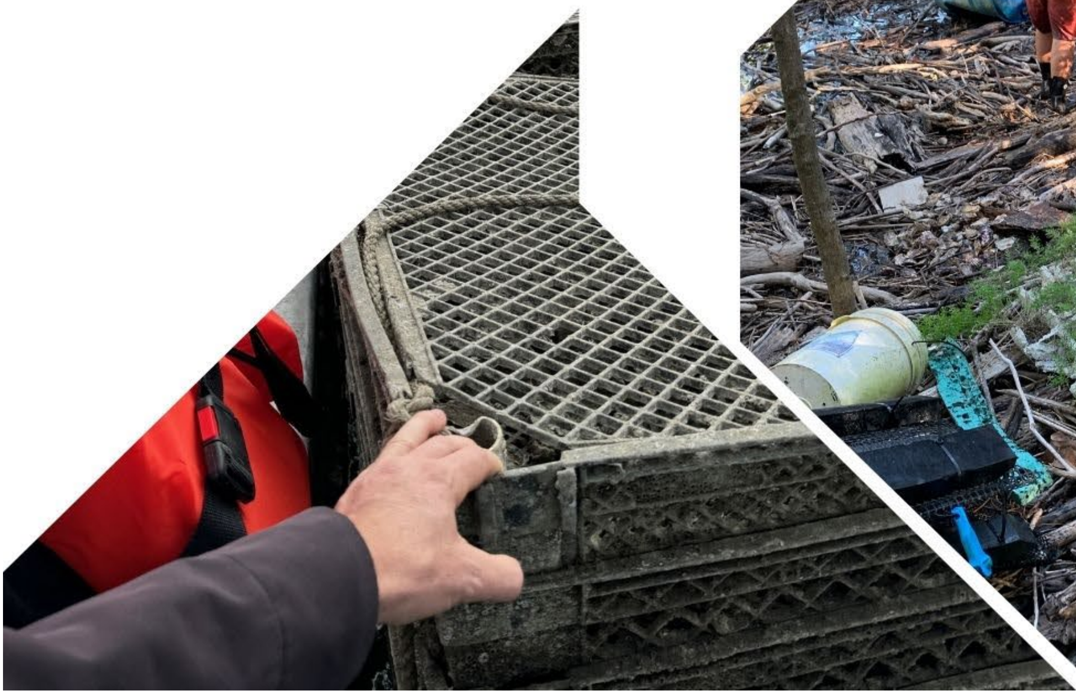
OCEANWATCH AUSTRALIA

The N.S.W Oyster and plastic recycling project feasibility study 2024



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Authors: Simon Rowe (Operations Manager) and Andrei Sosnin (volunteer)

Simon@oceanwatch.org.au

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Australian Government

NSW GOVERNMENT

Contents

ACKNOWLEDGEMENT OF LAND AND SEA COUNTRY

OceanWatch Australia respectfully acknowledges the Indigenous people to whose Land and Sea Country this Plan is relevant and pays its respects to Elders past and present while recognising their important role as custodians of cultural and ecological knowledge for the benefit of all Australians.

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EXECUTIVE SUMMARY

This study looked to quantify the waste situation and seek both to action an immediate reduction of stockpiled waste while progressing discussions on a circular economy end goal.

The NSW Oyster Industry

In 2022-23 the NSW Oyster Industry produced Sydney Rock, Pacific and Native Oysters that amounted to 5.6 million dozens or near on 67 million individuals worth a total value of $71.4 million. Spat production contributed another $6.1M (the juvenile oyster form) split between hatchery raised stock ($2.1M) and wild caught stock ($4M).[1]

The NSW oyster aquaculture industry is Australia's largest producer of edible oysters, the fourth largest Australian aquaculture industry, and accounts for 73% of the value of NSW aquaculture production. It was the state's most valuable fishery in 2018-19. In that period 3,695 tonnes were produced driven by increasing investment in new environmentally sustainable farming technology. NSW Department of Primary industries estimates that the sustainable production level for NSW estuaries is around 7,500 tonnes.

To reflect on the states peak, in the 1976/77 financial year, annual production was approaching 9375 tonnes or 17 million dozen oysters. Since this point, production has declined attributed to factors of oyster disease, Pacific oyster inundation and proliferation in some estuaries, degradation of water quality and demand side factors from oyster grown in other states and diversification of consumer tastes.

Since the late 1990's the oyster industry has been moving away from the use of treated timber infrastructure developed in the early 1900's to the use of resilient UV stable and recyclable high-density polyethylene (HDPE) infrastructure which includes the use of HDPE encapsulated recycled timber support posts and HDPE mesh baskets and trays for the cultivation of oyster crops. There has also been a significant shift away from traditional intertidal post and rail supported farming methods to the use of floating and post supported long-line basket farming systems.

The use of these systems has also reduced the industry's demand for high value native marine grade timbers that are in short supply and significantly reduced the amount waste generated by the industry. It has also enabled the development of more efficient and cost-effective farming methods and an increase in the productive capacity existing oyster lease areas.[2] The 2021 floods caused a $17m direct impact and resulted in significant stock loss and infrastructure damage.

The waste challenge

Production of these oysters originates from 32 export approved harvest area estuaries, the northernmost in the Tweed River and southernmost in Wonboyn Lake, some 1,372 km by road. It was unknown prior to this study how much waste the industry produced, how much is stockpiled, and what the end-of-life plan was for infrastructure currently in use.

Each article used in the production process – including demarcation and structural posts, ropes and long lines, timber (and other material) spat collectors/lattices, plastic mesh baskets and bags, and discarded oyster shells themselves – is at risk of becoming Abandoned, Lost and otherwise Discarded Fishing Gear (ALDFG). These risks are exacerbated by the fact that:

- Farming equipment is constructed from durable materials built to withstand the marine operating environment and has the potential to remain intact for a long time.
- Estuaries may be in high-risk areas for adverse weather events on the eastern coastline.
- Damaged, discarded and gear not-currently-in-use is stockpiled on-premises at oyster farms close to the water, increasing its risk of becoming ALDFG in an adverse weather event.

Findings of waste audit

Top level insights generated by an equipment and waste audit/survey conducted in late 2023 across 48 responders (representing farmers who operated 61% of the NSW Priority Oyster Aquaculture Area) include:

- A potential stockpile of plastic in the order of 126 tonnes of HDPE and 4,425 tonnes of shell waste ready to be processed across the state.
- Whilst a transition from timber sticks to plastic equipment was confirmed by the vast majority of sites, some indicated ongoing usage of timber infrastructure, as well as preference for timber as a "natural alternative" to plastic.
- Some sites indicated that different methodologies (trays/racks and longline/floating pillows) were used simultaneously.
- Most farmers do not make changes to infrastructure or equipment for many years or decades; however this is contradicted by a small number who frequently experiment with new equipment designs and technology.
- Longevity of gear appears to be heavily dependent on the maintenance and operating routines of individual farmers, as well as the environmental conditions specific to an individual estuary, however some responders indicated clear disparities in lifespan between different gear manufacturers.
- Shell waste is generally disposed of on-site (as a landscaping surface, or as fill for holes/ditches etc.), and the limited engagement with partner organisations (who may use shell waste for the pharmaceutical industry, agricultural purposes, reef restoration or similar) suggests an opportunity for greater circularity in this aspect of oyster waste.
- Whilst more than half of responders confirmed that they stockpiled plastic waste on site, only a small handful were engaged in recycling low volumes of old plastic through municipal recycling.

The report recommends:

- Ensuring this grant provides an immediate reduction to the waste stockpiles.
- Now that waste volumes are better understood, move beyond landfill to seeking/supporting plastic recyclers who can economically use the waste. Improve handling practices that maximise its value to a recycler and continue to seek interested parties if limited opportunities exist currently, recognising that the marketplace is evolving.
- Deriving new value from waste resources through investing in joint research innovations with academia and importantly end user industry who can capitalise on findings.
- Encouraging infrastructure manufacturers to consider end of life in their future designs.
- Seeking higher value uses for waste oyster shell by filling in gaps of knowledge and trialling treatment options to reduce contamination.

- Labelling oyster infrastructure for ease of recovery and enabling software to return post flood items to growers.
- Removing legacy tar treated timber posts and trays to landfill through subsidy after considering use in energy production.
- Recognising with growing scientific literature and concern over the impacts of plastics in ecosystems and human health the oyster industry may need to advance material use in the near future away from plastics.

INTRODUCTION

Specific outcomes expected from the study

a) Considered direction on how best to remove stockpiles from estuaries to be processed through existing facilities and businesses using project funding and industry co contributions.
b) Considered research and development targeting gaps in reuse knowledge/options limiting future customer uptake or appetite of current waste or infrastructure as it reaches end of life.
c) Context to drive industry adoption of the suggested measures and processes which may in turn influence the supply chain to adopt longer term considerations of its manufactured infrastructure, thus entering the circular economy.

Figure 1. Stick culture was the mainstay cultivation method prior to the early 2000's. (A. Myers)

Background

OceanWatch Australia Ltd is a national not-for-profit environmental organisation that works to advance sustainability in the Australian seafood industry and operate community-based coastal habitat restoration programs. The Australian Government has recognised OceanWatch as the national organisation responsible for the delivery of its marine Natural Resource Management (NRM) related programs. This can take the form of contestable grants, which when successful, allows OceanWatch to partner with industry to address areas of market failure.

Since 1989 OceanWatch has had a deep affinity with coastal waterways users, the environment and those that harvest seafood. OceanWatch is well positioned to instigate a circular economy approach with the oyster industry of NSW for several reasons including its industry expertise, established relationships, local presence and environmental focus.

The oyster industry has been a natural partner in many projects because of its need to maintain clean catchments for healthy oysters. OceanWatch was instrumental in applying for subsidies to allow the NSW oyster Industry to transition away from tar coated stick culture with wild caught spat towards single seed culture in plastic trays and baskets in the early 2000's. An emerging market failure is the need to now plan for that infrastructure's end of life.

Market failures occur when the allocation of goods and services by a free market is not efficient, often leading to negative externalities such as environmental pollution. This waste can inadvertently end up as marine debris if stored on low lying flood prone locations, often where oyster farmers operate. Unmanaged waste can lead to significant environmental and social costs, which are not reflected in the market prices of oyster farming. This mismatch is a classic example of a market failure and highlights the need for better waste management strategies.

Resource inefficiency is another critical aspect. Waste represents a loss of valuable resources that could be reused, recycled, or repurposed, leading to inefficient resource utilization. Industries that do not manage waste effectively may face future regulatory pressures and costs as governments impose stricter environmental laws and penalties. This creates an economic burden that could have been avoided with proactive planning and sustainable practices.

Additionally, companies that fail to address waste management may impact their social licence to operate, affecting their competitiveness and market position. The long-term costs of unmanaged waste, including cleanup, health impacts, and loss of biodiversity can far exceed the costs of proactive waste management planning. Therefore, incorporating waste management into industry planning is essential to avoid these failures and promote sustainable economic practices.

Problem statement

The oyster industry, like many others in Australia, currently operates largely on a linear waste model. Plastic waste is either stockpiled indefinitely or taken to the tip once it reaches end of life. Some plastic items used in the industry originate from recycled content, but that feedstock comes from plastic waste generated by other sectors, largely because of biofouling and material contamination in oyster waste, and the requirement to use equipment such as injection moulders that has limited tolerance for contaminants. Shell waste is used in driveways, fill, poultry feed or more recently in environmental restoration or human pharmaceuticals. Timber waste is burnt or landfilled. While it is a very resourceful industry by and large, the focus on mechanisation and rapid advancements in production techniques means farmers use large numbers of plastic baskets and trays and there is no plan once they reach end of life.

This project aims to propel the sector towards circular thinking by initiating actions and conversations, starting by addressing existing NSW stockpiles.

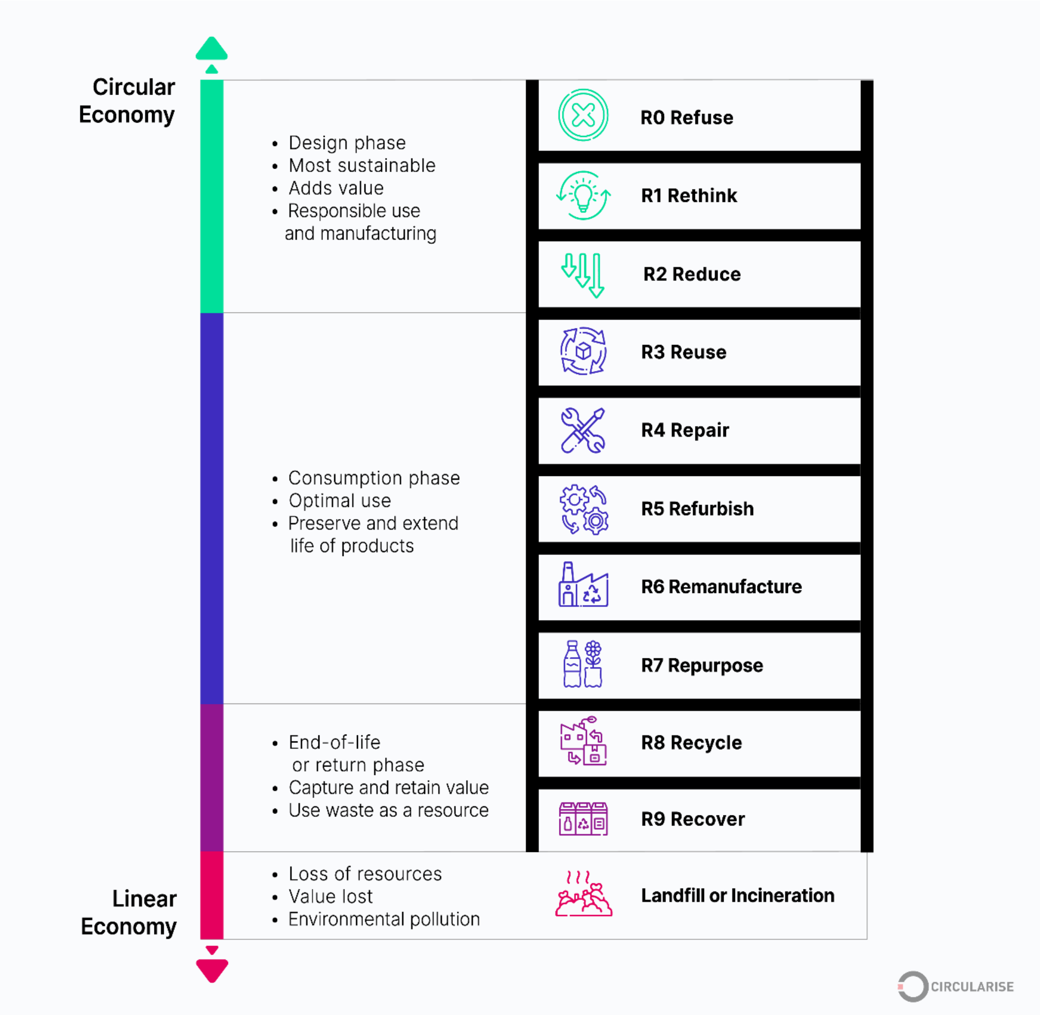


Figure 2. Transitioning from a Linear Economy to a Circular Economy: The R0-R9 Framework emphasizes designing products for sustainability, maximizing their use, and effectively managing end-of-life stages to minimize waste and environmental impact. Many stages and pathways lead to a circular economy.

Objectives of the Study

The study will inform this project titled “From Waste to Product - Identifying plastic and shell recycling pathways in the NSW oyster Industry”. It aims to transition the NSW Oyster industry to a more resilient business model, focused on partnering with recycling ventures to add value to waste and byproduct stockpiles.

It aims to do this through 3 sub projects.

Project 1 involves the oyster circular economy feasibility study and extension. A detailed estuary by estuary assessment of shell and cultivation gear audit will be undertaken to quantify material type, construction, condition and quantities, as well as likely future demands and willingness/ability to participate in end-of-life sorting, treatments and processing for timber, plastics and shell.

Project 2 involves statewide estuary clean-up events in flood impacted estuaries. It involves a tipping fee subsidy to encourage the removal of legacy timber sticks and trays out of the system. The outcomes of this project include cleaner and more resilient estuaries through industry-led estuary clean-ups in key oyster growing regions, including flood impacted estuaries, by removing marine debris, retrieving oyster cultivation infrastructure dislodged and damaged in floods, promoting sustainable practice and environmental stewardship among the industry, and improving social license.

Project 3 involves using the findings from Project 1 in a source reduction plan that moves to solutions and trials. It was envisaged on commencement to include the set-up/activation of three regional hubs (south, mid and northern centres) that work specifically on collecting, cleaning and processing local oyster waste. This will complement the needs of, but not competing with, existing businesses to allow partners to trial the logistics of sourcing, handling and processing current plastic feedstock to a reusable base format.

LITERATURE REVIEW

While the remit and initial aims of this project are focused on removing the flood risk to estuaries of oyster industry related waste, it would be remiss of OceanWatch to not consider the global pressures the oyster industry in NSW is exposed to in the context of the wider challenges facing the world over. We do this because the project needs legacy beyond the initial cash injection for it to fulfill its aims into the future. Economics are deeply intertwined with resource use.

Capitalism, an economic system characterized by private ownership of the means of production and the pursuit of profit, has been the dominant economic model in many parts of the world for centuries. Its foundation rests on principles such as free markets, competition, and consumer choice, which theoretically drive innovation and economic growth. Proponents of capitalism argue that it creates wealth, fosters innovation, and provides a framework for individual freedom and prosperity. However, critics point out that it often leads to income inequality, environmental degradation, and social injustice. The relentless focus on growth and profit can sometimes overlook the societal and ecological costs associated with economic activities.

In contrast, the concept of the circular economy represents a shift from the traditional linear economy of "take, make, dispose" to a regenerative model aimed at minimizing waste and making the most of resources. The circular economy emphasizes designing out waste, keeping products and materials in use, and regenerating natural systems. This approach seeks to create a closed-loop system where products are reused, repaired, refurbished, and recycled for as long as possible, reducing the need for new resources and minimizing environmental impact.

The integration of circular economy principles into capitalism presents both challenges and opportunities. On the one hand, the profit-driven motives of capitalism can drive companies to innovate and adopt more sustainable practices, as there is growing consumer demand for environmentally friendly products and increasing regulatory pressures. Businesses that embrace circular economy practices can potentially reduce costs, mitigate risks associated with resource scarcity, and gain competitive advantages. On the other hand, transitioning to a circular economy requires significant changes in business models, supply chains, and consumer behaviour, which can be challenging in a system primarily focused on short-term profits.

