Reducing CO_2 to Combat Climate Change: Shipping Vessels Carbon Footprint from Cradle to Grave

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Summary:

As Climate Change and its effects are impacting the planet at an ever-faster pace, all industries are forced to assess the effect of their own footprint on the environment. The shipping sector globally generates over 2.6% carbon dioxide[1] (CO_2) and between 18-30% of the world's nitrogen oxides.[2] While these emissions occur during the life span of the ships operation, extensive amounts of CO_2 are already generated beforehand during the production process and subsequently at the end-of-life disposal of the ship. As large volumes of materials are required to assemble these vessels, with some reaching each up to 400,000 tons in weight, the choice of raw materials could significantly affect the total ship carbon footprint even before commissioning. It is even more critical when considering the LCA (Life Cycle Assessment). After a vessel decommissioning, recycling could further be carbon intensive in relation to the disposal of materials selected at the design phase.

Background:

Climate Change is occurring at a faster rate than predicted by some of the most advanced scientific models. Additional regulations for end-of-life disposal of any new products, be it vehicles, or ships, are likely to come into effect faster than anticipated. In addition, corporate Environmental, Social, and Governance (ESG) requirements as well as brand image, coupled with demand for greener supply chains, could further impact these industry expectations and thus potentially add new strict end-of-life requirements, making new products obsolete prior to their standard disposable timeline.

Subsequently, reducing GHG (Greenhouse Gas) emissions early, is paramount in achieving the goals set by the Paris Agreement for limiting global warming to 1.5°C. In addition to the 2.6% of the global carbon dioxide (CO_2) generated, studies show that shipping is the source of 18-30% of the world's nitrogen oxides. Fifteen of the largest container ships alone emit more of the noxious oxides of nitrogen and sulfur pollutants than all the cars in the world combined.[3]

Shipping lines are now carefully evaluating the challenge of balancing additional costs associated with new technologies to meet their climate goals versus real operational savings. While the upfront cost of new technologies is in most cases higher, on a 30-year scale, the economic benefits would prevail. Furthermore, adapting to the ever-increasing environmental regulations would increase the existing systems' operating expenditures, leading to more pressure on profits.

The economic assessment of additional indirect costs associated with the ship's total life cycle must now to be considered. These include not only the disposal budget but also the CO_2 cost (in the form of Carbon Tax) generated during vessel production, operation, and end-of life of the product. These will, in part, be imposed by legislation, which in turn will be driven by internal ESG requirements, brand images, and consumer demand for sustainable solutions. It has already become necessary to adopt the concept of total Life Cycle Analysis (LCA) in conjunction with GHG emissions. Other sectors, which are being confronted with similar obligations, have this same strategy which is still being implemented. This new comprehensive "CO_2-based LCA" used for new ship designs is key to successfully addressing current and expected future regulations, while simultaneously addressing the "Total Real Cost" and "Real Environmental Impact" of ownership.

There are three main areas in the ship building industry that impact not only the cost, but can also have a dramatic influence on carbon emissions: ship design, propulsion system, and material selection.

a) Ship design

Many new design ideas developed in recent years have potentially demonstrated significant impact in fuel efficiency and CO_2 reduction. Just some "simple" design modifications to the ship's bulbous bow, for example, has resulted in a verified 23% reduction in CO_2 emissions during a six-month period. These savings were achieved in one case study with one shipping company. In an additional case study, fuel costs were reduced by approximately 8%.[4]

Another effective design that has been considered, is the Air Lubrication System originally developed by Mitsubishi, that reduces the resistance between the ship's hull and seawater using air bubbles.[5] The air bubble distribution across the hull surface reduces the resistance working on the ship's hull, creating energy-saving effects. With the right ship hull design, the air lubrication system is expected to achieve up to a 10-15% reduction of CO_2 emissions, along with significant savings of fuel.[6]

A further unique asymmetric stern design, which helped optimized the flow around the propeller was incorporated in Carl Büttner's latest ship, which resulted in an increased efficiency of the CB Adriatic by around 3%.[7]

As most of these technologies are in their early stage, not every ship can be cost-effectively retrofitted to realize the CO_2 and fuel savings benefits. But even "modest" improvements of 3% would have a significant impact on the emissions expelled and money saved by ships as they travel millions of miles within their operating lifespan.

