS) have a methodology that offers a low cost alternative to heavy lift vessels and allows for multiple mattresses to be transported to shore. Their system utilises a large subsea skip which uses control of buoyancy and ballast to facilitate surface and subsurface transport of the load (see Figure 4-9 below). SDS stated they could supply skips with a load capacity of up to 500 Te (up to 100 x 5 Te mattresses).

![Figure 4-9: SDS Buoyancy/Ballasted Subsea Skip](image)

The methodology that SDS would propose to implement during a mattress decommissioning campaign is as follows:

1. Initially a DSV or RSV would be mobilised to pre-load the mattresses into speed loaders or cargo nets. These would then be left on the seabed and spread at strategic locations ready to be loaded into the skip when it arrives on site.

2. Once the mattresses have been bundled up and are ready for loading the skip would then be towed out to site using an anchor handling tug vessel (AHT) and then placed in position on the seabed using the control chains shown.

3. Once in position the DSV or RSV crane would be used to lift the cargo nets / speed loaders into the skip. These would be loaded into segregated areas to ensure an evenly distributed load is achieved. The rigging from the cargo nets/speed loaders is then disconnected and hung off the topside of the skip so they can be used to facilitate direct offloading at the quayside. SDS quoted
that time required to fully load the skip would be no more than 6 – 8 hours, provided all the preparation work was done beforehand.

4. When the skip is fully loaded the skip is then de-ballasted. This is achieved by connecting air hoses from the surface vessel to the lower tubular member on the skip and pressurising to water depth. If the skip is not fully loaded; only some compartments will be de-ballasted or a ballast weight will be used. Time to de-ballast depends on the load and the water depth, SDS quoted approx. 170 mins to de-ballast a 500 Te capacity skip at 150 m water depth.

5. Once de-ballasted, the skip can be submerged towed by recovering the control chains to lift the skip off the seabed. The skip could then either be submerged towed to calmer inshore waters before surfacing, or it can be surface towed from offshore if weather permits. Submerged tow minimises the effects of surface weather thus minimising roll and pitch.

6. Once at an inshore location the skip would be surfaced and secured before offloading using a quayside crane.

The main advantage offered by using the SDS skip is that it reduces working time and transit time for the more costly DSV or RSV vessels by ensuring they are used as efficiently as possible by removing the need for them to leave site to offload recovered mattresses. The system is also less sensitive to weather as there is no requirement to perform lifts through the splash zone and consequently there should be less operational downtime. Safety risks to personnel are also reduced as there is no requirement to perform overhead lifts to deck. As the system is a low-tech solution there is less risk of project failure.

Subsea Deployment Systems quoted that the initial CAPEX cost would be in the region of £1.5m - £2.0m for a 300 Te capacity skip. For smaller projects it may be hard to justify the additional CAPEX however for large projects then this option becomes more competitive as the additional CAPEX is offset against reduced OPEX costs as the customer will be paying for tug vessel day rates rather than construction vessel day rates for transporting the mattresses back to shore.

SDS has a patent and considers their technology as proven but are currently seeking a project partner with whom they can take this technology from concept to market and make mattress decommissioning safer and cheaper.

For more information contact SDS Ltd. UK (see Appendix B).
4.3.6. UTROV Mattress Removal Tool

Utility ROV Services Ltd (UTROV) is developing a new method of lifting single concrete mattresses that will be fast, efficient and versatile while removing the requirement for diver assistance, increasing the safety of mattress removal operations [10].

It has developed a bespoke mattress recovery grab tool that integrates on to a utility ROV. The grab consists of four talons that are clamped around one of the long sides of the mattress (see Figure 4-10). The ROV is positioned over the mattress edge and the grab tool is then closed to secure one side of the mattress. The ROV then ascends so that the mattress is suspended in the vertical plane. The mattress can now either be recovered directly to deck by winching in the ROV umbilical (15 Te SWL) or it can place the mattresses into half height containers or lifting frames that have been pre-positioned on the seabed.

![Figure 4-10: UTROV mattress recovery grab][11]

This method is designed to keep the mattress as intact as possible to allow for safe and predictable cargo loading on the rear of the vessel whilst maximising the potential for re-use of the mattresses. UT ROV stated that they would intend to have a number of excavators available on deck to organise and efficiently stack the recovered mattresses. It uses a number of the company’s existing technologies and equipment currently used in successful recovery of cargo from sunken ships. They have previous success in completing 40 lift cycles in 24 hours at a water depth of 570 m for similar contents. UTROV estimate that they will be able to achieve average recovery times of one mattress every 33 minutes; this is based on
mattresses installed at a water depth of 50 m and a 22 hour working day (2 hours for crew change / handover).

One of the key advantages of this technology is its ability to operate in a wider range of sea states and strong currents because the tool carrier is a utility ROV. This therefore minimises operation downtime.

The system is designed with a compact footprint to ensure that it can fit onto vessels of opportunity. The overall spread required would be approximately 8 m x 11 m and consists of; the Utility ROV, tooling, umbilical winch, HPU container, transformer container, control container, stores container and a workshop container. UTROV have stated that if there is limited deck space the control, stores and workshop container can be removed and the contents transferred to a suitable space within the vessel.

UTROV has recently formed a joint venture with Fletcher Shipping and is installing its system onto the FS Pegasus; an 84 m x 18.8 m PSV with a total deck load of 2700 Te. The large deck space is a major advantage which would allow a considerable number of mattresses to be stored following recovery. UTROV has quoted a total cost of £28k per day for the full vessel spread, exclusive of fuel and lubricant.

UTROV is building its mattress recovery tool in summer 2015 and is testing it at SPS’s (mattress manufacturer, see Appendix A) yard in Dundee. UTROV would like to complete offshore trials as soon as possible; any contractor interested in collaborating with offshore trials should contact UTROV.

For further detail please contact Utility ROV Services Ltd (see Appendix B).
4.4. Discussion

The research conducted for this report indicates that there has previously been little development of technologies to facilitate the removal of concrete mattresses. This lack of development is most likely attributed to the fact that only a handful of concrete mattress removal programmes have so far been completed. As a result existing removal solutions have not been fully optimised.

For significant cost reductions to be seen in the short term there needs to be strong a drive on technology development. In response to this a number of equipment suppliers have now identified the gap in the market and begun developing solutions with the aim of making mattress removal safer and more efficient. The scope of this project identified the aforementioned solutions discussed in sections 4.3.1 through 4.3.5; however other solutions may exist which are not identified herein and may be the subject of future industry studies.

It would be a useful reference for the industry for an impartial third party to perform a detailed cost benefit analysis to compare the alternative removal solutions that were presented during this study against the existing removal solutions. A cost benefit analysis should consider like for like conditions for a mattress removal operation (such as location and water depth) and also take account of influencing factors that may affect the overall costs of an operation such as ability to operate in harsher sea states etc. As many of the solutions considered are at the conceptual or development stage, it has not been possible to carry out a detailed cost comparison at this stage. As options develop, it is recommended that a full cost analysis be carried out in future industry studies.

To enable successful solutions to be developed collaboration within the industry is crucial. This can be promoted through the regular capturing and sharing of lessons learnt at industry forums (such as Decom North Sea lunch and learns) which will allow for the refinement of designs.

A number of equipment providers have indicated that they would also require investment to allow their technologies to be developed, trialled or tested. It may be useful for these suppliers to offer extra incentives to attract investment from vessel contractors or operators. Examples of incentives that could be offered include offering lump-sum hire contracts for mattress removal campaigns. Joint Industry Projects (JIP’s) would also help to identify the performance of new technologies in the field. In the first instance the International Technology Facilitator (ITF) should be engaged and the gap in the market defined. This may then lead to securing funding for a joint industry project (JIP) to be launched.

Industry bodies such as Oil & Gas UK and the Oil & Gas Authority could galvanise technology development by negotiating additional Government subsidies or tax-relief incentives to operators who pilot new technologies as part of their decommissioning programmes.

Due to the forecasted increase in mattress decommissioning activity over the coming years and given the relative inexperience of the industry, it may be helpful for the industry to develop guidelines or a best practice document on the topic of mattress removal / decommissioning and classification perhaps under DECC or under the auspices of industry bodies such as Oil & Gas UK or Decom North Sea.
4.5. Removal Solutions Summary

4.5.1. Key Findings

The following key findings arise from the investigation into mattress removal solutions:

- All existing removal solutions, with the exception of subsea grabs, are diver intensive. There are significant health and safety issues associated with diver based operations and they require DSV mobilisations which are inherently expensive.

- Subsea grabs are an existing diverless solution and can be effective when there are small numbers of mattresses to be removed. However they are not an efficient solution when decommissioning large volumes of mattresses. They also eliminate the potential for re-use as the method of handling commonly damages the mattress.

- Speed loaders (see Figure 4-3) have been perhaps the most successfully used mattress removal technology to date in the CNS and NNS. Average recovery times were quoted at approximately 45 minutes per mattress when the mattresses are in good condition. However speed loaders are not a suitable recovery method for all types of mattress. They have also not been used for mattress recovery in the SNS and their suitability for use in this region is not certain.

- There are inefficiencies with current mattress removal practices, primarily centred on inefficient use of the lifting vessels’ time. Research has shown that during decommissioning programmes that involve recovery of large volumes of mattresses the heavy lift vessel is required to leave the field to offload recovered mattresses at the quayside before returning to the field to continue the recovery operation.

- Lack of mattress decommissioning experience in the North Sea has hindered technology development.

- A number of mattress removal technologies were presented to Jee which have good potential for reducing the overall cost of mattress decommissioning operations predominantly through facilitating quicker operations or through utilising lower cost vessels. Some of the technologies presented also offer the advantage of diverless solutions. Knowledge to date is that none of these technologies have so far been piloted as part of a mattress removal operation.

- Two of the technologies presented proposed the methodology of crushing or mulching mattresses ‘in-situ’ and depositing the resultant concrete slurry on the seabed as a means of satisfying the regulators. Following a discussion with DECC it was confirmed that this would not be permitted. Subsea crushing of mattresses may be viable but the resultant debris would need to be transferred to a subsea container and removed to surface.

4.5.2. Recommendations

The following recommendations arise from the work into mattress removal solutions:

- It is recommended that a detailed cost benefit analysis is performed by an impartial third party to compare the emerging removal solutions against the existing removal solutions. A cost benefit analysis should consider like for like conditions for a mattress removal operation and also take account of influencing factors that may affect operation costs such as ability to operate in harsher sea states etc. As many of the solutions considered are at the conceptual or development stage, it has not been possible to carry out a detailed cost comparison at this stage. As options develop, it is recommended that a full cost analysis be carried out in future industry studies.
• It would be useful if industry guidelines or best practice documents could be developed on mattress removal / decommissioning and classification, perhaps by DECC, or under the auspices of industry bodies such as Oil & Gas UK or Decom North Sea. However, the industry may first have to gain more experience before this is possible.

• A number of the technology solution providers have indicated that they are keen to work with industry to develop their mattress handling solutions (see section 4.3). It is recommended that contractors with practical experience of mattress decommissioning engage with innovative solutions providers to provide input in this respect, and include consideration of the various styles of mattress.

• Others have indicated that they would like to complete offshore trials of their tools and are seeking vessel contractors and Operators who may be interested in mattress decommissioning and a collaborative approach to facilitate offshore trials of their solutions. Equipment providers who require investment to allow their technologies to be developed trialled or tested may have more success in attracting investment if they offer additional incentives such as lump-sum hire contracts for mattress removal campaigns. The ITF should also be engaged and the gap in the market defined, this may then lead to the launch of a JIP

• Industry bodies such as Oil & Gas UK and the Oil & Gas Authority should negotiate with the Government for additional subsidies or tax relief for Operators who pilot new technologies as part of their decommissioning programmes.
5. Mattress Classification

5.1. Condition

The condition of subsea mattresses varies throughout the North Sea, based on a number of different factors. It is important to try and quantify the expected condition prior to embarking on a decommissioning programme. This ensures that the appropriate recovery methods are employed and necessary safety precautions put in place. It is also important to determine the condition to select the most appropriate disposal method, i.e. if the condition is good then there may be re-use opportunities, alternatively if the condition is known to be poor then arrangements can be made for disposal via recycling or landfill.

The first port of call is to assess the mattress inventory. This should include details of the style and size of mattress installed, locations and the design specifications (if available). Key items of information are concrete density, quality, diameter and condition of the linkage material.

Once the expected inventory has been drawn up, a general visual inspection (GVI) survey should be completed to confirm the detail. The GVI will also enable some conclusions to be drawn on the integrity of the mattresses. The structural condition of a mattress is sometimes difficult to quantify from GVI footage. However, some key characteristics to look for, which are likely to indicate some degree of structural integrity loss, are detailed in section 5.1.1.

GVI survey footage may provide an image of the static mattress appearing in good condition. However, it is not uncommon for a seemingly structurally sound mattress to be found in poor condition during subsea interaction tests or during the retrieval process. Experience has however shown that there are a number of dependant factors which influence the structural condition of a mattress and hence should also be used to help evaluate its recoverability. The key influential factors are:

- Region of the North Sea (and water depth)
- Mattress type
- Length of time in service
- Transportation, storage and installation history

These are discussed in sections 5.1.2 to 5.1.6.

