Marine Estate Research Report

Carbon footprint of marine aggregate extraction

THE CROWN ESTATE

Carbon footprint of marine aggregate extraction

Simon Aumônier, Bryan Hartlin and Adam Peirce

Environmental Resources Management Limited (ERM)

ERM

For and on behalf of ERM

Approved by: Simon Aumônier

Signed

Position: Partner

Date: 27th July 2010

Environmental Resources Management Limited
Incorporated in the United Kingdom with registration number 1014622
Registered Office: 2nd Floor, Exchequer Court
33 St Mary Axe, London, EC3A 8AA

ISBN: 978-1-906410-18-6

Published by The Crown Estate on behalf of the Marine Estate.

This report is available on The Crown Estate website at
www.thecrownestate.co.uk

Dissemination Statement

Disclaimer

Suggested Citation

Aumônier, Hartlin and Peirce 2010. 'Carbon footprint of marine aggregate extraction'. Prepared Environmental Resources Management Limited (ERM)

The Crown Estate, 17 pages

ISBN: 978-1-906410-18-6

First published 2010

CONTENTS

EXECUTIVE SUMMARY

The Crown Estate owns the majority of the mineral rights to the seabed extending to the edge of the UK continental shelf and issues consents for non-exclusive sampling (1) and licences for commercial aggregate extraction (2). A combination of changing regulatory framework, environmental obligations, technology, research, regulation and the industry itself has led to dramatic changes in the marine aggregate industry over the last several decades (3).

Environmental Resources Management Limited (ERM) was commissioned by The Crown Estate to conduct this study to provide a better understanding of the current carbon footprint of the extraction of marine aggregates from the seabed areas surrounding England and Wales.

METHOD

The streamlined study was delivered using primary data collected for the dredging vessels and wharves and secondary data elsewhere. The data collected are considered to be both a robust and accurate representation of the marine dredging operations carried out on The Crown Estate property. The results can be used as baseline data to inform decision-making and as a foundation for any future and more detailed analyses that may explore process changes.

Additionally, non-greenhouse gas emissions to air associated with the combustion of fossil fuels have been calculated. These emissions include: sulphur oxides (SOx); nitrogen oxides (NOx); particulate matters (PM); and non-methane volatile organic compounds (NMVOCs).

CARBON HOTSPOTS

The total carbon footprint per tonne of aggregate landed was calculated to be 6.41 kg CO_2-eq for the short haul scenario (4), 11.73 kg CO_2-eq for the long haul scenario or an average of 10.01 kg CO_2-eq for all vessels. Over 75% of the carbon footprint is related to vessel activities, with the vast majority from transit/steaming to and from the dredge sites. As expected, the fuel used during vessel activities is also responsible for the majority of non-GHG air emissions analysed in this study. The wharves are responsible for 14% (short haul) and 19% (long haul) of the footprint whilst prospecting/monitoring and capital burdens can be considered to have minimal contributions. These results are based on typical operating conditions.

(1) Excludes oil, gas and coal
(2) http://www.thecrownestate.co.uk/marine_aggregates#licences
(3) http://www.thecrownestate.co.uk/aggregates_history
(4) Refer to *Section 2* of the report for scenario descriptions

A cradle to grave scenario was considered to determine the significance of distribution, use and disposal life cycle stages within context of this study's results. Distribution of the aggregates to market can have a significant impact on the overall carbon footprint and lower carbon transport modes such as shipping should be used where possible. Proximity to market is a key principle of the industry, with wharves strategically in place close to end users, which shortens travel distances. Efforts to promote low carbon solutions for the use and disposal stages, which are further discussed in the main report, are recommended to reduce the overall cradle to grave footprint.

GREATEST POTENTIAL FOR ENVIRONMENTAL IMPROVEMENT

Using alternative energy and reducing greenhouse gas (GHG) emissions are key challenges for the industry. Efforts to reduce the impacts of climate change should focus on increasing efficiency to reduce vessel fuel use and land-based energy use. This may include promotion of operating vessels only at full capacity and using smaller vessels for near shore dredging. Alternative energy sources, such as wind energy, should be explored for wharves where wind power is deemed feasible or where infrastructure may currently exist.

The operation and maintenance of the vessels are outside the scope of this study, but are fundamental in reducing fuel consumption and therefore lowering the overall carbon footprint. Efforts to select marine fuels with a lower carbon footprint, where available, could have significant influence on the overall carbon footprint.

One of the main benefits of using marine sources of aggregate is that ships can deliver the material directly to wharves in urban areas, which minimises road and rail transport. Emissions from a lorry are up to 25 times more than those from a large sea vessel, whilst those from rail are approximately four times more than shipping.

CRITICAL DATA POINTS

Accurate fuel use data is most critical to calculating a footprint for marine dredging operations as the majority of the footprint is from fuel used on the vessels.

Market demand has influenced the results for 2009. Wharves have decreased the throughput of marine aggregates, which may not have led to a linear decrease in electricity and fuel consumption. Vessels may also not have been filling to capacity if demand was low. Throughput for 2009 is 3.2% lower than for 2008 (based on BMAPA data) and 5.8% lower than 2006.

1 INTRODUCTION

The Crown Estate owns the majority of the mineral rights to the seabed extending to the edge of the UK continental shelf and issues consents for non-exclusive sampling (1) and licences for commercial aggregate extraction (2). A combination of changing regulatory framework, environmental obligations, technology, research, regulation and the industry itself has led to dramatic changes in the marine aggregate industry over the last several decades (3).

During this time, emissions from shipping have been placed under greater scrutiny. Various energy and operational efficiency programmes have been undertaken in an effort to reduce greenhouse gases (GHG) and other air emissions, such as (SOx), nitrogen oxides (NOx) and particulate matter (PM).

Environmental Resources Management Limited (ERM) has been commissioned by The Crown Estate to conduct this study to provide a better understanding of the current carbon footprint of the extraction of marine aggregates from the seabed areas surrounding England and Wales. Additionally, an estimate of non-GHG emissions to air associated with the combustion of fossil fuels will be calculated.

This study is structured as follows:

- *Section 2* defines the method used to conduct the carbon footprint;
- *Section 3* explains the scenarios;
- *Section 4* presents the results and analysis;
- *Section 5* summarises conclusions; and
- *Annex A* provides technical detail.

1.1 CONTEXT

Aggregate is sand, gravel and crushed rock used as raw materials by the construction industry. Today, approximately 21% of the sand and gravel used in England and Wales is supplied by the marine aggregate industry. Proximity to market is a key principle of the industry, with wharves strategically in place close to end users. In the south east of England, 33% of the primary aggregate demand for construction comes from the seabed and has been used in a number of major developments in the east London corridor. In South Wales, marine aggregate supplies approximately 90% of the market.