Just potentially combining the above technologies together could show that these design changes alone can have a real impact in reducing emissions and improving fuel efficiency.

b) Propulsion systems

With changes in ship design to increase propulsion efficiency, the selection of fuel systems to propel the engines also significantly impacts the environment. Up to now, almost all cargo ships and cruise liners use bunker fuel as a propellant for their engines. As of 2020, the maritime industry is set to shift away from bunker fuel to diesel.[8] Bunker fuel is a heavy and thick fuel, which is "left over" after refining of raw oil into diesel, gasoline or jet fuel. It is inexpensive but very polluting, expelling significant amounts of sulfur (in the form of SOx). It is particularly hazardous to human health, causing respiratory symptoms and lung disease. In the atmosphere, SOx can lead to acid rain, which can harm crops, forests, and aquatic species, and contributes to the acidification of the oceans.[9]

The International Maritime Organization (IMO) will require that all fuels used in ships contain no more than 0.5% sulfur, which will be a significant reduction from the existing sulfur limit of 3.5% and is well below the industry average of 2.7% sulfur content.[10]

Switching to alternative fuels brings additional challenges besides the potential increase in costs, as some of the options still have a large carbon footprint. Many companies are nevertheless working to comply with the cap, including by installing exhaust scrubber systems and switching to liquefied natural gas (LNG).[11] But a new report from the International Council on Clean Transportation (ICCT) has found that the most popular Liquefied Natural Gas (LNG) ship engine, particularly for cruise ships, emits between 70% and 82% more life-cycle greenhouse gas (GHG) emissions over the short-term compared to clean distillate fuels.[12]

Some shipping companies have also started considering full electric or hybrid technologies, combining rechargeable batteries either with existing fossil-based systems. Currently, the world largest plug-in hybrid ferry is the Color Line Hybrid, operating on the crossing between Sandefjord in Norway and Strømstad in Sweden.[13] It can accommodate 2,000 passengers and between 430 and 500 cars. Its 5 MWh (megawatt hour) batteries can operate for 60 minutes at speeds up to 12 knots.[14]

It is clear that the type of fuel selected for operating the ship can have a dramatic impact on the environment. It is crucial for government and companies to accelerate the investments and prioritize the evaluation of new technologies at an even higher pace, as once these systems are installed in ships, their real impact to the environment cannot be changed.

c) Materials

As previously highlighted, evaluating the full impact of materials depends on three domains that are to be taken into consideration with LCA: raw material origin and production, total costs of operations and end of life disposal.

The shipbuilding industry requires massive volume of raw materials in order to build each ship. The gross weight of a typical cruise ship is around 200,000 tons and reaching up to 403,342 tons for a crane ship, such as the *Pioneering Spirit*.[15]

Even though over 90% of the materials currently used are steel based, the remaining 10% would still leave over 20 to 40,000 tons of "other" materials, which includes various plastics and composite parts that have a significant impact on GHG emissions in their own production and end-of-life recycling.

As per the Hong Kong International Convention for the Safe and Environmentally Sound

Recycling of Ships, 2009 (the Hong Kong Convention), it aimed at ensuring that ships, when being recycled after reaching the end of their operational lives, do not pose any unnecessary risks to human health, safety and to the environment.[16]

Subsequently, the ship recycling yards will be required to provide a "Ship Recycling Plan", specifying the way each ship will be recycled, depending on its particulars and its inventory.[17]

Since 2009 though, the CO_2 impact of various materials including plastics on Climate Change has become more prevalent amongst consumers, companies, and governments. In addition, the IMO launched its initial strategy to reduce GHG emissions in 2018 moving to 50% reduction of GHG emissions by 2050. All reductions are relative to the 2008 levels. The shipping industry has already and continues to adopt various new technologies with the goal of reducing their CO_2 footprint.[18]

As the shipping industry is adapting to meet CO_2 reduction obligations, it will require them to start considering the transition to more sustainable materials. As the ships are expected to last for at least 25 to 30 years, this will ensure that their ships being built are not only aligned with new regulations and user/consumer pressure, but also warrant an effective sustainable recycling solution, as more stringent regulations will be created as the impact of Climate Change will accelerate over the coming years.

This is a very cost sensitive industry and changing cost structure needs to be carefully examined for impact when compared to the total LCA. Additionally, the large range of various raw materials applied in manufacturing modules for shipbuilding, exhibit a large range of carbon intensity levels. The overall environmental impact is massive before the vessel is even commissioned.

In the pursuit of lightweighting, strength and cost efficiency, the industry has been turning to high performance engineered plastic alternatives for replacing steel counterparts.