Ultimately, the successful merging of capitalism with circular economy principles could lead to a more sustainable and equitable economic system. This would involve rethinking production and consumption patterns targeting the oyster industry, investing in sustainable technologies by manufacturers, and fostering a culture that values long-term ecological and social well-being over short-term financial gains. By aligning the profit motives of capitalism with the sustainability goals of the circular economy, it is possible to create an economic system that supports both economic growth and environmental stewardship.[3]

Minderoo Foundation key findings

Many different organisations around the world are working to integrate and merge circular economy principles into existing capitalist economic structure. A key Australian group is the Minderoo Foundation. The Minderoo Foundation's Key findings in this topic include;

There is more single-use plastic waste than ever before (139 million tonnes in 2021).

Despite rising consumer awareness, corporate attention, and regulation, an additional 6 million metric tons (MMT) of waste was generated in 2021 compared to 2019 — still almost entirely made from fossil fuel-based "virgin" feedstocks.

Single-use plastic is not only a pollution crisis but also a climate one.

Cradle-to-grave greenhouse gas emissions from single-use plastics in 2021 were equivalent to the total emissions of the United Kingdom (460 million tonnes CO_2e). Most emissions are produced by the oil and gas and petrochemical industries in the "upstream" part of the lifecycle. Mechanical recycling reduces cradle-to-grave emissions by at least 30 to 40 per cent compared to producing polymers from fossil fuels by avoiding upstream emissions. While the emissions reduction opportunities from recycling are significant, they can only be part of the solution towards a net zero plastics economy.

Recycling is failing to scale fast enough and remains a marginal activity for the plastics sector.

Only strong regulatory intervention can solve what amounts to market failure. From 2019-21, growth in single-use plastics made from virgin polymers was 15 times that from recycled feedstocks. Petrochemical companies are (naturally) only expanding into recycling in markets where the economic conditions are (somewhat) more favourable. These are markets where policies are more progressive and demand for recycled plastics is stronger. However, across all polymers and technologies, only 3 MMT of additional on par recycling capacity is expected to be brought online by 2027 (0.7 MMT by the petrochemical industry).

Within the petrochemical industry, there are two outliers making strong commitments to recycling and producing recycled polymers at scale.

In addition to these commitments, Far Eastern New Century (FENC) and Indorama Ventures are also now producing on par recycled polymers at scale. A further eight companies have recently set ambitious 2030 recycled polymer targets of at least 20 per cent of production. Compared to the first edition of the Index, we see signs that the industry in general is taking circularity more seriously, but this will only amount to "greenwashing" if words are not backed up by action and investment.

The key recommendations made by the Minderoo Foundation are:

1. Limit fossil fuel plastic production and consumption.

2. Increase plastic products and materials that are designed for circularity and are circulated in practice.

3. Eliminate plastic leakage to the environment across the lifecycle through environmentally sound waste management.

Figure 3. This study acknowledges the recycling problem is far greater than just Industry waste and strongly supports the key recommendations arrived at by the Minderoo Foundation [4]

Tackling marine debris requires a focus on the sources

Groups that tackle marine debris are considering how to reduce the predicted increase outside of physical removal from beaches. Some have recently called for Australia to consider mandating recycled plastic packaging as beaches drown in rubbish to Australia's north.

The United Nations estimates the 11 million tonnes of plastic going into the sea each year will triple within two decades, driving organisations like Sea Shepherd to request that the federal government consider new taxes aimed at reducing the amount of plastic produced. Sea Shepherd remote debris campaigner Grahame Lloyd believes that "if we had a tax on virgin plastic, making recycled plastics cheaper than virgin plastics, we'd see plastic producers globally make more re-usable options." He doesn't think such a tax would make Australian produced goods uncompetitive.

"We could make it that all products coming into this country need to be of a certain quality, so there aren't cheaper products which aren't environmentally friendly on offer," he said. As an example, European Union countries are already taxing virgin plastic, and Spain levies a 45 per cent tax on every kilo of non-reusable plastic produced.

Australia Institute think tank researcher Rod Campbell recommended Australia follow the UK's example of taxing all produced or imported plastic which didn't contain at least 30 per cent recycled material. "They're imposing a direct tax on the manufacture and import of plastic at a rate of about $400 Australian per tonne, and its first year that tax raised around $500 million Australian dollars, which is a lot of money that could be directed to plastic waste problems," he said. Federal Environment Minister Tanya Plibersek provided a statement indicating a desire for all future packaging in Australia to be designed to be reused or recycled which "will include…mandatory targets…for recycled content[5]."

Government policy

In New South Wales (NSW), the cost of landfill disposal has been on the rise due to increasing waste levies aimed at promoting recycling and reducing the amount of waste being landfilled. The waste levy is applied to licensed waste facilities and varies based on the location of the landfill and the type of waste. For instance, the levy is higher in regulated areas, including the Sydney metropolitan area, the Illawarra and Hunter regions, and the central and north coast local government areas.

The waste levy is an economic instrument used by the NSW Government to encourage waste reduction and resource recovery. By increasing the cost of landfill disposal, the levy incentivizes businesses and households to recycle more and reduce their waste generation [6,7].

In 2001, the levy was around $15 per tonne in the metropolitan area, and by 2020, it had escalated to approximately $146 per tonne [8,9]. This substantial rise reflects ongoing efforts by the government to incentivize recycling and waste reduction and to cover the increasing costs associated with waste management infrastructure.

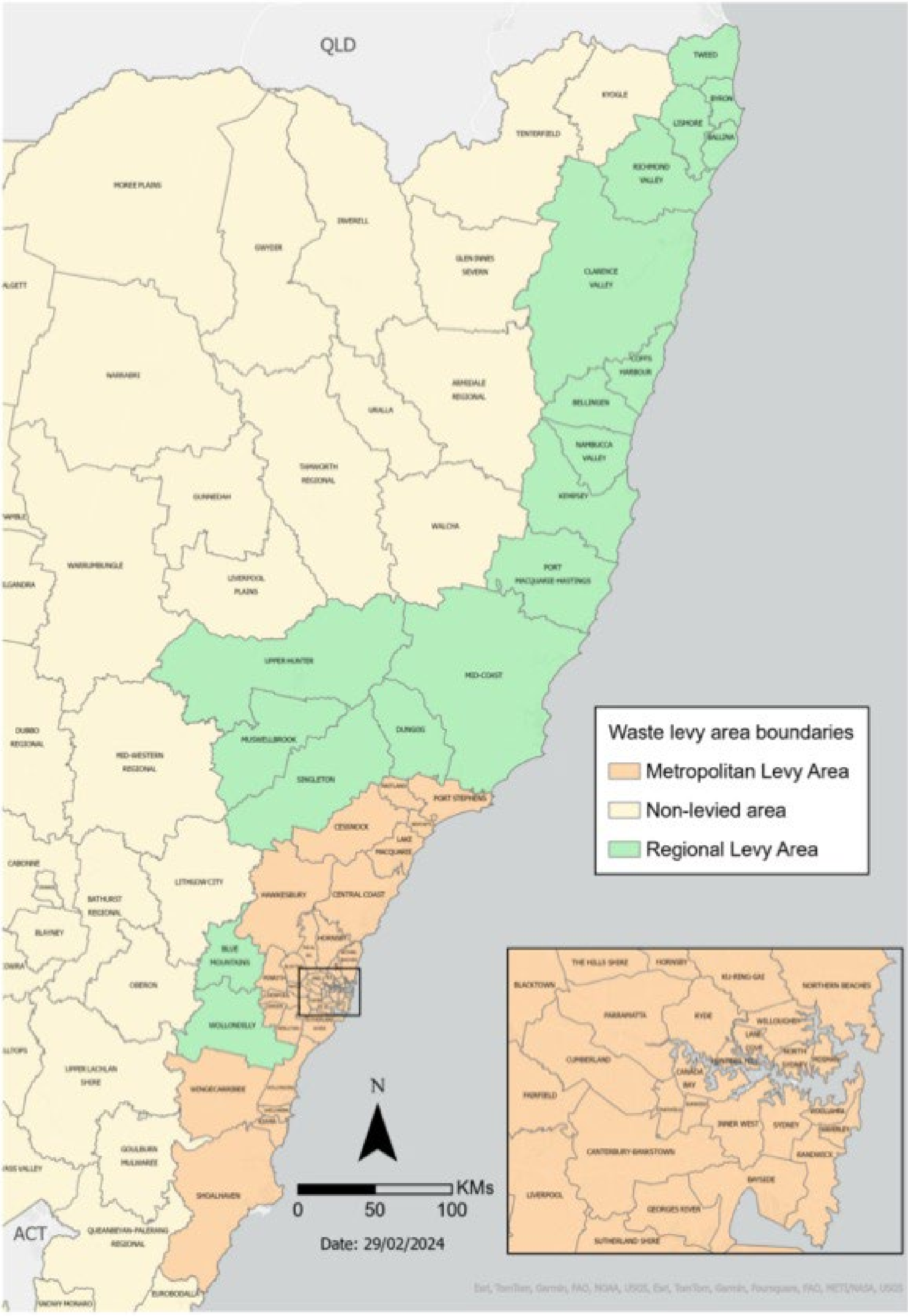


Figure 4. Waste Levy area boundaries [10].

It is intended that waste is not transported across boundaries in an effort to obtain cheaper rates, however for some waste types a depositor may have to travel to find a location that accepts their waste. An example of this is domestic animals/pets, including oyster meat. The tip's licensing conditions may have limitations in offsite odours and charge a premium to accept the waste or reject it outright. Some sites are transfer stations rather than sites with planned burial requiring ongoing monitoring of environmental considerations such as leachate, runoff and gas.

Landfill costs are expected to continue increasing due to population growth, stricter environmental regulations, and the push towards more sustainable waste management practices. As a result, the trend shows a strong and steady upward trajectory in landfill disposal rates in NSW over the last 50 years [11,12].

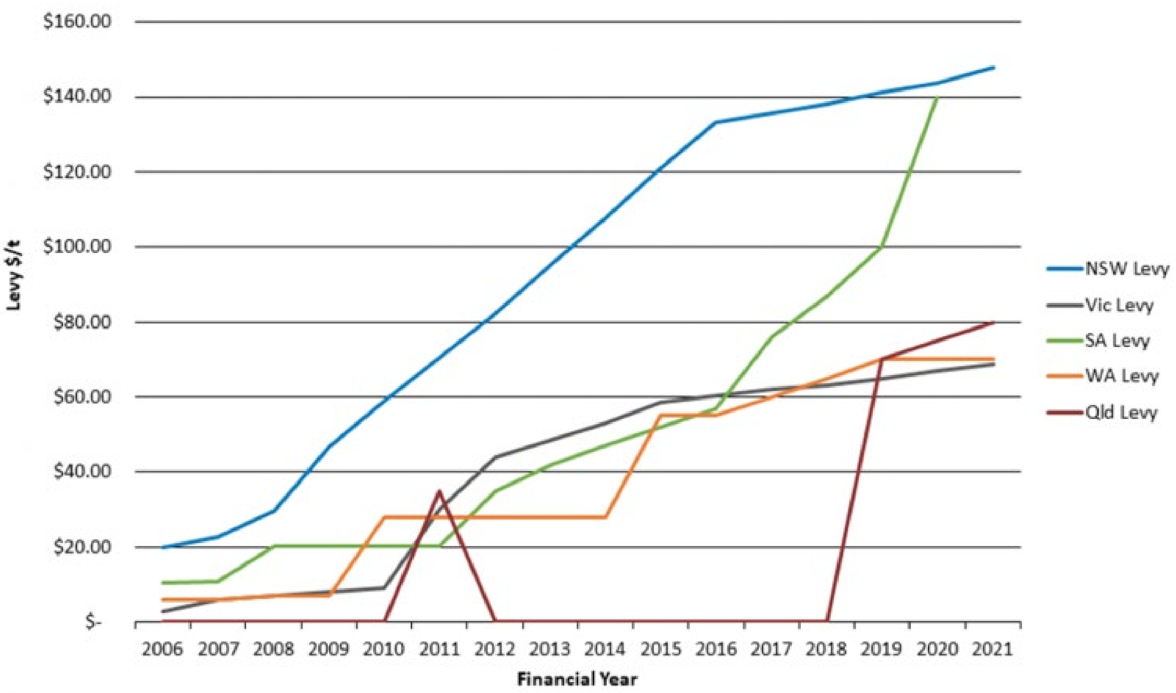


Figure 5. Changes in National Landfill Levies (excluding ACT, TAS and NT) over time, MRA Consulting Group, October 2019 [13].

Whilst various policy and regulatory instruments exist at the state and federal level to help drive circularity, they are most effective when coupled with financial leverage (incentives, subsidies, levies) and investment into research and infrastructure development to simultaneously reduce recovery/recycling costs and source volumes with consideration given to the unique challenges and opportunities of industry-specific contexts.

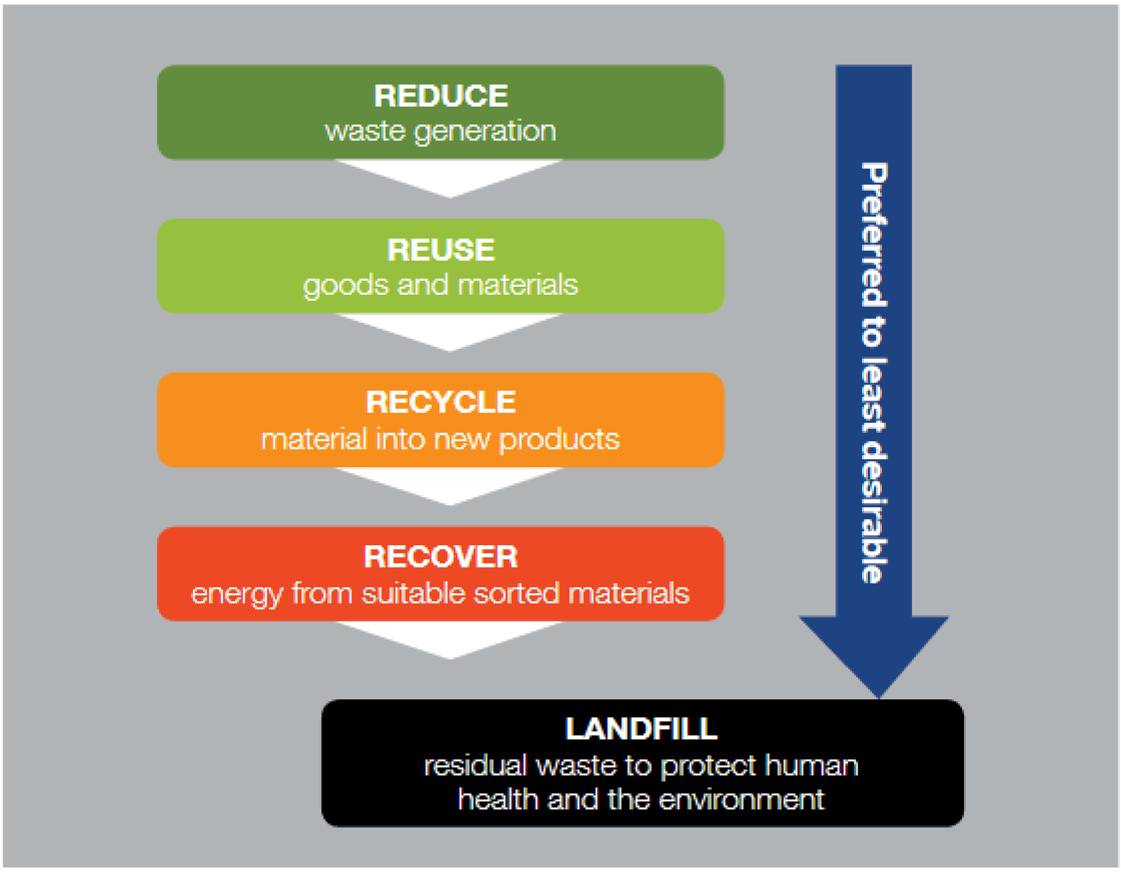


Figure 6. ACT Waste Management Strategy, towards a sustainable Canberra [14]. The principles being: 1). avoid products becoming waste (reduce and reuse); 2). find an alternative use for waste Disposal to landfill (recycle and recover); and 3). ensure safe and appropriate disposal as a last resort.

Oyster farming equipment

Oyster farming equipment can be considered in terms of the key life stages of the oyster – spat, juvenile and adult – and also in terms of farming methodology. Both the oyster life stage and the farming method employed dictate the equipment in use. Whilst international examples may still use bottom culture or "broadcast" methodology (where oysters are dispersed on the seabed and later harvested by dredge), Australian practices predominantly involve "off-bottom" culture, where oysters are elevated above the seabed, generally in an intertidal zone to permit cyclical periods of both submersion and drying/aeration.

Broad categories of off-bottom culture include:

- Sticks and slats
- Trays and racks
- Suspended/long line (baskets and pillows)
- Flip Farms

Within this paradigm, various factors such as estuary and environmental conditions, as well as costs and resource/labour availability can influence a choice of farming methodology. In general, however, each methodology will employ one equipment type for the collection and settling of spat, one type for the growing and nurturing of juveniles, and potentially a third equipment type (which may simply be a larger, more robust basket) for the maturation and further growth of adults.

Sticks and Slats

Spat collection can be undertaken in several ways, but the basic principles of all methods are similar. The material must encourage the settlement of spat, whilst providing the maximum amount of surface area for settlement. Protection from predators such as fish and birds are important, as is the ability for the farmer to remove them without damage.