5.1.1. Survey Checks

Surveys are important to determine whether any of the mattresses are under burial prior to beginning the decommissioning operation. If mattresses are found to be buried then the extent of burial should be determined as far as possible. Overburden may increase the lift load to a level that exceeds safety limits. If mattresses are found to be buried then de-burial by means of jetting or dredging should be performed prior to the recovery operation.

The configuration is important to quantify during the survey. Mattresses are commonly laid in an overlapping fashion to ensure no sections of the spool or pipeline are left exposed. This introduces lift complexities as the mattress to be recovered may have to be dragged from underneath its adjacent overlap. At pipeline crossings mattresses are often laid on top of one another for additional protection and the resultant crossing is commonly rock dumped to allow fishing vessels to trawl over.
The mattresses should be checked for any signs of damage. There have been reports of cases where the lifting lugs on the mattresses have been found to be cut, either during the survey or during the recovery operation. This is thought to have been a result of the installation practice at the time and clearly adds another complexity to the removal process. The survey should check for any signs of mechanical damage such as third party interaction from anchor drag, which may have affected the structural integrity of the mattress.

The condition of linkage material in multi-segmented mattresses is a key piece of information. On mattresses linked with polypropylene rope, fraying of the polypropylene rope can indicate that the material has degraded; this will nominally be a result of UV exposure. If signs of fraying are noted on the lifting loops during the survey then this indicates that the lifting points are not suitable for subsea lifting. If this is the case then lifting frames or speed loaders are unlikely to be suitable for the recovery operation. Multi-segmented mattresses linked with steel wire should be inspected for signs of corrosion to the steel lattice. If divers are in the water inspecting the mattresses then using a pinch bar to test how well the blocks hold together will give a good indication of the linkage material condition.

Signs of pitting in the concrete block work may indicate that the concrete has degraded. This may be a result of an incorrect concrete mix during the manufacturing process. In this case lifting may result in the concrete blocks breaking up and presents a risk to diver safety. If pitting of the concrete is seen then it may constitute a cause to apply for leaving a mattress ‘in-situ’.

Multiple loose threads in grout bags provide an indication the grout bag may have rotted. In this situation the bag may not have sufficient strength to retain the grout during recovery. Grout bags may also have been filled while in position on the seabed and in this case may lack lifting points, this should be checked.

The bitumen filler in bitumen mattresses commonly becomes brittle over time. Upon recovery the mattresses are likely to break up due to cracking of the bitumen, therefore recovery techniques using divers should not be pursued. Signs of cracking or rigidity to the structure should be looked for.

More modern mattresses usually have a unique tag number imprinted on the polypropylene lifting loops. If the tag number can be identified during the visual survey then this can be cross referenced with the supplier to determine the mattress history i.e. when it was installed and if it was dry or wet stored prior to installation. Mattress suppliers have to keep records of stock sold for at least seven years.

If the visual survey does not provide adequate confirmation on the condition of the mattresses then it may be necessary to perform a sample lift. A sample mattress could be recovered during the survey to allow for a more detailed assessment of the mattress condition and assist in determining the recoverability and the most appropriate method of recovery.
5.1.2. Location

The location in which the mattress is installed has an impact on the mattress condition. The environmental conditions such as current velocities, wave conditions, temperature range, water depth (in the Southern North Sea this can be as little as 10m) and seabed type should all be checked.

The condition of mattresses recovered from the deeper waters of the Central and Northern North Sea has generally been found to be very good. The deeper water depth provides protection from UV, which causes degradation of the polypropylene rope, as well as shielding from the hydrodynamic forces at the surface. Most of the UV spectrum is filtered out at a water depth of 20 m and at depths of 50 m and greater the hydrodynamic effects from surface waves are reduced. Mattresses at greater depths have also been found to have less marine growth fouling as a result of the decrease in UV light. Marine growth can make deck handling difficult, can limit the applications for re-use / recycling and increase the level of onshore processing required to remove the marine growth prior to re-use / recycling.

Experience of mattress decommissioning in the shallower waters of the Southern North Sea has found that mattress conditions tend to be relatively poor. The SNS is characterised by highly mobile sandy seabed, leading to mattresses self-burying and de-burying regularly which causes complications when it comes to locating and recovering mattresses. The mobile seabed can also result in current/sediment erosion to the mattress or linking materials impacting the recoverability in one piece. The water depths at which mattresses are installed in the SNS can be as little as 10 m (e.g. Camelot field, SNS). At these depths they are exposed to increased wave loading and there is less UV filtering, this again can have a negative effect on the condition of the mattress material. Marine growth fouling is more prominent at the shallower water depths which have implications for recovery and the onshore disposal options.

5.1.3. Mattress Type

The style of mattress has a significant impact on its recoverability and potential for re-use. Each style of mattress has its own challenges associated with handling and recovery; if at all possible. This is due, in part, to the fact they were never design to be removed. The older style mattresses in particular (e.g. Armorflex and Bitumen) have significant challenges with their recoverability. Similarly in assessing the potential for re-use certain styles of mattress will have more scope than others. Generally the flexible concrete mattresses have the greatest scope for re-use. The table in section 5.2 details the specifics in relation to determining recoverability and re-use potential of various mattress types.

5.1.4. Length of Time in Service

The length of time the mattress has been in service may influence the condition in which the mattress is found. The longer the mattress has been in service the higher the likelihood that it will have experienced some form of third party interaction i.e. dropped object impact, anchor drag, trawl snagging etc. The mattress will also have been exposed to hydrodynamic forces for a longer period of time e.g. wave and current loading. If the mattresses have been situated in shallower waters where UV light penetrates then this too will have a time dependant impact on the mattress condition.
5.1.5. Transportation, Storage and Installation History

It is good industry practice and aids safety awareness to consider the transportation and storage history of the mattresses being mobilised prior to their installation. This provides the installation contractor and divers with confirmation that the mattresses have been adequately stored with minimal exposure to UV light. If the records are available then it would be useful to check the transportation and storage history prior to the decommissioning operation. However, often such records are unavailable.

Installation reports may be more readily available and these should be checked for anything of note that may impact the recoverability. The example of lifting loops being cut during installation has already been mentioned and is a good example of available information which would help to make an informed decision on the mattresses recoverability or best recovery method.

5.2. Recoverability and best solutions

Recoverability is influenced by a combination of mattress characteristics, condition and environmental constraints. The various styles of mattress each have their own issues in respect to handling. The removal considerations for the different mattress types are discussed in Table 5-1 along with suggestions on the most suitable removal methods to employ and the scope and considerations for re-use. If recovery cannot be completed both safely and efficiently then this effectively makes the mattress ‘non-recoverable’.
Table 5-1: Removal and re-use considerations

<table>
<thead>
<tr>
<th>Mattress style</th>
<th>Industry use</th>
<th>Recoverability / Removal considerations</th>
<th>Most appropriate available recovery method</th>
<th>Re-use considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexible concrete mattresses</td>
<td>Widely used</td>
<td>Most common style of mattress. Easiest to recover successfully. Degradation of the polypropylene rope possible in shallow waters; this can hinder handling, not commonly an issue in deeper waters.</td>
<td>• Speed loaders&lt;br&gt;• Subsea baskets</td>
<td>Widest scope for re-use. Can be processed to produce concrete aggregate</td>
</tr>
<tr>
<td>Link-lok mattresses</td>
<td>Rarely used. No longer considered on new projects</td>
<td>Also one of the easier to recover mattresses. Degradation of the linkage material is the biggest consideration. External plastic shell means the concrete should be in good condition.</td>
<td>• Speed loaders&lt;br&gt;• Subsea baskets</td>
<td>Good scope for re-use. Difficult to process for recycling due to the additional layer of hard plastic outer shell</td>
</tr>
<tr>
<td>Armorflex</td>
<td>Widely used on older installation. No longer considered on new projects</td>
<td>Internal steel wire lattice prone to corrosion. On recovery steel wires have disintegrated and mattress falls apart causing dropped object concerns and safety issues with divers in the water.</td>
<td>• Seek approval to ‘leave in-situ’</td>
<td>Potential for re-use of individual concrete blocks (if recovered). Concrete blocks can also be processed for aggregate.</td>
</tr>
<tr>
<td>Bitumen</td>
<td>Widely used on older installations. Generally no longer considered on new projects</td>
<td>Common for the outer bag to rot over time and for internal bitumastic material to turn brittle. Causes the mattress to break up during lifting.</td>
<td>• Seek approval to ‘leave in-situ’</td>
<td>No known re-use applications</td>
</tr>
<tr>
<td>Grout bags</td>
<td>Widely used</td>
<td>Exact quantity in place is often difficult to quantify prior to mobilisation. Many will not have lifting points attached. The integrity of the canvas bag also comes into question during recovery.</td>
<td>• Subsea baskets or cargo nets for smaller grout bags&lt;br&gt;• Seek approval to ‘leave in-situ’ for larger grout bags</td>
<td>Limited re-use potential. Could be used as scour protection or as coastal defences. No scope for recycling.</td>
</tr>
<tr>
<td>Fronded mattresses</td>
<td>Widely used around the base of structures e.g. manifolds in the SNS</td>
<td>Difficult to locate. Would usually require de-burial through jetting or dredging prior to removal.</td>
<td>• Seek approval to ‘leave in-situ’ if burial depth &gt;0.6 m&lt;br&gt;• Subsea grapnel if burial depth is &lt;0.6 m</td>
<td>Limited scope for re-use due to polypropylene fronds also makes recycling more complex</td>
</tr>
</tbody>
</table>
5.3. Mattress Classification Summary

5.3.1. Key Findings

The following key findings have been drawn from the research into the factors which affect mattress condition the biggest contributing factors are mattress style and location:

- Flexible concrete mattresses and Link-lok mattresses retain their structural integrity best and are the most readily recoverable.
- Armorflex and Bitumen style mattresses, as well as grout bags commonly lose their structural integrity and as a result have reduced recoverability.
- Fronded mattresses are typically more difficult to recover as they are designed to self-bury, this was demonstrated during decommissioning of the Camelot field.
- The water depth at which a mattress has been installed has a strong influence on its condition.
- The condition of mattresses has been found to be best in the deeper waters of the Central and Northern North Sea where the water depth exceeds 50 m. Mattresses in the NNS and CNS also tend to experience less marine growth fouling due to the increased depth. The combination of these factors gives mattresses recovered from the CNS and NNS most scope for re-use following recovery.
- Mattresses in the Southern North Sea tend to be found in more advanced states of degradation on account of the shallower water depths, greater wave loading and faster currents. The seabed material in the SNS is also finer and heavily prone to scouring which will result in mattress burial, the suspended sediment combined with the current can also have erosive effects on the mattress materials harming their integrity during recovery. Marine growth fouling is also more common on mattresses removed from the SNS on account of the shallow water depths. These factors make recovery of mattresses from the SNS more difficult and mean that the scope for re-use may be limited.
6. ‘In-situ’ Decommissioning

The default standpoint of the UK regulation body for mattress decommissioning (DECC) is that the Operator must abide by the clean seabed rule which states that everything must be removed and the seabed returned to its original state following a decommissioning programme. However certain events may have occurred over the field life which could have caused the mattresses to suffer structural damage or deterioration which may have rendered them to be considered ‘non-recoverable’. In this case the most appropriate option for decommissioning may be to leave them ‘in-situ’ on the seabed. This section of the report explores the leave ‘in-situ’ decommissioning option; where and when it may apply (see Section 5.2), how an application should be presented to DECC and what is required, and finally the legacy implications.

6.1. Definition of a ‘non-recoverable’ mattress

A non-recoverable mattress would generally be defined as a mattress which cannot be recovered safely and efficiently. This may apply to any mattress however the following mattresses may be more readily considered as appropriate candidates for ‘in-situ’ decommissioning:

- **Armorflex mattresses**: Armorflex mattresses are known to degrade significantly underwater due to corrosion of the steel wire lattice that connects the concrete blocks.
- **Bitumen mattresses**: Bitumen mattresses are known to degrade significantly underwater due to hardening of the bitumastic material resulting in them becoming brittle. This causes them to be prone to break-up when lifted.
- **Fronded mattresses**: Fronded mattresses are designed to self-bury and therefore tend to meet the 0.6 m burial criteria which is generally accepted for leaving pipelines in-situ during decommissioning and thus this burial criteria is often also accepted for mattresses.
- **Grout bags**: Recovery is difficult as these have minimal lifting points attached and as such the factor of safety is far less than that of a standard concrete mattress with 16 point lift attachments. In previous decommissioning programmes, grout bags, particularly large 1 Te grout bags, have typically been left in situ.

Standard flexible concrete mattresses and Link-lok mattresses retain their integrity well and would not generally constitute a case for leaving ‘in-situ’ unless they had been damaged.

6.2. DECC standpoint

As the DECC guidelines state (see section 1.5); the Operator will be expected to remove all subsea mattresses as part of a decommissioning programme. This is DECC’s default standpoint, however they do take a pragmatic approach and recognise that in some cases it may not be practical to perform mattress recovery and that in such situations an approval to ‘leave in-situ’ may be the most suitable decommissioning option for mattresses.