There are two primary issues with components based on oil-based plastic:

1) Limited availability of end-of-life recycling solutions
2) Increased CO_2 footprint of the plastic material itself

1) End-of-life recycling:

In recent years, several companies have started to build innovative renewable energy and emissions reduction technologies for both shipping and offshore applications. These solar or hybrid based power solutions include marine hybrid power, computer control systems, marine solar power, and energy storage solutions with hybrid battery technologies.[19] All these systems contain various high performance plastic parts, which need to be sorted and recycled or disposed of at the end of their life.

Furthermore, there has been an increase in the use of fiber-reinforced plastics in the shipbuilding industry. The greatest advantage of using these types of materials are that compared with steel, they have a very favorable strength-to-weight relationship. However, as ship must meet stringent Safety-of-Life-at-Sea Convention (SOLAS) regulations, which details fire prevention, detection and extinguishing measures, some of these new plastics exhibit problems in fire-safety properties. To overcome these challenges, most materials are used for interiors as insulation “sandwiched” between non-flammable materials within the ship’s superstructure,[20] thus creating additional challenges for recyclers to separate and remove these materials at the end of the life of the ship.

Most of these engineered or fiber-reinforced parts are oil-based plastic compounds. They are generally made of a mix of different types of materials and polymers, which are often in the form of blended or composite materials.

The current recycling paradigm globally requires collection and separation of plastics based on a set of standard resin codes. The codes indicate the type of plastic from which an item is made. Both collection and separation must be functional and cost-effective, and the pathway used varies greatly from location to location.

For example, if you have a polymer which is recyclable, then you or the state or local or the federal authorities must have a workable collection method. Some of the methods could include drop-off by the individual or pick-up by a recycling agency, and if there is no agreed upon or functional method then for all practical purposes it does not matter whether your polymer is recyclable or not.

Similarly, the specific polymer needs to be segregable. Right now, polymers are classified as being in 1 of 7 categories[21]. These categories include 1) PET or PETE (polyethylene terephthalate polyester), 2) HDPE (High density polyethylene), 3) PVC (polyvinyl chloride) 4) LDPE (low density polyethylene), 5) PP (polypropylene), 6) PS (polystyrene) 7) Other (including acrylic, polycarbonate, nylons, all biopolymers to name a few). If the recycling provider accepts all categories (1-6) (which is not the usual situation) then the material can be recycled. However, water bottles, for example, can be made from 3) (PVC) or 5) (PP) and still cannot be recycled in most jurisdictions in the U.S because most public recycling centers generally do not accept these grades.

Note, to further complicate the recycling narrative, categories are much narrower than they look. For instance, category 1) PETE (PET) polyester, does not accept all polyesters like PBT (polybutylene terephthalate) or any other polyester like Polylactic acid (which is a polyester). Categories 2) (HDPE) and 4) (LDPE) are both polyethylene, where 2) is high density and 4) is low density. If you are using one of the six narrowly defined polymers and the recycler accepts that material, it can be recycled. However, if any of these “basic” polymers are combined with each other or in a composite, as it’s mostly done for engineered or fiber reinforced plastics in ships, then they cannot be recycled at all and would be automatically classified as Category 7).

Furthermore, there is a plethora of polymers outside of these six categories. All other polymers fall into Category 7). Category 7) is not recyclable and includes bio and oil-based polymers, such as nylon (polyamide), acrylic, polycarbonate, etc. as well as blends and composites. This means, most often, that separating them effectively within this category is almost impossible at the product’s end-of-life. At this point, they turn into an environmental dilemma.

It is worth realizing that if the recycling location only does landfill disposal of plastics, it does not matter whether the polymer is recyclable or not, it will be still disposed of in a landfill.

There are specialized plastic scrap dealers that collect large volumes of specific Category

7) plastics, such as bio-based plastics, Nylons, Polyesters and Polycarbonates to name a few. But they are very selective depending on the color, purity, and quality of such materials. Generally clear or white color products are preferred, as they can be mixed more easily with other polymers, while colored polymers are limited in their application. Also, materials have to be in pure form and not be blended with other materials.