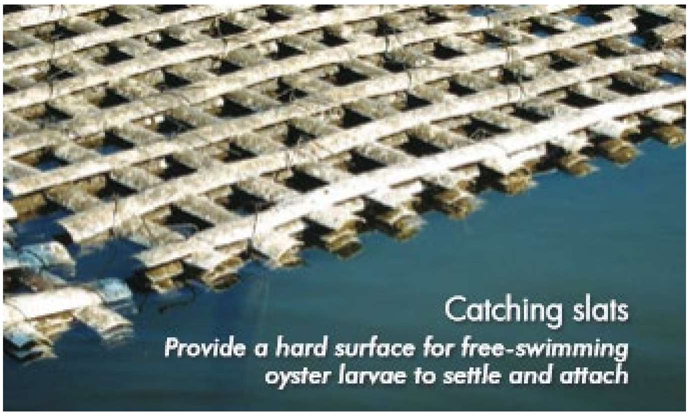


Figure 7. Often PVC pipe is cut and bound together with wire into racks to catch spat. (OWA)

Figure 8. Timber sticks like the ones above were coated with tar to attract spat and extend the timbers life. As of 2025 these sticks are to be phased out from farming practice. Until recently, some

estuaries such as Wallis Lakes and Port Stephens relied on this technique as the mainstay cultivation method with harvest occurring from the sticks all the way to maturity. (OWA)

Trays and Racks

Figure 9. A modern tray is stackable with sections within to maintain population density. Lids secure the oysters in place from human theft and animal predation. Initially the industry used bread trays however these have now been phased out along best practice guidelines. (OWA)

Figure 10. Use of plastic poles or timber lined with plastic is becoming common across the state. Here pillows are suspended on a rack. The pillows in this form are cheap and light and easily moved by hand. (OWA)

Figure 11. Floating pillows stacked awaiting use. Note the degradation of the foam by marine organisms which is common. (OWA)

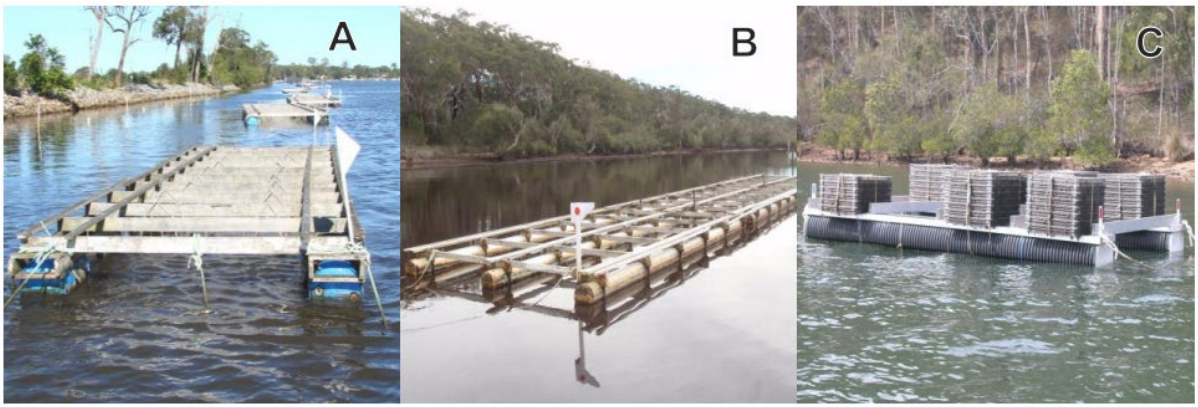


Figure 12. Tray, raft and rack cultivation equipment, using either blue HDPE plastic drums (A), PVC piping (B) or an aluminium raft with polyethylene ribbed piping for buoyancy (C). [15]

Suspended long line

Figure 13. A typical long line with healthy seagrass beneath. Note the lines can be raised to dry the baskets to reduce overcatch, and the baskets allow the oyster to roll around within to gain a desirable shape. Clips hold the baskets in place on the line. The image also show the foam used for each baskets buoyancy usually held in place with cable ties. Timber slats on a rack in the background. (OWA)

Figure 14. Another design with dual baskets and two floats per basket. This design requires the baskets to be manually flipped for drying as per the picture on the right. (OWA)

Figure 15. Mechanisation and advancements in technology have allowed graders to fill baskets far faster than by hand. This type of basket is kept closed with the use of an 'occy' strap. (OWA)

Figure 16. Baskets may be cylindrical and may contain smaller mesh sizes made from wire for younger spat within. Thousands of spat can fit into these smaller mesh designs, and as they mature they can be moved into larger mesh sizes. Spat is either wild caught on slats, or bought as a single

seed from a commercial hatchery or other farmer, and can be nurtured in either the estuary or under more controlled setting is a on-site hatchery. (OWA)

Flip farm

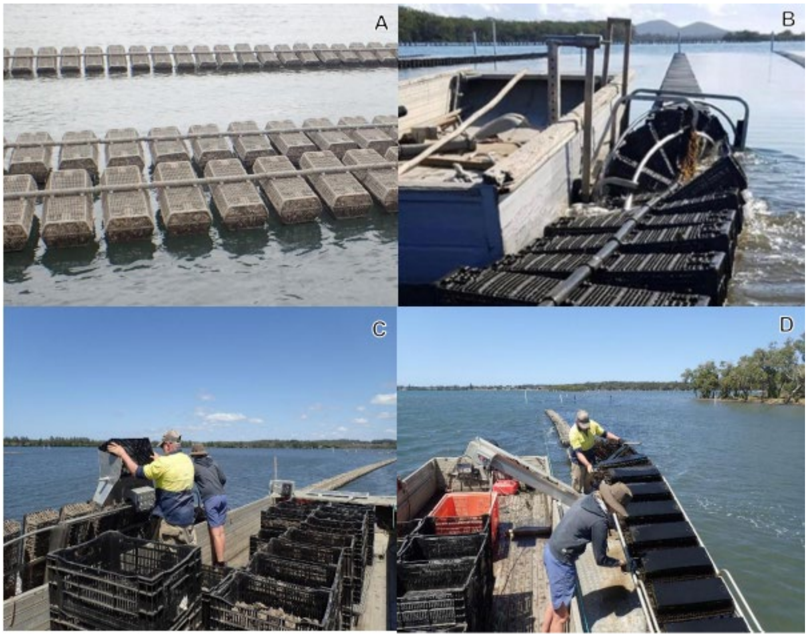


Figure 17. A FlipFarm system, in its drying configuration (A), in the process of being flipped by a mechanical attachment fixed to the oyster punt (B), being loaded in bulk with the assistance of an electric motor-driven line hauler (C), and being transferred back to bins using a conveyor belt (D).[16].

Figure 18. Close up of a new flip farm basket. (OWA)

Figure 19. Sliding collar post attachments used in a floating longline system. Baskets are supported by floating apparatus (foam blocks), and secured via post collars at either end. In a FlipFarm, the baskets are permanently attached to the line (and are flipped/rotated around the line for drying cycles etc.), whereas in a 'normal' long line system the baskets can be unclipped [17].

From around Camden Haven northwards, rafts become a more frequent infrastructure type due to the wider horizon/strata of the upper water layer (in which food is available for the oysters). Raft design varies; the original designs rely on a timber frame held in place by ropes and bolts and attached to blue HDPE barrels. Typically, 10 barrels make up a raft and 4 rafts might be connected to make a pontoon.

Figure 20. A typical raft design on the Nambucca River. (Plastic Collective).

Flooding can destroy rafts and send a larger mass downstream, taking out other infrastructure and eventually ending up in mangroves, beaches, or out to sea. To combat this new means of anchoring have been developed.

Figure 21. Use of a hydraulic drill and screw anchors provide up to 9 times the holding force of traditional block weights. (OWA)

Figure 22. A new design from Camden Haven features sealed HDPE blocks replacing the blue barrels. (OWA)

Figure 23. The new design constructed of aluminium with black blocks being examined during the 2024 NSW oyster conference field day. Note the existing trays with lids, which are raised for drying here, but usually hang below the raft in the water column. (OWA)

Technological and logistical considerations

To help contextualise the challenges in recycling contaminated HDPE, brief treatment must be given to HDPE manufacturing techniques, common use applications, and the recycling process itself.

High-density polyethylene or HDPE is a commonly used petroleum thermoplastic and the most used of the three polyethylene's for a wide range of applications. Under a microscope, this plastic appears to have a linear structure with few branches, lending to its optimal strength/density ratio. As a result of its molecular makeup, it is often employed in applications where moisture resistance and cost-effectiveness are needed.

Low density polyethylene (LDPE) was created in the 1930s and introduced to the market commercially soon after, with high density polyethylene (HDPE) following in the 1950s. While its higher density versions yield a more rigid result, HDPE can vary in flexibility. Low-density grades of the thermoplastic are less stiff, and the high-density grades have equally high crystallinity. Both HDPE and LDPE are considered as polyolefins, a family of plastics that also includes polypropylene, and represent a large proportion of both consumer and industrial plastics.

LDPE and linear low-density polyethylene (LLDPE) have lower usage rates in the marine/aquaculture context, and are predominantly used for bags, films and cable coatings in other industrial contexts, however polypropylene (PP) is frequently found in aquaculture settings in the form of ropes.

Plastic manufacturing techniques

Whilst variations in the manufacturing process may depend on the manufacturer, HDPE production can generally be understood as the process of applying intense heat and steam to ethane, a substance that is isolated from petroleum-based hydrocarbons (natural gas). This intense heating process applied to the ethane, known as cracking, causes ethylene gases to form, which then combine and polymerize into a sludgy, viscous resin, ready to be further manufactured into usable products. The final stages of manufacturing generally involve extruders, injection moulds, and similar equipment depending on the use case.

Common Uses of High-Density Polyethylene

HDPE is regarded as an incredibly versatile material, and has a diverse array of applications such as:

- Plastic vessels, such as milk cartons, shampoo bottles, and other food and beverage containers
- Wood plastic composites
- Corrosion resistant piping (including both rigid and flexible varieties)
- Rope products (including marine netting) when spun in its fibrous form

Among other factors, its moisture and corrosion resistant qualities, low weight and low cost of production lend itself to a variety of aquaculture applications, including baskets used in shellfish farming, and many structural applications in sea-pen operations.

Key Advantages and Disadvantages of HDPE

Advantages [18.]

- Cost-effective
- Can withstand temperatures from -148 to 176 degrees Fahrenheit
- Non-leaching
- UV-resistant
- Dishwasher safe
- Resistant to most chemical solvents and corrosion
- Stiff material

Disadvantages

- Poor weathering resistance
- Flammable
- Sensitive to stress cracking
- Difficult to bond
- Non-biodegradable and challenges in recyclability

A recent study found that 90% of ghost nets retrieved from the Gulf of Carpentaria were made from HDPE. The vast majority (98%) of the marine plastic waste detected in Australian waters is made of polyolefins (polyethylene (PE) and polypropylene (PP) [19].

Is plastic the future material Oyster Infrastructure will be made of? Why not move to a completely new material?

The potential future state of oyster farming equipment is best understood within the context of global aquaculture trends and the reasons behind using existing products such as HDPE plastics in the first instance.

HDPE plastics are primarily used in oyster farming and other aquaculture applications due to their chemical, corrosion and water resistance, ultraviolet (UV) resistance, general durability, flexibility, shock absorption and low cost [20]. The versatility of HDPE lends itself to a variety of applications within aquaculture operations, such as oyster bags/baskets, sea-pen structural components, netting, cages, and similar componentry.

Consequently, a large body of literature exists that considers ways in which HDPE products can continuously be improved for applications specific to the aquaculture industry, such as the use of anti-fouling additives to further mitigate biological growth in the marine environment, or the development of geomembranes with low permeability for pen type enclosures. Similarly, a large degree of ongoing investment in HDPE-based aquaculture equipment is evident on the part of oyster farming gear manufacturers. For instance, New Zealand's innovative FlipFarm oyster baskets (developed 2017), as well as the 'next-generation' of oyster farming products developed by internationally renowned, innovative basket manufacturer SEAPA (Australian-based) continue to be produced using HDPE. Financial incentives exist for farmers to leverage improved designs and underlying materials used in oyster bags, such as increased stock retention/survivability rates, stock size and quality, and reduction in maintenance and manual handling requirements. Thus, the prevalence of HDPE in new products and in scientific material suggests that industry desire for HDPE-based equipment will continue for some time.

Against this backdrop, the use of recycled HDPE within the oyster bag manufacturing industry appears to be contradictory. Some manufacturers, promote their oyster bags as being manufactured from 'virgin' (i.e., non-recycled) HDPE that is claimed to offer strength and durability, implying that manufacturers (and in turn, farmers) may see recycled HDPE as being inferior. Contrarily, large Spanish manufacturer Intermas promotes itself as offering an 'ecological oyster bag,' manufactured from 50% recycled aquaculture plastics, and 50% virgin material 20 although the remainder of their oyster bag range appears to be manufactured from virgin material alone. Additional academic material suggests that HDPE has a limited number of times that it can be recycled (sometimes quoted as up to 10 times, although this figure varies), due to the degradation of polymers that occurs [20].

In spite of this economic and industrial momentum favouring the ongoing use of (primarily virgin HDPE), several factors drive the research and occasional implementation of alternative materials:

- Paradoxically, for the same reasons it is useful in aquaculture (due to long lifespan in the marine environment), HDPE and similar plastics present a considerable risk to marine ecosystems whenever oyster bags and other items become Abandoned, Lost or otherwise Discarded Fishing Gear (ADLFG)
- Consumer and community sentiment opposed to plastics use in ecologically vulnerable locations, such as marine areas, including an emerging discourse surrounding microplastics overshadowing the use of plastics in general
- Societal desire to move away from a 'dig-burn-use' mentality and the utilisation of 'fossil fuels' in both energy production and manufacturing
- Some farmers indicate a preference for timber or similar infrastructure and equipment as a natural alternative to plastic

Within the context of oyster farming specifically, the viability of alternative material types remains unclear. Whilst studies have been conducted on the use of alternative materials in oyster farms globally, they primarily relate to the testing of biodegradable ropes and similar apparatus, rather than direct alternatives to hard-plastic equipment such as baskets.

Figure 24. Common practice synthetic rope left and right manilla rope [21,22].

OceanWatch has experimented with manilla, flax and coir fibre ropes in the context of growing oysters in coir fibre bags tethered to wooden stakes with rope. The aim was a restoration of oyster habitat, so organic materials were required under the “Living Shorelines” brand. In the marine environment most of the natural material was degrading rapidly by 12 months, with little left after 18-24 months. In terms of longevity, natural ropes need replacement after time to retain strength. The tethering of infrastructure in the oyster industry relies on quality ropes, due to ALDFG/pollution risk from floods and more extreme weather. Little development has been placed on organic materials as substitutes for synthetics since they fell out of popularity in the 1960’s. Perhaps a look back to the past is required looking forward.

“Several farmers spoken to during the study have resisted the move to widespread plastic use on moral grounds. One even suggested perhaps a marketing edge could be gained by developing a lobster style wicker basket design in the face of higher public interest in microplastic impact on health”.

The net effect of these various factors appears to be an overarching indication that existing plastic gear will continue to be refined to improve durability, longevity, stock survivability and quality, and reduce maintenance requirements and risk of biofouling and predation, whilst limited research on alternative materials continues in parallel.

Some even have a counter argument: substituting plastics with alternative materials is likely to result in increased GHG emissions, according to emerging studies. University of Sheffield-led research has examined the environmental impact of plastic products versus non-plastic alternatives across various sectors.

Despite concerns about plastics' contribution to greenhouse gas (GHG) emissions, the research reveals that in 15 out of 16 applications examined, plastic products actually result in lower GHG emissions compared to alternatives.

Plastics demonstrate superiority in factors such as energy intensity during production and weight efficiency, contributing to their reduced environmental footprint. Additionally, plastic packaging is highlighted for its crucial role in preserving food quality and preventing food spoilage, which in turn helps mitigate GHG emissions. These benefits are balanced by the study's emphasis on the importance of optimising plastic use, extending product lifetimes, boosting recycling rates, and enhancing waste collection systems as effective strategies for reducing emissions associated with plastic products [23].

Future basket designs

Australian farmers and gear manufacturers have played a leading role in evolving oyster farming equipment. Australian designs have been implemented globally, and Australian-based equipment manufacturers have widespread use in NSW oyster operations.

Key equipment performance factors that drive improved profitability – reduced stock loss, improved stock health, lower maintenance/manual intervention requirements, and gear reliability/longevity - may also help drive sustainability and improve the circularity of waste in the oyster industry, resulting in mutual benefit to both environmental stewardship and business performance.

This is reflected in FRDC research into material flows in the aquaculture sector: a clear disparity has been demonstrated between the volumes of absolute plastic and material intensity of gear types with respect to production volumes of oysters, indicating that Hexcyl-design baskets were favourable to floating mesh baskets in this respect [24].

Accordingly, the direction for future plastic basket designs employed in NSW should recognise that the underlying commercial and operational concerns of growers (profitability, stock survivability, human resource intensity) is not in conflict with circular economy and environmental stewardship goals, and a movement towards improved engagement with equipment manufacturers in this respect is recommended.

While not on the mainstream radar of most Infrastructure manufactures, if the concern around plastics and human health becomes acute, then the industry may need to quickly pivot to alternatives. The industry is especially sensitive to this risk farming filter feeders.

Labelling infrastructure

Where flooding occurs, material from the catchment ends up out to sea, with a majority washed up or caught on beaches or amongst mangroves. Rafts can dislodge and end up removing other infrastructure downstream in a tangled mess. This can also occur with longlines should a rope be severed for other reasons. Oyster gear is somewhat distinctive and can generally be collected in a state of reuse.

At the annual OceanWatch "Tide to tip" estuary clean ups, infrastructure is regularly returned or sent to landfill. What complicates the process is that gear isn't labelled with the owner's name or details. Reasons for this are usually around the tedious nature of doing so, what's seen as a unnecessary task as the owners use a different gear type to adjoining leases, or the lack of off-the-shelf solutions for individualisation of tags or branding. NSW DPI "Oyster Cultivation Best Practice Guidelines" state that all raft drums used as buoyancy devices for oyster raft construction should be labelled as aquaculture equipment (preferably with the owner's aquaculture permit number) so that they do not result in a hazardous materials (HAZMAT) response by emergency services if drums are somehow lost (i.e., during flooding) and are subsequently mistaken for toxic chemical vessels by the public. However, this instruction is not extended to or employed on other cultivation equipment such as long line baskets.

Discussions with Crimestoppers and a number of identification companies have confirmed there is certainly merit in trying to label possessions for their return or in the event of theft for a prosecution to succeed. Methods to do this were investigated and include microDots, aluminium and plastic tags, or heat branding. Successful implementation would be dependent on an easy and fast application with low cost, whilst meeting expectations of 15-20 plus years durability. A method to unite missing equipment with respective owners/farmers is also required for the process to be adopted.

Waste-generating materials other than HDPE and PP

Whilst HDPE baskets present a key pain-point for circularity in the oyster industry, waste is also generated by other pieces of farming equipment.

Spat collectors

Spat collectors are generally formed into designs with a high surface area (often stacked, partially flexible discs) that provide a medium for the juvenile stage of the oyster to attach on to. Modern production methods have increasingly replaced timber slat or lattices with plastic designs (generally made of polypropylene, polyethylene or polyvinyl chloride/PVC), and various factors experienced in the marine environment such as UV irradiation, photooxidation and mechanical stressors have been shown to degrade these plastics, leading to material damage, and ultimately removal from service. Nylon strings and nets are also used as spat collectors internationally [25].

Ropes and lines

Ropes form an integral part of farming componentry, particularly in longline and floating culture methodologies. Due to the demands of the marine environment, these ropes are generally manufactured from plastics such as polypropylene (PP) and polyethylene (PE), with polyester also used in some applications. As ADLFG, ropes present an entanglement risk, and also experience limited in-service life spans due to their difficulty to clean and their critical nature in terms of securing payload/stock (i.e., one length of rope may be responsible for securing many baskets).