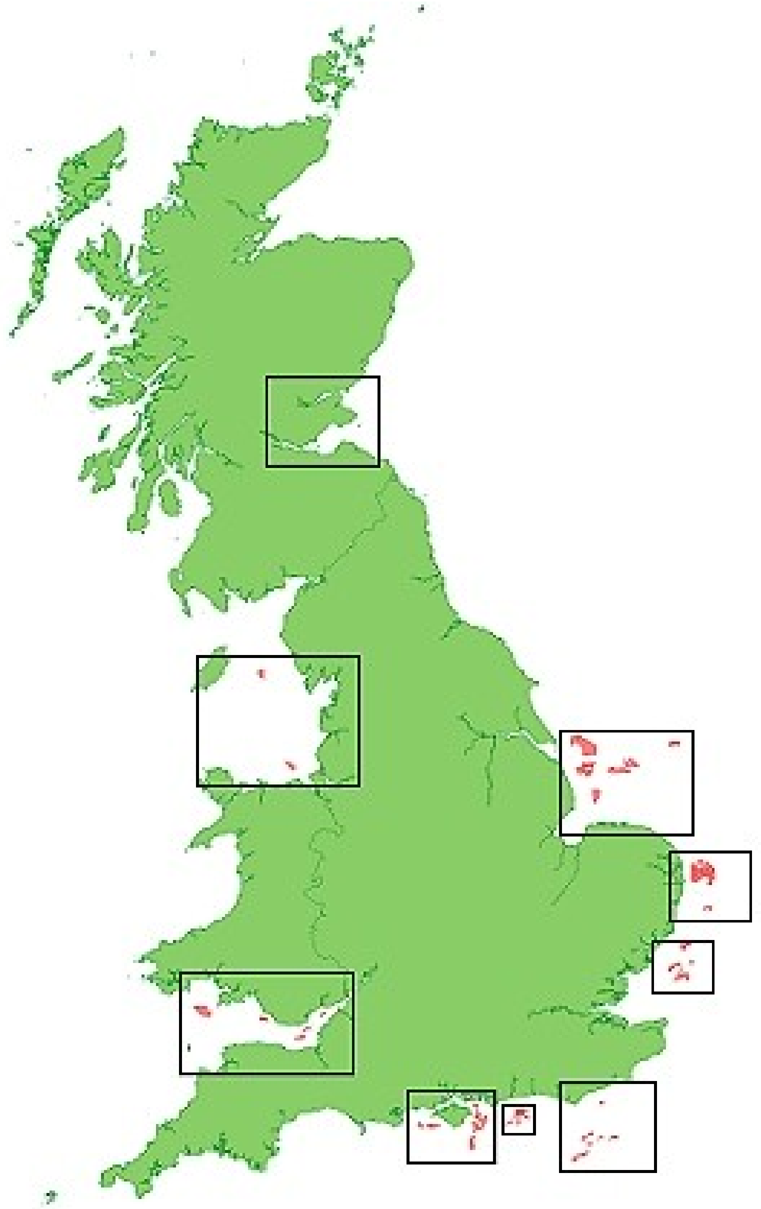
Marine aggregates are also used in beach replenishment schemes. Large volumes of aggregates are pumped directly from dredgers onto beaches,

(1) Excludes oil, gas and coal
(2) http://www.thecrownestate.co.uk/marine_aggregates#licences
(3) http://www.thecrownestate.co.uk/aggregates_history

providing coastal protection as well as enhancing the amenity value and therefore the economy of an area.

There are currently 79 production licences in nine main dredge areas (refer to *Figure 1.1*) producing approximately 21 million tonnes (Mt) of material per annum. The licences only cover about 0.12% of the UK continental shelf and, of this, only about 11% was actively dredged during 2008, equating to an area of sea bed of 138 square kilometres [1].

Figure 1.1 License areas



Source: http://www.thecrownestate.co.uk/dredge_areas_statistics

(1) http://www.thecrownestate.co.uk/marine_aggregates#licences

2 METHOD

A carbon footprint reports the GHG emissions, as carbon dioxide equivalents (kg CO_2-eq), which arise from the life cycle of a product. The goal of this study is to conduct a streamlined carbon footprint to determine the emissions associated with the winning of marine aggregates.

Additionally, non-GHG emissions to air associated with the combustion of fossil fuels have been calculated. These emissions include SOx, NOx, PM and volatile organic compounds (VOCs).

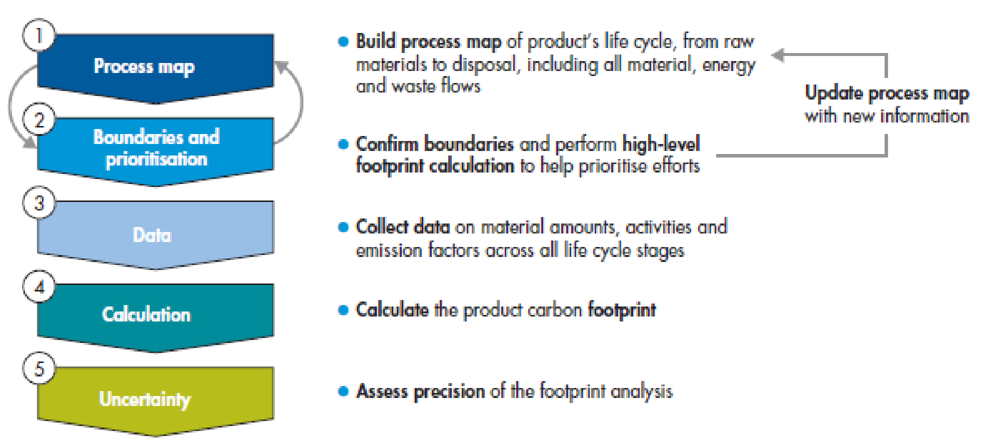
2.1 ABOUT CARBON FOOTPRINTING

Carbon footprinting is a specialised version of life cycle assessment (LCA), in which the environmental impacts of a product or service are catalogued across the life span, which can be further defined as 'cradle to gate' or 'cradle to grave'. A full LCA looks not only at climate change impacts, but also other criteria such as ozone layer depletion and resource depletion. Furthermore, a full LCA in compliance with the International Organization for Standardization (ISO) guidelines involves the collection and collation of raw data and requires careful peer review by an independent third party.

A streamlined carbon footprint is a LCA that is restricted to a single environmental impact and limits itself to using secondary data where primary data is unavailable.