Any material that falls into Category 7) and is not preselected by scrap dealers is generally disposed of in landfills or in many cases, end up in the oceans or exposed in the environment. The subsequent danger is illustrated in a recent study demonstrating that plastic, when exposed to the elements, release methane and ethylene - two powerful greenhouse gases that can exacerbate Climate Change[22]. One ton of Methane, for example, is a greenhouse gas that has 25 x higher warming potential than 1 ton of CO_2.[23]

It is estimated that plastic demand will increase from the current 311 Million tons to 1.2 Billion tons per year by 2050.[24] It is expected that plastics' GHG emissions will reach 56 gigatons, consuming 10-13% of the entire remaining carbon budget, critical to achieve the goal to remain below a 2°C increase in global warming by 2050.[25]

Furthermore, the global recycling industry has been impacted dramatically by the changes in the regulatory landscape, as waste transport across borders has become limited and increasingly hindered by regulations and trade restriction. People's Republic of China was the largest market for plastics waste in 2016, accounting for around 8 million tons (or 60%) of global imports.[26] The largest exporters of plastics waste to China in 2016 were Hong Kong, the United States, Japan, Germany, and the United Kingdom, with each shipping between 0.5 million tons and 1.3 million tons of material.[27]

On December 31 2017, China, previously the center of the global recycling trade, abruptly shut its doors to imports of recycled material, citing the fact that large amounts of the waste were "dirty" or "hazardous" and thus a threat to the environment.[28] This created a sudden collapse of plastic scrap prices and this once lucrative trade of shipping recyclables around the world, was in crisis.

Concurrently, the Basel Convention on the Control of Transboundary Movement of Hazardous Wastes and their Disposal (1989) was modified in May 2019 to list plastic waste, as a result, transboundary shipments of plastic waste have stalled.[29]

These unpredictable and continually changing dynamics driven by the pace of recycling law changes around the world, pose a further challenge for plastic waste processors striving to build an efficient and viable recycling system. This in turn will create additional challenges for the shipbuilding industry, trying to switch to alternative materials, but are faced with an uncertainty in end-of-life recycling of the parts used. Thus, it is paramount for this industry to carefully evaluate new shipbuilding materials, in particular alternative plastic-based materials, on their true effective global recyclability.

Subsequently, and of equal importance to all these new "green" technologies, end-to-end LCA imposes the obligation to include costs of recycling and each individual component's carbon footprint, which become even more critical for generating a true economic profile of the end product.

2) Total CO_2 footprint of plastics:

Carbon dioxide makes up the vast majority of the greenhouse gas emissions. CO_2 accounts for approximately 82% of GHG emitted in 2018.[30]

It is critical to note that the oil-based plastics components used in these new “green” technologies have a large carbon footprint associated with their own raw material production phase as they are based on non-renewable oil and are very energy intensive to convert.

Looking at the entire life cycle of oil-based plastics today, research shows, nearly two-thirds of its greenhouse gas emissions are produced in the early stages, progressing from fossil fuel extraction through the production of resins. Converting resins to pipes, bottles, bags, and other products generates just under a third of its emissions. The remainder comes from the disposal phase (Figure 1 – Life-Cycle Emissions of oil-based Plastics (2015)).[31]