Figure 25. Waste generated by ropes in oyster farming operations (OWA)

Foam

Foams such as expanded polystyrene (EPS) are used in various aquaculture applications, particularly as buoyancy devices for apparatus like floating oyster baskets. Its various properties (such as low density and light weight) mean that it fragments and breaks relatively easily and can be dispersed into the marine environment when equipment sustains damage.

Polyvinyl Chloride (PVC)

PVC comes in both rigid and flexible forms, and within the context of oyster farming is generally used as a structural component for tray/raft type infrastructure. Such structures are often built by the oyster farmers themselves and are not purchased equipment. Until recently, PVC was considered one of the hardest polymers to recycle due to a broad variety of material formulations in use, exacerbated by a lack of material specifications on PVC items themselves[26] (making it unclear for recycling facilities to understand which particular variant they are dealing with). It is also recognised as having the potential to leach toxic chemicals into the marine environment [27].

Recycling options for oyster shell

Existing marketplace

Oyster shell recycling and repurposing has been the subject of various academic literature and research projects in Australia and internationally, and historical evidence suggests that oyster shell recycling has been practiced for many centuries. For instance, 'tabby concrete,' a form of concrete using burnt oyster shells as a liming agent was used as a construction material by British and Spanish colonists in the Americas sat least as early as the 1500s.

Contemporary examples of recycling generally involve:

- the use of oyster shells in artificial reef projects or as growth substrate for oyster restoration work
- as a soil-conditioning/liming agent (due to the calcium carbonate content)
- as an ingredient in cement and construction mediums, including as a replacement for synthetic stone or for pathways/driveways
- as a vitamin for human or animal consumption (again due to high calcium content)

Shell waste often carries with it various biosecurity risks, since it may be generated through die-offs (often caused by disease) or through biofouling and growth of opportunistic or parasitic organisms (including other oysters) that attach themselves to the shells of farmed stock and growing equipment and reduce survivability. Trade and economic factors can also generate shell waste in situations where oyster stock is unable to be sold and requires disposal.

Figure 26. Labelling used on a FlipFarm product, including the type of polymer.

METHODOLOGY

Research Design and data collection methods

A waste audit was conducted in late 2023 across a number of estuaries along the NSW coastline to help better understand qualitative and quantitative aspects of:

- Oyster farming equipment types in use
- Equipment life span
- Frequency of equipment/infrastructure changes
- Shell and plastic waste volumes
- Approaches to recycling/landfill/repurposing of waste
- Additional commentary and perspectives provided by farmers

The following sheet of 26 questions with an approximate 10-minute completion time was completed both remotely and in-person. While not a complete picture for the entire state, the results have been tabulated and extrapolated to derive insights. The initial plan called for only 3 estuaries to be examined, however results varied so widely that this was expanded to around 20 estuaries of the 30 main estuaries under production. The key intent was to help inform circular economy project work, drive further research, and understand the scope and size of waste situation in NSW.

WASTE AUDIT FORM

OCEANWATCH AUSTRALIA

1. Name:__
2. Business Name : ______________________
3. Bus. Address : ______________________________
4. Best Contact Number: _________________
5. Best Email Address: __________________
6. LGA ; Ballina Clarence Valley Richmond Valley Tweed Valley Other
7. Estuaries:____
8. AP#; ________________
9. Ha Leased Approximately; ________
10. Percentage of lease area under plastic infrastructure; _______%
11. What shellfish farming systems do you use?

Trays on rack & Rail Stick Culture Floating/Longline System

Cylinders/Tumblers PVC Spat Catcher Slats Other

12. TYPES – See all the options. Tick all that apply

	BST Bskt		Mussel Float		TT6/8Trays		Z FoamFloat
	BST Clips		Mussel Rope		Wood Post		Z Tumblers
	BST LongLne		PVC DIY Slat		Wood Rail		Z Spat Traps
	BST Posts		PVC GreyPosts		Wood Sticks		Other
	FF Plas Float		PVC Lease Mkr		Wood Trays		
	FF Spine		TT Aquapurse		Zapco Flip 4		
	Foam Floats		TT Sq Tray		Zapco Flip 6		
	Hexcel Bskt		TT Sq Lid		Zapco Bags		

13. LIFE CYCLE ASSESSMENT: - How long do your baskets and/or trays last?
Do different systems have differing LCA? ________________________________
____
____
14. MAINTENANCE – Do your different systems require more maintenance than others?
Briefly describe what is required for diverse types of gear ?____________________
____
____
15. CHANGE – How often do you change farm systems? What did you change and why?

____
16. PLASTIC DISPOSAL – Circle all that matter
When gear breaks what do you do? Please choose multiple options.

Repair/Reuse Incinerate Recycler
Stock Pile/Store Tip to Landfill Other

17. Do you currently have plastic infrastructure stored and no longer in use?
Δ YES ΔNo, go to Q19

OceanWatch Australia Ltd
Locked Bag 247, Pyrmont, NSW 2009
Ph: +61 2 9660 2262
www.oceanwatch.org.au
ABN 86 071 195 901

18. Why have you stored this gear? ____

19. TONNAGE: - #xUNits x Weight of unit = plastics by weight: ____________________

20. VOLUME: - WxDxH= Volume : ____

21. SHELL STOCKPILE or Annual production estimate= t/p/a: ____________________

22. HOW Shell Disposal – how is shell disposed of now?

23. HOW do you currently dispose of shells? Circle all that matter

Pot Holes Powdered for Pharma Mangrove/Reef Restoration Landscaping

Fill- Land, Drainage or Filtration Agricultural/Livestock/Soil+ Landfill Other

24. MORTALITY %loss in normal seasons: - ________%

25. MORTALITY %Loss in disaster ridden seasons: - ________%

26. PARTCIPATION IN PROJECT TRIALS; - Δ Yes Δ No Δ Maybe

Thank you for taking the time in completing this OceanWatch Australia Oyster Industry Waste Audit Form. We genuinely appreciate working with the oyster industry and all the information you have provided us today will help keep the industry environmentally friendly and at world's best practice in circular economics

Figure 27. Data sheet used by researchers to gather survey responses.

PLASTIC AUDIT FINDINGS

48 responses were received (some of which were multi-site operators), and data was collected from farmers growing product on a total lease of 1,078.5 Ha, corresponding to approximately 61% of the priority oyster aquaculture area in NSW. With discretion, some responses were collated into aggregate groupings (such as estimated ranges of gear lifespan) for the purposes of simplifying any analysis. Where invalid data was provided (i.e., written commentary in a field that required a numerical response), effort was made to still understand the qualitative/context-building aspects of this information.

Farming systems

Responses reflect anecdotal observations that the transition from legacy tarred timber stick systems to plastic equipment is in a mature and almost fully progressed stage. However, some responders indicated that they preferred to continue using timber infrastructure, as it is “a more natural product.” Additionally, some sites use disparate systems simultaneously, such as the use of tray/rack systems in conjunction with long line/floating basket systems.

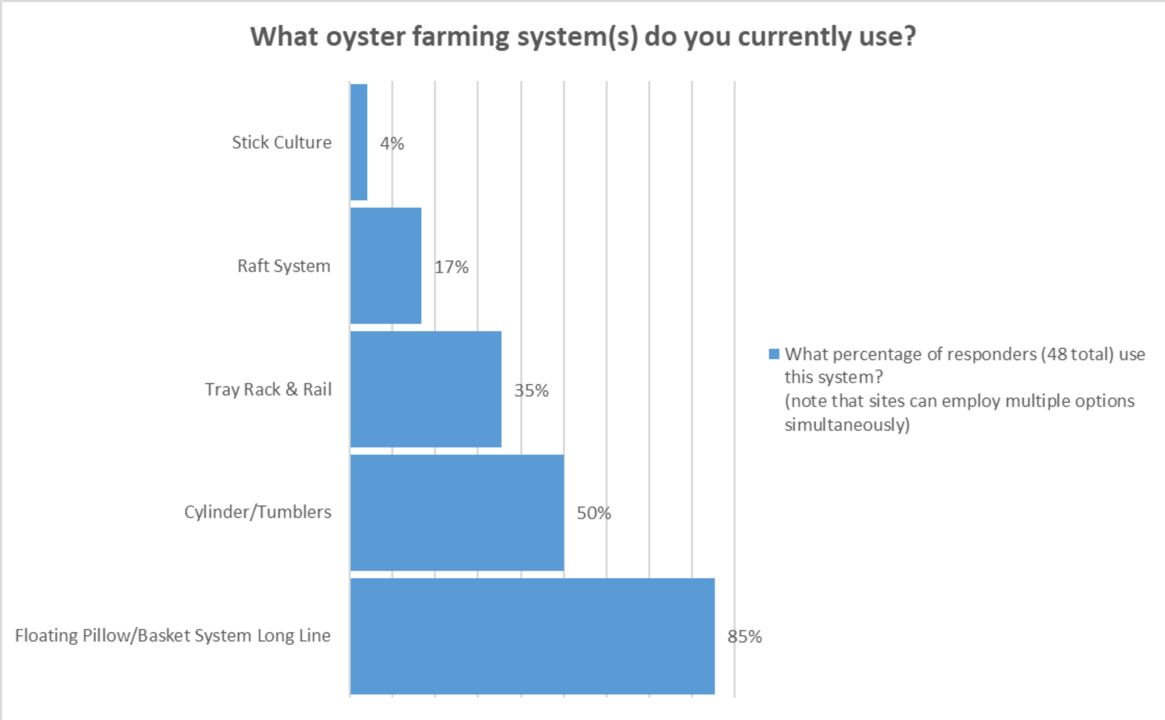


Figure 28. Oyster farming systems currently in use by survey respondents.

Several key suppliers/manufacturers of growing equipment were identified in the data, which can aid in further exploration of gear lifespan, recycling viability, and material composition of equipment, as well as enabling direct engagement with gear manufacturers themselves.

Equipment life cycle

Responders varied in their reckoning of gear lifespan, with end-of-life (EOL) generally estimated to be between 10 to 20 years, dependent on factors such as design, quality of plastic and/or quality of production, usage in different environment, level of handling, and subsequent maintenance. Given that the NSW oyster industry moved away from tarred stick culture in the early 2000's, the EOL for plastic baskets has not yet been realised. Additionally, some responders indicated that they had only been in operation for less than ten years and could not actually quantify the EOL for their equipment either.

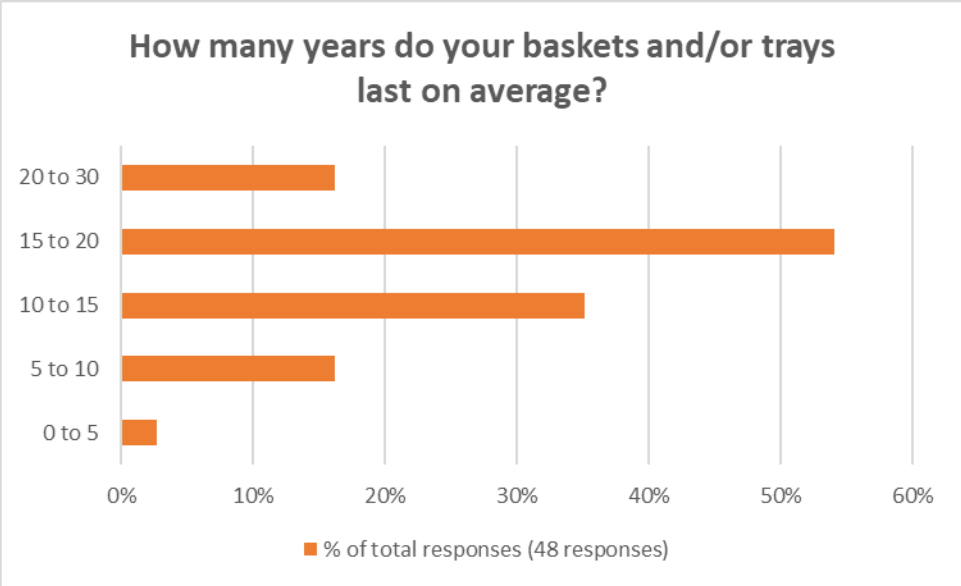


Figure 29. Estimated life span of basket and tray equipment.

Despite this ambiguity, trays were generally stated to have a longer life than baskets, and some basket manufacturers were noted to have a shorter lifespan than others for analogous products. Maintenance to prolong the life of gear included the use of extraneous componentry such as cable ties, clips and joiners, as well as drying on land (i.e., stockpiling with intent of returning the basket to service) to remove biofouling. Notably, some of these items are made from nylon and metal and are regarded as contaminants for plastic recycling.

Farming Infrastructure changes

The majority of responders indicated that they use the same infrastructure for many years or even decades before making any changes. However, a small segment of farmers indicated high rates of new technology adoption, and stated that they regularly tested new equipment or made changes based on emerging designs and technologies. These responders may prove to be a useful information source for further data collection (to understand the benefits or drawbacks of different equipment types), given their propensity and receptiveness towards change. Notably, one multi-site/multi-lease operator indicated a preference for timber infrastructure, "as it is a natural product in a natural environment."

Increased production volumes/growth were only identified as a catalyst for infrastructure changes by 1 responder, however it is unclear whether this referred to a change of equipment type, or simply an expansion of the scale of equipment in use.

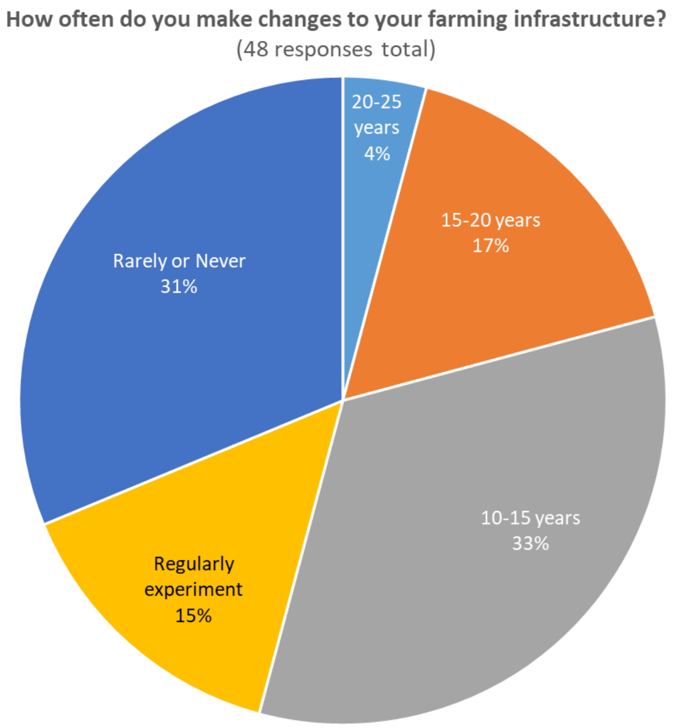


Figure 30. Survey responses related to infrastructure changes and experimentation with new types.

Shell waste and disposal methods

Responses related to shell waste and disposal options are discussed under the Oyster Shell Audit Findings section.

Plastic waste

It was thought that plastic basket stockpiles would be prevalent on farms in NSW, however on audit it was found that only a small percentage (15%) of 48 responders indicated that they stockpile gear in a semi-permanent state (i.e., without later taking it to landfill or a recycler).

42% (20 responses) of the 48 responders indicated that they were stockpiling at least some of the equipment with the intent of re-using it – either awaiting repair, reuse or resale. An example of this might include the temporary storage of plastic equipment on dry land (to allow biofouling to naturally dry/die and fall off), or stacks of partially damaged baskets that are soon to be repaired by cable ties, clips and so forth. 40% of responders had no plastic waste stockpiles altogether.

Stockpile volume estimates were again quite variable and were difficult for farmers to precisely quantify in the absence of measuring equipment. Self-disclosed data collected during the survey indicated that 76.3 tonnes were currently stockpiled amongst survey respondents, which could be linearly extrapolated to 125.75 tonnes if it is assumed that respondents equated to 61% of the total area under lease in NSW.

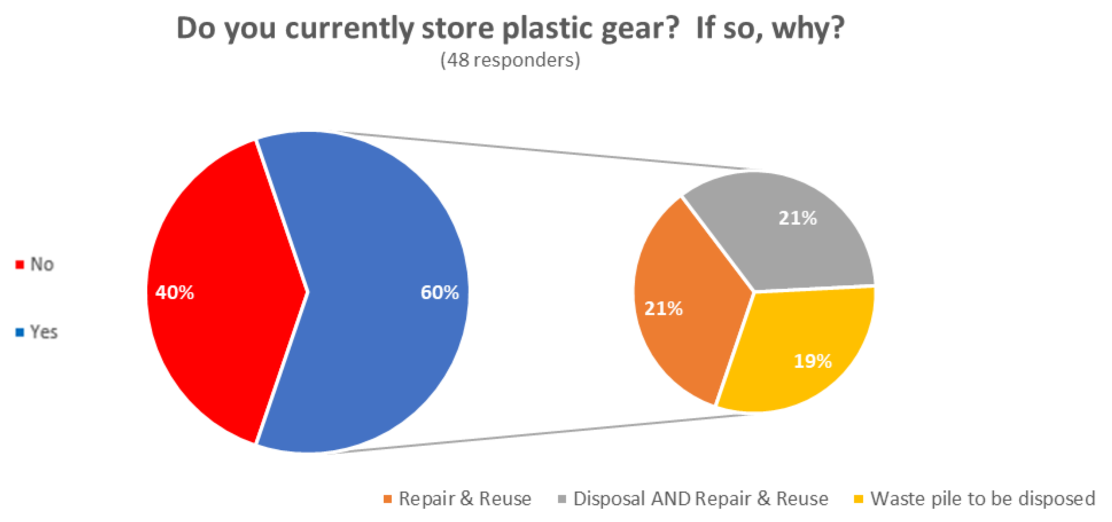


Figure 31. Indication of rates of stockpiling and reasons for doing so.

Over 80% of responders indicated that they would either repair and reuse damaged gear, or take it landfill, although logic would dictate that this figure could be nearer to 100% if the survey question was subjectively interpreted (the survey asked what farmers did when gear "breaks," rather than when it sustains damage or wear-and-tear). Only 5 responders indicated that they had engaged with recyclers to dispose of unserviceable plastic equipment.