The following figure outlines ERM's method for this streamlined study. It is based on the framework set out by the ISO standards for LCA and the BSI Publicly Available Specification (PAS) 2050 *Assessing the life cycle greenhouse gas emissions of goods and services*.

Figure 2.1 Steps to calculate a carbon footprint



Source: Carbon Trust PAS 2050 Guide

2.2 *DEFINING THE LIFE CYCLE*

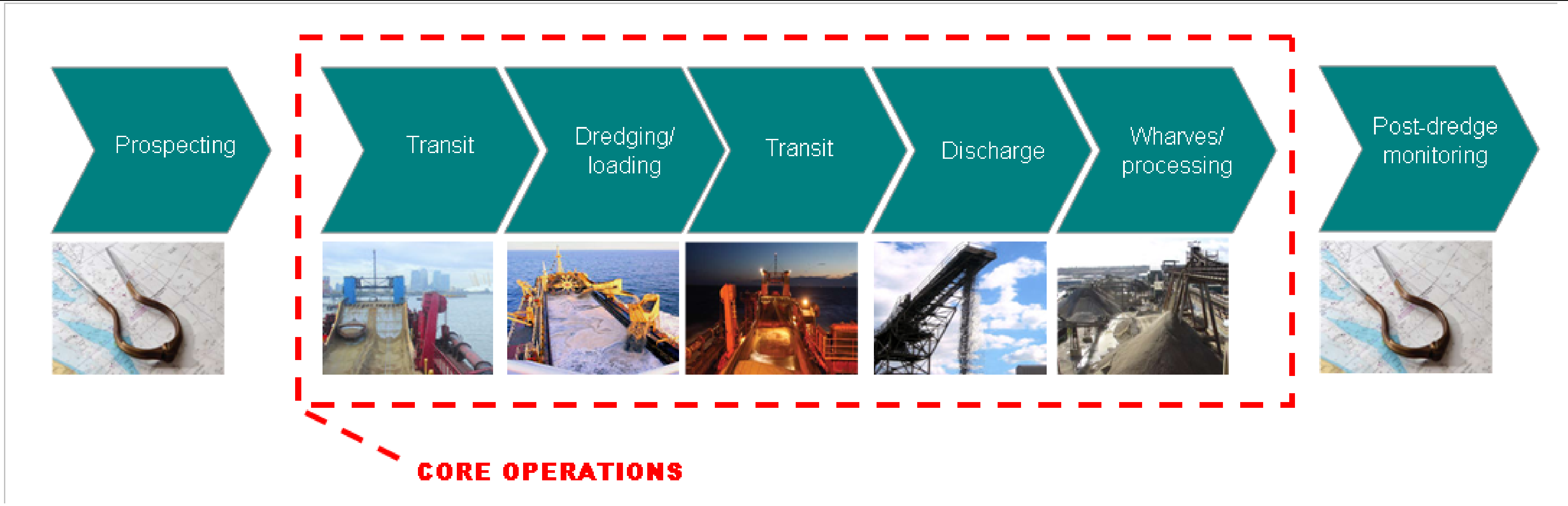
The scope of this streamlined carbon footprint is from 'cradle to gate', which includes the life cycle stages related to the vessel and wharf operations (refer to *Figure 2.2*). These stages are summarised below.

- *Prospecting*: Activities prior to winning licenses.
- *Transit*: Empty vessel sails from wharf to licence area.
- *Loading*: Sediment is dredged from the licence area and loaded into the vessel.
- *Transit*: Fully laden vessel sails from licence area to wharf. Often a different wharf from its origin.
- *Discharge*: Offloading the cargo from the vessel at the wharf.
- *Wharf operations*: Processing of the aggregate including: conveyors, feeder devices, screening, crushing and separation (where applicable).
- *Post-dredging monitoring*: Activities after dredging of the licensed area is complete.
- *Capital burdens*: Associated with the embedded carbon in the vessel itself.

Although not a principal focus of the study, the carbon footprint implications related to staff commuting, modes of product distribution to market (ie rail, road and sea), product use (ie construction and beach replenishment) and end of life (ie construction and demolition waste) are discussed. No primary data were collected for these life cycle stages.

The operation and maintenance of the vessels are outside the scope of this study, but are fundamental in reducing fuel consumption and therefore lowering the overall carbon footprint. The recent report by Marin, *Reduction of environmental impacts of dredger operations*, which was commissioned by the Marine Aggregate Levy Sustainability Fund (MALSF), was reviewed to consider the impact of operations.

Figure 2.2 *Process map and boundaries for calculating a cradle to gate carbon footprint for marine aggregates**



* *Capital burdens are not included in this diagram*

3 CARBON FOOTPRINT SCENARIOS

The carbon footprint data collected from vessel and wharf operators is presented in two scenarios: short haul and long haul. The characteristics of each scenario are summarised in *Figure 3.1*.

Figure 3.1 *Scenarios*

	SHORT HAUL	LONG HAUL
Capacity	< 3000 tonnes	> 3000 tonnes
Cycle time	12 hours	24-36 hours
Cycle distance	92 km	404 km
Cargoes/year	400+	200-230
Typical wharf	Bristol Channel	East Anglia/EEC* & London

**Eastern English Channel*

Detail on the scenarios is provided below. Data collection methods, assumptions and emission factors are summarised in *Annex A*.

3.1 PROSPECTING AND POST-DREDGE MONITORING

Due to limited available data for these activities, a fuel use per tonne dredged was estimated for each operator based on one sample data set. More detailed data collection is not deemed necessary for this step due to the low contribution to the overall footprint.

3.2 VESSELS

The dredging fleet included in the carbon footprint includes 23 ships (excluding the Sand Serin, which was sold in 2009) operated by six companies (summarised in *Table 3.1*). The fleet can be split into two main categories: larger ships with a typical displacement of 6200 tonnes used for long haul and smaller ships with a typical displacement of 1500 tonnes used for short haul work (1).

