High-Level Science Review for
'A Plastic Oceans' Film

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1 Foreword

The Plastic Oceans Foundation is committed to reducing and ultimately eradicating the pernicious impact that plastic pollution is having on the environment and human health. We strive to promote, support, encourage and educate, at all levels of societies.

We believe that plastic waste is primarily the result of poor waste management processes, a lack of understanding and knowledge, business and society neglect, all of which can be addressed through changes in behavior. With the support of individuals, groups, business, industry, and governments, we can change this in a generation by stopping this pollution, and valuing plastics much more as a valuable substance, not one that is treated 'disposably'. We simply have to act now because the problem is growing inexorably.

It has always been vitally important to the Plastic Oceans team that any science quoted in the film is backed by solid evidence; our reputation in the media and with the scientific community depends on this. It was evident from the beginning, however, that there are huge knowledge gaps that raise many questions and it is equally important that the film raises these points so that much needed research will result.

The stories will unfold through the eyes of the two people taking the journey to discover the extent of the problem. Neither one is an expert but this will make the task of highlighting questions much easier since they can freely question and speculate upon their observations.

Given the fact that policy-makers tend to act upon proven fact rather that exercising the precautionary principle, it is our intention that the footage will raise global concern and pose enough unanswered questions to encourage funding to be directed towards science, education and solutions. These programmes are now in development by the Foundation, working closely with Brunel University, where we plan to establish the world's first interdisciplinary 'science hub' looking at all aspects of the plastics in the environment issue.

There is a substantial amount of data and research available in the public domain regarding the issues of plastic pollution. Our review has assessed literature on presence of plastic/ microplastic in beach litter, rivers, lakes and oceans/gyres – surface, column and benthos; plastic properties and composition/sorption of other chemicals and metals; properties and effects of chemicals associated with plastics – body burdens and toxicology; waste management and treatment and solutions. The science statements are taken from peer-reviewed papers from high quality academic journals (wherever possible). Our focus has been on papers that have been highly cited, as well as the most recent papers to May 2015. References cited in italics are drawn from an earlier review – these will be added in the next iteration.

Our review is a snapshot in May 2015, and builds on the reviews we have produced over the last four years. It is constantly being updated we engage continuously with scientists and receive new literature. We have gathered many hundreds of papers that we will be using in our full peer-reviewed integrated science review and risk assessment. This will be produced before the movie release, working with Brunel University and our planned 'science and research hub' in the institute for Environment, Health and Societies.

Overall, the review identifies the key supporting statements to the messages being prepared for the movie.

2 Background - the Age of Plastic

The invention of plastic has brought about a new era in the history of mankind. It is quite possible, that in several hundred years time, people will look back on the 20th century as the 'plastic period' (Attenborough, 2010) in the same way that archeologists and anthropologists regard the iron and bronze ages, or the age of steam. Since its introduction, plastic has become an integral part of our lives - quite simply we cannot live without it. The reason for its growth lie within its qualities:

- Low cost, high volume production methods
- Chemical and light resistance
- Practical design and performance specifications
- The ability to take on shape and colour
- Functionality and convenience for the consumer
- Lightweight and durable
- Strength and toughness, ductility, corrosion resistance

As a result its proliferation has been exponential, its pervasiveness global. Plastic pollution now reaches virtually every part of the planet. One of the most observable changes on the planet in the last 50 years has been 'the ubiquity and abundance of plastic debris'[1]. It is likely that in the first ten years of this century we have used more plastic than we did during the whole of the last.

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2. Thompson, Richard C.; Moore, Charles J.; vom Saal, Frederick S.; et al. (2009) Plastics, the environment and human health: current consensus and future trends. Philosophical Transactions of the Royal Society B- Biological Sciences **364** 2153-66

3 Main Premises for the Plastic Oceans Film

3.1 Plastic material is entering our oceans.

- There is more plastic at the centres of our oceans than plankton; plastic is being eaten by marine life
- 'Plastic is one of the best materials ever invented but it doesn't belong in the ocean'[1]
- Plastic material causes physical harm to animals; plastic is ingested directly, and indirectly if eaten through the food chain

3.2 Chemicals associated with plastics cause harm to wildlife and people

- Plastics contain/are formulated with chemicals that are known to be toxic, and cause a broad range of effects including critical diseases and health conditions
- Plastic also attracts chemicals the moment it enters the ocean[2]
- As well causing physical harm to marine life, the chemicals present in plastic as well as what it adsorbs, accumulate in their body tissue, particularly fat and muscle tissue, can accumulate into the marine food chain
- These toxic substances are associated with a range of health and disease outcomes in the human population, through a variety of mechanisms including endocrine disruption, can accumulate into the human food chain through consumption of fish and cause health effects in the human population.
- Plastics should be considered to be toxic when released to the environment[3]

3.3 Plastic is a valuable resource – more needs to be done to collect, reuse and recycle

- Plastic production is increasing inexorably, particularly in the developing world; it is an indicator of development;
- Waste management practices are not keeping pace with this rate of production and consumption;
- More is needed to be done by regulators, the plastics producing, using and ultimately, waste, industries to reduce consumption, and collect, reuse and recycle plastics.

3.4 Plastics - Persistent, Pervasive and Pernicious

- To date, the material in the open ocean cannot be collected – and because of plastic durability, it will persist in the oceans for many years;
- There is an urgent need to prevent plastic material entering the marine environment to prevent physical and toxic harm to wildlife and people. Now.