DECC do enter into discussions with Operators around leaving mattresses in-situ, and have granted approval for mattresses to be left in-situ as part of decommissioning programmes in the past (see section 6.5), but the Operator must present DECC with a properly thought through and logically argued case as to why mattresses are considered ‘non-recoverable’ and why the ‘leave in-situ’ option is most
appropriate. Such applications are always considered on a case by case basis and it can never be assumed that a 'leave in-situ' application will be granted.

When making an application for approval to leave 'in-situ' the key deliverable that will be presented to DECC is a Comparative Assessment (CA) report. This report details the options available for mattress decommissioning, an assessment of each option and a conclusion on the most appropriate option to progress with for the decommissioning programme. Supporting information will need to be presented to DECC alongside the CA, this should detail the inventory that is in place (number and types of mattress) and the burial status. Additional base surveys and studies may also be required to feed into the CA; these are discussed further in section 6.3. The approach for developing the CA is detailed in section 6.4.

6.3. Base Surveys and Studies

Prior to completing the comparative assessment it is necessary to complete a range of base surveys and studies which will feed in to the CA. These are detailed in sections 6.3.1 through to 6.3.4.

6.3.1. Survey

Typically for a discussion to happen around leaving mattresses in-situ DECC need the mattresses to be mapped and depth tested to confirm the inventory that is in place. The aim is to provide DECC with a plan view general arrangement showing the locations, number and type of mattresses intending to be left on the seabed.

This may involve undertaking surveys with a multi-beam, side scan sonar and video surveys by ROV. The survey can be used to visually confirm the 'as-laid' inventory and determine the mattress condition; points to note include the condition of lifting loops (see section 5.1.1). The survey will also show the bathymetry of the seabed and any exposed mattresses. The burial depth of any buried mattresses needs to be determined – DECC may be willing to accept an application to leave in-situ for mattresses which are buried to a depth of 0.6 m or below (this is the minimum burial criteria for pipelines being decommissioned in-situ). It should be noted that the burial status of the mattress is taken at the point of survey regardless of any scouring the may take place after. There are various ways of determining burial depth; a sub-bottom imager could be deployed on a work class ROV to produce a comprehensive survey map. This can then be presented to DECC showing the mattress burial depths and then used in the comparative assessment. Regardless of the decision regarding the application to leave in-situ, this is still useful information to have as it documents exactly what mattresses need to be removed.

6.3.2. Geotechnical Assessment

An application to leave in-situ should present facts to back up the case. To complement a 'leave in-situ' application an interpretative geotechnical assessment of the mattresses in-situ is required. This may include CFD analysis of the mattresses in a few locations to demonstrate that they would remain stable and not become exposed significantly or become a snagging hazard if they were subject to worst case storm and current conditions. This would predominantly be required within the shallower waters of the Southern North Sea where mattresses and seabed material are likely to be displaced during storm conditions. This is a key report in proving the safety case that mattresses would not prove a hazard to fishermen if they were left 'in-situ'.
6.3.3. Socioeconomic Base Case Study

A socioeconomic base case study reports on the fishing activity in the area. Once decommissioning is complete an over-trawl survey will need to be undertaken to prove the seabed is snag free, this report determines the various types of fishing used in the area, interaction with the seabed and the snag risk. It also identifies the best type of over-trawl survey to be undertaken post decommissioning operations.

6.3.4. Environmental Impact Assessment

When applying for approval to leave in-situ, an environmental impact assessment (EIA) will be required to support the comparative assessment (CA). The EIA considers the environmental impacts that may arise through the decommissioning works. Such factors include; impacts on marine life, disturbance of seabed caused by the various decommissioning options and CO₂ emissions omitted through operations. The leave in-situ option often has the least impact on the environment. An environmental base line survey may need to be completed to feed into the EIA if recent survey data does not exist.

6.4. Comparative Assessment

When all the base surveys are complete, a review should be held to discuss the decommissioning options (inclusive of leave in-situ) and carry out an initial hazard identification assessment (HAZID) with representatives from the base survey disciplines present. The risks associated with each option are assessed against several criteria and then compared to determine the most suitable option for decommissioning. The criteria against which the decommissioning options are assessed are:

- **Safety**
  - Define the risks to project personnel
  - Define the risks to other users of the sea
  - Define the risks to onshore project personnel

- **Environmental**
  - Define the marine impacts of operations
  - Other environmental compartments (including emissions to the atmosphere such as CO₂)
  - Energy resource consumption
  - Other environmental consequences (including cumulative effects)

- **Technical**
  - Define risk of major project failure

- **Societal**
  - Define fisheries impact
  - Employment
  - Impact on communities or amenities

- **Economic**
  - Define the different options
  - Indicate the costs for each option
  - Indicate what the differences are between the methods
Indicate whether each option is considered to be a cost effective solution.

Once the risks have been assessed and agreed they are then tabulated and presented in a Comparative Assessment report along with a conclusion on which decommissioning method is most appropriate.

The CA criteria are discussed in the following sections, specific to mattress decommissioning and the ‘leave in-situ’ option.

6.4.1. Safety

The CA shall consider the potential safety implications of each mattress decommissioning option. This will include a HAZID of each option and a subsequent risk assessment of the risk levels posed to the various sub criteria; i.e. project personnel (offshore), other users of the sea (such as fishermen), project personnel (onshore).

It has already been discussed that there are significant safety concerns related to the recovery of certain styles of mattress. Specifically, the Armorflex and bitumen style mattresses which are known to suffer significant degradation and are both prone to breaking up during lifting. It appears from discussions held with industry, that DECC are more open to considering accepting an application to leave in-situ for these types of mattresses due to an unnecessary level of risk to personnel safety.

An example safety assessment summary of the options available for decommissioning either of these types of mattress (Armorflex and Bitumen) is shown in Table 6-1. Two example options are presented for the safety assessment; complete removal and leave in-situ. The conclusion of the safety assessment in this case would be that the complete removal option carries an unnecessary level of risk and therefore the leave in-situ option would be the most appropriate. Such a conclusion would then be presented to DECC and the statutory consultees as a proposal for leaving in-situ. As there is a moderate risk posed to other users of the sea acceptance of this option would likely be on the condition that the operator rock dumped the remaining mattresses and performed subsequent surveys.
Table 6-1: Safety assessment summary

<table>
<thead>
<tr>
<th>Sub criteria</th>
<th>Complete removal</th>
<th>Leave in-situ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risks to offshore project personnel</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>- Diving activities required</td>
<td>- No diving activities required</td>
</tr>
<tr>
<td></td>
<td>- Lifting operations required</td>
<td>- No lifting operations required</td>
</tr>
<tr>
<td></td>
<td>- Significant man hours required</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Integrity of mattresses is unconfirmed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Environmental conditions may make operations more hazardous</td>
<td></td>
</tr>
<tr>
<td>Risks to other users of the sea</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>- Snagging risk removed</td>
<td>- Potential snagging risk to trawlers remains</td>
</tr>
<tr>
<td>Risks to onshore personnel</td>
<td>Moderate</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>- Multiple onshore lifts required (boat to quayside, quayside to onshore transport, onshore transport to disposal)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Integrity of mattresses is unconfirmed</td>
<td></td>
</tr>
</tbody>
</table>

6.4.2. Environmental

The risks to the environment, as a result of decommissioning activities or legacy, are assessed against the sub criteria. DECC considers the environmental case as part of their decision as to whether mattresses can be left ‘in-situ’. However, DECC have also stated that they would not accept an application to leave mattresses ‘in-situ’ on environmental grounds alone. This is because the ‘leave in-situ’ option almost always carries the least risk to the environment.

Jee consulted with Professor Mike Elliot, of Hull University, on this matter - a specialist in estuarine and coastal sciences, who has previously advised on oil & gas decommissioning projects.

Marine impacts of operation

This sub-criterion may be defined as the impact to marine and terrestrial environments from planned operational events. If it can be shown that removal operations carry a high risk of resulting in a directly negative impact on the marine environment then this may be put forward as additional justification for leaving in-situ. Factors to consider in this assessment include the following:

- Duration of operations
- Vessel discharges to sea
- Noise from operations
- Disturbance to seabed
- Presence of any protected species

The duration of operations will have a direct impact on the vessel discharges to sea and the noise from operations. These factors can be readily quantified based on estimates of how long the operations are
expected to take and the type of work required (cutting, lifting etc.). The type of marine life common to the area will play an important part in this assessment as certain species of marine mammals are especially sensitive to noise pollution.

A 'leave in-situ' conclusion often has the least impact on the marine environment. The process of installing mattresses results in a disturbance to the seabed and the local marine environment, however the environment will have reached a new equilibrium over the time that the mattresses have been in place and are likely to have been inhabited by a number of marine species. To remove the mattresses would act to introduce a new period of 'non-stabilisation' to the local marine habitat which would then have to stabilise again over time. Another important point to consider is to try and identify whether there are any hazardous materials on the seabed local to the mattresses. Mattresses are commonly installed around the base of the jacket structure to protect pipelines and spools. If there are any drill cuttings piles in close proximity then understanding whether removal operations are likely to disturb the drill cuttings pile is important. Disturbance of a drill cuttings pile may present a reasonably high level of risk to the marine environment as they may contain toxins which could then be released and through the water column if disturbed. Oil & Gas UK conducted a Joint Industry Project (JIP) on the issue of drill cuttings which has more information on this matter; see Appendix D for more information.

It is good practice to perform a Net Environmental Benefit Analysis (NEBA) when assessing the environmental impacts of the various mattress decommissioning options (see Appendix D for more information on NEBA). A NEBA is a standardised methodology that can be used for assessing the gains in environmental services or other ecological properties attained by actions, minus the environmental injuries caused by those actions. This can be used to compare and rank the net environmental benefit associated with each of the decommissioning options. Placing hard man-made structures, such as mattresses, on the seabed can provide certain benefits to the ecosystem. For example they can be beneficial to the recovery of certain marine populations, such as coldwater corals. Conversely, such structures can also be counter beneficial to the ecosystem; some may argue that they can act as a stepping stone to aid colonisation of non-indigenous and invasive species, and in this case there may be benefit to be gained in removing them. In the environmental case it is helpful to try and quantify, as far as possible, what benefits are gained by leaving them in place and alternatively what the benefits are in removing them.

It would be useful to try and identify particular types of marine species that are believed to inhabit the local environment on the basis of understanding if there are any protected species which would be threatened by removal operations. If the mattresses can be proved to serve some nature conservation enhancement purpose then this may act as a stronger justification for 'leaving in-situ'. The DECC guidelines mention two species of conservation interest in particular; the coldwater coral, *Lophelia pertusa* and reef forming worm, *Sabellaria*. Both these species are known to exist on or around offshore installations and survey worksopes should try to establish the presence of either. If there is a significant growth of coral or an established *Sabellaria* reef the potential impact of the operations on these species should be assessed in the EIA and the CA. If the coral is present and the installation upon which it is located is to be returned to shore (typically the requirement for mattresses) it will be necessary to discuss with DEFRA the requirements of the Convention on International Trade in Endangered Species.

The EU Marine Strategy Framework Directive outlines a set of eleven high level descriptors which can be used to assist in defining the impacts of removal operations on the marine environment. Each descriptor...
can be assessed individually to determine what effect the decommissioning options will have on that particular descriptor. See Appendix D for more information on the EU Marine Strategy Framework Directive.

An objective approach is best employed when assessing the impacts of mattress decommissioning on the marine environment.

**Emissions (CO\textsubscript{2}) and Energy Expenditure**

An estimate of the total expected CO\textsubscript{2} emissions and energy expenditure associated with each decommissioning option is calculated. This should include direct emissions and energy use from the whole lifecycle of the decommissioning option i.e. emissions generated and energy required for vessels, onshore transportation and recycling activities. Again if the cumulative emissions and energy expenditure associated with removing mattresses significantly outweighs the environmental benefit to be gained from recovering them, then this may provide additional justification for the proposed case of leaving ‘in-situ’.

6.4.3. Technical

The technical aspect of the CA is simply concerned with assessing the risk of major project failure. The technical feasibility of the various decommissioning options will be assessed based on existing industry experience and the availability of equipment. At present industry experience of mattress decommissioning is relatively limited and available equipment is primarily confined to that outlined in section 4.2. The style and condition of the mattresses will play an important factor in determining the risk of major project failure, i.e. if they are in poor condition the risk is likely to be high. If it is concluded that recovery operations will prove too technically challenging and that the project has a high risk of failure then it may take a test lift to prove to the regulators that best endeavours have been attempted.

6.4.4. Societal

Societal assessments will help assess the commercial impact of the decommissioning options; this will normally be with respect to fishing activity; as well as the employment impacts of the various options of decommissioning, recovery and processing, and if there are any impacts to communities or amenities. The societal impacts associated with leaving in-situ are likely to count against it as a decommissioning option. This is because the removal option provides the greatest employment opportunities. The leave in-situ option involves no offshore and onshore operations and therefore provides no comparative increase in employment.