(1) Marine Aggregate Levy Sustainability Fund (MALSF) (2010) *Reduction of environmental impacts of dredger operations* MEPF Ref No: MEPF 09/P133 prepared by Thijs Hasselaar (MARIN), John Evans (Noble Denton)

Table 3.1 Vessels included in the carbon footprint

Operator	**Name of the ship**	**Built**	**Capacity (tonnes)**
Britannia Aggregates	Britannia Beaver	1991	4850
CEMEX UK Marine	Sand Falcon	1998	8500
	Sand Fulmar	1998	6800
	Sand Harrier	1990	4250
	Sand Heron	1990	4250
	Sand Serin	No data provided	
	Sand Weaver	1974	3650
	Welsh Piper	1987	1050
DEME Building Materials	Charlemagne	2002	10250
Hanson Aggregates Marines	Arco Adur	1988	5000
	Arco Arun	1987	5000
	Arco Avon	1986	5000
	Arco Axe	1989	5000
	Arco Beck	1989	4500
	Arco Dart	1990	1250
	Arco Dee	1990	1250
	Arco Dijk	1992	8800
	Arco Humber	1972	8000
Northwood (Fareham)	Donald Redford	1981	775
	Norstone	1971	1400
Tarmac Marine Dredging	City of Cardiff	1997	2300
	City of Chichester	1997	2300
	City of London	1990	4750
	City of Westminster	1990	5200

Source: British Marine Aggregate Producers' Association (2009) Third strength from the depths: Sustainable development report for the British marine aggregates industry

Cycle times can be broken into three stages: transit, loading and discharge. Transit is the most significant stage of the cycle and varies according to the geographical location of the dredging area compared with the originating and final wharf locations. The time for an average cycle was collected from operators and typically falls within two main categories: short haul (12 hour cycles) and long haul (24 to 36 hour cycles).

The time spent loading the vessel depends on capacity, the power of the dredge pump, the amount of screening taking place and the composition of the seabed sediment. Discharge time is related to the amount of material loaded.

The average cycle times, based on data collected from the ship operators, are summarised in *Table 3.2*.

Table 3.2 ***Average cycle times***

Time	Short haul (hours)	Short haul (%)	Long haul (hours)	Long haul (%)
Transit	7.9	64%	24.6	70%
Loading/dredging	2.0	16%	6.2	17%
Discharge	2.4	20%	4.5	13%
Total	12	100%	35	100%

3.3 WHARVES

There are two main types of wharves that receive marine aggregates, which differ mainly by their level of mechanisation. Material from short haul work is typically sand and therefore requires a wharf with very little processing machinery. Whereas, material from long haul work is not only greater in quantity but also often mixed materials. Wharves that receive this type of aggregate typically have a high level of mechanisation for conveyors, screening, crushing and other processing activities.

Wharves receiving aggregate from the Bristol Channel and North West are generally less mechanised than those receiving material from East Anglia, Eastern English Channel and South Coast.

3.4 CAPITAL BURDENS

Capital burdens in a carbon footprint relate to the embedded carbon in the ship itself, spread over the life time. The emissions for this stage have been calculated based on the average anticipated life span of a vessel (ie an average of 30 years for the fleet) and the dead weight tonnage of an average vessel for each scenario, which was provided by operators.

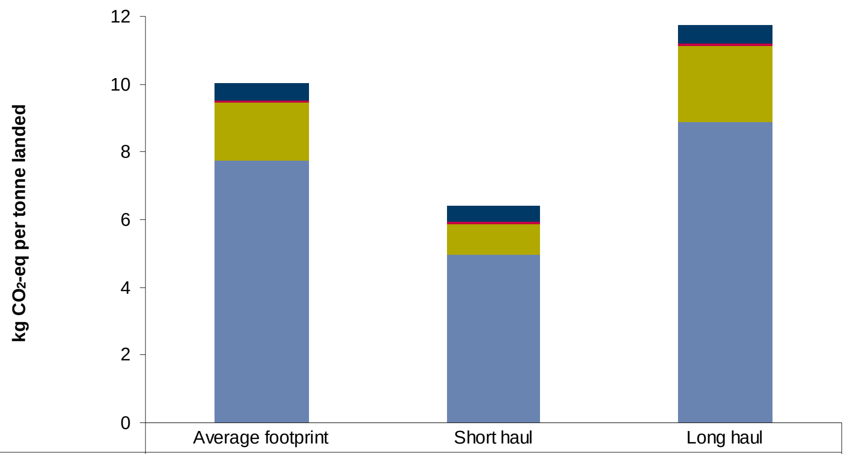
The total carbon footprint per tonne of aggregate landed was calculated to be 6.41 kg CO_2-eq for the short haul scenario, 11.73 kg CO_2-eq for the long haul scenario or an average of 10.01 kg CO_2-eq for all vessels. The majority of the footprint (more than 75% for each scenario) is from the fuel used to operate the vessels, followed by 14% (short haul) and 19% (long haul) from the electricity and diesel used at the wharves. Capital burdens related to the embedded carbon in the vessels themselves account for approximately 7% (short haul) and 4% (long haul) of the carbon footprint. Prospecting/monitoring has an insignificant impact on the footprint.

For all aggregates dredged by the entire fleet, the carbon footprint is 153,757,390 kg CO_2-eq.

These numbers were calculated by analysing operational data collected directly from vessel and wharf operators for typical operating conditions. This data is considered confidential. *Sections* 2 and *3* describe the method and scenarios and *Annex A* provides technical detail.

The cradle to gate footprint per tonne of marine aggregate dredged is presented in *Figure 4.1* and *Figure 4.2*. Further detail on each life cycle stage is provided below.

Figure 4.1 Carbon footprint summary



	Average footprint	Short haul	Long haul
Capital burdens	0.48	0.49	0.55
Prospecting/ monitoring	0.07	0.05	0.06
Wharves	1.73	0.92	2.23
Vessels	7.73	4.95	8.89

For comparison purposes, general purpose concrete has a carbon footprint of approximately 130 kg CO_2-eq per tonne (refer to *Annex A* for more detail).

Figure 4.2 Carbon footprint summary (kg CO_2-eq per tonne of aggregate landed)

		SHORT HAUL		LONG HAUL	
	Prospecting and monitoring	0.05 kg CO_2-eq	1 %	0.06 kg CO_2-eq	1 %
	**Vessels**				
	Capital burdens	0.49 kg CO_2-eq	8 %	0.55 kg CO_2-eq	5 %
	Transit	3.17 kg CO_2-eq	49 %	6.20 kg CO_2-eq	53 %
	Loading/dredging	0.81 kg CO_2-eq	13 %	1.55 kg CO_2-eq	13 %
	Discharge	0.98 kg CO_2-eq	15 %	1.14 kg CO_2-eq	10 %
	Wharves	0.92 kg CO_2-eq	14 %	2.23 kg CO_2-eq	19 %
		6.41 kg CO_2-eq	100 %	11.73 kg CO_2-eq	100 %
		Total for entire fleet:		153,757,390 kg CO_2-eq	

4.1 *PROSPECTING AND POST-DREDGE MONITORING*

The carbon footprint for prospecting and post-dredge monitoring is 0.05 and 0.06 kg CO_2-eq/tonned dredged for the short and long haul scenarios, respectively. This is equivalent to approximately 1% of the total cradle to gate carbon footprint.