3.5 We can solve this

- Who is responsible for this – governments, industry – manufacturing, consumer product and waste management- and society
- Plastics can be reused and recycled for a wide range of beneficial uses – different products, energy, fuel….
- Consumers can play a vital part in valuing plastics more, not seeing this material as disposable but one that can be re-used many times, and dispose of plastic responsibly.

1. van Sebile, E. (2015) the ocean's accumulating plastic garbage. Physics Today **68** 60-1
2. Rochman, Chelsea M.; Kurobe, Tomofumi; Flores, Ida; Teh, Swee J (2014). Early warning signs of endocrine disruption in adult fish from the ingestion of polyethylene with and without sorbed chemical pollutants from the marine environment. Science of the Total Environment **493** 656-61
3. Rochman, Chelsea M.; Browne, Mark Anthony; Halpern, Benjamin S.; et al. (2013) Classify plastic waste as hazardous Nature **494** 169-71

4 Science Evidence

4.1 Plastic material is entering our oceans

- There is more plastic in the open ocean than plankton; plastic is being eaten by marine life [1, 2]
- There are no 'islands of trash',[3] this is a misrepresentation by the media but the truth is more insidious
- Plastic material causes physical harm to animals; plastic is ingested directly, and indirectly if eaten through the food chain [4-8] and many more)

4.1.1 Global Oceans:

- The oceans provide more than half the oxygen we breathe and absorb much of the CO_2 we produce [9]
- 60% of the global population sources its protein from the sea (UN, Oceans: The Source of Life)
- More than half of the world's population lives close to the sea (UN, Oceans: The Source of Life)

4.1.2 Plastic material: [10-15]

- The material size ranges from large (many metres length such as fishing nets), to micro plastics in cosmetic products. The source of plastics is a combination of:
- Poor waste management practices for plastic, particularly in the developing world
- Marine litter, from beaches and coasts, and rivers
- Lost nylon nets and other debris from fishing
- Plastic material in products discharges down the wastewater system, such as microbeads in facial scrub cosmetics
- Plastic is responsible for 80% of all waste that accumulates in the oceans
- An estimated 8 million tonnes of plastic enters the ocean every year [16]
- An estimated 5 trillion pieces of plastic are afloat on the ocean [17]
- Plastic waste is now in every area of the oceans from the surface to the deep and the most remote parts
- Rivers provide an easy pathway to transport plastic waste from the land to our oceans. In the Danube, Europe's second largest river, plastic litter outnumbers fish larvae [18]
- Plastic pollution is just as prevalent in freshwater lakes with toxins threatening the health of the animals that live there [19-21]
- A tiny population can still heavily pollute their local environment with plastic no matter how remote [20] – this paper has relevance to Tuvalu, where no such studies have been done

4.1.3 Uptake of plastics and associated chemicals into wildlife

Marine Debris Overview [7]

Marine debris is listed among the major perceived threats to biodiversity, and is cause for particular concern due to its abundance, durability and persistence in the marine environment. An extensive literature search reviewed the current state of knowledge on the effects of marine debris on marine organisms. 340 original publications reported encounters between organisms and marine debris and 693 species. Plastic debris accounted for 92% of encounters between debris and individuals. Numerous direct and indirect consequences were recorded, with the potential for sublethal effects of ingestion an area of considerable uncertainty and concern. Comparison to the IUCN Red List highlighted that at least 17% of species affected by entanglement and ingestion were listed as threatened or near threatened. Hence where marine debris combines with other anthropogenic stressors it may affect populations, trophic interactions and assemblage

Microplastics Overview[23]
Research examining the occurrence of microplastics in the marine environment has substantially increased. Field and laboratory work regularly provide new evidence on the fate of microplastic debris. This debris has been observed within every marine habitat. In this study, at least 101 peer-reviewed papers investigating microplastic pollution were critically analysed. Microplastics are commonly studied in relation to (1) plankton samples, (2) sandy and muddy sediments, (3) vertebrate and invertebrate ingestion, and (4) chemical pollutant interactions. All of the marine organism groups are at an eminent risk of interacting with microplastics according to the available literature. Dozens of works on other relevant issues (i.e., polymer decay at sea, new sampling and laboratory methods, emerging sources, externalities) were also analysed and discussed. This paper provides the first in-depth exploration of the effects of microplastics on the marine environment and biota. The number of scientific publications will increase in response to present and projected plastic uses and discard patterns. Therefore, new themes and important approaches for future work are proposed

Microplastics[23]
Three-quarters of the (scrub) brands had a modal size of <100 microns and could be immediately ingested by planktonic organisms at the base of the food chain. Over time the microplastics will be subject to UV-degradation and absorb hydrophobic materials such as PCBs, making them smaller and more toxic in the long-term. We believe that microplastics in facial cleansers are largely unnecessary, and may result in long-term impacts to the marine environment

Invertebrates - Mysid shrimps were exposed to the microspheres not only directly, but also indirectly, which implies that there are several alternate routes for microplastic transfer in the pelagic food webs. Both mysids and polychaete worm larvae live partially in the pelagial and partly in benthic realm having potential to transfer microplastics between the food webs of these environments. Based on our studies we conclude that high-concentrations of microplastic litter has the potential to enter marine food webs[24].

Invertebrates – sea urchin: virgin pellets had toxic effects, increasing anomalous embryonic development by 58.1% and 66.5%, respectively. Plastic pellets act as a vector of pollutants, especially for plastic additives found on virgin particles [25].