6.4.5. Economic

Full cost estimates should be prepared for each decommissioning option. If it can be shown that a disproportionate cost is involved with removal then this may form grounds for an application to leave mattresses ‘in-situ’. Factors to consider include:

- Vessel day rates
- Equipment hire
- Onshore processing

Accurately understanding the costs is not only important for the Operator but also for the Government as under the current UK tax regime, the Government offers tax relief at 50% (or 75% for older fields) on the
costs of decommissioning equipment. An application for leaving a mattress ‘in-situ’ is unlikely to be accepted purely on a cost basis unless all other criteria show no significant difference between the alternative options.

6.5. Successful Applications

There have been a number of cases to date where operators have had applications to leave mattresses ‘in-situ’ granted by DECC. For a ‘leave in-situ’ application to be accepted, DECC also require agreement from the statutory consultees (NFFO, SFF, NIFF and Global Marine Systems). In the majority of successful ‘leave in-situ’ cases to date, the Safety Case has proved to be the most influential (see section 6.2.1). However, a ‘leave in-situ’ application may be approved on the basis of the other factors provided that the case was strong enough. It will be useful to maintain current knowledge of cases under discussion with DECC where possible, as this may have an impact on the project under consideration.

Examples of successful mattresses left in-situ cases can be found in the decommissioning of Ivanhoe and Rob Roy (Hess), FFFA (Hess) and Camelot (Energy Resource Technology (UK) Ltd.).

Hess was granted approval to leave 120 of its mattresses ‘in-situ’ during the Ivanhoe and Rob Roy decommissioning programme, and 76 mattresses during the decommissioning of FFFA. In both of these cases the style of mattress was the wire-rope Armorflex style mattresses. Trial lifting campaigns were undertaken and in both cases the Armorflex style mattresses disintegrated upon lifting making them unsuitable for recovery by speed loader. A revised comparative assessment was completed of feasible alternative decommissioning options. The comparative assessment demonstrated that the recovery by divers and subsea skips or mechanical grabs was undesirable for safety and environmental reasons respectively and that the recommended option was to leave the wire-rope Armorflex mattresses ‘in-situ’. DECC and the stakeholders accepted that any degraded wire rope Armorflex mattresses could be left ‘in-situ’ and that they would be rock dumped with a suitable profile to protect demersal fishing activity.[14]

At Camelot 3 concrete mattresses gained approval to be left ‘in-situ’ as they were buried to a depth greater than 0.6 m under a rock dump berm. In addition to this a further 6 buried concrete mattresses were left ‘in-situ’ after attempts to recover them with a grapple failed. Attempts to recover 22 fronded mattresses with the grapple were also unsuccessful these too remained ‘in-situ’.[15]. It is understood that DECC accepted that the mattresses that could not be recovered could be left ‘in-situ’ on the basis that reasonable effort to recover them had been attempted and that following a trawl sweep operation there were no obstructions or debris that could be attributed to the Camelot development.

It should be noted that all of the aforementioned decommissioning programmes which have had a ‘leave in-situ’ application approved have originally specified that all mattresses will be removed, then on execution they have found that the mattresses cannot be located due to burial (Camelot) or may disintegrate on moving (IVRR, FFFA). Revised comparative assessments were then submitted to DECC concluding that the mattresses should be left ‘in-situ’ and these were approved.

6.5.1. Pull test

It should be noted that in the aforementioned cases it has taken trial lifts or pull tests to prove to DECC that the mattresses are non-recoverable; that is that they cannot be safely or efficiently recovered. A pull test proves to the regulators that best endeavours have been made to recover the mattresses but that recovery is either not practical or that the mattresses are buried sufficiently that they will remain stable.
over time. DECC has indicated that this is likely to be a standard requirement for any discussion over leaving mattresses ‘in-situ’. If an application is being made to leave a significant number of mattresses ‘in-situ’ then they may request that pull tests of a suitable sample are performed.[16]

6.6. Engagement & Communication

It is key to begin engagement with the statutory consultees early in the discussions when considering an application to leave mattresses ‘in-situ’. The Fishing Federations (SFF, NFF, NIFF) have a significant influence on the final decision to accept or reject an application to ‘leave in-situ’. Jee consulted with the Scottish Fishermen’s Federation (SFF) to understand their stance on the matter of leaving mattresses ‘in-situ’.

Representatives from the SFF expressed that their preferred option for any decommissioning programme is that the operator satisfies the ‘clean seabed rule’. However, they also acknowledge that this is not always possible and are willing to enter into discussions with the Operators to try and find a workable solution. In a situation where leaving a mattress in-situ is the preferred option following completion of the CA, it is important to begin discussions with the relevant Fishing Federations as early as possible to try and find a solution that works for both parties. Early engagement will hopefully avoid encountering a situation where solutions are proposed that don’t satisfy the fishing industry.

An example that was discussed was a hypothetical situation where the Operator wished to leave a number of mattresses in-situ and as mitigation against the snagging hazard proposed to rock dump the mattresses. If the mattresses were located in scallop fishing grounds then rock dumping would be an unsuitable mitigation from the fishing community’s perspective. Avoiding such situations would ultimately save the Operator time and money and be constructive to maintaining good relations between the two industries.

6.7. Perpetual Liability

The Operator retains liability for any mattress that is approved for being left ‘in-situ’. These cases, to date, have typically been accompanied with the condition that the Operator rock dumps or buries any mattresses left ‘in-situ’ and that the Operator also agrees to perform periodic surveys and overtrawling trials to confirm there have been no changes over time. These conditions will be required by DECC and informed by stakeholders such as the fishing federations as mattresses can present a significant snagging hazard to trawlers. The frequency of the surveys will be dependent on the terms of the ‘Leave in Situ’ decision and influenced by factors such as the intensity of fishing in the area. For mattresses left ‘in-situ’ in busy fishing corridors the survey frequency could be as much as every two years and the conditions will also require repeats of overtrawling trials to be performed. This is always performed at the operator’s cost. If subsequent surveys show that there have been changes and that the mattresses have become uncovered, as a result of seabed movement or storms etc., then the operator will be required to perform rectification work to rebury them. This can be a significant problem in the SNS where the seabed is very mobile and the water depth shallow.

The cumulative cost of surveys and trials should be considered prior to making an application to leave mattresses ‘in-situ’. Although the initial capital required for recovering the mattresses may be significant it could be quickly surpassed with the on-going expense of providing assurance that there is no risk to other users of the sea.
The perpetual liability means that the operator will have liability for any incident (gear snagging etc.) that occurs between surveys. In cases where liability cannot be determined, claims for compensation can be paid from the Fishermen’s Legacy Trust Fund. There is also the potential for serious incidents occurring, resulting in serious damage and loss of life, for example the Westhaven incident in 1997, where a trawler sank after snagging its trawl gear on a pipeline span. All decommissioning decisions must be made to avoid the possibility of such tragic incidents in future.

6.8. SWOT Analysis (Recovery vs Leave in-situ)

An example SWOT analysis has been performed to indicate the case of complete mattress removal against leaving in-situ. This should be completed for each project, as the indicative results shown overleaf may not apply to the case under consideration. The results are included in Table 6-2, overleaf.

Note, some of the strengths, weaknesses, opportunities and threats may not have been discussed in detail above, where these are encountered please refer to section 7 for more detail.
<table>
<thead>
<tr>
<th>SWOT</th>
<th>Complete removal</th>
<th>Left in-situ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strengths</td>
<td>• Snagging hazards removed (fishing)</td>
<td>• Less disturbance to marine habitat that has reached equilibrium</td>
</tr>
<tr>
<td></td>
<td>• Return habitat to its natural state</td>
<td>• Employment opportunities for subsea survey contractors, fishing fleets</td>
</tr>
<tr>
<td></td>
<td>• Perpetual liability removed</td>
<td>(overtrawling trials)</td>
</tr>
<tr>
<td></td>
<td>• Less disturbance to marine habitat that has reached equilibrium</td>
<td>• Reduced cost during decommissioning</td>
</tr>
<tr>
<td>Weaknesss</td>
<td>• Negative impact on marine habitat (new period of non-stabilisation)</td>
<td>• Rock dumping or burial likely to be a condition (associated costs)</td>
</tr>
<tr>
<td></td>
<td>• Potentially dangerous operations to personnel (offshore and onshore)</td>
<td>• Continued financial costs associated with periodic surveys and trials</td>
</tr>
<tr>
<td></td>
<td>• Relatively little industry experience in mattress decommissioning</td>
<td>• Operator retains perpetual liability while mattresses remain in-situ</td>
</tr>
<tr>
<td>Opportunities</td>
<td>• Re-use opportunities, onshore or in other locations subsea</td>
<td>• Possible spread of non-indigenous species</td>
</tr>
<tr>
<td></td>
<td>• Increases circular economy awareness within O&amp;G industry</td>
<td>• Reduction of employment opportunities for decommissioning contractors</td>
</tr>
<tr>
<td></td>
<td>• Carbon emissions savings from avoiding new concrete production (re-use)</td>
<td>and waste management contractors</td>
</tr>
<tr>
<td></td>
<td>• Good PR (CSR associated with certain re-use opportunities)</td>
<td>• Reduced cost during decommissioning</td>
</tr>
<tr>
<td></td>
<td>• Government tax relief for decommissioning programmes</td>
<td>• Increase in fish stocks and other marine species through provision of</td>
</tr>
<tr>
<td></td>
<td>• Development and investment of novel removal techniques</td>
<td>sheltered habitat</td>
</tr>
<tr>
<td></td>
<td>• Increased employment opportunities</td>
<td>• Potential for creation of marine biology research site</td>
</tr>
<tr>
<td>Threat</td>
<td>• Increased carbon emissions from vessel recovery operations</td>
<td>• Potential creation of recreational diving sites</td>
</tr>
<tr>
<td></td>
<td>• Snagging hazards to fishing remain in place</td>
<td>• Spread of non-indigenous species</td>
</tr>
<tr>
<td></td>
<td>• Spread of non-indigenous species</td>
<td>• Inhibits building of industry experience in offshore mattress decommissioning</td>
</tr>
<tr>
<td></td>
<td>• Inhibits building of industry experience in offshore mattress decommissioning</td>
<td></td>
</tr>
</tbody>
</table>
6.9. ‘In-situ’ Decommissioning Summary

6.9.1. Key Findings

The following conclusions can be drawn from the investigation into the leave ‘in-situ’ decommissioning option:

- Certain styles of mattress are likely to be more readily considered for leave ‘in-situ’ decommissioning on account of their susceptibility to structurally degrade (Armorflex mattresses and Bitumen mattresses), design to self-bury (Fronded mattresses) and absence of sufficient lifting points (Grout bags).

- An application to leave mattresses ‘in-situ’ may be more readily considered if it can be shown that mattresses are buried to a minimum depth of 0.6 m and it is shown (through CFD or similar) that they are unlikely to de-bury significantly overtime.

- Justifying a leave ‘in-situ’ application for standard flexible concrete mattresses with polypropylene rope could be very difficult as these mattresses retain their integrity well.

- DECC assesses every leave in-situ application on a case by case basis and their default standpoint is always that the Operator will be expected to remove all mattresses. Therefore it should never be assumed that approval will be granted to leave mattresses ‘in-situ’ even if the mattresses conform with the styles or burial depths outlined in the above bullet points. Any application to leave a mattress ‘in-situ’ must be backed up by a thorough, logically argued and evidenced case in the form of a comparative assessment (CA) report.

- When presenting a comparative assessment to DECC safety is of primary importance for an application to leave mattresses ‘in-situ’ with focus being on minimising risks in the long term to other users of the sea and in the short term to those involved in the decommissioning operation.

- When presenting a comparative assessment to DECC the environmental case, although considered, would not be accepted on a standalone basis, this is because the ‘leave in-situ’ option almost always carries the least environmental risk.

- To date, all decommissioning programmes in which mattresses have gained approval to be left ‘in-situ’ have been revised. In these cases the original programmes submitted to DECC all specified that all mattresses would be removed.

- In light of the above point; there is an expectation on the Operator to apply ‘best endeavours’ in relation to mattress recovery. Therefore even if it is felt that mattress removal operations cannot be completed safely or efficiently then it may take a trial or test lift (pull test) to prove to DECC that a recovery operation is not the best option for mattress decommissioning and that they should be left ‘in-situ’.

- The Operator will retain liability for any mattresses that are granted approval to be left ‘in-situ’ and this will also come with the condition that periodic monitoring and trawl sweeps will be performed, at the Operators expense. The frequency of the survey and trawl sweeps will depend on the intensity of fishing activity in that area among other factors and will be determined by DECC with input from other stakeholders where appropriate. Therefore although the ‘leave in-situ’ option may be the cheapest option in the short-term, there are long-term cost implications associated with the conditional monitoring that will need to be performed.
6.9.2. Recommendations

The following recommendations have been made following the investigation into ‘in situ’ decommissioning (all cases must be discussed with DECC and a full CA of all options submitted):

- A ‘leave in-situ’ application may be considered by DECC (subject to appropriate surveys and comparative assessment) where Armorflex mattresses, Bitumen mattresses and large grout bags are installed. This is predominantly on account of the significant safety risks to personnel and inefficiencies of operation as a result of the susceptibility of these styles of mattress to lose structural integrity.