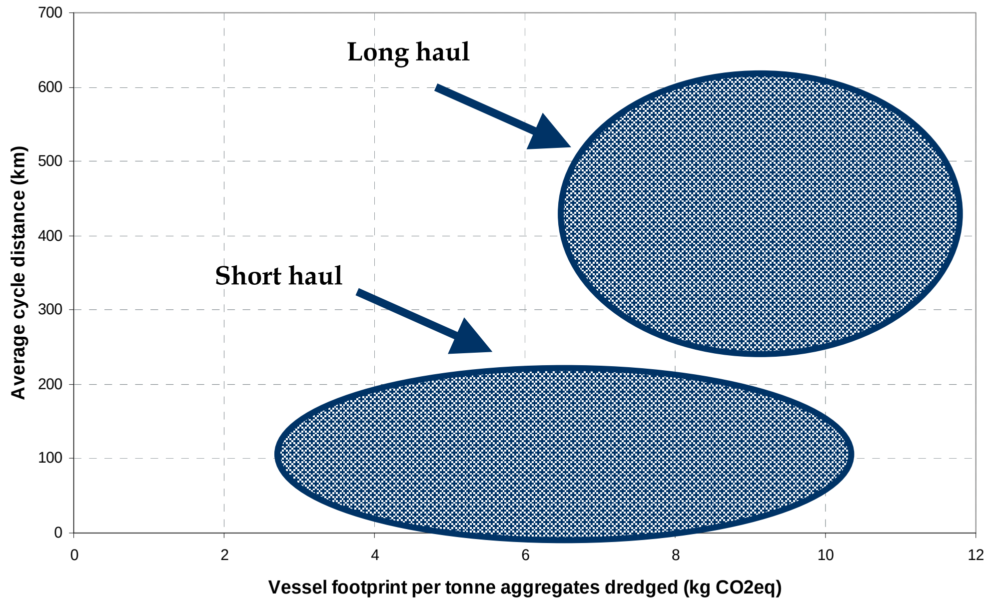
A limited data set was used to derive the footprint for this life cycle stage. Nonetheless, it provides an estimate for prospecting and monitoring activities, and provides some confidence in the prior assumption that the contribution to the overall footprint of this life cycle stage is small. ERM considers this method to be reasonable in the light of the low contribution of these activities to the overall footprint.

4.2 *VESSELS*

Long haul vessels have a greater carbon footprint than short haul although they are capable of landing a greater load (tonnes) per kilometre steamed. This is believed to be due to larger cargoes adding increased loads upon the vessels' engines, with the result that they burn more fuel per kilometre.

Of the fuel used on the vessels in both scenarios, the majority is used steaming to and from the licensed dredging areas: 49% for short haul and 53% for long haul. Approximately 13% of the footprint results from the actual loading itself, whilst 15% (short haul) and 10% (long haul) is related to the discharging of the aggregates. The footprint of the dredging phase includes a contribution from the screening of cargo.

Figure 4.3 Range of carbon footprints for each scenario



The operation and maintenance of the vessels are outside the scope of this study, but are fundamental in reducing fuel consumption and therefore lowering the overall carbon footprint. The Marin/MALSF (Hasselaar & Evans, 2010) study noted that increased awareness of fuel saving potentials and small changes in operation and maintenance strategies can result in large fuel and emissions savings. In particular, four conclusions were made.

1. Reducing speed by fractions of a knot, especially when sailing in shallow water, can results in large savings.

2. Using trim optimisation studies, the optimal trim can be found for ships sailing in ballast, so that the resistance and hence emissions can be minimised.

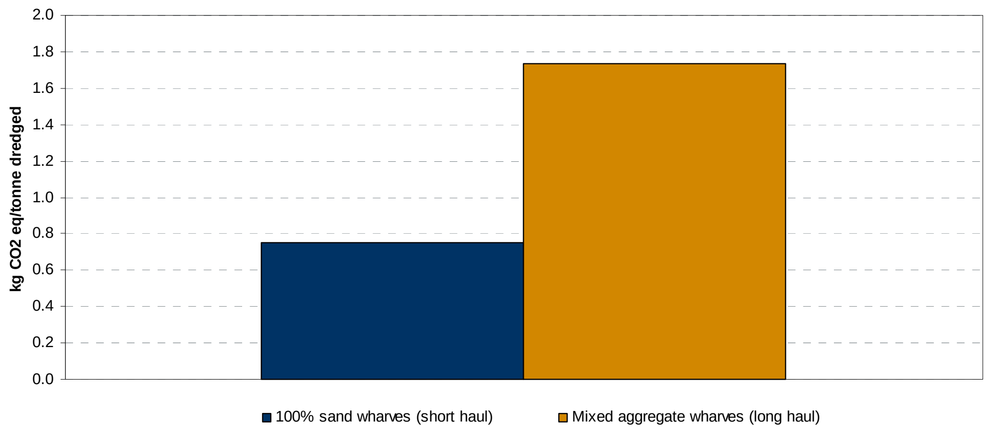
3. Improving the awareness of the effect on performance of hull roughness and fouling will therefore have a large impact in reducing fuel consumption and emissions.

4. Installing fins and nozzles at the aft end of the ship in order to improve the flow around and into the propeller can improve the performance of the ship's hull and propulsion system.

4.3 *WHARVES*

Wharves that receive mostly sand (short haul) have a footprint 59% lower than those that receive mostly mixed aggregates (long haul).

Figure 4.4 Wharf carbon footprint (%)



The majority of the emissions at short haul wharves, 86%, are from diesel emissions and the remaining are from electricity. These wharves generally have less processing machinery, as screening is done on-board the dredger and diesel is used for wheel loaders and other equipment.

For long haul wharves, 49% of the carbon emissions are from electricity, 42% from diesel and 9% associated with transporting silt material to landfill (1). These wharves have more processing equipment and include the higher throughput sites with more complicated machinery, which use electricity rather than diesel.

4.4 CAPITAL BURDENS

Capital burdens have been calculated based on the life span of the ship and the deadweight tonnage of an average vessel. The average life span of a vessel was calculated to be 30 years. Due to this relatively long lifetime, the carbon footprint of the steel used for the ship (known as its embodied carbon) is a very small part of the overall footprint – approximately 8% (short haul) and 5% (long haul).

4.5 NON GHG EMISSIONS

The linear relationship between fuel use and air emissions explains the results, which show the fuel used during vessel activities is responsible for the vast majority of additional air emissions (ie SOx, NOx, PM and VOCs) analysed in this study.