Quantity of plastics
Pelagos Sanctuary mean abundance of microplastics estimated same order of magnitude as that found for North Pacific Gyre pelagic Marine Protection Area of the Mediterranean Sea[26]

Transfer of chemicals into organisms
Microplastics taken up into planktonic species, and into whales; MEHP (Monoethyl hexyl phthalate (degraded from Di Ethyl hexyl phthalate the presence of harmful chemicals in Mediterranean fin whales, associated with the potential intake of plastic derivatives by water filtering and plankton ingestion, was demonstrated[27]

In exploring the toxicological effects of microplastics in these species measuring the levels of phthalates in both species, the results show higher concentration of MEHP in the muscle of basking shark in comparison to fin whale blubber[28]

Microplastic and macroplastic in stranded True's beaked whales, highlighting that top oceanic predatory species are interacting with plastic as a marine pollutant on macro- and micro-scales. Suggests that the whales can egest/excrete microplastics, but exposure to chemicals desorbed in the gut remains a key concern[29].

Marine plastics have been found to adsorb and transport chemicals, including high concentrations of organochlorines such as polychlorinated biphenyls (PCBs), dichlorodiphenyl trichloroethane (DDT) and PAHs. After the ingestion of plastics by an organism, the presence of digestive surfactants is known to increase the bioavailability of these compounds sorbed to plastics[30] by markedly increasing the desorption rate of plastics compared with that found in seawater [31,32]

Experimental transfer of polyaromatic hydrocarbons on microbeads to mussels. Results indicated a marked capability of contaminated microplastics to transfer this model PAH to exposed mussels. Mytilus galloprovincialis tissue localization of microplastics occurred in haemolymph, gills and especially digestive tissues where a marked accumulation of pyrene was also observed. Cellular effects included alterations of immunological responses, lysosomal compartment, peroxisomal proliferation, antioxidant system, neurotoxic effects, onset of genotoxicity; changes in gene expression profile was also demonstrated through a new DNA microarray platform. The study provided the evidence that microplastics adsorb PAHs, emphasizing an elevated bioavailability of these chemicals after the ingestion, and the toxicological implications due to responsiveness of several molecular and cellular pathways to microplastics[33]

<u>Dolphins and feeding habit</u>
Differences between plastics ingested in two species suggesting different food strategies changes risks to individual species of dolphins – bottom-feeding species more likely to have plastic in it, and that correlates to the greatest amount of debris in that part of the Brazilian Atlantic coast[34]

<u>Birds</u>
As top predators, seabirds are considered sentinels of the marine environment. Flesh-footed Shearwater (Puffinus carneipes) fledglings with high levels of ingested plastic exhibited reduced body condition and increased contaminant load ($p < 0.05$). More than 60% of fledglings exceed international targets for plastic ingestion by seabirds. The amount of plastic ingested and corresponding damage to fledglings is the highest reported for any marine vertebrate, suggesting the condition of the Australian marine environment is poor[35].

<u>Turtles</u>
Intake of plastics into loggerhead turtles in Indian Ocean between Mauritius and Madagascar included rope, line, polystyrene, hard and soft plastic and plastic caps– plastics 51.4% of the turtles had ingested marine debris, the majority of which was plastic (96.2%). This was the highest number and weight and volume per turtle most reported to date. Plastics found in turtles in the SW pacific, Gulf of Mexico, Mediterranean (up to 79.6%).[36]

<u>Fish</u>
504 Fish were examined and plastics found in the gastrointestinal tracts of 36.5%. All five pelagic species and all five demersal species had ingested plastic. Of the 184 fish that had ingested plastic the average number of pieces per fish was 1.90. Hence, microplastic ingestion appears to be common, in relatively small quantities, across a range of fish species

irrespective of feeding habitat. Further work is needed to establish the potential consequences.[37]

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4.2 Chemicals associated with plastics cause harm to wildlife and the human population

- Plastics contain/are formulated with chemicals that are known to be toxic, and cause a broad range of effects including critical diseases and health conditions
- Plastic also attracts chemicals 'like a magnet' the moment it enters the ocean (from Rochman 2012)
- as well causing physical harm to marine life, the chemicals present in plastic as well as what it adsorbs, accumulate in their body tissue, particularly fat and muscle tissue, can accumulate into the marine food chain
- these toxic substances are associated with a range of health and disease outcomes in the human population, through a variety of mechanisms including endocrine disruption, can accumulate into the human food chain through consumption of fish and cause health effects in the human population.
- Plastics should be considered to be toxic when released to the environment

4.2.1 Chemical route from plastics to humans [1]

- Food containers
- Contained in food
- Flooring and wall coverings
- Medical devices (tubing and blood gags)
- Concern over toys
- Cosmetics
- Varnishes
- Personal care products

4.2.2 Human health effects from chemicals associated with plastic

BisPhenol (BPA) and phthalates act as **endocrine-disrupting compounds (EDCs)**, i.e., compounds capable of causing dysfunction in hormonally regulated body systems.

Phthalates are esters of phthalic acid, primarily used to enhance plasticity of industrial polymers[2]. While these plasticizing agents impart beneficial properties to plastics, they are not bound to the polymer by a covalent linkage which makes them susceptible to leaching from the matrix[3]. Once released into the atmosphere, they have the potential for long-range transport, eventually entering the food chain[4].