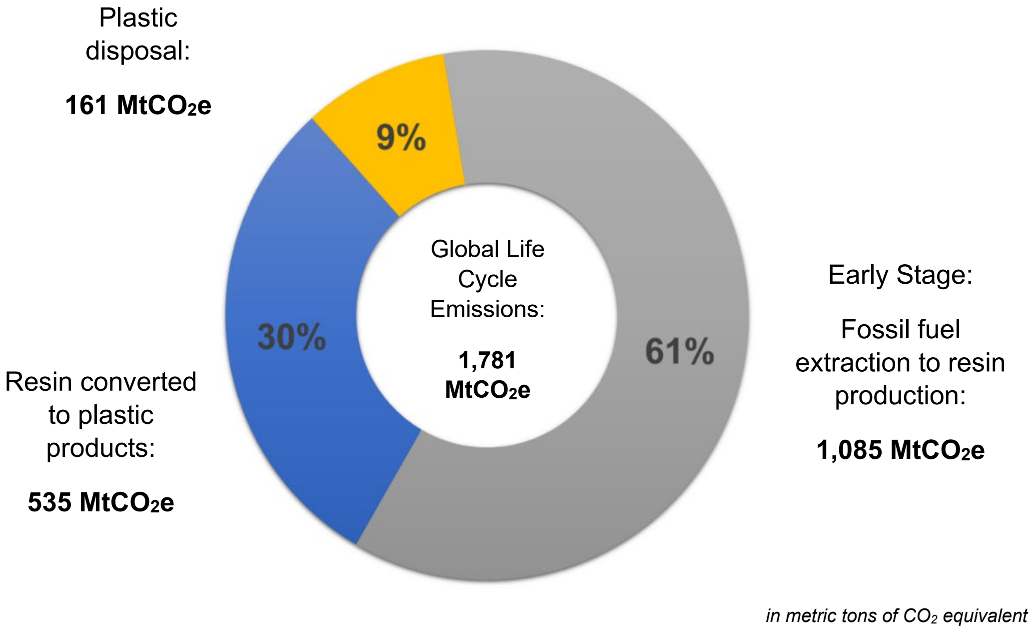

Figure 1 - Life-Cycle Emissions of oil-based Plastics (2015)

Some of the common engineered plastics used in the manufacturing of “green” technologies are Polycarbonates (PC), Polymethyl methacrylate (PMMA), Vinyl Ester (VE) resins, and various epoxies, to name a few.

The greenhouse gas emissions vary greatly depending on the types of polymers used (see Figure 2 - GHG of selected Plastics). As an example, producing 1 million tons of Polycarbonate would emit 7.6 million tons of CO_2. This would equate to 1,286,725 homes’ electricity use for one year.[32] A comparable bio-alternative plastic based on PLA, for example, would emit only 270,000 tons, a 96.5% reduction. In addition, biomaterials that exhibit a negative carbon footprint, such as NB-INOV, would not only erase the 7.6 million tons of CO_2 emissions, but additionally eliminate an actual extra 700,000 ton of CO_2 from the atmosphere through their unique manufacturing system.

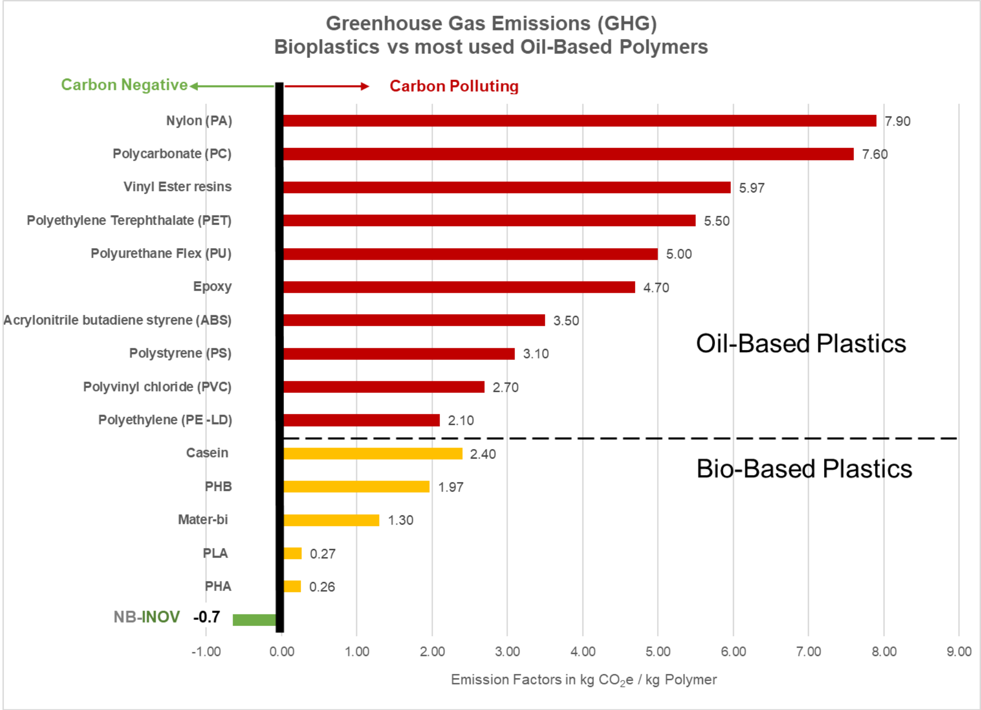

Figure 2 - GHG of selected Plastics

The impact of the selection of the plastic type can be demonstrated in an example based on a NYK Super Eco Ship concept design for a container ship for 2030. The company proposed additional supported propulsion systems based on solar, totaling a coverage of 31,000 m^2 with a peak energy output of 9 MW.[33] Most solar panels are currently made with glass to protect the solar cells and electronics from the elements.

Even though solar panels have a positive impact on the climate, as they do not pollute the environment during their life in operation, this is not necessarily true during the production phase of the actual panel itself and the end of life stage.