Table 4.1 Non GHG emissions summary

Life cycle stage	Short haul (g/tonne dredged)				Long haul (g/tonne dredged)			
	NOx	SO_2	PM	VOC	NOx	SO_2	PM	VOC
Vessels	166	48	9	8	166	48	9	8
Wharves	4.14	0.01	0.09	0.36	4.14	0.01	0.09	0.36
Total	170	48	9	8	170	48	9	8

All vessels use marine fuels with a sulphur content not exceeding 0.1% when berthed in EU ports, as required by European Union (EU) Directive 2005/33/EC. In addition, marine diesel with sulphur content over 1.5% and gas oil with more than 0.1% cannot be marketed in the EU.

4.6 CRADLE TO GRAVE CARBON FOOTPRINT

The commuting of crew, distribution to market, use and end of life are highly variable, depending on market conditions as well as various other factors. Each of these stages are discussed below in *Table 4.2* to estimate the scale of impact in comparison to this study's footprint. Further detail can be found in *Annex A*.

(1) The amount of silt to landfill is estimated based on data collected from a typical wharf that receives mixed aggregate material.

Table 4.2 Cradle to grave discussion

Life cycle stage	Discussion	Potential impact on carbon footprint
Commuting of crew	A scenario was created that assumed each crew member drove 150 km (round-trip) to their berthed vessel and a shift rotation pattern of three weeks on/ three weeks off. Under these assumptions, this activity would represent less than 0.1% of total carbon emissions and is considered to have an insignificant impact.	Low
Distribution to market	One of the main benefits of using marine sources of aggregate is that ships can deliver the material directly to wharves in urban areas, which minimises road and rail transport. Emissions from a lorry are up to 25 times more than those from a large sea vessel, whilst those from rail are approximately four times more than shipping.	Medium
Use	The majority of marine aggregates dredged from The Crown Estate's waters are used in construction with a small amount being used for beach replenishment. Within construction, most material is used as a vital ingredient in concrete production. No data were available that specifically analysed the use of concrete due its versatility and range of applications. Even though sand and aggregates always have the greatest mass input to concrete, cement is the greatest source of carbon emissions, contributing over 90% of total emissions. The carbon footprint of general purpose concrete has a carbon footprint of approximately 130 kg CO_2-eq per tonne (refer to *Annex A* for more detail). Beach replenishment has a very small footprint per tonne compared to concrete production.	Medium Low
End of life	This disposal of concrete in an inert landfill can have a significant impact; however as mentioned in the use stage above, only a portion of this is attributed to the aggregate in concrete. This portion is more significant as it is related to the mass used within concrete, which is much larger than the weight of cement. The Environment Agency Carbon Calculator emission factor related with recycled aggregates is 3.69 kg CO_2-eq per tonne [1]. This is approximately 39% of the final footprint of marine aggregates. It is believed to be mainly due to the fuel used in demolition, transport and crushing of the rubble. BMAPA estimated that in 2008 approximately 26% of the total aggregate market was from recycled and secondary aggregates.	Medium-High

(1) http://www.environment-agency.gov.uk/static/documents/Business/Carbon_calculator_v3_1_1.xls

5 CONCLUSIONS AND RECOMMENDATIONS

Carbon hotspots

Over 75% of the carbon footprint is related to vessel activities, with the vast majority from transit/steaming to and from the dredge sites. As expected, the fuel used during vessel activities is also responsible for the majority of non-GHG air emissions analysed in this study. These results are based on typical operating conditions.

A cradle to grave scenario was considered to determine the significance of distribution, use and disposal life cycle stages within context of the study's results. Distribution of the aggregates to market can have a significant impact on the overall carbon footprint and lower carbon transport modes such as shipping should be used when possible. Proximity to market is a key principle of the industry, with wharves strategically in place close to end users, which shortens travel distances. With regards to the use stage, the production of concrete has a high carbon footprint, but the proportion of concrete's footprint that is from the aggregates is low. Disposal at end of life can also potentially have a significant impact due to the energy required in demolition and transport of the rubble. Efforts to select marine fuels with a lower carbon footprint, where available, could have significant influence on the overall carbon footprint.

Greatest potential for environmental improvement

Using alternative energy and reducing GHG emissions are key challenges for the industry. Efforts to reduce the impacts of climate change should focus on increasing efficiency to reduce vessel fuel use and land-based energy use. This may include promotion of operating vessels only at full capacity and using smaller vessels for near shore dredging. Alternative energy sources, such as wind energy, should be explored for wharves where wind power is deemed feasible or where infrastructure may currently exist.

The operation and maintenance of the vessels are outside the scope of this study, but are fundamental in reducing fuel consumption and therefore lowering the overall carbon footprint. Efforts to select marine fuels with a lower carbon footprint could have significant influence on the overall carbon footprint.

One of the main benefits of using marine sources of aggregate is that ships can deliver the material directly to wharves in urban areas, which minimises road and rail transport. Emissions from a lorry are up to 25 times more than those from a large sea vessel, whilst those from rail are approximately four times more than shipping.

Critical data points

Accurate fuel use data is most critical to calculating a footprint for marine dredging operations as the majority of the footprint is from fuel used on the vessels.

Market demand has influenced the results for 2009. Wharves have decreased the throughput of marine aggregates, which may not have led to a linear decrease in electricity and fuel consumption. Vessels may also not have been filling to capacity if demand was low. Throughput for 2009 is 3.2% lower than for 2008 (based on BMAPA data) and 5.8% lower than 2006.

6 REFERENCES

Boston Consulting Group (BCG) (April 2009) *Aggregates Sector Strategy Review Consolidated Steering Committee Presentations* Accessed on 27/05/10 from: http://www.carbontrust.co.uk/Publications/pages/publicationdetail.aspx?id=CTC755&respos=0&q=ctc755&o=Rank&od=asc&pn=0&ps=10

British Marine Aggregate Producers' Association (2007, 2008 and 2009) *Strength from the depths: Sustainable development report for the British marine aggregates industry (first, second and third editions)*

British Standards Institute (2008) *PAS 2050:2008, Specification for the assessment of the life cycle greenhouse gas emissions of goods and services* ISBN: 978-0-580-50978-0

Cefas, Lowestoft, 50pp. ISBN: 978-0-907545-44-6

The Crown Estate and the British Marine Aggregate Producers' Association *Marine aggregate dredging 1998-2007: a ten year review*

Defra/ DECC (September 2009) *GHG conversion factors* Accessed on 27/05/10 from: http://www.defra.gov.uk/environment/business/reporting/conversion-factors.htm

Ecoinvent (2008) *Life Cycle Database 2.0*

Highley, D E, Hetherington, L E, Brown, T J, Harrison, D J & Jenkins, G O (2007) *The strategic importance of the marine aggregates industry to the UK* British Geological Survey Research Report