Rodent models: Phthalates reported to affect multiple biochemical processes in humans and wildlife. Effects in Animal models (rat) Di-2-ethylhexylphthalate (DEHP) (identified as most biologically-active of phthalates in most studies), to Di Butyl phalate (DBP) – there is a range of effects and potencies in the phthalate chemical 'family' but they are reported to be reproductive and developmental toxicants:

- endocrine disruptor; weak oestrogen; antiandrogen; [4,5]
- testicular germ cell disruption [6]
- reproductive toxicity in rodents [7]
- genital tract and undescended testes changes [8]
- uptake of metabolites into breast milk [9]
- neurobehavioural effects in young rats [10]
- Anxiety and behaviour [11]
- Affects steroidogenesis (and in rat testes) [12]
- Epigenetic alteration of sperm DNA, leads to transgenerational ovarian disease and obesity in F3 generation when dosed as a mixture (DEHP, DBP and BisPhenol A) [13]

Human effects/associations:

- Developmental and reproductive toxic effects [14]
- Reproduction, damage to sperm and fertility [15]
- Early onset of puberty in females [16]
- Genital tract damage [17]
- Anomalies of reproductive tract [18]
- Development of the brain [19]
- Allergies [20, 21]
- Asthma [22 23]
- Biochemical and toxicogenomic mechanisms affected - genital, prostatic, endometrial, ovarian and breast diseases [24]
- Cardiovascular, liver, urologic, genital and endocrine (hormone-related) diseases [25]

- **Bis Phenol A (BPA)** is a plasticizer, and component of polycarbonate plastics, epoxy resins, food and beverage can linings. BPA leaches out into food and by direct contact, exposing the human population[26]

Zebrafish model:

- Interferes with Thyroid specific gene expression and disrupts the thyroid function [27] and gonad damage [28]

Rodent models:

- Fertility and fecundity reduced [29]
- Changes to the uterus and ovary [30, 31]
- Altered puberty [32, 33]
- Sexual behavior [34]
- Hyperactivity [35]
- Disruption to mammary tissue [36, 37]

Human effects/associations:

- Weak oestrogen [38]
- Effects are complex and wide ranging [39]
- Evidence that BPA contributes to infertility in human population [37]
- Higher levels associated with diabetes, obesity and liver dysfunction [40]
- Cardiovascular disease and hypertension [41]
- Decrease in sperm quality [42]
- Affected childhood behavior [43]

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4.3 Plastic is a valuable resource – more needs to be collected, reused and recycled

4.3.1 Plastic production

- Plastic production is increasing inexorably, particularly in the developing world; it is an indicator of development.
- In the first ten years of this century we produced more plastic that the whole of the last century.
- We are now producing nearly 300 million tonnes of plastic every year, half of which is for single use *(Plastics Europe, 2009)*

- Our annual plastic production is equivalent to the weight of all the adult humans on the planet *(Walpole et al. 2012)*
- It is estimated that half of all the plastic produced is for single use (*Hopewell, Dvorak & Kosier, 2009)*
- In 2007 it was estimated by water-filtration company 'Brita', that Americans throw away 38 billion plastic water bottles per year; it takes 1.5 billion barrels of oil to produce them *(Kiley, 2007) - Note this is a newspaper article and is not substantiated.*
- More recent figures estimated that the US alone gets through 50 billion bottles annually. Given the current US plastic recycling figure of just 23% it means that 38 billion bottles are thrown away every year, resulting in 2 million tonnes of plastic going into US landfills. The issue is not only the impact of the plastic getting into the environment. The process of producing bottled water requires around 6 times as much water per bottle as there is in the container. When 'many expect a dramatic rise in areas experiencing water scarcity in coming decades' this is clearly an unsustainable strategy
- The two other major market segments for plastic products are building and construction (20.4%), and car manufacturing (7.0%) *(Plastic Europe, 2009)*
- The view of plastic as disposable unfortunately does not reflect the importance, now and in the future, as a resource. The oil industry is well aware of ever decreasing global resources and the growth of other sources of hydrocarbons within the plastic industry would suggest that they are as well.
- Bioplastics already account for 10 – 15% of the global market and this is expected to grow to a third of total production over the next decade *(Thomas, 2008)*
- The view of plastic needs to shift, from being a disposable item to a valuable resource. This is not a new idea. In the UK, experts estimate that landfill sites could offer up 200 million tonnes of plastic worth up to £60 billion at current prices. *Kelland (2008)* suggest that Landfill mining could be an industry of the future.
- With the exception of a comparatively small amount that has been incinerated, every single piece of plastic that has ever been made is still somewhere on the planet. The resource potential is enormous.

4.3.2 Waste management

Waste Management practices are not keeping pace with this rate of production and consumption

- More needs to be done by regulators, the plastics producing, using and ultimately, waste, industries to reduce consumption, and collect, reuse and recycle plastics:
- Consumers can play a vital part in valuing plastics more, not seeing this material as disposable but one that can be re-used many times, and dispose of plastic responsibly.
- Recycling has the dual benefits of reducing the depletion of finite resources and also reducing the environmental impact of plastic waste. *(Hopewell et al 2009).* However it is not energy neutral **and** has a reliance on individuals and society in general to play a role in the process.
- Energy recovery from plastic waste is a well-known process. It comes in two main forms. One is the generation of energy through incineration, the other is a process that converts plastic back into fuel. Both of these processes have been around for some time but only more recently have they been environmentally sound and cost effective.