- A ‘leave in-situ’ application may also be considered where mattresses are shown to be buried to a minimum depth of 0.6 m. Fronded mattresses typically self-bury – again however surveys, comparative assessments and local condition studies must provide evidence that this is likely to remain the case in future.

- Emerging mattress removal technologies should be taken into consideration before proceeding with an application to leave non-recoverable mattresses ‘in-situ’. Although mattresses may not be considered recoverable using market ready removal technologies there may be developing technologies (such as those outlined in section 4.3) which can more readily facilitate removal.

- Where the leave ‘in-situ’ option has been selected as most appropriate, it is recommended that Operators enter into discussions early with DECC and the area fishing federation, to identify a solution which is acceptable to all parties. In every case, minimum monitoring conditions will be agreed if the mattresses are permitted to remain ‘in-situ’ and other measures determined to minimise the snagging risk to trawlers.

- When considering an application to leave mattresses ‘in-situ’ a cost comparison should be performed between the estimated cost of a recovery operation against the cumulative costs of continual monitoring and overtrawling trials.
7. Circular Economy

7.1. Overview

The purpose of this section of the study is to explore circular economy principles with respect to concrete mattresses. The following is an extract from Zero Waste Scotland’s Circular Economy Scotland Report \(^{[17]}\) which defines what is meant by a ‘circular economy’:

“A circular economy restores old products, parts and materials back to their original use in a way that uses the least resources to deliver the same function.

Ideally, this means direct re-use of products, which preserves both the highly engineered character of a product and its useful function. Where a product needs repair or reconditioning before it can be used again, remanufacturing preserves the most value. These are the tightest ‘loops’ within a circular economy.

The next best route is recycling, which can be closed or open loop. Closed loop recycling turns products into materials that can be used to create the products they were recovered from. In contrast open loop recycling or downcycling creates material suitable only for lower value applications. Although lower value, this avoids the use of new materials.”
The four loops of the circular economy will be explored relevant to concrete mattresses. This will involve attempting to identify alternative re-use applications as well as identifying the benefits to be gained and the challenges associated with re-use.

The methodology was to consult with industry experts based on their involvement with recent and ongoing mattress decommissioning projects.

7.2. The Opportunity

The exact number of concrete mattresses in the North Sea is not readily available. However Oil & Gas UK estimates that between 35,000 and 40,000 concrete mattresses have been deployed on or around oil and gas subsea infrastructure since operations began in the North Sea. There has been an increase in oil & gas decommissioning projects over the last few years and this trend is expected to continue to rise as North Sea fields mature and production becomes unsustainable.

Current regulations state that operators must remove any mattresses or grout bags for disposal onshore, unless a leave ‘in-situ’ case can be made. This represents a significant opportunity for re-using the reclaimed materials. To date, it has been more common practice to recycle reclaimed mattresses for the production of concrete aggregate; however there have been instances where mattresses have been re-used on a small scale.

Zero Waste Scotland want to explore how circular economy principles can be applied to concrete mattresses and it is the intention of this study to identify potential re-use opportunities with the aim of promoting re-use rates.

7.3. Primary Re-use

Primary re-use applications are situations in which the mattresses can be re-used in their entirety. This would be the ideal solution. Re-use is much more valuable than recycling. This is because re-use preserves some or all of the mattresses function. There have already been instances where mattresses have been used onshore however there may also be subsea re-use opportunities. The scope for re-use is limited by the style of the mattress and the mechanical condition of the mattress following recovery. Certain styles of mattresses are not suitable for re-use and similarly mattresses found to be in a poor structural condition are also unlikely to be suitable. Feedback from the industry suggests that the more widely used articulated concrete mattresses have the most scope for re-use. All other mattress styles are likely to have very limited, if any, scope for re-use. The expected condition should be defined as far as possible based on the findings from the survey and the factors outlined in section 5.1.

7.3.1. Oil & Gas Pipelines

Re-using recovered mattresses for their original design intent i.e. stabilisation and protection of subsea pipelines and structures would be the ideal re-use solution and would appear to be the most logical.

Re-using recovered mattresses on other oil & gas pipelines could theoretically be done but they may need to be subject to a re-certification process to show that they have retained the strength properties required to perform their function and provide impact protection from a dropped object. The consequences of a pressurised oil & gas pipeline failure are severe and Operators are likely to be hesitant to re-use uncertified second hand mattresses on their live assets on a wide scale. The cost associated with re-
certifying a mattress would be likely to exceed the outlay of a new mattress; workshop delegates reported costs of around £250 for a new mattress.

There may however be more of a market for re-using recovered mattresses on mothballed or decommissioned lines. The consequences of failure of depressurised pipelines are much reduced and as such it may be acceptable to re-use uncertified mattresses on such assets.

There are lifting implications with redeploying recovered mattresses. The lifting loops are no longer certified to handle a secondary deployment through the high loading splash zone and therefore the Lifting Operations and Lifting Equipment Regulations (LOLER, 1998) requirement which states that ‘all equipment used for lifting is fit for purpose and is accompanied by the appropriate certification’ is no longer valid.

However, workshop delegates suggested that mattresses could be re-used on infrastructure that is local to the initial installation site without re-certifying. In this situation the mattresses would not be recovered to deck but would be moved subsea by the vessel. This may be a suitable option if the whole field was not being decommissioned; however opportunities are likely to be minimal. Redeploying reclaimed mattresses from deck to the seabed would require them to be contained in appropriately rated equipment such as speed loaders or subsea baskets. Once safely on the seabed then it would be acceptable to reposition the mattresses individually using spreader bars or lifting frames connected to the installation hoops.

Redeploying mattresses in a different location on the seabed would require a marine licence to be obtained from Marine Scotland before they could be redeployed (see section 7.10.4).
7.3.2. Offshore Renewables

The offshore renewable energy sector is an emerging market that will potentially require thousands of concrete mattresses over the coming years. It is important for renewable energy projects to keep capital costs as low as possible to make them economically viable; therefore there may be keen interest in obtaining stabilisation equipment at a reduced cost.

![Offshore wind farm](image)

**Figure 7-1: Offshore wind farm**

Development in offshore wind is increasing and 135 GW of offshore wind energy is predicted to be installed in the Central and Southern North Sea by 2030 [18]. This aligns well with the expected rate of oil & gas fields decommissioning. Offshore wind is an industry that will potentially require thousands of concrete mattresses for scour protection around the base of the mono-piles and for cable protection/stabilisation. There is a 50 m exclusion zone imposed around turbine monopiles which means that fishermen will be excluded from operating within this area anyway, therefore any mattresses repositioned to the windfarm locations within the 50 m exclusion zones would not pose a new snagging hazard to trawlers. The Neath na Gaoithe, offshore wind development, 15 km off the coast of Fife in the outer Firth of Forth, has recently been given the go ahead and construction is projected to commence around 2017. This development consists of 75 large 6 MW turbines with a combined capacity of 450 MW. This development is ideally located to make use of decommissioned oil & gas concrete mattresses which could offer substantial cost savings to the project by negating the requirement to purchase new scour or stabilisation equipment for array cabling and monopile structures. If North Sea oil & gas mattress decommissioning activities are projected to coincide with the Neath na Gaoithe project then
there may be scope to avoid recovering the mattresses to the surface and instead using a subsea transport method (such as those outlined in sections 4.3.1 and 4.3.5) to relocate the mattresses to the wind farm site.

This would ideally work with mattresses that will be required for wind farm purposes within a similar geographic location to where they are being decommissioned. This minimises transport and also limits the transfer of organic material to different areas of the North Sea.

Similar to offshore wind, the tidal energy sector is an emerging industry. There are known issues with inter array cable stability in high tidal regions and this has been identified as one of the key issues with the technology. Cable burial is not usually a viable option due to the high costs associated with burial and the desire to keep CAPEX and OPEX costs down to increase the returns of the technology. Concrete mattresses could be used to provide stability to the cable. Again, reclaimed mattresses could also be used to provide scour protection around the footings and piles of the turbines.

Large tidal lagoons have been approved for construction in the Swansea Bay area of the Severn Estuary [19]. These are large steel walled structures which have to be created and which will require concrete and granite blocks to be brought in to build up the foundations for the steel walls. The walls will also require breakwaters to be built up around them to prevent impact damage in rough weather. Concrete mattress might well serve some purpose for this project and other similar projects which are in the pipeline.

In all of the above applications a marine licence would need to be obtained from Marine Scotland to allow the mattresses to be repositioned to another area, see section 7.10.4 for more information.

To serve the renewables industries with decommissioned concrete mattresses there would need to be various subsea storage points available. Decommissioned mattresses could be wet stored inside the exclusion zones of decommissioned oil & gas infrastructure, such as NWH, or within exclusion zones of current offshore windfarms until they were required. When required the stored mattresses could be moved into location using a subsea transport method.

Other potential areas outside those discussed may exist or materialise as the Renewables industry develops.
7.3.3. Artificial Reefs

Decommissioned mattresses could potentially be used to construct artificial reefs which would act to encourage fish breeding. This is similar to work done in the Caribbean and the Mediterranean where modules called ‘Reef Balls’ have been installed to provide marine habitat enhancement. ‘Reef Balls’ are concrete modules with holes built in to them which have been shaped to optimise protective void spaces for fish and other marine species and include features such as rough surface textures to enhance coral settlement [20], (see Appendix D for more information). The geometrical nature of a concrete mattress also provides voids and protective spaces which lend themselves well for providing a good habitat for marine biota especially if multiple mattresses were stacked to provide a large reef structure.

Given that artificial reefs act as fish attraction devices then this solution may be of benefit to the fishermen. They would also provide an excellent habitat for species like lobsters and brown crabs and so would be an ideal area for creel caging and lobster potting. The Poole Bay artificial reef, created off the South coast of England, was constructed from concrete blocks and cement stabilised pulverised fuel ash (PFA) from power stations. The reef was designed to assess the environmental acceptability of this novel material and was deployed off Poole Bay in 1989. The reef was then subject to a monitoring programme to study a number of factors related to the environmental acceptability of the materials but also to observe the changes in fauna close to the reef and the fisheries potential of the structures. The monitoring programme showed that the reef blocks were rapidly colonized by a wide variety of epibiota, fish and crustaceans [21], (see Appendix D for more information). Experiments such as the Poole Bay reef show that artificial reefs do actively encourage marine life.

Aside from the environmental benefits artificial reefs also become a magnet for divers and recreational fishermen. The Scylla artificial reef in Plymouth was created by sinking a decommissioned naval warship in 2004. Since placement it has been estimated that the Scylla Reef has attracted over 30,000 divers and contributed in the region of £5 million to the local economy [22], (see Appendix D for more information). The economic appraisal of recreational fishing against commercial fishing also shows that recreational fishing is much more valuable to the economy. This is a result of the additional revenue that is gained from associated recreational expenses such as; transport, tourism, hotels and fishing licence costs. The success of the Scylla artificial reef shows the type of economical returns that such a project can offer.

It may take a test case to prove that such a scheme works but if it is proven to then a number of artificial reefs could be set up for specific purposes. For example; dedicated reefs could be set up for commercial fishing activities such as creel and lobster potting, dedicated reefs could be set up for recreational diving and fishing and dedicated reefs could be placed for protected environmental monitoring. This way there are a number of benefits there to be gained; environmental, societal and economical.

The success of the ‘Rigs to Reefs’ initiative in the Gulf of Mexico shows that such programmes can deliver benefits to all stakeholders. This scheme allows the operator to deposit the decommissioned platform on the seabed to serve as an artificial reef. The state also assumes responsibility for the asset from the operator. In the GOM, oil & gas companies that donate platforms to the state’s RTR programs are asked to donate half the disposal savings realised by not having to recover the platform to shore, to the states artificial reef program fund [23](see Appendix D for more information). Similar initiatives could be investigated for the North Sea.
7.3.4. Sea Defences

Mattresses could be used for coastal defence projects at areas around the country where the shoreline is weak and are prone to coastal erosion, such as the Dorset coast. By depositing the mattresses a certain distance offshore, they would act to artificially decrease the water depth and encourage larger waves to break further out to sea helping to reduce their strength when they hit the shoreline [24]. Mattresses could also be installed on the beach as wave breakers to absorb the energy of waves or the concrete blocks used to construct gabion walls (see section 7.4.2).

A workshop delegate mentioned that the Churchill barriers; which now act as causeways with road links, located around Scapa Flow in Orkney, are now degrading and require patching. The Orkney Islands council are seeking industrial quantities of concrete or rubble to reinforce the existing structures. This may be an ideal opportunity to re-use reclaimed concrete mattresses as the materials are very similar to those used in the existing defences. The mattresses may require a cleaning process to remove any marine organisms and ensure the transfer of parasites or alien species to different areas of the sea does not occur at an accelerated rate relative to naturally occurring rates.

Reclaimed mattresses could also be used to extend piers or harbour walls. Mattresses reclaimed from the North Sea decommissioning programmes have previously been used to extend the walls at Lerwick Harbour and the construction of a pier in Norway.