Kemp, R (2008) *Energy consumption of marine aggregate extraction* The Crown Estate, 21 pages, February 2008. ISBN: 978-0-9553427-9-0

Marine Aggregate Levy Sustainability Fund (MALSF) (2010) *Reduction of environmental impacts of dredger operations* MEPF Ref No: MEPF 09/P133 Prepared by Thijs Hasselaar (MARIN), John Evans (Noble Denton)

Marine Aggregate Levy Sustainability Fund (MALSF) (2010) *Mitigation of Marine Aggregate Dredging Impacts – Benchmarking Equipment, Practices and Technologies against Global Best Practice* MEPF Ref No: MEPF 08/P33 Prepared by Emu Limited and Delft University of Technology

Pinnegar, J K, Viner, D, Hadley, D, Dye, S, Harris M, Berkout, F & Simpson, M (2006) *Alternative future scenarios for marine ecosystems: technical report* Cefas, Lowestoft, 109pp

Annex A

Technical Detail

CONTENTS

A1 DATA COLLECTION

This streamlined carbon footprint uses a combination of: primary data collected for the licensed operators/aggregate suppliers; and secondary or generic data from industry and government sources. Data were collected through a series of site visits, bespoke questionnaires and industry reports and represents best estimates for the 2009 calendar year.

The primary data were obtained from the operators of the dredging ships for:

- fuel consumption;
- distances travelled;
- percentage energy and/or time used for each process;
- quantity of the aggregates won; and
- gross tonnage and capacity of the ships.

Wherever possible, data for a complete year of operations has been used.

Secondary data has been used for energy production, transport processes and production of the materials associated with the construction of new dredging vessels. Data were also obtained from two existing reports:

- The sustainable development reports of the British Marine Aggregate Producers' Association (BMAPA); and
- The Marine Estate Research Report, Energy consumption of marine aggregate extraction, undertaken by Professor Roger Kemp of Lancaster University. February 2008. ISBN: 978-0-9553427-9-0.

These studies have also been used to verify the data obtained from the operators.

The total fuel consumed in 2009 to dredge 19,123,584 tonnes of aggregate was 42,994 tonnes (equivalent to 50.9 million litres). This includes 5,737,749 tonnes that were dredged on The Crown Estate property and exported outside of England or Wales and 1,155,340 tonnes that were dredged outside of The Crown Estate waters. The tonnes dredged on The Crown Estate property, but exported, has been included in the vessel footprint, but excluded from the wharves footprint. The tonnes dredged outside The Crown Estate property has been excluded from the total carbon footprint.

A2 DATA ASSUMPTIONS

Assumptions related to the data used in this study are listed below.

- The prospecting and post-dredging monitoring vessels were assumed to use marine gas oil (MGO) fuel.
- All MGO figures (in litres) were converted using an average density derived from: http://shellservice.dk/productdocs/docs/341250_english.pdf
- Road diesel figures in litres were converted using an average density derived from: http://www-static.shell.com/static/aus/downloads/fuels/msds/shell_diesoline_50_msds.pdf
- The weight of the vessel associated with the capital burdens portion of the footprint uses the gross tonnage figures provided by the dredging operators.
- The steel emission factor was assumed to have low-alloy content.
- The gross tonnage was referenced for the vessel Charlemagne, as it was believed the deadweight tonnage was given by the operator: http://www.maritimephoto.com/collection/vessel/9519
- Transport to landfill was assumed to travel 100 km in a >17 tonne rigid lorry.
- The Department of Energy and Climate Change (DECC) GHG emission factor for electricity was scaled up by 20% (estimated by ERM) to account for the upstream emissions associated with the extraction of fuels from their sources.
- If possible, the split of fuel use between the different life cycle stages was based on the percentage fuel split between the stages. If this was not available, the percentage of time spent in the cargo cycle was used.
- One dredging operator had apportioned a percentage for waiting for tidal discharge. This was added to the steaming to/from license areas life cycle stage.
- One wharf stated that its electricity was sourced from wind power. It was assumed that this was the sole source and was assigned an alternative emission factor from: www.parliament.uk/documents/post/postpn268.pdf
- Some vessels also dredge aggregates in foreign waters and discharge the material at wharves in other countries. Where provided by the vessel operator, this material was not included in the carbon footprint or in the calculations of the non-GHG emissions to air.
- For aggregates dredged on The Crown Estate property, but discharged to a wharf in another country, the carbon footprint includes the vessels' operations, but excludes the wharf/processing operations.

A3 EMISSION FACTORS

The following emission factors can be used to facilitate carbon footprint calculations for future licenses and potentially used in policy, forecasting, or bid evaluation. It should be noted that the references for these emissions factors should be checked before they are used in the future to ensure they are the most appropriate.

Table 3.1 Carbon emission factors

Activity	Amount	Unit	Source
Fuel use: marine diesel oil (MDO)	3,223	kg CO_2/ tonne	www.naei.org.uk
Fuel use: MGO	3,190	kg CO_2/ tonne	www.naei.org.uk
Fuel use: Diesel	3,164	kg CO_2/ tonne	www.naei.org.uk
UK grid electricity	0.649	kg CO_2/ kWh	Defra GHG conversion factor + 20% ERM estimate for upstream emissions
Steel (for capital burdens)	1.77	kg CO_2/ kg steel	ICE v1.6 www.bath.ac.uk/mech-eng/sert/embodied/

Non-GHG air emissions

Air emissions were calculated by taking the product of the total fuel consumed and the emission factors noted below in *Table 1.2*.

Table 3.2 Additional air emission factors

Fuel	NOx (kg/tonne)	SO_2 (kg/tonne)	PM_{10} (kg/tonne)	VOC (kg/tonne)
Fuel use: MDO	72	53	7.8	3.5
Fuel use: MGO	72	20	3.7	3.5
Fuel use: Diesel	23	0.031	0.513	2

Source: National Atmospheric Emissions Inventory (NAEI)

A4 LIMITATIONS

The limits to the analysis relate to the large number of variables that can affect the fuel consumption and cargo that the vessels dredge. These include:

- capacity, age and size of vessel;
- weather conditions when steaming/ dredging; and
- market demand.

Limited wharf data has been provided, but the data set has been extrapolated to account for all material dredged from The Crown Estate seabed that is not exported. The data collected from wharf operators (5,843,445 tonnes) does not represent all aggregate wharves in England and Wales that processed marine aggregates. An estimated total of 13,385,835 tonnes of marine aggregates were believed to be processed, which would include independent wharves and aggregates companies that did not operate dredging vessels. This number excludes aggregates that are exported. The total footprint calculation is based on extrapolated numbers for the total estimate rather than only the data collected. The estimated wharf data also includes an estimate for the amount of waste silt that is transported to landfill – this number is uncertain and should be considered only an estimate.