4.3.3 Economics

- It is interesting that the indicator used by economists for assessing national economic viability is the GDP. However perversely, there is no measure for the depletion of environmental resources.
- Plastic pollution is having a significant environmental and also an economic impact. It results in clean-up costs, harms marine wildlife through entanglement, ingestion and the spread of alien species, and has a detrimental impact on tourism *(DEFRA, 2011)* and human health.
- One estimate is that plastic pollution alone is costing developing and industrialized nations up to $1.27 billion annually as it threatens the fishing, shipping and tourism industries *(McIlgorm, Campbell & Rule, 2008).* A UN study in 2002 estimated the economic benefits that humanity derives from the ocean to be about $7 trillion per year *(United Nations, 2002).*
- Environmental damage can undermine economic growth:
    - Cost of human health (sick people, sick fish), is not just about the medical treatment. For example in Peru a cholera epidemic as a result of poor sewage treatment resulted in in lost revenue of $1 billion from exports and tourism – more than 3 times the amount eventually spent of fixing the sewage treatment plant.
    - Cost to productivity
    - Intangible costs (well being)
    - The resources that are the most important to the economy are often those that play no role in the economic markets such as the hydrological cycle, the carbon cycle, and the ocean.
- In the future, many businesses will be constrained by natural resources. It follows therefore that in order to gain a competitive advantage in the future, businesses will need strategies that facilitate environmentally sustainable economic activities *(Hart n.d)* The 'winner' in the future will be the organization that utilizes resources most efficiently.

4.4: <u>Plastics - Persistent, Pervasive and Pernicious</u>

- Plastic in our oceans is a growing phenomenon. In the last 10 years its proliferation has been almost exponential, its pervasiveness global. The most significant growth, in disposable plastics, and much of this ends up in our oceans. Left unaddressed the 'plastic oceans problem' is set to increase.

- There is an urgent need to prevent plastic material entering the marine environment to prevent physical and toxic harm to wildlife and people. Figures estimating the amount of plastic waste in the oceans have generally tended to involve the collection of data about floating plastic found during surface trawls and an extrapolation of those figures on a global scale. Using such methods a study in 2014 estimated that there was 245,000 tonnes of floating garbage in the oceans. However, these figures do not reflect the amount of waste we are generating or disposing of ineffectually. This difference is unsurprising given the length of time it can take for waste to get from land to the centres of the gyres. New research methods are based on calculating the amount of waste being generated and the methods in place to capture that waste. Using this figure it was estimated that 8 million tonnes of waste went into the oceans in 2010[1]. If we accept these figures then there is an enormous discrepancy and the problem is almost incomprehensible. If plastic production increases at the rate we expect and waste management systems don't chage, it is estimated that by 2025, 155 million tonnes of waste, predominantly plastic, will be put into our oceans in a year.

- Studies have shown that even on mid-ocean islands, far from their sources, accumulation levels are high enough to be visible on a daily basis *(Barnes DKA)* In 2010, research undertaken by *Anna Cummins and Markus Eriksen* from the 5 Gyres institute reported that all of the water samples collected 3,000 off shore between Perth and Mauritius contained plastic.

- The figures demonstrate that there is already a convincing argument to change the unidirectional flow of plastic waste, and much of the change may rest with the designer. The qualities that make plastic such a useful commodity are the very same that make it such a problem in the environment. It is therefore fair to say, that designers may hold a part of the solution. Panapek points out that by 'creating a whole new species of permanent garbage to clutter up the landscape … designers have become a dangerous breed' (quoted in *Margolin* 1997).

1. Jambeck, J.R., R. Geyer, C. Wilcox, et al. (2015) Plastic waste inputs from land into the ocean. Science **347** 768-771

4.5 We can solve this

4.5.1 The Simple Context – why is plastic seen as waste, whose waste is it, why is it there, who is responsible?

- **Waste = resource**: Lovins (1999)[1] asserted over 15 years ago in his paper on Natural Capitalism that any business (model) that wastes natural resources also wastes money. The plastic industry currently uses 8% of the world's oil resources annually. Bioplastics will fill the gap left by oil depletion, but will impinge on scarce food reserves.

- Plastic has a very broad range of properties and applications. But, simply, plastic is a resource that is too easily seen as disposable. Indeed, as a material it is frequently designed to be disposed of after a single use when designed for medical hygiene, food, drink and consumer good packaging uses. But it is the low cost in manufacture, and at a marginal cost to the product it is holding or protecting, mean that plastics are of low 'value' to the consumer. Disposing of plastic also is a driver for continued production, and profit by the plastics industry.

- However, there are many examples where plastic is seen as a valuable resource – built into consumer and industrial products that are reused many times (following its property as a durable product), and be reprocessed (into more plastics, construction materials, fuel oil and energy).

- What needs to happen when the plastic product is at its end of useful life, that it can be efficiently and effectively managed not to enter the marine environment where it causes harm, and be directed into reprocessing streams.

- **Is plastic waste in the Oceans = 'lost at sea?'** *Charles Moore* concluded that the collection of plastic debris from the oceans was impractical, for both economic and environmental reasons, a view held by a large number of environmental organizations. And given the scale of the issue there are currently no viable solutions on the horizons. That is not to say that we shouldn't consider them. Boyen Slat's barrier across the Pacific is at least making people look at the problem. However, the fundamental issue is that there is little point in clearing up a flood while the tap is still running.

- Plastic pollution is largely due to human neglect and poor waste management systems and practices. Both of these can be resolved through education, changes in behaviour and improvements in processes and technology. Even developed countries can and must do more – much of the waste seen in the Mediterranean comes from the EU.