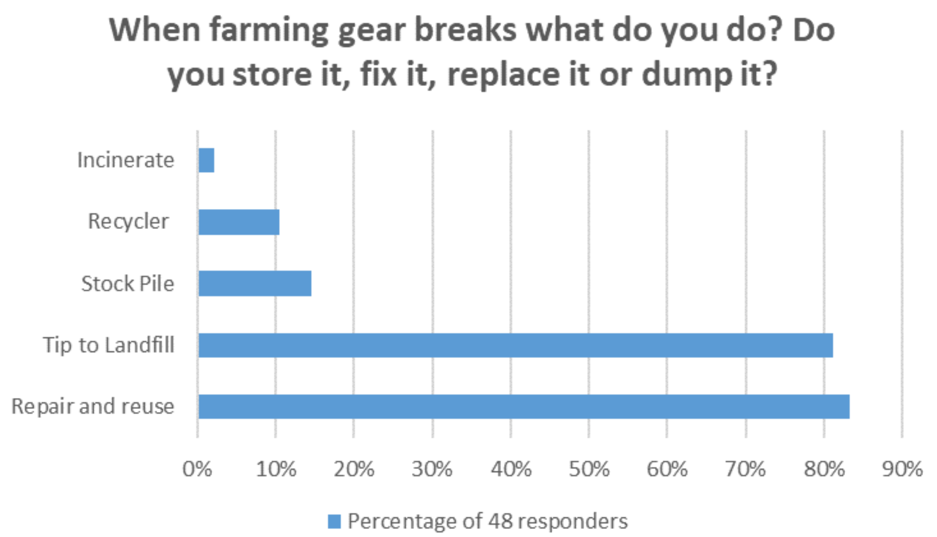


Figure 32. Outcomes for broken gear by survey respondents.

Despite the fact that only 15% of responders were permanently stockpiling discarded gear, a latent or dormant risk of ecological and reputational/industry damage exists: as current gear reaches its end of life, if no adequate preparation for either recycling, reusing or disposal is deployed, future stockpiles may be lost into surrounding ecosystems during adverse weather events such as flooding. The fact there are limited numbers of stockpiles today can be considered a positive, as it gives sufficient time for future planning, implementation of preferred options for circularity and uptake by the NSW oyster industry.

Whilst farmers were not asked to explicitly define the types of plastics being used, they were asked to provide details of equipment types (and manufacturer), indicating that the types of plastics in use include HDPE, PE, PP and PVC.

Mortality and stock loss

Reported mortality rates were highly variable, but could generally be considered to be at least 17% annually on average across respondents, although this figure varied between different species, different sites in the same estuary, and even different equipment types, indicating that mortality events could be exacerbated (or mitigated) by very site-specific conditions, including equipment in use.

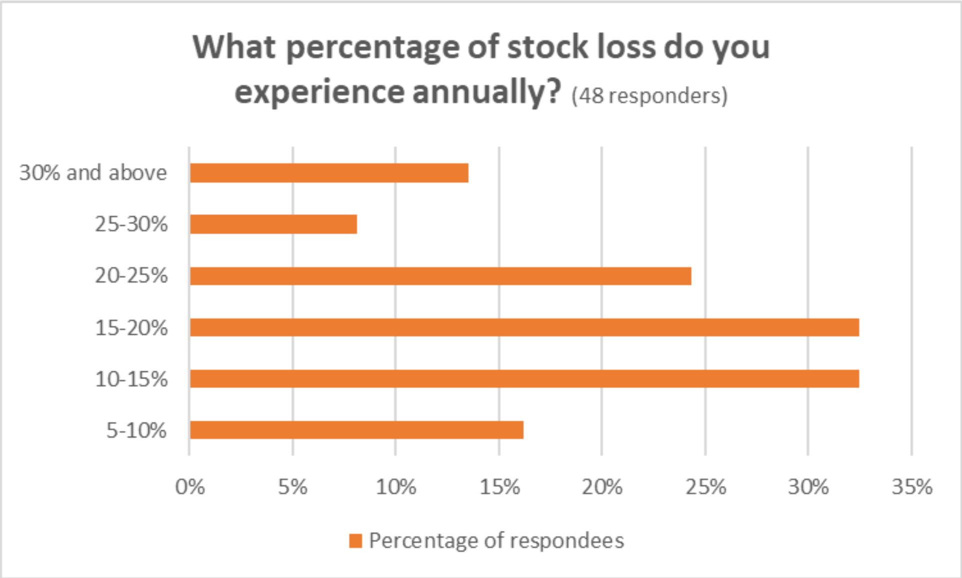


Figure 33. Estimates of annual stock loss varied between respondents.

Estimates again varied when respondents were asked to provide mortality rates during "the recent floods or historically during natural disasters," and were 64% on average, although a number of sites quoted mortality rates of 80, 90 and even 100%.

Mortality does not only result in the generation of shell waste, but also of plastic waste if it involves significant biofouling or overcatch, or if the adverse weather events that have led to stock mortality have also resulted equipment loss or damage. Additionally, high mortality may mean that working/serviceable plastic equipment also becomes stockpiled if production volumes are decreased. Thus, an understanding of stock mortality can help inform plastic waste management strategies.

Recycling options for plastics

To dispose or recycle?

Disposal into landfill comes with benefits and a downside. There is the ability to take small amounts of waste baskets at intermittent drop-offs with little cost to the grower, however capacity to take large collections of waste baskets may present problems. Landfill also requires transport and logistical considerations (which may vary depending on geographical location), and the idea of an oyster farmer excessively contributing to landfill may impact their social license to operate (SLO) in the eyes of the community.

Financial and other resource costs aside, the overarching key processes in recycling of plastic materials can be summarised as follows:

1. Cleaning
    a. removing all contaminants from the HDPE, using various processes such as manual sorting, pressure washing and similar
    b. Previous figures have quoted roughly 20 minutes manual cleaning per basket, followed by a wash process
2. Separation of HDPE according to 'thickness'
    a. HDPE film products must be processed through different machinery than thicker items, as the film has a tendency to be caught around rotating machinery components such as rollers
3. Homogenization, where other plastic products mixed in with HDPE are removed from the batch, generally using sink-float separation (separation according to density/buoyancy) or Near-Infrared Radiation (NIR)
4. Granulation, where the HDPE wasted is shredded/granulized and melted, before being cooled and formed into pellets which can then be re-manufactured into recycled plastic

The final recycling method and service provider dictates the specifics of each prior step. For instance, a recycling partner may have specific requirements for the preparation of the waste product (i.e., it may not be accepted if it has already been shredded by growers due to the lack of assurance that all contaminants were first removed), and caution must be exercised in this respect before prior steps are undertaken.

International case studies also appear to benefit from leveraging external industry expertise and partnering with individuals or organisations with experience in recycling operations, alleviating the challenge of working out the finer details of recycling options and processes.

Within the Australian context, various approaches can be taken to identifying organisations that may be able to assist in disposing, recycling or otherwise repurposing oyster farming waste, such as:

- Simple web searches of waste facilities and organisations in close proximity to estuaries
- Reviewing recipients of circular economy and recycling grants to identify viable partners
- Existing knowledge of waste infrastructure and organisations
- Contacting organisations based on their inclusion in relevant literature

To this end, relevant companies were contacted to assess their willingness and ability to process and recycle waste oyster baskets. This exercise found that whilst there are currently limited options for recovery/recycling of oyster waste in NSW, some organisations did offer promising regional solutions (the details of which are found on a table in the following pages). Notably, additional recovery/recycling options were found in other states.

Aside from stockpiling, international literature generally indicates one of five broad outcomes for plastic oyster farming equipment, namely:

1. Landfill (through rebate and exemption schemes with participating facilities where possible)
2. Recycling (through rebate and exemption schemes with participating facilities where possible)
3. Incineration in waste-to-energy plants
4. Repurposing in low-volume niche applications, such as reinforcing material for laneways and fencing on oyster farming properties, or as a temporary surface-tread for vehicles parking in fields (i.e., for music festivals, or for the construction of solar and wind farms in fields prone to mud), or even applied in similar contexts by national parks authorities when constructing reinforced trails
5. Advertisement of discarded gear on online community reuse/repurposing boards with the intention that novel/bespoke solutions will be self-generated by members of the public interested in taking the waste [28]

Whilst the serviceability and end-of-life (EOL) of baskets can be extended through ad hoc repairs to damaged items using fasteners such as cable ties, clips and bands, these items ultimately become extraneous gear componentry that must be treated as contaminants when preparing source material for recycling. Employing damaged bags in service also creates a risk to stock (of predation, stock loss/failure) and of complete gear loss, and a subjective decision is eventually made to remove the bags from service.

Processing of materials to make ready for recycling

The preparation of materials for recycling is primarily challenged by the bulk and volume of gear (potentially managed through shredding and baling), and the presence of contaminants, which can broadly be categorised as either biofouling or extraneous gear components.

Biofouling refers to the various aquatic organisms (including other oysters) that attach themselves to stock and gear, resulting in decreased stock survivability, increased stress on gear, and ultimately breakage of gear and reduction of serviceable lifespan. Whilst biofouling can be mitigated through gear selection and farming practices (such as the regular tossing/aerating of stock, and lower bag densities), it is inevitable that stockpiled/discarded gear will contain a degree of biofouling.

Within the Australian and international context, best practice appears to be the passive removal of biofouling (by storing bags in the open air with exposure to sunlight and atmospheric conditions) over long periods of time to allow material to fall off on its own accord, before some form of pressure washing and lower intensity manual cleaning to remove the remaining detritus.

On the other hand, extraneous gear componentry refers to the various non-HDPE fasteners, clips, ties, hooks and other devices that are attached to grow bags that may potentially be manufactured from diverse materials such as rubber, nylon, metal and other plastics. It is impossible to predict the degree of extraneous gear componentry, firstly due to the diversity of equipment used in the industry, but also because of the prevalence of ad hoc repairs on damaged-but-serviceable bags by farmers (i.e., cable tying a slightly torn bag together).

Where biofouling can largely be removed in-part by passive storage practices, extraneous gear componentry can require resource intensive manual intervention to remove (i.e., bag-by-bag snipping of cable ties, clips, etc.). Extraneous gear also faces the challenge of 'wish-cycling,' where farmers may incorrectly believe they are doing the right thing by leaving fasteners attached in the hope that it may also be recycled.

Notably, the relatively unskilled nature of source material preparation may allow greater opportunities for farmers to employ external, short-term labour in this process, potentially leveraging gig-based economy platforms (such as Gumtree and Airtasker), volunteer resources such as local coastal care groups or World Wide Opportunities on Organic Farms (WWOOF) homestay labourers, and historical participants of Tide-to-Tip cleanup events.

Spanish aquaculture gear manufacturer Intermas quotes 20 minutes per basket manual cleaning, followed by a mechanical wash process using water.

List of relevant waste (recycling and landfill) locations, recovery options and prices

Table 1 – list of waste facilities in close proximity to estuary locations, with details of recovery options and disposal costs per tonne relevant to the 2024/2025 Financial Year. Prepared by Oscar Gallagher-Resource Hub.

Key:	
	Possible recovery option
	Recovery option confirmed
	No recovery option

ESTUARY - LOCALE	WASTE FACILITY	2024 metrics	Plastic baskets	Plastic trays	Broken and whole oyster shells	Coal tar treated timber	All mixed together
Tweed River	Stotts Creek Waste Mgmt	$ per tonne 2024	$ 165.10	$ 165.10	$ 165.10	$ 165.10	$ 165.10
		$ per tonne levy	$ 97.90	$ 97.90	$ 97.90	$ 97.90	$ 97.90
		Total disposal cost	$ 263.00	$ 263.00	$ 263.00	$ 263.00	$ 263.00
	No option for recovery on any elements. A recommendation was provided to liaise with NEWASTE for a potential regional solution to waste, which covers Ballina, Byron, Clarence, Kyogle, Lismore, Richmond and Tweed Councils.						
Brunswick River	Byron Resource Recovery Centre Myocum	$ per tonne 2024	$ 360.00	$ 360.00	$ 360.00	$ 360.00	$ 360.00
		$ per tonne levy	$ 97.90	$ 97.90	$ 97.90	$ 97.90	$ 97.90
		Total disposal cost	$ 457.90	$ 457.90	$ 457.90	$ 457.90	$ 457.90
	No option for recovery on any elements. A recommendation was provided to liaise with NEWASTE for a potential regional solution to waste, which covers Ballina, Byron, Clarence, Kyogle, Lismore, Richmond and Tweed Councils.						
Richmond River	Southern Cross Drive	$ per tonne 2024	$ 357.00	$ 357.00	$ 357.00	$ 357.00	$ 357.00
		$ per tonne levy	$ 97.90	$ 97.90	$ 97.90	$ 97.90	$ 97.90
		Total disposal cost	$ 454.90	$ 454.90	$ 454.90	$ 454.90	$ 454.90
	No option for recovery on any elements. A recommendation was provided to liaise with NEWASTE for a potential regional solution to waste, which covers Ballina, Byron, Clarence, Kyogle, Lismore, Richmond and Tweed Councils.						
Richmond River	Nammoona Waste & Resource Recovery	$ per tonne 2024	$ 284.10	$ 284.10	$ 284.10	$ 284.10	$ 284.10
		$ per tonne levy	$ 97.90	$ 97.90	$ 97.90	$ 97.90	$ 97.90
		Total disposal cost	$ 382.00	$ 382.00	$ 382.00	$ 382.00	$ 382.00
	No option for recovery on any elements. A recommendation was provided to liaise with NEWASTE for a potential regional solution to waste, which covers Ballina, Byron, Clarence, Kyogle, Lismore, Richmond and Tweed Councils.						
Clarence, Sandon & Wooli Rivers	South Grafton	$ per tonne 2024	$ 244.00	$ 244.00	$ 244.00	$ 244.00	$ 244.00
		$ per tonne levy	$ 97.90	$ 97.90	$ 97.90	$ 97.90	$ 97.90
		Total disposal cost	$ 341.90	$ 341.90	$ 341.90	$ 341.90	$ 341.90
	No option for recovery on any elements. A recommendation was provided to liaise with NEWASTE for a potential regional solution to waste, which covers Ballina, Byron, Clarence, Kyogle, Lismore, Richmond and Tweed Councils.						
Coffs & Boambee Creek	Coffs Harbour	$ per tonne 2024	$ 365.00	$ 365.00	$ 365.00	$ 365.00	$ 365.00
		$ per tonne levy	$ 97.90	$ 97.90	$ 97.90	$ 97.90	$ 97.90
		Total disposal cost	$ 462.90	$ 462.90	$ 462.90	$ 462.90	$ 462.90
	Domestic plastics (1-7) can be dropped off for free. Recommend engaging with Council to explore this option as a commercial customer. A recommendation was provided to liaise with NEWASTE for a potential regional solution to waste, which covers Bellingen, Kempsey, Coffs Harbour, Nambucca, Port Macquarie Councils.						
Bellinger & Kalang Rivers	Raleigh Waste Facility	$ per tonne 2024	$ 252.10	$ 252.10	$ 252.10	$ 252.10	$ 252.10
		$ per tonne levy	$ 97.90	$ 97.90	$ 97.90	$ 97.90	$ 97.90
		Total disposal cost	$ 350.00	$ 350.00	$ 350.00	$ 350.00	$ 350.00
	No option for recovery on any elements. A recommendation was provided to liaise with NEWASTE for a potential regional solution to waste, which covers Bellingen, Kempsey, Coffs Harbour, Nambucca, Port Macquarie Councils.						

ESTUARY - LOCALE	WASTE FACILITY	2024 metrics	Plastic baskets	Plastic trays	Broken and whole oyster	Coal tar treated timber	All mixed together
Nambucca River	Nambucca Heads	$ per tonne 2024	$ 224.10	$ 224.10	$ 224.10	$ 224.10	$ 224.10
		$ per tonne levy	$ 97.90	$ 97.90	$ 97.90	$ 97.90	$ 97.90
		Total disposal cost	$ 322.00	$ 322.00	$ 322.00	$ 322.00	$ 322.00
		Total cost of $322 for inside LGA. Total cost of $380 for outside LGA. Proof of residency required. A recommendation was provided to liaise with NEWASTE for a potential regional solution to waste, which covers Bellingen, Kempsey, Coffs Harbour, Nambucca, Port Macquarie Councils.					
Macleay River	Kempsey Waste	$ per tonne 2024	$ 249.90	$ 249.90	$ 249.90	$ 249.90	$ 249.90
		$ per tonne levy	$ 97.90	$ 97.90	$ 97.90	$ 97.90	$ 97.90
		Total disposal cost	$ 347.80	$ 347.80	$ 347.80	$ 347.80	$ 347.80
		No option for recovery on any elements. A recommendation was provided to liaise with NEWASTE for a potential regional solution to waste, which covers Bellingen, Kempsey, Coffs Harbour, Nambucca, Port Macquarie Councils.					
Hastings & Camden Haven Rivers	Pembroke Cairncross Waste Facility	$ per tonne 2024	$ 177.60	$ 177.60	$ 177.60	$ 177.60	$ 177.60
		$ per tonne levy	$ 97.90	$ 97.90	$ 97.90	$ 97.90	$ 97.90
		Total disposal cost	$ 275.50	$ 275.50	$ 275.50	$ 275.50	$ 275.50
		No option for recovery on any elements. A recommendation was provided to liaise with NEWASTE for a potential regional solution to waste, which covers Bellingen, Kempsey, Coffs Harbour, Nambucca, Port Macquarie Councils.					
Manning River & Wallis Lakes	Taree Waste Mgmt Centre	$ per tonne 2024	$ 198.10	$ 198.10	$ 198.10	$ 198.10	$ 198.10
		$ per tonne levy	$ 97.90	$ 97.90	$ 97.90	$ 97.90	$ 97.90
		Total disposal cost	$ 296.00	$ 296.00	$ 296.00	$ 296.00	$ 296.00
Manning River & Wallis Lakes	Stroud Waste Facility	$ per tonne 2024	Non weighed facility - cost determined by vehicle size.				
		$ per tonne levy	$ 97.90	$ 97.90	$ 97.90	$ 97.90	$ 97.90
		Total disposal cost	Variable				
Karuah, Myal Rivers, Tiligerry CK, North Arm Cover & Pt Stephens Bay	Salamanda Bay Waste Transfer Station	$ per tonne 2024	$ 224.90	$ 224.90	$ 470.00	$ 224.90	$ 224.90
		$ per tonne levy	$ 170.10	$ 170.10	$ -	$ 170.10	$ 170.10
		Total disposal cost	$ 395.00	$ 395.00	$ 470.00	$ 395.00	$ 395.00
		Shells are potentially accepted as putrescible (food) waste if separated and not overly odorous.					
Newcastle	Summerhill Waste Mgmt Centre	$ per tonne 2024	$ 208.90	$ 208.90	$ 263.90	$ 208.90	$ 263.90
		$ per tonne levy	$ 170.10	$ 170.10	$ 170.10	$ 170.10	$ 170.10
		Total disposal cost	$ 379.00	$ 379.00	$ 434.00	$ 379.00	$ 434.00
		Clean and segregated HDPE (2) or PP (5) plastics are eligible for the plastics recycling program. The plastics recycling program is a new trial on offer. No fee reduction is associated however this may be reduced once the trial has concluded. Oyster shells are deemed putrescible waste and attract a higher disposal cost. It is recommended that the oyster shells are separated from the other materials, otherwise all mixed together, these would all be charged at the higher putrescible waste cost. Offensive/odorous material may will attract a higher fee of $526 total. Recommended reducing odour where possible.					
Macquarie Lake	Awaba Waste Mgmt Facility	$ per tonne 2024	$ 269.90	$ 269.90	$ 269.90	$ 269.90	$ 269.90
		$ per tonne levy	$ 170.10	$ 170.10	$ 170.10	$ 170.10	$ 170.10
		Total disposal cost	$ 440.00	$ 440.00	$ 440.00	$ 440.00	$ 440.00
		Odorous waste may be transacted as Special Waste which is charged at $480 total (incl levy). Recommend to ensure odours are reduced where possible.					
Broken Bay	Buttonderry Waste Management Facility	$ per tonne 2024	$ 257.90	$ 257.90	$ 257.90	$ 257.90	$ 257.90
		$ per tonne levy	$ 170.10	$ 170.10	$ 170.10	$ 170.10	$ 170.10
		Total disposal cost	$ 428.00	$ 428.00	$ 428.00	$ 428.00	$ 428.00
		No option for recovery at facility. All must be disposed in landfill together. Odorous material that is not contained appropriately with attract a special waste rate of $566 (incl waste levy). This happens with a current oyster farmer. Most waste directed to Woy Woy facility.					
Brisbane Waters	Woy Woy WMC	$ per tonne 2024	$ 257.90	$ 257.90	$ 257.90	$ 257.90	$ 257.90
		$ per tonne levy	$ 170.10	$ 170.10	$ 170.10	$ 170.10	$ 170.10
		Total disposal cost	$ 428.00	$ 428.00	$ 428.00	$ 428.00	$ 428.00
		Potential end market solution for plastic baskets and trays directly with Cleanaway. Potential end market solution for shell materials as flocking material. Potential end market solution for with local timber remanufacturer Redirect Recycling. When all waste is mixed together, recommend ensuring waste is washed/ bagged to prevent special waste fee.					