Market demand has influenced the results for 2009. Wharves have decreased the throughput of marine aggregates, which may not have led to a linear decrease in electricity and fuel consumption. Vessels may also not have been filling to capacity if demand was low. Throughput for 2009 is 3.2% lower than for 2008 (based on BMAP data) and 5.8% lower than 2006.

No correlation/ relationship could be found between the age of the vessel and the fuel consumption per tonne of aggregate landed. This might be due to vessels being retro-fitted with new engines and equipment. A detailed analysis of the vessel engine efficiency was outside the scope of this study.

A5 CRADLE TO GRAVE CARBON FOOTPRINT

This study considered the carbon emissions that occur up to when the aggregates leave the wharves. The commuting of crew, distribution to market, use and end of life are highly variable, depending on market conditions as well as various other factors. Each of these stages are discussed below in order to estimate the scale of impact in comparison to the cradle to gate footprint.

A5.1 CREW COMMUTING TO VESSELS

A scenario was created that assumed each crew member drove 150 km (round-trip) to their berthed vessel and a shift rotation pattern of three weeks on/ three weeks off. This meant there would be 17 trips in a year with a week spare. Using a DECC, 2009 emission factor for an average car (0.20487 kg CO_2-eq per km) the total emissions for 267 crew were calculated to be 139,486 kg CO_2-eq. This represents less than 0.1% of total CO_2 emissions and can be deemed to have an insignificant impact.

A5.2 DISTRIBUTION

One of the main benefits of using marine sources is that ships can deliver aggregates directly to wharves in urban areas, which eliminates road and rail transport. These transport modes have a higher carbon footprint per tonne km travelled. The emission factors in *Table 5.1* indicate the scale of difference between each mode of transport. Assuming a 50km trip with an even split across transport modes, distribution may add up to approximately one third to the cradle-to-grave carbon footprint.

Table 5.1 Onward transport to user of marine aggregates source: DECC, 2009

Transport Mode	kg CO_2-eq per tonne per km travelled
Road (>17 tonne rigid)	0.17797
Rail (diesel)	0.0285
Sea (large bulk, 14201 tonnes dwt)	0.007

Promotion of transport by sea (ie barge) in large quantities, followed by rail as a secondary mode of transport, can help to reduce the carbon impact of this life cycle stage. It is acknowledged in some circumstances using these transport modes would not be possible due to lack infrastructure at wharf or destination.

A5.3 *USE OF MARINE AGGREGATES*

The majority of marine aggregates dredged from The Crown Estate's waters are used in construction with a small amount being used for beach replenishment. Within construction, most material is used as a vital ingredient in concrete production.

The quantity of aggregates used in concrete varies significantly with the desired properties that are required. General purpose concrete has a cement:sand:aggregates ratio of 1:2:4 and emissions of 130 kg CO_2-eq per tonne. High strength concrete commonly has the ratio 1:1:2, which is reflected by emissions of 209 kg CO_2-eq per tonne. Even though sand and aggregates always have the greatest mass input to concrete, cement is the greatest source of carbon emissions, contributing over 90% of total emissions. This is due to the energy-intensive nature of the production process for cement, with considerable direct emissions. Emissions are approximately 830 kg CO_2-eq per tonne. This is supported by Nielsen's (2008) study of the carbon footprint of concrete buildings. He states that aggregates traditionally only account for a small proportion of CO_2-eq emissions even though it contributes about two thirds of concrete volume. From previous Japanese experiences, he states that crushing and sorting of demolition waste has similar CO_2-eq emissions equivalent to the excavation of the aggregates.

Beach replenishment, which is an alternative use for marine aggregates, has a very small footprint per tonne compared to concrete production. This use involves pumping aggregates to shore and moving the material onshore. This is estimated to have a similar impact to the dredging, between 0.81-1.55 kg CO_2-eq per tonne of aggregates, if using the vessel's pumps in addition to emissions associated with the onshore plant. This use footprint is significantly lower per tonne than its use within concrete.

A5.4 *END OF LIFE*

ERM's database emission factor (confidential) for concrete waste to landfill approximates the disposal footprint for the marine aggregates to be roughly 26% of the total footprint. However, it accounts for concrete as a whole rather than the aggregate component, which varies considerably with concrete type.

Approximately 26% of aggregates in the UK come from recycled or secondary sources, which would include concrete that has used marine aggregates (1). The Environment Agency Carbon Calculator emission factor related with recycled aggregates is 3.69 kg CO_2-eq per tonne (2). This is approximately 39% of the final footprint of marine aggregates.

(1) http://www.wrap.org.uk/downloads/WRAP_Aggregates_Programme_2_.587615a8.4078.pdf
(2) http://www.environment-agency.gov.uk/static/documents/Business/Carbon_calculator_v3_1_1.xls

The calculated footprint is higher than the BMAPA 2008 sustainability report figure of 6.818 kg CO_2-eq, even though the two studies have comparable fuel usage and tonnes of aggregate dredged. There are several factors that have contributed to the difference in the footprint. The scope of ERM's study is broader, and includes prospecting/monitoring, wharves and capital burdens. This results in a larger footprint by approximately 10% compared to the BMAPA study. This difference can be explained by the different emission factors that were used for MGO.

The calculated footprint is lower than the BCG (2009) figure, which was between 10 and 11 kg CO_2-eq per tonne. Their figure is calculated from a combination of three reports. They also calculate the total CO_2 emissions from marine aggregate dredging at 150 kT of CO_2-eq, which is within 5 kT CO_2-eq of the study's figure.

The calculated energy consumption of dredging activities by Kemp (2008) was between 25 and 35 kWh per tonne of aggregates, which included electricity use at the wharves. Converting this study's energy consumption figures produces a value of 27 kWh per tonne of aggregates. The vessels contribute 24 kWh per tonne, while wharves contribute 3 kWh per tonne. Kemp also calculated that between 1.5 kg and 3 kg of fuel was consumed per tonne of aggregates landed. This study had an average fuel consumption of 2.4 kg of fuel consumed per tonne of aggregates landed. These figures are consistent with the previous study's range even though all UK dredging vessels were sampled rather than four as seen in Kemp's.

THE CROWN ESTATE

The Crown Estate
16 New Burlington Place
London W1S 2HX
Tel: 020 7851 5080

www.thecrownestate.co.uk

ISBN: 978-1-906410-18-6