- Responsibility, rests with **business, industry, government** and **consumers** to address the issues *where they are best placed to do so*.

- **Business responsibility**. There is a view that business has a moral obligation to safeguard the future of the environment and society. The view that corporations should serve the public interests. Plastics Europe believes that business and industry should 'investigate feasibility and methods of capturing floating garbage'. *(Plastics Europe 2012)*

- The pursuit of social causes is a legitimate business practice. Activities that do not support social values and the subsequent public outcry can be extremely damaging.

- Green alternatives in business can attract new customers and increase market share, ergo a competitive advantage and increased long term profits. 10 – 25% of consumers are willing to pay more for sustainable products (TEEB). Crucial is the need to balance the competing needs of the stakeholders. On one hand the manufacturers, on the other the planet and the oceans. There is a political struggle *(Zerk, 2007)* between the needs of corporations and the needs of society that results in conflicts of interest. This needs to be addressed.

- Global industry leaders are embracing sustainability, not just to serve green customers, but to achieve mainstream industry leadership. *(Lazlo 2011)*

- 'Companies that take the environment seriously find themselves changing not only their processes and their products, but also the way they run themselves.' *(Klaus North 1997)* Environmental protection and economic success are complimentary not contrary.

- **Government Responsibility**. Governments need to be involved in the development of legislation and policy that best achieves the aim of reducing the plastic in the oceans. Targets and goals should be set that demonstrate reduction and highlight benefits for business and individuals. Each government should develop a strategic mix of solutions that best suits its economy, demographic, location, culture and general situation, as well as support business, industry and individuals in a way that engages them with those processes. It is not government's role to pay for the clean up – it is their role to be proactive in turning off the tap.

- Governments have competing priorities. Top of the list in any governments environmental policy should be those that harm human health. The long term nature of the harm that is caused by plastic pollution does not align with the (relatively) short term nature of governments. The plastic issue needs to be worthy of concern and debate.

- The problem is that governments appear to have seized on recycling due to the push of environmental groups as if it meets the need to atone for modern materialism. In doing so they set unrealistic targets and they fail to measure success or calculate the economic costs of achieving those targets *(Cairncross 1995)*

- **Consumer Responsibility**. Consumers are the lynchpin if we are to bring about change. This will need education and changes in behavior and culture. Some of this will be achieved through the introduction of legislation, and the changes in technology and processes already mentioned. From a business perspective, 'raising public awareness has led to raising expectations' *(Lazlo 2011).* It is not just about how much, but how?

- There is inevitably a dilemma. Decisions about environmental priorities often become based on moral and political decisions. In the past this has occurred without an understanding of the implications – we need to understand the costs and benefits of what we are doing. Without understanding the cost of an outcome we cannot make a decision about what action to take. So surely, by explaining the costs and benefits of our actions we will influence people in the right way. But, an environmentalist will argue that if the water is dirty it should be cleaned. An economist will argue that the water should be cleaned to the point where the environmental benefits of further action are smaller than the costs they incur….

1. Lovins, AB; L.H. Lovins, P. Hawken. (1999) A road map for natural capitalism **77** p145

4.5.2 Outcomes

Plastic material does not enter the oceans – Plastic is valued more

4.5.3 Solutions

<u>*Society/comsumers values plastic more*</u>

Re-use via deposit system

- Pricing for drinks in plastic bottles includes deposit paid by consumers – incentive to return them
- Conveniently placed machines at supermarket entrance accepts bottles in exchange for vouchers creating incentive for recycling
- Machines sort bottles into plastic types on site ready for specific recycling

Culture change

- driven by greater awareness and not wanting plastic to be in our oceans
- dispose of plastics in waste streams (where available)

<u>*Plastics disposed of enter managed waste streams*</u>

- Plastic waste is collected and segregated from other waste, separated into different plastic types
- Plastics are baled and available for reprocessing

<u>*Plastics are taken into reprocessing and further value gained from this valuable resource:*</u>

Recycling into new plastic products

- Reduces our requirement on virgin plastics thereby reducing our consumption of oil
- Prevents used plastic from ending up in the environmen
- Most plastics can be recycled including simple household items, buckets, plant pots, garden furniture
- low cost
- 'Closed loop' (separating out plastics) recycling is most sustainable system available

Reconfiguration – using plastic, without changing with heat, as a raw material for other products – www.affresol.com, www.cynarplc.com

- Plastic is used as a raw material for other products, no need to change its properties but chemicals or other products are added eg. Material for building blocks, clothing, cartons etc.

Biodegradable Plastic Products

- Will degrade naturally given the right conditions – currently only available in commercial composting plants
- Could replace many 'disposable' plastic products and therefore reduce dependence on oil reserves
- Fungi and Algae are being used successfully to produce polymer chains that may eventually become more 'degradable'.