7.3.5. Road Foundations

Reclaimed mattresses can also be used in their entirety for providing the sub-base for roads. The dimensions of standard concrete mattresses (6 m x 3 m) lend themselves well to the standard width of road carriageways. There have been cases in the past where mattresses have been used for the sub-base of roads and this is believed to have happened in the local area in recent years. They can be laid down and the ‘notches’ can be filled in with fine aggregate or wet concrete to give a smooth finish. It is more common to crush reclaimed mattresses to produce a second class aggregate; this is then sold on to the construction industry and the aggregate used in building foundations and also for road foundations. By using the mattresses whole to lay road foundations, a level of the onshore processing is removed saving both money and energy by avoiding the recycling stage and going straight to re-use. Projects such as the Aberdeen Western Peripheral Route could be a large scale source of mattress re-use. See section 7.7 for the cost saving incentives available from avoiding recycling.

The forestry commission has also, in the past, used reclaimed concrete mattresses for building temporary roads. This has been commonly applied in creating stable forestry access roads in soft ground for the moving of heavy equipment required in the forestry business. The mattress roads allow heavy vehicles to complete operations year round as they are not exposed to the same access problems during periods of bad weather.

Similarly, onshore windfarms could employ reclaimed mattresses to create access roads to the turbines.
7.3.6. Agricultural

There may also be a number of agricultural applications for reclaimed mattresses. Tubular & metal recycling company John Lawrie has had previous experience of providing recovered concrete mattresses to the agriculture sector in North East Scotland. The end user was a farmer who wanted a number of reclaimed mattresses. The intended purpose was to use the mattresses as flooring for cattle sheds, see Figure 7-3. John Lawrie Group also had other enquires as a result of this for mattresses to be used as temporary roads and for car parks.

A waste management contractor who attended one of the Jee workshops mentioned that he had received a request for a number of reclaimed mattresses from the owner of an off-road motor bike track. The owner wanted to acquire concrete mattresses to build a perimeter fence around his track to stop break-ins.
7.3.7. Gravity Based Foundations / Moorings

Mattresses could be stacked in an organised fashion as ballast for gravity based tidal turbines or other renewable infrastructure. Dependent on the shape and profile of ballast required, the mattress could be trimmed if required and the constituent blocks inserted into gabion style structures to suit the profile of the gravity base.

There may also be scope for re-using mattresses either in their entirety or partly to create mooring anchors for floating structures such as buoys.

7.4. Secondary Re-use

Secondary re-use applications are defined as applications in which the components of mattresses can be re-used. This situation would involve minimal processing, but specifically cutting the mattress into its constituent blocks. There may be opportunities such as those detailed in the following sections.

7.4.1. Scour Protection / Rock Dumping

Whilst it may not be possible to re-deploy reclaimed mattresses subsea in their entirety, it might be feasible to use the individual blocks for scour protection or stability purposes. The individual blocks could be used to fill in areas of scour around the base of structures or to fill in pipeline or cable trenches. There may also be scope for using the individual blocks around the top layer of rock dump berms for pipeline protection and trench transitions. The size of the blocks would likely be too large for the base layer of rock on live pipelines but may be suitable for the top layers which tend to consist of larger sized rock to sustain the current loadings. However, they may be suitable to use directly on abandoned or decommissioned trunk lines left in-situ where the consequence of damage to the pipeline is less. Other
decommissioning programme statutory consultee’s, such as Global Marine Systems, may have re-use applications for reclaimed mattress materials.

7.4.2. Gabion Walls

The individual concrete blocks could be used to construct gabion walls for shoring up potential land slide locations or road/rail cuttings. The symmetrical geometry of the blocks would make them ideal for stacking in the wire mesh cages which are used to contain the concrete filler. This avoids the need to quarry new rock.

![Figure 7-4: Gabion wall embankment](image)

7.4.3. Rip-Rap

The concrete block work could be utilised as rip rap; rock or material to protect shorelines/bridge abutments/pilings etc., to minimise the erosive effects from water around the shore line or river bank. Alternatively the mattresses could be placed along the shore line in their entirety; the articulated nature of the mattress would contour the ground well. Using the individual concrete block work may give a more pleasing aesthetic although slightly less natural looking erosion defence.

The use of mattresses on the river bank may not be recommended too far upstream from the river mouth due to the possible salt leaching from the blockwork, this could be detrimental to the fresh water ecosystem.

7.4.4. Building Blocks

If in a suitable condition the individual concrete blocks could be used for building material. The geometry of the blocks may result in some restrictions of what they could be used for but they would likely be suitable for constructing retaining walls or small outhouses. There may be some scope for the materials
to be donated to developing countries. The costs associated with transport would be likely to be in excess of local disposal costs; however this could contribute to Operator’s CSR initiatives.

7.5. **Repair and Remanufacture**

After re-use, repair and remanufacture is the next loop in the circular economy. Following discussions with industry it was concluded that this is unlikely to be an economically viable step in the CE as applied to concrete mattresses.

If the mattress is found to be damaged to some extent then the costs associated with the repair and remanufacture work is likely to exceed the monetary value of a new mattress. Therefore, repair and remanufacture is not to be a viable option. In the case where the mattress is damaged to the point that it cannot be used in its entirety without repair work then the suitable disposal option would be recycling.

7.6. **Recycling**

If no re-use application, primary or secondary, can be sourced then the next loop in the circular economy is recycling. The mattresses are crushed and the polypropylene rope is removed to give a concrete aggregate which is usually rated as a second class aggregate. Closed loop recycling is not considered suitable for concrete mattresses as they are manufactured by casting which the aggregate would not be suitable for. Open loop recycling is therefore the only viable option for recycling and common uses from the resultant aggregate are using it to form a sub-base material for trunk roads or as filler in new concrete structures. The salt content of the concrete may limit what the aggregate can be used for; concrete structures reinforced with steel rebar would not be suitable due to concerns about corrosion of the steel.

7.7. **Cost Incentives for Re-use**

7.7.1. **Cost benefit to operator**

The general consensus from the workshops held was that it is unlikely that reclaimed mattresses will have any real monetary value for re-sale. However there is a cost incentive for the operator associated with the re-use option, over the alternatives of recycling and disposal to landfill.

Detailed of indicative costs associated with each option are provided in the following sections.

Re-use is the cheapest disposal option for the operator as it involves little or no onshore processing. The only costs associated with re-use are transport and logistics; this is dependant to some extent on the quantity of mattresses (and hence the size of the load) and the distance they are to be transported; local projects are key to success of this to help minimise transportation costs. However, from discussion with local waste management and recycling contractors it is expected that re-use would cost less than disposal or recycling. Three waste management contractors were consulted to provide estimates on the costs associated with re-use. Indicative values of onshore transport and logistics are given in Table 7-1.
Table 7-1: Re-use costs

<table>
<thead>
<tr>
<th>Contractor</th>
<th>Total estimate (£/tonne)</th>
<th>Cost breakdown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contractor 1</td>
<td>£ 20</td>
<td>Based on the total cost to transport 5 x 5 Te mats (i.e. a 25 Te load), distance not specified (quoted price was combined cost of transport and logistics)</td>
</tr>
<tr>
<td>Contractor 2</td>
<td>£ 70</td>
<td>Transport £1000 per load (3 x 9.5 Te mats)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Logistics £125 per hour (Total of 8 hours hire assumed to move all mattresses)</td>
</tr>
<tr>
<td>Contractor 3</td>
<td>£ 100</td>
<td>Based on 100 x 5 Te mats being transported 250 – 300 miles (quoted price was combined cost of transport &amp; logistics)</td>
</tr>
</tbody>
</table>

**Average re-use cost (£ / tonne)** £ 63

Mattresses can also be disposed of to a recycling facility, where they will typically be crushed to produce concrete aggregate. There are costs associated with the required processing and most recycling centres also charge a gate fee in addition to the transport and logistics costs. An estimate cost for mattress recycling (per tonne) is provided in Table 7-2.

Table 7-2: Recycling costs

<table>
<thead>
<tr>
<th>Recycling charges</th>
<th>Cost (£/tonne)</th>
<th>Cost breakdown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recycling charge</td>
<td>£ 19</td>
<td>Cost quoted by recycling centre was £16 plus VAT (@ 20%)</td>
</tr>
<tr>
<td>Gate fee</td>
<td>£ 35</td>
<td>Based on quote by landfill site owner (see Table 7-3)</td>
</tr>
<tr>
<td>Transport &amp; logistics</td>
<td>£ 63</td>
<td>Based on average quote provided by waste management contractors (see Table 7-1)</td>
</tr>
</tbody>
</table>

**Total cost (£ / tonne)** £ 117

The Scottish Landfill Tax replaced the UK Landfill Tax in Scotland from the 1st of April 2015. This tax is charged on the disposal of waste to landfill and is charged by weight. From the 1st of April 2015 the standard rate of tax is £82.60 per tonne of waste. A lower rate of £2.60 per tonne of waste applies to less polluting wastes including concrete, however following discussions with HM Revenue & Customs it was confirmed that subsea concrete mattresses would qualify for the standard rate of tax due to the polypropylene rope and marine growth fouling. The waste owner, in this case the Operator, will also have to pay a landfill gate fee; this is dependent on the landfill site but quotes obtained typically puts this in the region of approx. £35 per tonne. Transport and logistical costs charged by the waste contractor to transport the waste from quayside to landfill also apply. An estimated cost for mattress disposal to landfill (per tonne) is provided in Table 7-3.
Table 7-3: Landfill costs

<table>
<thead>
<tr>
<th>Landfill charges</th>
<th>Cost (£/tonne)</th>
<th>Cost breakdown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landfill tax (2015/2016 rate)</td>
<td>£ 82.60</td>
<td>• Quoted price for the landfill waste qualifying for the higher rate (UK) effective 1st of April 2015</td>
</tr>
<tr>
<td>Landfill gate fee</td>
<td>£ 35</td>
<td>• Based on quote provided by landfill site owner</td>
</tr>
<tr>
<td>Transport &amp; logistics</td>
<td>£ 63</td>
<td>• Based on average quote provided by waste management contractors (see Table 7-1)</td>
</tr>
<tr>
<td><strong>Total cost (£/tonne)</strong></td>
<td><strong>£ 180.60</strong></td>
<td></td>
</tr>
</tbody>
</table>

7.7.2. Cost benefit for end user

If an end user can be sourced to re-use mattresses there is scope for them to receive a free product. This was the case in the example discussed in section 6.3.5. The farmer who received reclaimed mattresses for cattle shed flooring did not pay anything to receive the mattresses and the only cost was an exemption from the Scottish Environmental Protection Agency (SEPA) to deposit waste material on his land. The cost of the exemption was approx. £200 and thus minimal in comparison to the cost of purchasing raw materials to achieve the same purpose.

7.8. Carbon Savings

There are also significant carbon savings to be gained through re-using concrete mattresses. The production of concrete is one of the biggest contributors to CO₂ emissions, in 2012 it was reported that the production of the cement in the concrete contributes around 5% of the global carbon dioxide[^25]. Re-using the concrete from reclaimed concrete mattresses for the type of applications mentioned above saves the production of new concrete and thus saves the resultant CO₂ emissions from being released into the atmosphere.

The carbon factor for concrete production is 0.135 tCO₂e/tonne (tonnes of CO₂ equivalent per tonne)[^26]. Table 7-4 shows estimates for the amount of CO₂e embedded in low density and high density standard sized flexible concrete mattress.

Table 7-4: Embedded CO₂

<table>
<thead>
<tr>
<th>Length (m)</th>
<th>Width (m)</th>
<th>Height (m)</th>
<th>Density (kg/m³)</th>
<th>Mattress weight (kg)</th>
<th>Embedded CO₂ (tCO₂e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.00</td>
<td>3.00</td>
<td>0.15</td>
<td>Standard (SG 2400[^27])</td>
<td>6480</td>
<td>0.87 (low)</td>
</tr>
<tr>
<td>6.00</td>
<td>3.00</td>
<td>0.30</td>
<td>High (SG 3900[^28])</td>
<td>21,060</td>
<td>2.84 (high)</td>
</tr>
</tbody>
</table>

Oil & Gas UK estimate that there are between 35,000 and 40,000 concrete mattresses in the North Sea. Based on this estimate the total carbon savings can be calculated for 100% re-use of all mattresses for the upper and lower bounds of embedded CO₂. This is shown in Table 7-5.
Table 7-5:  Carbon savings per mattress type

<table>
<thead>
<tr>
<th>Mattress weight (kg)</th>
<th>Embedded CO₂ (tCO₂e)</th>
<th>Total carbon saving (tCO₂e)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low estimate (35,000)</td>
<td>High estimate (40,000)</td>
</tr>
<tr>
<td>6480</td>
<td>0.87</td>
<td>30,450</td>
</tr>
<tr>
<td>21,060</td>
<td>2.84</td>
<td>99,400</td>
</tr>
</tbody>
</table>

The estimates above are best case where all recovered mattresses are re-used. However, this is unlikely to be the case given that there will inevitably be left in-situ cases, mattresses found in too poor a condition for re-use etc. Table 7-6 below therefore gives the carbon savings for various percentages of mattress re-use:

Table 7-6:  Carbon savings per mattress type per re-use rate

<table>
<thead>
<tr>
<th>Re-use rate</th>
<th>Carbon savings</th>
<th>Worst case (30,450 tCO₂e)</th>
<th>Best case (113,600 tCO₂e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td></td>
<td>3045</td>
<td>11,360</td>
</tr>
<tr>
<td>25%</td>
<td></td>
<td>7613</td>
<td>28,400</td>
</tr>
<tr>
<td>50%</td>
<td></td>
<td>15,225</td>
<td>56,800</td>
</tr>
<tr>
<td>75%</td>
<td></td>
<td>22,838</td>
<td>85,200</td>
</tr>
<tr>
<td>90%</td>
<td></td>
<td>27,405</td>
<td>102,240</td>
</tr>
<tr>
<td>100%</td>
<td></td>
<td>30,450</td>
<td>113,600</td>
</tr>
</tbody>
</table>

The figures shown in Table 7-4 to Table 7-6 assume like for like re-use based on weight i.e. reusing a 21 tonne mattress displaces the use of 21 tonnes of new concrete. This may not be exactly the case but the numbers still show that significant amounts of carbon could be saved through promoting mattress re-use. To put the numbers into perspective - the best case carbon saving scenario of 113,600 tCO₂e is the equivalent to CO₂ emissions from 10,365 homes’ energy use over one year \(^{[29]}\), or the equivalent of 47,300 UK cars on the road (based on 2010 data which gave an annual emission figure per car of 2.4 tonnes).