ESTUARY - LOCALE	WASTE FACILITY	2024 metrics	Plastic baskets	Plastic trays	Broken and whole oyster shells	Coal tar treated timber	All mixed together
Hawksbury River, Berowra, Cowan, Smiths/ Marramarra Cks	Kimbriki	$ per tonne 2024	$ 291.90	$ 291.90	N/A	$ 291.90	$ 291.90
		$ per tonne levy	$ 170.10	$ 170.10	N/A	$ 170.10	$ 170.10
		Total disposal cost	$ 462.00	$ 462.00	N/A	$ 462.00	$ 462.00
	Can't take shells - not licensed to receive "food."						
Mona Vale	Kimbriki Tip	$ per tonne 2024	$ 291.90	$ 291.90	N/A	$ 291.90	$ 291.90
		$ per tonne levy	$ 170.10	$ 170.10	N/A	$ 170.10	$ 170.10
		Total disposal cost	$ 462.00	$ 462.00	N/A	$ 462.00	$ 462.00
	Can't take shells - not licensed to receive "food."						
Hawksbury River, Berowra, Cowan, Smiths/ Marramarra Cks	Ryde	$ per tonne 2024	$ 315.46	$ 315.46	$ 315.46	$ 315.46	$ 315.46
		$ per tonne levy	$ 187.11	$ 187.11	$ 187.11	$ 187.11	$ 187.11
		Total disposal cost	$ 502.57	$ 502.57	$ 502.57	$ 502.57	$ 502.57
Shell Harbour - Dunmore	Dunmore Recycling & Waste Disposal	$ per tonne 2024	$ 301.90	$ 301.90	$ 240.00	$ 301.90	$ 301.90
		$ per tonne levy	$ 170.10	$ 170.10	$ -	$ 170.10	$ 170.10
		Total disposal cost	$ 472.00	$ 472.00	$ 240.00	$ 472.00	$ 472.00
	Recommend to engage with gatehouse to determine acceptance protocols/ preferences for food waste. Shells may be accepted as FOGO if not overly odorous.						
Crookhaven & Shoalhaven Rivers & Berry Bay & Conjola Lake	West Nowra Waste Depot	$ per tonne 2024	$ 334.90	$ 334.90	$ 334.90	$ 334.90	$ 334.90
		$ per tonne levy	$ 170.10	$ 170.10	$ 170.10	$ 170.10	$ 170.10
		Total disposal cost	$ 505.00	$ 505.00	$ 505.00	$ 505.00	$ 505.00
Clyde, Tomaga, Maruya Rivers	Surf Beach	$ per tonne 2024	$ 201.00	$ 201.00	$ 201.00	$ 201.00	$ 201.00
		$ per tonne levy	$ -	$ -	$ -	$ -	$ -
		Total disposal cost	$ 201.00	$ 201.00	$ 201.00	$ 201.00	$ 201.00
	Offensive material requiring immediate burial will attract a higher gate fee of $286. Recommended reducing odour where possible.						
Tuross River, Wagona Inlet	Brou	$ per tonne 2024	$ 201.00	$ 201.00	$ 201.00	$ 201.00	$ 201.00
		$ per tonne levy	$ -	$ -	$ -	$ -	$ -
		Total disposal cost	$ 201.00	$ 201.00	$ 201.00	$ 201.00	$ 201.00
Merimbula, Pambula, Wallaga Lakes, Wapengo, Nelson & Wapengo Lagoon, Bermi, Bega & Womboyn Rivers	Central Waste Facility	$ per tonne 2024	$ 307.00	$ 307.00	$ 307.00	$ 307.00	$ 307.00
		$ per tonne levy	$ -	$ -	$ -	$ -	$ -
		Total disposal cost	$ 307.00	$ 307.00	$ 307.00	$ 307.00	$ 307.00
	Transfer stations use cubic metres (no weigh bridge) and anything > 3 cubic metres will be directed to Central Waste Facility. No option for recovery, except on broken and whole oyster shells - potential end market solution if oyster shells are separated. Ocean Earth are local and specialise in marine waste compost. Currently undergoing a Development Approval to set up at their own facility in Eden.						

The below table provides an overview of plastic basket/tray disposal and recycling scenarios, with further information on the pages following. Some scenarios may occur in tandem, and this table provides a holistic breakdown.

SCENARIO	DESCRIPTION
S 1	**Base case, do nothing;** • Stockpiles remain on farms • Delayed disposal could mean a higher disposal costs in the future (i.e., inflation) • Highest risk for future flooding events and oyster baskets entering waterways • Stockpiles may impact individual oyster farmers social licence to operate (SLO)/community impression, depending on how visible they are to members of the public (i.e. farm gate visitors) and how they are perceived
S 2	**Disposal at least cost** • Disposal of stockpile of baskets and other plastic waste affiliated with production • Disposal in landfill or recycling centres, whichever is the lowest cost • Disposal will be the waste basket in its entirety, taking up maximum landfill space
S 3	**On farm processing by farmers** • Growers grind waste plastics on site to reduce volume • Purchase/hire of equipment (e.g., mobile shredder) • Material must still be transported to resource recovery centre for recycling or landfill • On farm processing can then lead into disposal at least cost, an industry recycling scheme, or a recycling agreement with gear manufacturers
S 4	**Contracted mobile processing** • Same as above, but a mobile contractor(s) is engaged by OceanWatch • Compacted ground product will then be delivered to a recycling facility or landfill • This will require sufficient participation rates to justify the cost • This can commence immediately and begin to process plastic waste • Will require collaboration with recycling partner • Sufficient participation or output cannot be guaranteed
S 5	**Recycling Scheme** • Industry commits to recycling and works together to cooperate and implement a recycling scheme • This may involve the creation of third-party funded drop hubs in localities to assist with centralised collection • This may involve co-investment, e.g. with state or local government • Will require collaboration with major recycling partner(s) • Drop hubs may also mitigate the risk of stockpiles becoming abandoned, lost, or otherwise discarded fishing gear (ALDFG) after adverse weather events whilst awaiting collection
S 6	**Recycling agreement with gear manufacturer(s)** • A rebate program where materials go back to the manufacturers to be partially recycled into new baskets • This follows European models, where gear manufacturers such as Intermas recycle used gear from European Union partners
S 7	**Plastic waste sent to waste-to-energy/incineration facility** • Waste is sent to facility to be incinerated and converted to energy • Limited options available nationally and in NSW • Not supported by current government policy or best-practice

Additional notes on selected plastic recycling scenarios

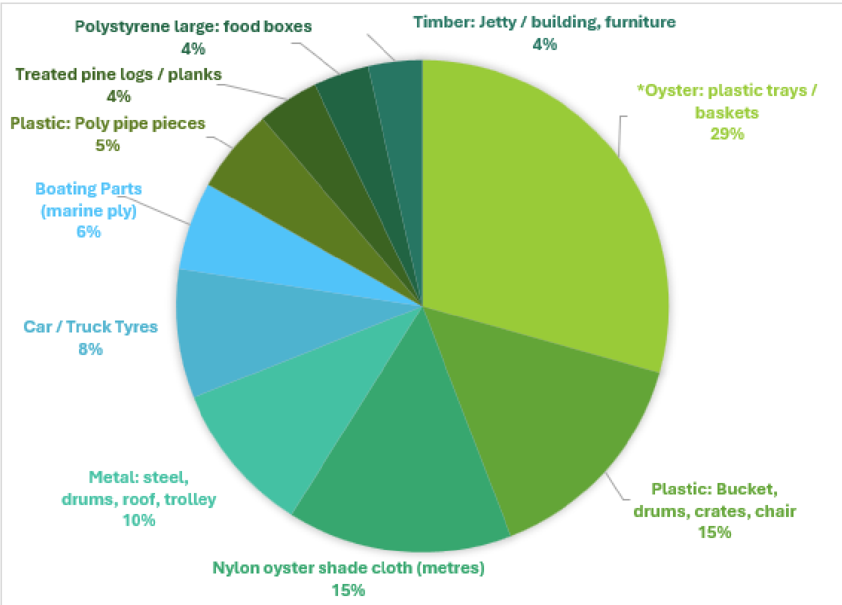
Scenario 1 – base case: change nothing and continue to stockpile

The current scenario of stockpiling without a plan leaves the industry open to criticism, largely from a social licence perspective. Organisations such as Clean 4 Shore sure regularly come across Industry related gear as highlighted in the 2023 Annual report below.

While several members of the oyster industry contribute to the efforts of these cleanups, the report highlights the fact that a continual volume of waste is to be expected without further intervention. Loss of storage space with shed sites in economic terms has not been calculated.

CLEAN 4 SHORE

Top Ten Larger Items Collected in 2023			
Oyster: plastic trays / baskets	884	Boating Parts (marine ply)	175
Plastic: Bucket, drums, crates, chair	446	Plastic: Poly pipe pieces	167
Nylon oyster shade cloth (metres)	445	Treated pine logs / planks	121
Metal: steel, drums, roof, trolley	302	Polystyrene large: food boxes	110
Car / Truck Tyres	255	Timber: Jetty / building, furniture	107



Note: *Oysters – plastic trays/baskets – larger numbers through industry assistance.

Figure 34. Possible future outlook in tonnes requiring an eventual treatment. Based on a prediction that end of life for all current materials is expected to occur within this period, and by 2050 an additional 20% of new infrastructure will also become waste.

Table 3. Stockpile estimates.

Current stockpile estimated in 2024 across the state	Predicted stockpile by 2035	Predicted stockpile by 2055
76.3 tonnes of plastic waste were self-disclosed in the late 2023 OceanWatch audit. This corresponds to 61% of the total priority oyster lease area in NSW, giving a linear extrapolation of 126 tonnes total for the state.	An estimate of total production volumes of oysters across the state is roughly 5,634,227 dozens, or 67,610,724 individual oysters. If an assumption is made that roughly 36 oysters can be grown per basket, then this gives an estimated total of 1,878,076 baskets currently in service in NSW. This can be extrapolated to give a figure of 1,315 tonnes of plastic in use in NSW if an average weight of 700g per basket is used. It is not possible to estimate production volumes of 2035 given variables such as economic conditions, disease, etc., however, even if half of the volume of this current serviceable infrastructure reached its EOL by 2035, this would give an estimated plastic waste volume of 657 tonnes by 2035.	If the same calculation is used as the 2035 estimates, but 100% of current plastic is rendered as waste and is stockpiled, this would give a plastic waste stockpile figure of 1,315 tonnes by 2055.

Scenario 2 – disposal at least cost: either recycling or landfill

Current financial year costs at selected NSW landfills and waste transfer stations were investigated along with willingness to accept the waste and recovery options, which were currently found to be very limited.

A report completed by Hyder Consulting (2009) finds that most population centres have sufficient approved physical landfill capacity to last many years (more than 15 years capacity in most centres). This conclusion allows for the transport of waste from the major centres to outlying landfill sites. Those population centres with less capacity appear to have arranged additional landfill space. The report notes that this does not mean landfill space is unconstrained. As landfills close they are generally replaced by sites further away, increasing the cost (and potential environmental impacts) of transport. Also, the availability of excavated sites for landfilling may be limited by regulatory constraints and possible community objections to new landfills. The costs per tonne look to only increase through landfill with time, while the cost of pure virgin plastics without additional taxes on import will continue to affect the profitability of seeking feed stock through recycling.

Table 4. Waste transfer/ landfill costs across selected NSW locations for 24/25 with unknown recycling implementation beyond handover for the predicted stockpiles.

Cost to take 25% of current waste plastic	Cost to take 50% of current waste plastic	Cost to take 75% of current waste plastic	Cost to take 100% of current waste plastic
$12,001	$24,003	$36,005	$48,006

*Based on the disposal of 126 tonnes at an average landfill price of $381 per tonne inclusive of the EPA Levy exemption but excluding any transport and preparation costs.

Scenario 3 – On farm processing by farmers

This scenario addresses the ability for the project to purchase or hire machinery that could be operated by farmers and moved around the estuaries. Consideration needs to be given to who would take custody of the equipment, operator skill, maintenance costs, and purchase or hire costs of a shredder and bailer. Significant in-kind support would be required.

A new shredding machine would roughly cost circa $45k for a 20kW model capable of processing the feedstock (Wiscon P260) with a throughput of 300- 2000 kg per hour[29].

Second-hand vertical bailers cost from $8k upwards, to around $45k new for a 30-tonne compaction. Durable "bulka" waste disposal bags are available for around $40 each. Suitable sites on level ground are needed to store the gear while its transportation between estuaries is beyond the capacity of a 1 tonne ute, requiring a small truck. The machinery needs to be secured when not in use and protected from the weather.

Once processed and bagged, material still needs to be moved to a recycler or landfill with both currently requiring a weighbridge price to accept it. This option has limited ability to ensure the quality of the shredded material which is a major drawback. Processing of the stockpile would need to be facilitated or overseen by a relevant organisation.

Scenario 4 – Contracted mobile processing

Mobile contractors process waste on-site (with shredders or similar plant), to then be delivered to recycling or landfill sites as a separate service. This scenario works off the model of the above 20kW shredder processing 126 tonnes, representing between 62.5 - 416 hours work. Assuming the labour is around $55 per hour, that equates to between $3,438 - $22,880. On top of this is the cost for travel between estuaries and set up/pack up.

The estimated timeframe for a processing plant on a flatbed truck to work the entire state would be between 6 and 12 weeks. Accommodation and meal allowances of $250 a day generates a cost range for that timeframe of between $7,500- $15,000.

Isuzu truck hire (Budget) with front mounted crane and diesel would be in the vicinity of $15,300 - $30,600.

Hire or purchase of the mobile plant above is still required.

A trailer mounted, 125 KVA Genset weighing 3 tonnes, costing $30k new could be hired (Coates rate is between 22,712- $45,425) and would negate the need for consistent 3 phase power.

A smaller unit on a trailer able to supply 120 amps (50KVA) for a 20kW shredder would cost $13,676- $26,772. This includes 20m of cable and is based on a 12-hour operation time per 24h.

It is estimated a contractor might cost between $70,000 - $120,000. The material then needs to be transported to an end user with associated freight costs. With both scenario 3 and 4 the value of the processed material (if the process works and can then be granulated) would be in the vicinity of $0.70 to $1.20/kg. This equates to feedstock worth between $88,200 and $151,200 (for 126 tonnes), noting that some might be contaminated to the extent that it is deemed unusable and would therefore still require landfill.

Scenario 5 – recycling schemes

Waste is trucked to processing factories to be then made into pellets for resale by the contractor.

Table 5. Likely cost per tonne for a recycler to accept waste to recycle

Estimated cost per tonne	Cost estimate to process 25% of current waste plastic	Cost estimate to process 50% of current waste plastic	Cost estimate to process 75% of current waste plastic	Cost estimate to process 100% of current waste plastic
@ $300	$9,431	$18,863	$28,294	$37,725
@ $474	$14,901	$29,803	$44,704	$59,606
Plus freight ($240)	$7,560	$15,120	$22,680	$30,240

$300 rate based on a clean feedstock to $475 per tonne based on a mixed polymer/ higher rate of contamination. Freight based on Sydney to Melbourne route at 500kg per pallet @ $120. Obviously, this will vary greatly depending on waste location.

Several existing companies were contacted to ascertain their desire and wiliness to process waste. PlastTech Recycling Ltd is a Victorian company that processes co-mingled and contaminated waste plastics chasing value, and then manufactures items or on-sells as feedstock. PlastTech provided insight that some types of contamination (e.g., cable ties) are acceptable, however plastic sheeting is not. Some bio contaminants can be separated out via acid baths and a wash cycle, however these are not in operation in NSW currently. Other polymer mixing is problematic for a consistent blend, and each batch if not consistent needs customised treatment. Overall, it can be surmised that the sector has on its hands a low-grade polymer, however **the cost to recycle is usually adjusted to the cost to landfill** (despite the recyclable materials being a commodity with its own value).

An indication of freight costs for movement between Sydney and Melbourne was investigated, finding that compressed shredded material weighs between 5-600kg per pallet, and the freight is around $110-130/ pallet.

Shredding and baling both have the same intended outcome – reducing the volume of discarded equipment to facilitate more space-and-cost-efficient storage and transport.

It appears that the decision to accept waste for recycling at a cost on par with landfill is designed purely to maintain a level of profitability and cover the labour and process costs associated with recovery. Adding freight cost (particularly long-distance) to this reduces the financial viability of recovery efforts. This is reflective of the number of businesses that are setup to recycle without a subsidy of some type in place. An additional comment was made that many waste recyclers are Victoria-based because of cheaper factory lands within the state, partly attributed to the presence of former Australian car industry manufacturing centres.