'Recovery'

Incineration

- Plastic can be converted into energy including electricity
- Prevents waste plastics from reaching the environment and raw material (oil) has a second life

Thermal Cracking - Molten Metal Incineration – www.stxmultifeed.com

- Plastic waste generates energy
- Waste gases can be used in cooling systems – cleaner process
- Higher efficiency rates that standard incineration

Pyrolisis

- Thermochemical decomposition of plastic changes its structure to produce oil for fuel
- Profitable
- Less dependence on fossil fuels
- Can be very small scale for individual or company use – www.blest.co.jp

Pyrogenesis

- A process that uses plasma to generate high temperatures which effectively vapourises the waste
- Plant small enough for very low scale incineration such as onboard vessels at sea
- Resultant solid residue is extremely small and benign
- Gases are collected and removed before entering the atmosphere and can be recycled to generate energy needed to power the process

The Plastics 'System' and Economics

A 'circular' economy exists whereby plastic material producers, plastic product manufacturers and waste companies set out efficient 'cradle to cradle' systems for plastics – so the raw material and resulting waste is minimized and value is maximized to the environment, business/industry and society (Aldersgate Group: *An economy that works: striong today, Great Tomorrow. 2015. www.aneconomythatworks.org)*

4.5.4 Delivering the outcomes in First world countries – US, Europe, developed countries in Asia/Australasia

The situation:

- These Governments have already well-established policies and legislation for the management of waste, including plastics.
- The rules exist, but the slow growth in plastic waste management is due to the economics of the existing systems.
- Financial instruments are needed to rebalance this economic system, putting more of a value on the costs to the environment and society, and of the resources being

consumed, together with better more efficient ways to gain the value back from the disposed plastic material.

- It is the appetite to drive this issue, the pace and progression that we need to challenge.
- EU Member States have mandated different systems, relying more on business to find the solution. This has not delivered effective waste management consistently and EU has advised that plastics waste is one of the top 4 priority waste streams to improve upon significantly.

Solutions in First world countries:

- Governments apply ‘best in show’ plastics ‘recycling’ economy, such as is in place in Germany by adding a cost charge for the plastic products in use.

- Governments set higher, more stringent targets for recycling rates to drive up innovation and *business* ownership of the problem:
  - Improved collection and separation of plastics (waste businesses and manufacturers to work on this);
  - non-recycled plastics used in ‘public consumption’ phased out;
  - for business, greater take-back plastic bottles programmes (e.g. drinks manufacturers);
  - for local authorities to secure a greater return of plastic material into the waste processing;

- Governments support and incentivise waste processing technologies being more widely applied:
  - Innovation – new technologies
  - More reprocessing sites planned for and built.

- Customers educated to dispose of plastics responsibly, by
  - Understanding the impact plastics is causing in the environment and to their health
  - Paying more for their plastic products - carrier bags and other single use items
  - Gaining value from plastic material when they return plastics to the recycling waste streams

4.5.5 Delivering the outcomes in the Developing World

The Situation:

- Consumer goods containing plastics are already being sold in these markets
- Consumption is rising as living standards and economies grow.
- There is limited/no waste management legislation, policies or regulation of business and public authorities managing waste (in general)
- There is limited/no infrastructure to manage the waste arising
- There is no culture of waste management – people accept waste around them as being normal, despite the impacts on human health
- There is no concern for the environmental impacts
- The plastics pollution issue will simply continue to grow out of control, until it affects normal community life. Thus has been seen on Tuvalu where the situation is simply overwhelming.

Solutions in the developing countries

- Governments
  - Establish a firm legislative basis for waste management, using the lead from first world countries
  - Construct the waste infrastructure to handle the waste streams, and recover the valuable commodities (not just plastics, but metals and food waste)
  - Develop their waste management systems and look for high-return solutions in the earliest days that helps economic growth – particularly energy from plastic waste
  - For island and remote communities, to look to a low cost, sustainable technology that turns the plastic waste into a valuable 'product', such as energy, building materials or fuel

- Companies
  - that sell products (from first world) implement a Corporate Social Responsibility charter to manage the plastics material they export to, or produce and sell within those countries through their franchisees.

- Waste management companies
  - To take a long-term view about the needs of developing world countries. Particularly to set out how those countries can maximize the value of the plastic material.

- Communities
  - To educate the local communities on the impact, on their health, livelihoods (such as fishing) and help them to find ways that they can collect and send away the plastic material for reprocessing.

Annex: Scientists involved with the film and Foundation

Prof Cristina Fossi – University of Siena. Cristina is one of the original scientists to study endocrine disruptors and was one of the consultants for Theo Colbourne's book, *Our Stolen Future*, which alerted the world to this issue in the 1980's. Cris pioneered the method of extracting skin and blubber tissue from living whales so that they can be tested for the presence of POP's without harming them. She can also determine their nutritional and stress levels from a tiny fragment of flesh. Before she developed the crossbow method Iin the film), scientists had to rely on stranded animals for their samples.

Dr. François Galgani – IFREMER laboratories Corsica (French Research Institute for Exploration of the Sea). François is a deep sea biologist who has been looking at the distribution of plastics on the sea floor in various locations around the world including the Arctic Circle. He has found plastic at every location using remotely operated vehicles and submersible to photograph and collect samples.

Dr. Jennifer Lavers – University of Hobart. Jenn is a Seabird Biologist based in Australia and she has been studying plastic accumulation in Albatross and Shearwaters at various locations but in particular Midway Island, Tasmania and Lord Howe Island. There is very strong footage of her in the film with dead chicks and with her washing the stomachs of live ones to remove plastic from them before they take their first flights.

Dr. Lindsay Porter – University of Aberdeen (based in Hong Kong). Lindsay was filmed as part of the Blue Whale sequence and is currently helping us with the analysis of the whale faeces obtained on the last day of filming to test it for plastic-related toxins (PAH's and Phthalates.

Dr. Bonnie Monteleone – University of North Carolina. Bonnie has been looking at the issue of plastic distribution in 4 of the 5 gyres. She was filmed in the South Pacific for a sequence concerning the marine food chain. She talks about the apparent clarity of the surface water and the problem of 'invisible' microplastics. Bonnie has also facilitated the filming ofmzooplankton eating plastics in the laboratory.