7.9. Corporate Social Responsibility

There is also a corporate social responsibility benefit to be gained for the operator through promoting re-use. If an operator was to donate their reclaimed mattresses to a cliff-erosion project or to a project in a developing nation for use as building material then there would likely be some positive press coverage associated.

The Operator has a duty of care to ensure that mattresses are re-used, recycled or disposed of in a responsible manner. Re-use is logically the most responsible option for mattresses that have been recovered in good condition, provided an end user can be sourced.
7.10. Re-use Challenges

To make the shift from recycling to re-use there are a number of challenges which the industry should be aware of to allow them to be tackled effectively and maximise the circular economy opportunities.

7.10.1. Market Demand

For mattress re-use rates to increase there needs to be a suitable level of demand for the product. Demand is going to be market driven rather than operator driven and therefore communicating the availability of this product with the various markets that have been identified will be key. Communicating the availability of mattresses to potential end users appears to have been largely word of mouth so far. Therefore there may be a market with a large demand for these products that has not been realised yet. Use of a website or on-line auctioning sites may improve re-use rates through reaching out to the wider audience.

Operators could also improve the channels of communication through more transparent sharing of information on upcoming decommissioning projects.

7.10.2. Information

Re-use companies need to know what’s available as far as possible in advance to be able to find a suitable end user. They also need to know what the expected condition of the mattresses will be prior to receiving them so that they can determine the level of onshore processing required and whether the mattresses are likely to be in a condition that suits the needs of their clients. The workshops suggested that this information is not readily disclosed by the operator prior to the mattresses landing at the quayside. As a result the waste management contractors are only aware of the mattress condition on arrival at quayside which makes sourcing a potential buyer more difficult. Operators should work to better in form the waste management contractors of the mattress details (drawings, manufacturer data sheets, etc.) and condition reports from recent visual surveys.

7.10.3. Condition

The potential for re-use is limited greatly by the structural condition the mattress is found in after it has been recovered. Concrete is known to harden with time and the marine environment could provide enhanced curing \(^{[30]}\). Therefore the condition of the concrete should generally not be inhibitive to re-use although salt content within the concrete may limit the locations or environments that the mattresses can be re-used in.

Marine growth can also be a significant problem for re-use due to odour levels produced as a result of marine growth dry-out and decomposition. Mattresses recovered from biologically productive areas of the North Sea or at biologically productive times of the year are likely to be a concern. Disposal yards have site boundaries which they are obliged to keep from odour and there is a limited time window in which marine growth would need to be cleaned off before it begins to decompose and odour levels increase. Effective marine growth management should be employed through rapid removal of marine growth by water jetting and spraying of odour suppressants. Ideally, as much of this would be performed offshore. If marine growth odour cannot be managed effectively then this may limit the scope for mattress re-use and they may have to be recycled or put to landfill.
7.10.4. Approval to re-use

Once recovered to shore mattresses are classified as a waste product. Therefore before re-using a mattress onshore an exemption to deposit a waste product would be required from the local regulator. Onshore waste activities in Scotland are regulated by the Scottish Environmental Protection Agency (SEPA), the regulator in England is the Environment Agency. Depending on the re-use application and the location in which it is being re-used this may require tests to prove to the regulators that there is no contamination.

To re-use a mattress again offshore a marine licence would be required, in Scotland this would require an application to be sent to Marine Scotland and in England the Marine Management Organisation. In either case the regulator would need to know the details of the mattress (size and materials etc.), where it has come from and where it is going. Introduction of non-indigenous species is something that they may be concerned about.

7.10.5. Handling

Even if reclaimed mattresses appear to be in good structural condition the lifting loops no longer carry the appropriate certification. This has handling implications for all re-use applications. Methods of handling recovered mattresses must be carefully considered both to ensure a safe lift and to preserve the integrity of the mattress to allow full re-use. A suitable risk assessment should be performed prior to any lifting.

The bulk of the mattress handling should ideally be done using adequately rated lifting frames or similar (i.e. speed loaders). Individual mattress lifts should be performed using a spreader bar with 16 separate slings connected from the spreader bar to the lifting lugs on the perimeter of the mattress. Each loop should be inspected and if any signs of fraying or degradation are identified then a different one should be used. The use of a spreader beam and multiple lifting points means that the stress on any given loop if minimised. It also means that there would need to be a catastrophic failure of numerous loops at one time to result in the mattress being dropped. If the ropes on any particular mattress are deemed to be unacceptably degraded so as to cause concern over the lift then the mattress may not be classified suitable for re-use and an alternative form of disposal should be used (i.e. cut into pieces for safe handling and send for recycling as aggregate).

7.10.6. Storage

Mattress re-use has so far typically been relatively small scale with waste contractors managing to source end users prior to the mattresses arriving onshore. However, for re-use to be viable on a large scale creation of central storage locations will be required to allow reclaimed concrete mattresses to be stored and supplied to the larger markets. It may be useful to consider numerous sites around the UK that are close to popular oil & gas ports i.e. Wick, Invergordon, Peterhead, Teeside, Hull, Great Yarmouth. Storing recovered mattresses at several locations around the UK would help to reduce the onshore transport and assist in serving the local markets.

Central storage locations would enable recovered mattresses to be stored during periods where supply out-weighs demand. It would also provide end users with an opportunity to inspect what is available. The facility would need to be equipped for correct storage and to ensure that exposure to UV light was kept to a minimum. This would prevent the UV rope degrading whilst onshore.
Creating a central storage point would inevitably involve additional overhead costs which would need to be offset either by the operator, the end user or both. The cost comparison shown in section 7.7 suggests that there is still a not insignificant saving to be made between re-use and re-cycling (the next cheapest disposal option) therefore a charge could be passed on to the operator as long as it maintained the overall cost below that of recycling. The overhead costs could also be offset by charging the end user to receive the mattresses. In this case the charge would have to be enough of a discount from the cost of alternative sourcing to make it worthwhile for the end user. For example if the end user wanted to use mattresses as a sub base for roads then the cost for the mattresses and transport would have be significantly less than the cost of new material and transport to make it an attractive option.

### 7.11. Circular Economy Summary

#### 7.11.1. Key Findings

The following conclusions can be drawn from the investigation into how subsea mattresses apply to the circular economy:

- Flexible concrete mattresses with polypropylene lattices have the biggest scope for re-use in the circular economy. Link-lok mattresses may also good scope for re-use.
- There does not appear to be much scope for re-using grout bags or Armorflex, bitumen and fronded mattresses.
- There are a range of onshore and offshore applications which can make use of reclaimed mattresses either in their entirety or in their constituent parts. There may be the greatest scope for re-use in offshore construction/renewables and onshore road building.
- The scope for re-use depends heavily on the condition the mattresses are found in during decommissioning. This is a key piece of information that onshore suppliers need to know in order to allow them to source an end user.
- Effective marine growth management is required to maximise re-use.
- Re-use is the most cost effective disposal option for reclaimed mattresses. Therefore by embracing circular economy principles and maximising mattress re-use the cost of onshore disposals can be significantly reduced thus contributing to reducing the overall costs of mattress decommissioning.
- Re-use and recycling of concrete mattresses can contribute to the reduction of CO₂ emissions by avoiding the manufacture of new concrete. The re-use option offers the greatest savings.
- Greater awareness of the availability of reclaimed concrete mattresses needs to be promoted across the various markets; they may serve a purpose for a company or individual that has not yet been realised. Communication and collaboration between the oil & gas industry and other industries (on and offshore) is key to developing the market.
- Recycling of concrete mattresses can also be carried out to produce concrete aggregate for the construction industry. There is little or no scope for recycling the other styles of mattress.
- Mattresses can be moved subsea from one location to another for re-use. If redeploying mattresses which have been recovered to deck then they would need to be redeployed using appropriately rated equipment such as speed loaders or subsea baskets. They cannot be redeployed for use subsea
using the lifting lugs as these are not certified and subsequent lifts are considered as new lifting operations.

- Local markets are key to promoting the onshore re-use of reclaimed mattresses, this minimises transport and consequently the overall cost of re-use.

7.11.2. Recommendations

There are a number of opportunities that have been identified in which concrete mattresses can be re-used and contribute to the tightest loops of the circular economy. There may be other opportunities yet to be realised and these may present themselves as re-use rates increase. One suggestion in which mattress re-use rates could be increased is through setting re-use targets, similar to the approach in the automotive industry.

- Setting re-use target rates for Operators to meet as part of future decommissioning programmes would help to stimulate mattress re-use.

- The industry should work to better inform onshore waste management contractors of the dimensions and expected structural condition of mattresses being returned to shore. Sharing of key information like as-built drawings and visual survey results of the mattress inventory being decommissioned would assist the sourcing of an end user.

- Creation of central storage locations throughout the country will be required to allow reclaimed concrete mattresses to be supplied and re-used to the larger markets. It may be useful to consider sites around the UK that are close to oil & gas ports such as Wick, Invergordon, Peterhead, Teeside, Hull, Great Yarmouth and others. Storing recovered mattresses at several locations around the UK would help to reduce the onshore transport and assist in serving the local markets.

- It appears that there may be significant scope to re-use mattresses whole for laying road and highway foundations. It is recommended that discussions are entered into with civil engineering / construction companies to determine the feasibility and identify any potential issues.

- There may also be significant scope for mattresses to be re-used in the offshore renewables market. It is recommended that discussions are entered into with renewable energy operators to determine whether there may be demand for reclaimed mattresses and identify any potential issues.
8. In-conclusion

It is apparent that the costs associated with concrete mattress decommissioning are a concern, particularly from the perspective of the operators. The main reason that costs are so high is because the industry has attained relatively little experience of mattress decommissioning to date. As a result current removal methods are not fully optimised.

It has also become apparent through the course of this study that the preferred method of many for reducing the costs of mattress decommissioning would be to push the regulators (DECC) to soften their stance on the requirement that mattresses are recovered during decommissioning. However, discussions with the regulators have indicated that leaving mattresses ‘in-situ’ is never going to be an acceptable mattress decommissioning option on a wide scale. The exception to this may be with respect to Armorflex and bitumen mattresses primarily, and also to some extent frothed mattresses and grout bags. Making an application for leaving ‘in-situ’ where these styles of mattresses are installed may assist in reducing mattress removal volumes to some extent.

In consideration of the above; for cost reduction to be seen in the short term there needs to be a drive on developing mattress removal technologies which can facilitate more efficient removal times and/or can utilise less costly vessels. A number of equipment suppliers have been recommended during the course of this study who can offer such solutions. However, none are field proven and collaboration within the industry is required to help get these technologies trialled and available to market. Recovery operations will then naturally become more efficient, and thus cheaper, through repeatability gains as more campaigns are completed.