Plastic waste materials can only be recycled when there is both a suitable technology for treatment and a market for the product. The historical market value remains difficult to determine with oyster waste where contamination is present. There is an example of a South Australian company that visited oyster farms with a mobile shredder and successfully worked a number of stockpiles, before the operator simply walked away from the machinery and left it at a particular site. Despite attempts, OceanWatch was not able to confirm the reasoning or context for this occurring. It is also understood that the material once shredded it was left on site awaiting a suitable market.

A CSIRO report into the market for recovered ghost net and marine debris suggests a more positive outlook. Recovered HPDE, of which most ghost nets retrieved from Australian waters are made, commands the highest price of the four major plastic resin types (HDPE, PET, PP and LDPE). The material is highly sought after both locally and overseas. The 2021 prices for scrap HDPE (prior to processing) were AU$100–450/ tonne. Partially processed, shredded HDPE was $800/ tonne. With further processing, the price increases to AU$1,200–2,000/tonne for pellets. As contamination levels determine the grade/quality of the product, it is expected that oyster infrastructure - like recycled ghost net product - will be at the lower end of the market price. It could not be ascertained if these prices have been obtained to date.

There is, however, growing demand for ocean-sourced recycled plastic, with online platforms such as Oceanworks selling 'shore-to-shelf' plastic shred, pellets and products and global brands such as Glad®, Patagonia®, and Adidas® promoting the use of ocean-sourced plastic in their products[30]. Partnerships with these companies may produce avenues to absorb the waste if they are not currently over supplied elsewhere in the world and have local manufacturing. This type of waste from the sea does have a certain market that places it in a niche position, but more local examples are needed to reduce transport costs.

The City of Newcastle is conducting a trial to divert HDPE from mixed domestic waste loads using staff to sort. The standard price of $379 per tonne is charged to accept the waste. The company Resourceful Living constructs sustainable furniture from the proceeds for offices, childcare, schools universities, cafes and restaurants.

Figure 35. School furniture made from recycled plastics [31].

Drop hubs have also been considered as part of this feasibility study as a convenient way of facilitating centralised waste collection points. A drop hub may take the form of a large skip bin, shipping container, or other facility that allows farmers to deposit plastic waste at a centralised point for future collection. Similar schemes have been used in Florida in the United States, where dumpster style skip bins (funded by industry associations and government programs) have been placed in the vicinity of farming operations to collect aquaculture waste. Such a concept allows waste to also be removed from high-risk areas (i.e., away from the waterline and immediate flooding zones) whilst it awaits collection. These drop hubs benefit from economies of scale in Florida, where high volumes of aquaculture take place, and in order for them to be feasible in NSW in the future, some form of broader inter-industry scheme may be required that allows other contaminated industrial polymers to also be disposed in the bin so that an adequate return on investment/resources is established.

Figure 36. Skip bins used as drop hubs for shellfish aquaculture equipment in Florida [32].

Centres of research are key to advancing understanding between Academia and Industry. The Sustainable Materials Research and Technology Centre or SMART for short at the University of New South Wales is one such successful model [33].

Other research institutions such as Swinburne University, Southern Cross University and James Cook University have staff that have contacted this study with expertise and initiative to assist in improving knowledge of process and outputs through joint venture partnerships.

Another model is the North Waste and MidWaste Regional Waste Forum, comprised of multiple Councils located on the Mid North and North Coast of New South Wales working collectively to strategically manage waste on a regional scale. This has been in operation for over 20 years. These groups of passionate waste industry professionals were engaged by the study to search for and investigate opportunities, however, at the time of writing, the issue of oyster equipment contamination would still be too problematic to insert waste into their current recycling initiatives.

Lastly, a partnership between waste collected by Eco Barge Clean Seas Inc. and Miimi Aboriginal Corporation sources ocean plastic (including blue barrels from NSW oyster industry rafts) which is taken and processed by a machine provided by the plastic collective. Toolcraft then melts and mixes the blend with other pre-sorted Australian domestic recycling waste to create a product. One such example is the WAW BadFish high performance body surfing handplane [34].

Ultimately the study is yet to determine a suitable business or number of hubs that can recycle the volumes identified with contamination as was initially envisaged. However, now that waste volumes are known, the project needs to further investigate and promote an opportunity for businesses to engage and use its budget to try and break down the barriers for that to occur.

Scenario 6 – recycling scheme involving oyster gear manufacturers

International case studies suggest that the involvement of oyster equipment manufacturers in a recycling scheme could be a viable option, depending on the specific aspects of the NSW context such as availability of technology and infrastructure. Discussion is ongoing with oyster peak bodies from Tasmania and South Australia around opportunities to combine scale and progress this option.

A working group was proposed to the major manufacturers and importers of oyster infrastructure in Australia as a part of this project. The response was lukewarm based on others proposing similar initiatives that didn't really provide viable forward-thinking options that suited the current business models. Some businesses rely on products that are marketed as stronger because of the presence of virgin plastics, whilst others differentiate themselves and drive market segmentation by promoting the fact they use recycled feedstock. However, all manufacturers rely on continued purchase by farmers with no current mechanism to return broken product. With that in mind, the project sought to become better informed of where similar proposals have occurred overseas and see what applicable that could be for Australia. Intermas (A European umbrella brand across packaging, aquaculture, agriculture, geosynthetics and building in 70 Countries) noted that in Spain, the final customers/distributors are able to return some of their old oyster baskets to the manufacturer. They must pay the transport cost, then Intermas will be responsible for receiving the product, cleaning the oyster bags, and carrying out the entire process to melt the "poches" and obtain the raw material that will be used to make new oyster bags. OceanWatch has sought further detail on how the model might be relevant to the Australian context.

Scenario 7. Plastic waste sent to waste-to-energy/incineration facility

A trial was conducted previously by the NSW DPI Aquaculture division to burn waste timber in a power station at the now decommissioned Liddell Power Station (a coal-fired thermal power station near Muswellbrook). High tip fees generated the initial interest to find another end use for the timber. Approximately 500 tonnes was transferred to the station and burnt under an amendment to the license of the plant, since strict emission controls limit what can be burnt for energy outside of coal. While successful, the 500 tonnes was consumed very quickly and the administration around the alternative fuel source meant further burning was unfeasible at that point in time. Whilst that site closed in 2023, others that burn coal wash waste might provide alternative solutions.

Redbank Power Station is a 151MW, former coal-fired power station, located in Warkworth NSW. The power station operated successfully between 2001 and 2014, before being shut down and placed into care and maintenance due to a lack of coal supply. Verdant is working to restart Redbank and convert the power station from operating on coal, to operating on biomass (excluding native forestry residues from logging) as a renewable fuel to produce near net zero CO_2 emissions and green electricity. The proposal is currently before a Development Application (DA).

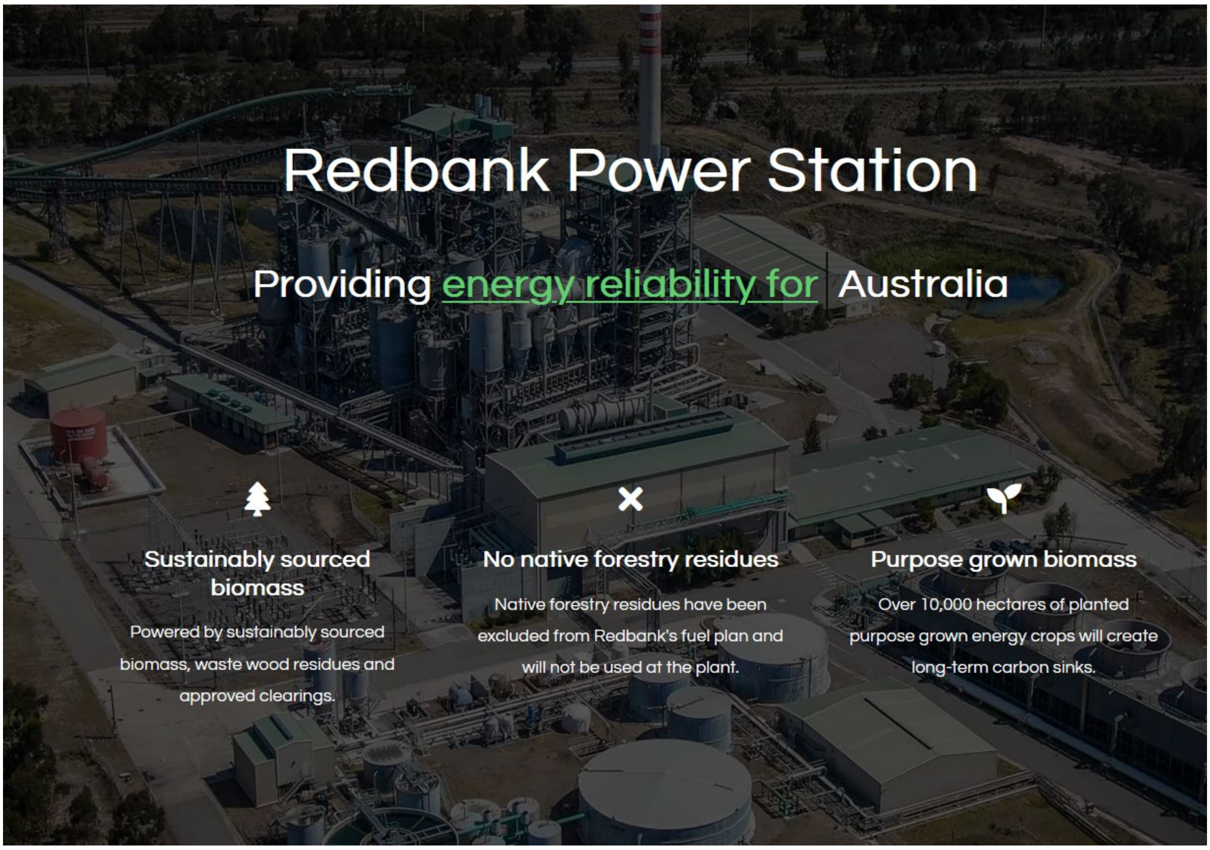


Figure 37. A DA is being assessed to convert an ex-coal power station to wood waste residues [35].

However, incineration is controversial. The organisation Zero Waste Australia publishes a map of 17 waste incineration projects across Australia which they claim will burn 3,909,500 million tonnes of waste every year and contribute more than 4 million tonnes of greenhouse gases into the atmosphere. Zero Wate Australia and other groups question the sustainability of such practices [36,] which may prove to be a legitimacy/social-licence-to-operate barrier that prevents the adoption of this scenario.

OYSTER SHELL AUDIT FINDINGS

The below table provides an indicative estimate of the volume of oyster shell material at each of the major NSW estuary farming locations. Estimates are based on assumed values for oysters-per-basket, average shell weight, mortality rates, and the overall aggregate production volumes of the leases in each estuary. Whilst the accuracy of estimated volumes may vary based on the validity of input parameters, the table nonetheless provides an overall sense of scale and an understanding of where the highest production (and therefore largest waste volumes) may be located.

Table 6- Oyster production by estuary and estimated infrastructure use (2022/23)

Estuary	Species	Total dozens	Basket or tray number **	Shell generation estimate in tonnes ***	Shell generation in cubic meters ****
Macleay River	Sydney Rock Oyster	28,882	9,627	23	18
Hastings River	Sydney Rock Oyster	129,841	43,280	102	482
Camden Haven	Sydney Rock Oyster	151,800	50,600	119	95
Manning River	Sydney Rock Oyster	36,236	12,079	28	23
Wallis Lakes	Sydney Rock Oyster	899,304	299,768	706	565
Port Stephens	Sydney Rock Oyster	498,401	166,133	391	313
Port Stephens	Pacific Oyster	39,740 54,323	13,246 18,107	31 43	25 34
Brisbane Water	Sydney Rock Oyster	14,583 131,906	4,861 43,968	11 104	9 83
Brisbane Water	Pacific Oyster	900	300	1	1
Hawkesbury River / Patonga Creek	Sydney Rock Oyster	49,052	16,351	39	31
Hawkesbury River / Patonga Creek	Pacific Oyster	46,486	15,495	37	29
CrookHaven / Shoalhaven River	Sydney Rock Oyster	204,716	68,239	161	129
CrookHaven / Shoalhaven River	Pacific Oyster	35,576	11,859	28	22
Clyde River	Sydney Rock Oyster	367,349	122,450	289	231
Clyde River	Pacific Oyster	240,742	80,247	189	151
Tuross Lake	Sydney Rock Oyster	253,149	84,383	199	159

Wagonga inlet	Sydney Rock Oyster	496,362	165,454	390	312
Wapengo Lake	Sydney Rock Oyster	306,763	102,254	241	193
Merimbula Lake	Sydney Rock Oyster	1,039,928	346,643	817	653
Pambula River	Sydney Rock Oyster	277,680	92,560	218	174
Wonboyn River	Sydney Rock Oyster	129,930	43,310	102	82
Others*	Sydney Rock Oyster	185,367	61,789	146	116
Others*	Pacific Oyster	15,211	5,070	12	10
Totals	All species	5,634,227 dozen	1,878,076	4,425 tonnes	3,540 m^3

* Not available for confidential reasons (≤ 5 current permit holders in the estuary). Estuaries include Tweed River, Richmond River, Wooli Wooli River, Bellinger River, Nambucca River, Botany Bay, Conjola River and Nelson Lagoon.

** Based on the broad assumption a typical basket used for cultivation holds 36 oysters (3 dozen) at some point in the production cycle . The calculation has not been adjusted to account for oyster produced in trays on rafts from around Port Macquarie north. Dozens divided by 3.

*** Based on the average oyster morality of 17% generated by survey results, with oyster shell weighing 0.385 gm x number of shells / 1000 for tonnes [37].

**** 1 cubic meter = 800kg [38].

How much waste is stockpiled or generated?

Based on production volumes, shell waste generated in the 2022-23 financial year has been calculated to be in the vicinity of 4,425 tonnes or 3,540 cubic meters. This figure will vary from year to year depending on disease cycles, natural disasters, catchment health, production success and a number of other consumer and industry factors. It is also based on the assumption that dead shells are stockpiled in accessible locations, which is sometimes not the case given some sheds are on islands or inaccessible to trucks. What is more difficult to calculate is the current consumption of those stockpiles by farmers and secondary parties for other current usage (i.e., driveways, erosion protection, stockfeed, human food or environmental oyster reefs).

Geographically most volumes are stockpiled in the Merimbula Lake estuary followed by Wallis Lakes, Port Stephens and Wagonga Inlet, based purely on estimates from production figures.

The other source of shell waste is post-retail. Excluding the 17% mortality rate, if it is assumed that the other 83% of cultivated production volumes reaches the consumer, that figure of shell distributed around the country increases to the vicinity of 21,605 tonnes or 17,284 cubic meters. Fortunately, there are schemes that collect and process a small percentage of that shell, however most would currently end up in landfill.

Discussion of potential disposal/recovery scenarios for oyster shell waste

Table 7. Several key scenarios for oyster shell recycling are detailed below, as well as the key challenges and broad requirements to execute each scenario.

SCENARIO	DESCRIPTION
S 1	**Do nothing** • This scenario does not imply that discarded shells are not being used for anything. Rather, that the process of stockpiling, handling and dispersal in an ad hoc manner would continue for the time being. • An inherent risk to this scenario is the lack of circularity: discarded shells become a wasted resource, rather than a recyclable commodity that can reduce overall waste.
S 2	**Human consumption** • Oyster shells are noted for their high calcium content, and as such, have been utilised for human consumption in the form of vitamin capsules and powders. • This scenario requires partnerships with the vitamin/pharmaceutical industry, which inherently imposes standards around the quality assurance of shell waste.
S 3	**Reef restoration** • Oyster shells present a natural substrate that adds habitat complexity and can act as a foundation material for pseudo-artificial reefs, where manufactured structures such as cages, twine and baskets are used to secure large quantities of discarded shells, which are then deposited in strategic locations in an effort to attract ecological communities. • Reef restoration can also involve the use of large volumes of bundled oyster shells as graduated seawalls to help mitigate erosion by dampening the shock force of wave collisions on vertical walls.
S 4	**Animal consumption** • Similar to human consumption, oyster shells have been used for animal consumption due to their high calcium content. Specific applications include as an additive to poultry feed to promote stronger eggshells, as well as for other livestock such as pigs and cattle as a general calcium booster. • Animal consumption still imposes standards around the quality assurance of shell waste which may differ from that of human consumption.
S 5	**Erosion control/ driveway medium** • When crushed and processed in bulk, oyster shells can be used as an alternative medium to crushed rock/gravel to build driveways, pathways and similar landscape elements. • This practice has a long history, particularly in areas such as the US Gulf Coast, where crushed oyster shells have also been burnt to create lime and used as ‘tabby’ concrete in building construction. • As a crushed medium, oyster shells can also help mitigate erosion, particularly in areas exposed to high rainfall.

S 6	**Agricultural (EPA approval pending)** • The calcium carbonate content of oyster shells also proves useful in agricultural applications, as a soil-conditioning or liming agent. This includes both industrial and commercial scale uses, as well as lower-scale domestic soil contexts.
S 7	**Use as a bioresin** • Composite materials used for a variety of multi-use and disposable use products

Scenario 1. Do nothing

Shell waste would continue to be a familiar site when visiting oyster land bases. Generally, the area of space consumed by piles can be accommodated for in the foreseeable future at most sites, based on the anecdotal/verbal feedback of some farmers. However, policy to control storage around stockpiles may tighten up in future. Another risk is that the social licence to operate (SLO) of oyster farmers is questioned or twisted to reflect negatively. An example of this occured at a farm in Western Australia where extra scrutiny was applied because of the owner's social status. The farm was proactively and legally disposing of waste at an approved tip in Albany, however the practice was being called into question in an attack on their social license [39].

Similarly, leases and land bases near to residential homes in some coastal locations (such as Brisbane Waters) have been subject to complaints around visual pollution and noise. In most cases, the oyster businesses outdate the new land uses, however it remains a cause of attack.

Scenario 2. Human Consumption

Calcium is the fifth most abundant element in the earth's crust and is necessary for both plant and animal life today. Moreover, the natural diets of all mammals are rich in calcium. The diet of Stone Age human adults is estimated to have contained 2000 to 3000 mg/d, three to five times the median calcium intake of present-day US adults [40]. This suggests many people are deficient and the supply of the mineral through supplements is a significant business. An examination of a number of different products and suppliers to assess the prevalence/presence of Country of Origin (CoO) labelling in pharmaceuticals suggests that this information is generally not included, and legislation indicates that it isn't a requirement at present[41]. However, with CoO Labelling laws currently being updated and implemented for seafood products, it would seem the area is somewhat grey. Subsequently it is thought many elements for supplements sold in Australia are imported.