Asst. Prof. Michael Gonsior – University of Maryland, Centre for Environmental Science. Michael has assisted Bill Cooper, Andrea Neale and Bonnie Monteleone on expeditions to the gyres. He studies chemical oceanography and biogeochemistry of aquatic systems.

Dr. Andrea Neale – University of California at Santa Barbara. Andrea was filmed on the original recce trip to the North Pacific Gyre and can be seen tipping buckets of sea water into a sieve and all the plastic pieces are evident. Her work has focused on how toxins are attached to plastic fragments.

SCIENTISTS WHO HAVE BEEN CONSULTED FOR SCRIPTING AND POSSIBLE FILMING AND SUPPORTING THE MOVIE MESSAGES

Dr. Mark Browne – Plymouth Marine Lab/National Centre for Ecological Analysis and Synthesis, Santa Barbara and graduate student **Chelsea Rochman**, who work with a group of 30 top scientists at the National Centre for Ecological Analysis and Synthesis in Santa Barbara California. Mark and Chelsea are looking specifically at the plastics in the coastal waters. Chelsea has been to the centre of the north Pacific gyre and tested the plastic particles there for toxins and although she found a significant number of them on those, the amount is much higher closer to the coast. The coast is where most fish have their nursery grounds even if they spend most of their adult lives offshore and where most of our shellfish and many species of bony fish are harvested. The toxins that Chelsea is finding have been linked to many types of human health issues including cancers, autoimmune disease and cognitive problems.

SCIENTIFIC ADVISORS

The late Prof. Theo Colborn – (died December 2014) Founder and President of The Endocrine Disruption Exchange (TEDX), she was based in Paonia, Colorado, and Professor Emeritus of Zoology at the University of Florida, Gainesville.

Endocrine disruption is an area of science that was first brought to the publics' attention by Professor Theo Colborn in the '80s following the publishing of her book, *Our Stolen Future*. She has shown that endocrine disruptors are linked to infertility, low sperm count, problems with foetal development and cognitive behaviour. She also firmly believed that gender dysphoria is a result of endocrine disruption in many cases.

Dr. Geoff Brighty – independent sustainability consultant with 26 year long career in science, strategy, policy and operations in environmental regulation and management. A published scientist (4000 citations), he led UK Government and Environment Agency research programmes on endocrine disruption, including groundbreaking discoveries of biologically-active chemicals, and their impacts on fish and invertebrates. He managed ecotoxicology laboratory and pollution investigation teams, to leading technical negotiations for UK in EU chemical and water Directives, and established the UK environmental quality standards programmes.

Professor Susan Jobling, Director of the Institute of Environment, Health and Societies is a leading Environmental scientist serves on the UNEP advisory committee in Environmental Health Sciences. Susan is Professor of Ecotoxicology and leads Brunel's world-leading research on ecotoxicology and toxicology, in particular on understanding the effects of mixtures of chemicals on human health and wildlife. Her research interests lie in exploring toxicological aspects of chemicals (particularly endocrine disruptors). As a pioneer of this field she is highly cited (14,000 citations). Her research papers have supported the need for risk management of endocrine disrupting chemicals and continue to deliver regulatory innovations in this area. Susan will advise on the scientists who can help us with the peer review process and will chair the group.

Dr. Paul Johnston – University of Exeter, Greenpeace consultant biochemist and co-author of the Greenpeace paper on plastic pollution.

Dr.Miriam Goldstein – Graduate Student Scripps Institution of Oceanography, studying the abundance and ecological effects of plastics in the ocean

Prof Michael DePledge – European Centre for Environment and Health. Professor Depledge holds the Chair of Environment and Human Health at the Peninsula Medical School (Universities of Exeter and Plymouth). He is Visiting Professor at the Department of Zoology, Oxford University and at University College, London. He is a former Commissioner of the Royal Commission on Environmental Pollution and former Chief Scientist of the Environment Agency of England and Wales.

Prof Richard Thompson – University of Plymouth – He is the leader in the field of the work that has been done on plastic distribution and effects on human health

Prof. Bill Cooper - Professor and Director, Department of Civil and Environmental Engineering, Urban Water Research Centre, University of California, Irvine. Bill is leading a scientific initiative aimed at quantifying the extent of plastic pollution on beaches of islands in gyres. He has worked with Bonne Monteleone, Michael Gonsior, Andrea Neale, Charles Moore and the Algalita and 5-Gyres scientists.

Prof. Hans Van Weenen - Associate Professor of Environmental Sciences at the University of Amsterdam. Hans has an extensive international research experience in waste prevention and waste reuse, ecodesign, design for sustainable product development, sustainable building and sustainable systems. He has been documenting the spread of pre-production plastic pellets around the world since the 1970's and now considers them to be ubiquitous throughout all of our the oceans, seas and beaches on the planet.

Algalita Research/5 Gyres – Dr. Anna Cummings and Dr. Marcus Ericsson. They have travelled extensively to the centres of 4 of the 5 gyres studying the plastics and documenting the amount in the ocean and in marine species including fish.

Prof. Tamara Galloway – Leading Scientist at Exeter University. Her research is focusing on uptake of plastics into the food chain, including fish larvae and invertebrates, and has produced short films.

Prof. Ed Kosior – He is a chemist who leads the field on pyrolysis and who has developed closed loop recycling systems which are being implemented around the world, including the one that is featured in the film, located in Germany.