This study has also shown that there are significant savings to be made from re-using mattresses rather than sending them for recycling or to landfill. Feedback has shown that mainstream industry practice so far is to crush recovered mattresses or send them to landfill. A small number of mattresses have been re-used and have been shown to offer significant benefits for both the Operator and the end user. The task for the industry is now to increase the rates of mattress re-use to maximise these benefits.
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Appendices

A. Industry experience to date
B. Technology contacts
C. Project Contributors
D. Useful links
### A. Industry experience to date

Table A 1 to Table A 3 below details some of the recent mattress decommissioning programmes:

#### Table A 1: Industry Experience in decommissioning mattresses NNS (1 of 3)

<table>
<thead>
<tr>
<th>Location / Water depth [m] / Operator / Field</th>
<th>Mattress details</th>
<th>Programme commitment</th>
<th>Justification</th>
<th>Mattress disposal</th>
</tr>
</thead>
<tbody>
<tr>
<td>NNS/143/ BP/North West Hutton [33]</td>
<td>63 flexible concrete mattresses were placed over the SSIV umbilical. 14 flexible concrete mattresses were placed over the “disused” 10in Welgas line. 30 flexible concrete mattresses were placed over the redundant 6in flexible</td>
<td>All mattresses were recovered with speed loaders to the surface</td>
<td>The current industry guidance is for removal of mattresses from the seabed. Mattress removal was based on the results of a general pipeline decommissioning comparative assessment.</td>
<td>All mattresses were recovered to shore and re-used as foundation material in agricultural buildings in NE Scotland</td>
</tr>
<tr>
<td>NNS/100/ Total/Frigg [34]</td>
<td>161 flexible concrete mattresses within the Frigg Installation 500m zone for 2 x 26in gas pipeline, a 4in condensate export pipeline and an 8in pipeline mud kill line.</td>
<td>All mattresses to be recovered from the seabed</td>
<td>Commitment was made in the decommissioning programme for full recovery as per guidance.</td>
<td>Mattresses are to be brought onshore for disposal or potential re-use/recycling</td>
</tr>
<tr>
<td>NNS/155/ CNR/ Murchison [35]</td>
<td>1 section of 40m of stabilisation mattresses protecting the untrenched pipelines.</td>
<td>Decommissioning is expected to commence after COP, subsea works 2018-2020.</td>
<td>It is recommended that protective mattresses be removed if safe to do so</td>
<td>Mattresses are to be brought onshore for disposal or potential re-use/recycling</td>
</tr>
<tr>
<td>NNS/122/ Exxon Mobil/Linnhe [36]</td>
<td>16 mattresses in total; - 6 mattresses (2.5 m x 5.0 m x 0.15 m, 3Te each) - 10 mattresses (2.4 m x 2.4 m x 0.3 m, 3.2 Te each) 6 Te of grout bags</td>
<td>All mattresses to be recovered from the seabed Method of recovery not specified</td>
<td>Commitment made for full recovery in the decommissioning programme</td>
<td>38.06 tonnes of mattresses were re-used at the South Nesting Marine, Shetland and 31.08 tonnes were recycled by AM Smith in Aberdeen</td>
</tr>
</tbody>
</table>
Table A 2: Industry experience in decommissioning mattresses CNS (2 of 3)

<table>
<thead>
<tr>
<th>Location / Water depth [m] / Operator / Field</th>
<th>Mattress details</th>
<th>Programme commitment</th>
<th>Justification</th>
<th>Mattress disposal</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNS/140/ Hess/ Ivanhoe &amp; Rob Roy[37]</td>
<td>Recovery of around 700 flexible concrete mattresses. 120 of the older style Armorflex mattresses were found in the fields and were allowed to be rock dumped in situ.</td>
<td>Mattresses to be recovered to the surface for disposal</td>
<td>The current industry guidance is for removal of mattresses from the seabed. Special dispensation allowed HESS to leave Armorflex mattresses in place and complete rock dump.</td>
<td>All retrieved mattresses were crushed and recycled as aggregate or put to landfill.</td>
</tr>
<tr>
<td>CNS/70/ Hess/FFFA [38]</td>
<td>Recovery of around 800 mats from the Fife, Fergus, Flora and Angus fields. 76 Armorflex mattresses proved unrecoverable and agreement was reached to leave them in-situ with a covering of rock-dump with a 1:3 profile.</td>
<td>Polypropylene mattresses were recovered to the surface and delivered onshore for disposal in 2012. Armorflex mattresses were rock dumped in 2013.</td>
<td>The wire lattice work on the Armorflex mattresses broke down during the recovery lifting process exposing the divers to significant risk of injury. Operation required to recover the individual blocks of the Armorflex mattresses was deemed manually intensive. Dispensation granted by DECC with terms and conditions approval from SFF.</td>
<td>3086 tonnes of concrete recovered from FFFA was re-used, 200 tonnes was disposed of. The number of mattresses this relates to was not specified in the decommissioning close out report.</td>
</tr>
<tr>
<td>CNS/85/ Centrica/ Kittiwake [30]</td>
<td>11 flexible concrete mattresses used as protection for the SAL Export pipeline. Unspecified number of mattresses at the Kittiwake Loading Buoy.</td>
<td>Mattresses to be recovered to surface for recycling</td>
<td>The current industry guidance is for removal of mattresses from the seabed. No specific comparative assessment was performed.</td>
<td>Mattresses from the SAL export line are in relatively good condition, but as there were no ongoing projects at Kittiwake, the mattresses are recovered and offloaded at a UK port for disposal (probable crushing) by a licensed waste disposal contractor. Mattresses from the KLB are specified as having been removed.</td>
</tr>
<tr>
<td>CNC/138/ Endeavour Energy UK/Renee Rubie [40]</td>
<td>200-250 segmented concrete mattresses due to be recovered using SPS speedloaders due to be decommissioned 2015. Exact quantity will be confirmed during operations.</td>
<td>Mattresses to be recovered to the surface for re-use.</td>
<td>Best practice is retrieving all mattresses where possible.</td>
<td>Return to shore for recycling or landfill.</td>
</tr>
<tr>
<td>CNS/97/ Premier Oil/Shelley [41]</td>
<td>48 mattresses are used to provide protection at the points where an umbilical emerges from a trench. 41 mattresses were placed at the points where the pipeline emerges from the trench. 17 mattresses are placed over production well jumper lines. 12 mattresses are placed over production jumper lines.</td>
<td>Mattresses to be recovered to the surface for re-use.</td>
<td>Best practice is retrieving all mattresses where possible.</td>
<td>All mattresses were re-used as foundations for agricultural structures.</td>
</tr>
</tbody>
</table>
### Table A 3: Industry Experience in decommissioning mattresses SNS (3 of 3)

<table>
<thead>
<tr>
<th>Location / Water depth [m] / Operator / Field</th>
<th>Mattress details</th>
<th>Programme commitment</th>
<th>Justification</th>
<th>Mattress disposal</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNS/31/Shell/Indefatigable [42]</td>
<td>35 high density asphalt bitumen mattresses at 16in Lima to Juliet crossing with 24in Kilo to Perenco AT pipeline buried to a depth of 1.5m to 3.0m. A few asphalt bitumen mattresses are placed, protecting the Lima to Juliet crossing with Kilo to AT. 18 flexible concrete mattresses protect the 10in gas line from November to Kilo at the November platform.</td>
<td>Concrete mattresses laid on top of pipelines are to be recovered. 35 high density asphalt bitumen mattresses to remain in place.</td>
<td>A dedicated mattress comparative assessment was conducted once issues had been encountered. Environmental concerns ranked highest when considering decommissioning impacts with minimal impact to the environment when leaving mattresses in place. Mattresses buried from 1.5m to 3.0m below seabed are left in place to maintain stability after pipeline decommissioning.</td>
<td>All retrieved mattresses to be disposed by a third party contractor to landfill.</td>
</tr>
<tr>
<td>SNS/40/Perenco/Welland [43]</td>
<td>45 flexible concrete mattresses and 85 frond mattresses located at the 3 subsea wellheads, the jacket base and pipeline crossing points.</td>
<td>Attempt to remove concrete mattresses. Where removal proves impractical, bury in-situ. Application has been made a number of Link-lok mattresses at the wellheads to be left in-situ.</td>
<td>Mattress decommissioning assessed with a comparative assessment which on discussion with the regulator concluded that the mattresses should be buried. Potential damage to wildlife area may occur during operations. A high risk of danger to divers during lift operations justifies burial option.</td>
<td>Any recovered mattresses will be disposed of to landfill via disposal contractors.</td>
</tr>
<tr>
<td>Site Details</td>
<td>Mattress Description</td>
<td>Action</td>
<td>Decommissioning Options</td>
<td></td>
</tr>
<tr>
<td>--------------</td>
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<td>-------------------------</td>
<td></td>
</tr>
<tr>
<td>SNS/35/Bridge Energy UK Ltd./Tristan NW</td>
<td>68 flexible concrete mattresses</td>
<td>Removal all to shore for recycling / re-use as appropriate</td>
<td>Mattresses have been in place for over two years. Consequently, lifting points cannot be certified and mattresses will be recovered using converted 20 ft debris baskets. An ROV will be deployed to locate and survey the mattresses before diver operations begin. Using mattress handling frames, the divers will lift the mattresses 1.5 m above the seabed into the debris basket.</td>
<td>The mattresses will be transported back to shore for reuse onshore or disposed of to landfill.</td>
</tr>
<tr>
<td>SNS/11/ Energy Resource Technology (UK) Ltd./Camelot</td>
<td>7 flexible concrete mattresses over the ends of Camelot CA pipelines at the platform 22 flexible concrete mattresses at various locations along Camelot CB pipelines these mattresses are fitted with frond nets</td>
<td>Remove the 7 concrete mattresses over Camelot CA pipelines. Only 5 of the expected 7 mattresses were identified during the as found survey. Of these 2 mats (and a grout bag) were recovered, with 3 mats left in-situ buried to a depth of &gt;0.6 m under the rock berm. Best endeavours will be made to recover the concrete mattresses with frond nets on the Camelot CB pipelines as these appear to have become buried over time. None</td>
<td>Decommissioning options for the concrete mattresses on Camelot CA and CB pipeline was assessed through a comparative assessment. The options considered were 'leave in-situ' and 'recover'. The duty holders selected the option of complete removal of the mattresses using remote equipment e.g. subsea grapnels in the first instance. This was the recovery method employed during execution of the decommissioning operation.</td>
<td>Not specified.</td>
</tr>
</tbody>
</table>
of the 22 concrete mattresses on the CB lines could be recovered during the removal operation. A subsea grapnel was deployed and achieved a burial depth of 1 m but no mattresses were recovered. A small number of fronds were recovered.
B. Technology contacts

Anyone interested in learning more about the emerging technologies detailed in section 4.3.1 through 4.3.6 should contact the below in the first instance:

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C. Project Contributors

This project involved contribution from a wide range of industry experts. Jee Ltd., also on behalf of Decom North Sea and Zero Waste Scotland, would like to thank them for their valuable contribution.

Table C 1: Project contributors

<table>
<thead>
<tr>
<th>Company</th>
<th>Contact</th>
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</thead>
<tbody>
<tr>
<td>Augean North Sea Services</td>
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<td>Hayden Stark</td>
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<td>BP Pic</td>
<td>Doug Johnston</td>
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<td>DECC</td>
<td>Audrey Banner</td>
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<td>Decom North Sea</td>
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<td>Decom North Sea</td>
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<td>Alan White</td>
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<td>IHC Mmewede</td>
<td>Will Stephenson</td>
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<tr>
<td>Imenco</td>
<td>Andrew Boddice</td>
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<td>Imenco</td>
<td>Michael Noble</td>
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<td>David Cumming</td>
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<td>Pipesheild International Ltd</td>
<td>John Wankowski</td>
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<td>TAQA Bratani Ltd</td>
<td>Stuart Heggie</td>
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<td>The Tay and Clyde Group</td>
<td>Paul Caruana</td>
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<td>Utility ROV Services</td>
<td>Patrick Crawford</td>
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<td>Utility ROV Services</td>
<td>Tim Bryant</td>
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<td>Wood Group Kenny</td>
<td>Graham Ling</td>
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<td>Zero Waste Scotland</td>
<td>Cheryl Robb</td>
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D. Useful links

IMCA Diver and ROV Based Concrete Mattress Handling, Deployment, Installation, Repositioning and Decommissioning:

Net Environmental Benefit Analysis (NEBA):
http://www.esd.ornl.gov/programs/ecorisk/net_environmental.html

OSPAR commission – Protecting and conserving the North-East Atlantic and its resources:
http://www.ospar.org/

OSPAR commission – Assessment of impacts of offshore oil and gas activities in the North-East Atlantic:
http://qsr2010.ospar.org/media/assessments/p00453_OA3-BA5_ASSESSMENT.pdf

Oil & Gas Authority:
https://www.gov.uk/government/organisations/oil-and-gas-authority

Drill cuttings, Joint Industry Project, Final Report, 2005:
http://www.oilandgasuk.co.uk/publications/viewpub.cfm?frmPubID=374

European Marine Management Directive, Eleven Descriptors for Good Environmental Status:
http://jncc.defra.gov.uk/page-5231#GES

The Reef Ball Foundation – Designed Artificial Reefs:
http://www.reefball.org/

University of Southampton, Long term monitoring of an artificial reef in Poole Bay, U.K.:
http://eprints.soton.ac.uk/2125/

Dive Scylla, National Marine Aquarium:
http://www.divescylla.com/

Bureau of Safety and Environmental Enforcement, Rigs to Reefs:
http://www.bsee.gov/About-BSEE/Divisions/EED/EED-Rigs-to-Reefs/

Society of Underwater Technology – Aberdeen Branch evening meeting - Subsea decommissioning 10th June 2015:
http://www.sut.org/event/aem_100615/
Key Project Contacts

For more information regarding this project, concrete mattress decommissioning, or for more questions around the Circular Economy and Re-use, please contact the following:

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