A few oyster/mussel/marine product companies are exploring domestic supply avenues, and have requested that the project unlock a current regulatory hurdle to the market by investing in Hazard Analysis of Critical Control Points (HACCP) processes, opening the way for them to seek Therapeutic Goods Australia (TGA) certification in Australia. A person or organisation wishing to supply a therapeutic good in Australia must apply for market authorisation from the TGA. Currently the burden of these costs sits with the producer (who may want to supply the product for perhaps another company with established factories and markets to sell the product). The project needs to be aware of the high level of private benefit should it invest in this area to open up what is expected to be a high value per tonne avenue for future waste shell utilisation.

Figure 38. an example of a health supplement range utilizing Calcium [42].

Scenario 3. Reef restoration

The utilization of shell for reef restoration has accelerated in the last 5 years with several large Not-for-Profits such as Ozfish and The Nature Conservancy, as well as State Government Fisheries departments applying shell. Much of this has been obtained from industry in-kind to date or through retail shell return recycling schemes. OceanWatch has in the past paid farmers a nominal fee to supply shell, however in NSW this fee was related to the pretreatment required to meet biosecurity requirements (over 80 degrees in water for 5 plus minutes) and the labour and logistics involved. State biosecurity departments need to be consulted on a case-by-case basis where people want to utilise shell in restoration activities. Unfortunately, in NSW the Fisheries aquatic habitat branch does not support shell as a preferred substrate alternative in reef restoration projects. Support varies greatly between states with large numbers being used in Queensland and South Australia.

If modified, the shell can be used in bioresins for multiple uses (here and later in scenario 7). To test the concept, the University of NSW was provided with 35kg of oyster flour (ground and sorted) procured from a farm on the Clyde River. Some projects were completed by students to utilise the flour in new products, including Quince So (UNSW student) with a project titled: RE:HABITAT, up-cycling oyster shell waste into 3D printed artificial reefs.

The project description states that RE:HABITAT up-cycles oyster shell into 3D printing oyster shell material that is ready to build new reef structures, based on the idea that returning shells to the waterways is vital as the calcium carbonate content is essential for oyster larvae to grow. The project argues that processing oyster shell waste into artificial reef structures could divert tonnes of waste going into landfills. Additionally, 3D printing additive manufacturing technology using oyster shell bio-materials could enable up-cycling: one step closer towards a circular economy. The artificial shellfish reef would be constructed of recycled oyster shell and aggregates, and placed on substrate-limited sites where “construction intervention” is required (i.e. sandy or muddy sea floors).

Figure 39. Reef restoration features made using recycled oyster shell by Quince So (UNSW)

A similar example is the sustainable oyster buoy - Oy - developed by Kyeongho Park from the Korea Advanced Institute of Science and Technology. From the project description: "Approximately 810,000 tons of plastics are being discharged into the ocean every year, with about 70% generated from the maritime industry. Oy is made from oyster shells and offers an environmentally friendly alternative to plastic waste from fishing nets. They are composed of oyster shells and cement, and when they reach the end of their buoyancy life and become damaged, they sink into the ocean, acting as artificial coral reefs, providing a habitat for marine life such as fish. Through oyster shell buoys, we can achieve sustainable cycles for both the fishing industry and marine life."[43]

Scenario 4. Animal consumption

A small number of companies currently sell shell grit to domestic poultry and bird producers, reportedly from 2 suppliers in Australia (in WA and SA). Green Valley Grains in Victoria retails a coarse grit for $3/kg, and packaged bird grit retails for $20/kg. The online retailer Pet Horse & Farm Supplies sells a 25kg bag for $30.85.

Figure 40. An example of grain sold in 2 and 5kg packages [44].

This suggests there is an established market that is currently meeting the needs of the pet and poultry sectors. One retailer quoted that they consume 144 tonnes a year. An expansion of this segment is unlikely unless a market can be developed in the wider pet or meat stock industry as a nutritional supplement. A literature review suggests that oyster shell product has previously been used as a roughage replacer in fattening beef cattle rations in 1968 (in Australia) and is in current use in farms around the world, such as the Phu Lam firm (Vietnam), which has added oyster shell powder to cattle feed in order to boost their mineral content. These products are made by drying oyster shells at 85 degrees Celsius to remove moisture and soften them before being ground into powder. When added to feed, oyster shells' organic calcium content helps cows boost milk output, meat production, bone development, and bone growth. This is beneficial for pregnant cows and young calves. In terms of proportional volume and usae, it is known that oyster shell powder mixed with concentrate is applied at a rate of 0.1 kg per head every day.

Figure 41. Shell use as a nutritional supplement in Vietnam in a feedlot arrangement [45].

The use of shell beyond established lines looks promising for feedlot produced stock and would benefit from further investigation in Australia.

Scenario 5. Erosion control

Through its 'Living Shorelines' project OceanWatch experimented with oysters held in coconut fibre bags as an erosion control measure. Shell has shown great properties in being able to absorb wave energy when placed in a flume tank at the University of New South Wales and assessed by engineers. For this reason, it is a popular erosion control element implemented informally around oyster farms.

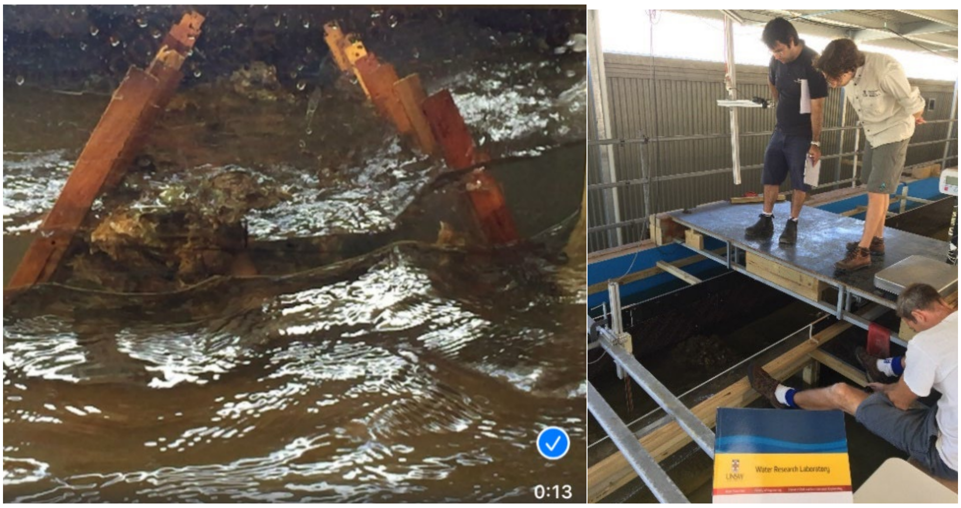


Figure 42. Shell held in place by pegs of timber or coconut bags were put through a wave treatment and the results measured. As a result of wave energy dissipation (which will vary throughout the tidal cycle), wave-driven foreshore erosion processes are expected to be attenuated immediately landward of oyster shell filled bag structures [46].

Significant policy hurdles remain in being able to use shell for erosion control in coastal sites in NSW, mainly around policy sensitivity of applied responses to climate change driven sea level rise where the state direction is managed retreat. However, the NSW Government will promote an adaptive, risk-based approach to managing the impacts of sea level rise and recognizes many local councils are "at the coal face" of responses. All coastal councils have worked on modelling and planning coastal hazards including erosion, inundation and flooding. Engineered property protection works are sometimes permissible, however the availability of shell in bulk from established landscape supply companies is rare, and other alternatives are much preferred by traditional engineers such as geotextile structures with sand and rock predominate. Current property protection works of a civil nature are overseen by strict engineering, building and construction codes, which leave less interpretation and creative innovation ability for those that pursue a softer landscape approach. Where built property is involved, this is unlikely to change, however on farmland or nature reserves this is much more likely to evolve over time. This is especially true in light of the use of plastics in coastal rehabilitation or eco engineering projects, and the public consciousness of plastic leakage into waterways.

Figure 43. Several projects on the mid north coast completed by the Hunter Local Land Services use oyster shell in combination with timber as a softer erosion control option working with nature (B. Huges Hunter LLS)

The cost of current bulk materials such as rock or sand sit around $100/ tonne. Biosecurity cleanliness, Crown Lands permissible activity, NSW Fisheries, and NSW EPA policy and permits all require consideration. This has to-date stifled the ability of the public to use shell for erosion control in estuarine locations, and as such little market exists.

Scenario 6. Agricultural

Studies suggest that about 40% of the planet is deficient in calcium. A calcium deficiency can have a profound effect on plants and can create a cascade of problems that are often difficult to diagnose[47].

Interest from the agricultural grazing sector in bulk supply of ground shell was obtained as part of this study. As a competing product, agricultural lime is currently the standard product in use and is made from limestone/chalk. During the study, a grazier west of Mudgee expressed interest in the order of 50 tonnes of a bulk crushed oyster product. He was seeking the additional mineral micro elements that it is thought shell contains, along with the neutralising value of the calcium carbonate for acidic soils. In terms of the agricultural machinery required to disperse the product, application via a twin spreader belt fed implement was considered adequate to spread the shell, meaning no need to pelletise the product. This may not be the case for a farmer with the traditional non-belt feed, gravity single power-take-off (PTO) model.

Notably, in this example the farmer was also requesting the chemical composition of the shell. Generally speaking, the appetite to pay more for shell beyond agricultural lime prices is limited unless marketing approaches can sell the benefits of trace minerals.

Table 8. Liming costs [48].

	Bulk per tonne (without freight)	**Bagged per tonne**
Current liming alternative (Agricultural lime)	$100	$220 - 275
Cost in a pelletised form (Calciprill)	NA	$460 - 688

No sales of oyster shell in bulk form could be found in the literature, however it is a key component being used by Ocean2Earth in soil mixes, as a soil enhancer retailed in a ready-to-use bag from $6.60- $9 a litre, with 250L and 1 tonne bags of soil mix also available. Notably, conservative “green tape” is currently being reviewed around terminology to facilitate marketing and retail distribution, and the NSW Department of Primary Industries and Regional Development (DPIRD) is in the process of refining the draft conditions proposed by the EPA for an Order and Exemption approval for the use of oyster shells as a soil enhancer and fertiliser. An Order and Exemption acts like a series of permit conditions for the crushed shell meal to be considered as a form of fertiliser and soil amendment, as opposed to a source of pollution.

This particular project was prompted following a series of QX outbreaks and flooding events across NSW leading to increased mortality and shell waste. NSW DPIRD was approached by Ocean2Earth, Bega Circular Economy Working Group, OceanWatch and NSW Farmers to explore circular economy and resource recovery options for oyster shells.

The project funding was granted through the LLS Early Needs Recovery Program in 2023, and DPIRD were advised to apply for an Order and Exemption, as a legal requirement from the Environmental Protection Authority (EPA).

Scenario 7. Bioresins

A number of bioresin products currently available on the market were investigated by the study as well as some design concepts. Many of these aim to replace a percentage of petroleum based feedstock with an organic component such as shell to reduce petroleum feedstock volumes. These show great promise as being high value shell users.

One such example is OCEANEX, a Bio-Renewable Polymer Supplement available in the UK. OCEANEX achieves high polymer replacement levels in plastics by harnessing the power of the compounds naturally found in powdered oyster shell. The shell is denatured, blended with some additional organic material to create super-fine OCEANEX powder.

This OCEANEX powder can be introduced directly into some manufacturing processes, and OCEANEX can supply it in a powdered form. However, OCEANEX is more commonly supplied as a compounded masterbatch pellet. The stock pellet carrier is HDPE which is compatible with most types of plastics. This HDPE carrier material is less than 10% of the pellet mass.

To create a fully bio-renewable masterbatch, OCEANEX offers the option to use Green PE (Braskem) as the carrier material, and can supply a version of OCEANEX compounded with the biodegradable polymer polybutylene adipate terephthalate (PBAT) that can be used with compostable bio-plastic films.

Calcite

Calcium Carbonate is a chemical compound with the formula CaCo3. Calcite is a naturally occuring polymorph of CaCo3 and it is the primary mineral found in limestone, marble and oyster shell. Powdered Calcite is widely used as a filler in the production of plastics but it comes from mining and quarrying. The advantage of using Calcite from Oyster shell is that it is bio-renewable.

Aragonite

Aragonite is the crystalline form of calcium carbonate. Aragonite has an orthorhombic crystal structure which helps it to integrate well with synthetic polymers. This helps blends of plastic + OCEANEX establish a stable material structure compared to using conventional fillers. Aragonite sourced from Oyster shell is of course also a bio-renewable material.

Chitin

In the nacreous layer of Oyster shells, the bio-polymer Chitin serves as the major component of the organic framework. Bio-polymers can be blended with synthetic polymers to increase the renewable content of plastics and to provide dimensional stability.

Figure 44. Descriptions of binding agents [49].

Oysterplast

Oysterplast ™ is a composite bioresin for HDPE, LDPE, LLDPE, PET, PP and PVE plastics that are made by Puro Renewables as a partner in the NaturePlast group. The technology they have developed allows oyster shell to be integrated with plastics and made into a wide variety of products. These products are generally recognized as safe by the Federal Food, Drug, and Cometic Act in America to be used for direct and indirect food and beverage contact [50].

Shellmet

Tokyo advertising agency TBWA\Hakuhodo and plastics manufacturer Koushi Chemical Industry Co. have created Shellmet, a hard hat made from 30% discarded scallop shells and 70% discarded/recycled PP plastic. The manufacturers promote the product as having reduced emissions, improved material circularity, and as having improved design strength.

Figure 45. Shellmet's materials can be recycled to remake another helmet or reused separately as building materials. According to its creators, the helmet draws on biomimicry – a design approach wherein systems found in nature are adopted by humans to solve problems [51].

Seawool

Seawool fabric is an innovative material made from oyster shells combined with recycled plastic bottles. It's an eco-friendly option that provides a better comfort-wearing experience and feels like wool. The shell once treated at 1000 degrees is grinded into a fine powder and incorporated with recycled PET bottles and made into a polyester yarn. Taiwan has a 300 year history in oyster farming and the innovation came in 2017 from Creative Tech Textile Co, Ltd [52].

Furniture from 'The sea by the sea'

Furniture from 'The sea by the sea' was a project by UNSW student, Arpad Bogdan. The design concept explored new ideas to align with the OceanWatch end of life product application of combining Oyster shell and HDPE baskets.

Figure 46. “Oyster Chair” by Arpad Bogdan (UNSW), utilises both shell and HDPE waste.

Ostra Plate

Christina Chen (UNSW student) Oyster serving platter- Ostra Plate. The design concept explored the relationship between eating oyster and serving oysters. It aimed to tell a compelling story with the design by transforming discarded oyster shell waste into beautiful oyster serving platters inspired by the forms and textures of the ocean. By turning old oyster shells into vessels for oyster consumption, each time oysters are served on this platter, a powerful story about sustainability and biophilic design can be told.

Figure 47. Ostra Plate is inspired by natural forms and textures. Christina Chen (UNSW).

Recycling options for shell.

To dispose or recycle?

In NSW there is policy which limits the transfer of living oysters between estuaries, as well as limiting what can be done with deceased oysters and their remains such as shell waste. In this respect, there is a fine line between treating a substance as a resource, versus treating it as pollution. Generally, oyster shell is currently underutilised and shows great promise in new innovative designs and applications. Hopefully current progressions will open further opportunities for this undervalued waste. It would be remiss for this (often already stockpiled) organic material to end up in landfill when at its core it is 98% composed of useful calcium carbonate.

Processing of materials to make ready for recycling

There is a certain degree of processing that can occur depending on the end use. Generally, the pasteurisation of shell is required in NSW (over 80 degrees for 5 plus minutes) if it is to be used for anything other than landfill. This is a significant financial burden with Australia's high cost of labour. Often piles can be made and let sit in the sun for days or weeks. This UV exposure is sufficient to dry the shell, remove any remaining meat, and also encourage the departure of any living sea creatures such as crabs that may have made the shell home. In addition, sorting the shell from contaminant manually is required to maintain a quality product. Cable ties, cigarette butts, seagrass etc., along with other general debris such as soil should be consciously avoided.

If using shell waste for erosion control, there is great benefit in maintaining the shape of the shell and no specific further treatment is required. If using for other purposes, a hammer mill can be used to beat up the shell into grit and further to flour if that is the consistency required.

NEXT STEPS

It is recommended that the NSW oyster industry works with oyster producers in other states and overseas to further proactively find value and use of their waste with companies in business to utilise it. An implementation plan specific to the OceanWatch grant will detail the next steps proposed for the project to action suggestions following feedback from the projects steering committee. OceanWatch remains committed to healthy oceans that are productive, valued and used in a responsible way.

GLOSSARY

- **Biodegradable:** products made of Poly (Butylene Adipate-Co-Terephthalate) (PBAT), Poly (Butylene Succinate) (PBS), Polylactic Acid (PLA) or Polycaprolactone (PCL). They have been created with the ability to slowly break down until they're able to be consumed on a microscopic level. They undergo degradation resulting from the action of naturally occurring microorganisms such as bacteria, fungi, and algae. **Australian Standard:** Australia has no mandatory standard on biodegradability or degradability. However, the voluntary Australian standard (AS) 4736–2006, Biodegradable plastics—Biodegradable plastics suitable for composting and other microbial treatment has stringent requirements for the time frame in which a product must break down in a commercial composting environment, its toxicity and the amount of organic material it contains.
- **Bioresin:** Is a type of bio-renewable that replaces fossil fuel polymers and thermoplastics. In this context it refers to a bioresin made from oyster shell waste, which can be formed into useful products such as hardhats/safety helmets.
- **Bio-renewable:** refers to materials that have been manufactured from biological sources/biomass, and are generally used as an alternative to conventional, mass-produced products made from fossil fuel source materials
- **Compostable:** products are made by organic elements or plants that can degrade with time. For example, corn starch, bagasse, PVAL/PVOH, and others. Compostable products produce humus, upon degradation, which is the richest and most important part of all soils. The high level of microbial activity in humus boosts beneficial microbes within your soil which, in turn, assists plants to strengthen their immune systems. Therefore, compostable products do not have any toxic element to the environment after degradation. It is important to recall that compostable products need a specific compostable environment to degrade which includes warm temperatures, nutrients, moisture and plenty of oxygen.
- **Extraneous componentry:** parts not directly connected or related to an item
- **Waste valorisation:** valorisation refers to giving something economic value, lending waste valorisation the specific meaning of "giving economic value to waste." This can take the form of recycling, recovery, or repurposing of waste materials.

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