Concurrently, as companies are trying to reduce the weight of solar panels in general, one of the heavy components targeted is the replacement of the glass with plastic alternatives, which could reduce the weight by up to 50%.[34]

The weight of a highly efficient glass based solar panel from Tesla is currently 8 kg/m^2.[35] A study in North America found that the global warming potential (GWP) of glass was 1.25 kg CO_2e/kg glass[36]. Using this as a base to cover the 31,000 m^2 of solar panel area, this would equate to 248 tons[37] of glass with carbon emissions of at least 310 tons CO_2.[38]

An oil-based plastic alternative material that could be used to replace the glass is Polymethyl methacrylate (PMMA)[39], which creates 7.0 kg CO_2e/kg of polymer[40] emissions during the production of the polymer itself. PMMA has a 11x greater impact strength[41] combined with much lighter weight, but the increased environmental impact cannot be ignored.

To replace 31,000 m^2 glass based solar panels with PMMA plastic would almost triple the carbon emissions to over 868 tons[42], while reducing the weight to less than 124 tons[43].

To offset these increases in CO_2 footprint of this ***one*** plastic alone (see Table 1 - CO_2 offset per large ship), it could potentially require shipping companies to either purchase carbon certificates or spend extra resources to cover for the offset.

Table 1 - CO_2 offset per large ship

Solar panel based on:	Tons of CO_2 emitted	Equivalent to number of homes' energy use for 1 year[44]	Carbon sequestered by number of Tree seedlings grown for 10 years[45]	Carbon cost based on EUR 44.6 / tCO_2[46] (France 2019 & 2020)
Glass	248	29	4,101	EUR 11,060
PMMA	868	100	14,353	EUR 38,713

These would invariably increase the overall cost and potentially limit or hinder new technologies.

Even though there is a significant weight reduction in switching to plastic based solar panels, which would benefit the fuel efficiency of the ship, the over 3x increase in CO_2 emissions of the oil-based PMMA would negate the positive advances in reducing the overall CO_2 footprint in the manufacturing of the ship.

To overcome this dilemma, alternative bio-based plastics need to be considered, in order to truly address the recycling and increase in CO_2 issues, which are unavoidable with oil-based plastics.

The GHG of bioplastics are substantially lower and at times even negative, compared with oil-based plastics (see Figure 2 - GHG of selected Plastics).

Furthermore, bioplastics' degradability can be custom formulated, based on usage and life expectancy of the end-product. This is clearly evident upon examining the requirements for a plastic bag, made from bio-based materials versus those of a solar panel made from bio-based materials. The plastic bag is expected to degrade within a few weeks after its use, compared to a solar panel made with bioplastics which should last at least 30 years.

The advantage of bioplastics is that at the end of their life, they can either be recycled into virgin material, composted, or incinerated without any additional negative GHG emissions, as they originate from plants. In either case, the CO_2 created in any of these processes will be reabsorbed by any plant-based feedstock – as it is bio-based - thus relying on the balance nature it has itself created.

On the other hand, CO_2 that is emitted by the incineration of oil-based plastics is not going to be "reabsorbed" by the oilfields, thus left above ground as an additional burden to the environment to be absorbed by the oceans, plants or atmosphere, creating an imbalance, which leads to subsequent rise in temperatures and acidification of the seas.[47]

Bioplastics are made from organic feedstock (including corn, potato, algae, milk, food and agricultural wastes) and subsequently are processed into a polymer. The raw material source and the conversion processing used to convert the organic materials into polymer, can be customized to yield different performing polymer that can compete directly with their oil-based counterpart plastics.

Although bioplastics show in general a significantly lower environmental impact (see Figure 2 - GHG of selected Plastics) than the production of traditional plastics, they do vary in their overall environmental significance. This is largely due to the source of their feedstock, processing technology, type of energy necessary for converting the feedstock to bioplastics and the number of "direct players" within the supply chain requiring higher transportation needs. As a result, various plastics can be created with different performance levels for many applications.

One additional advantage of certain bioplastics, such as PLA, is its recyclability back to a virgin material. This material can be then directly reused and converted 100% back to new PLA, without any performance loss, as is commonly seen with oil-based plastics. Concurrently, there is a significant cost benefit.

It is notable that "bio-plastic" and "bio-based plastics" are not the same. Bio-based plastic denotes that there is some type of bioplastic (eg PLA, PHA, PHB etc) mixed in with an oil-based plastic, as they commonly do with PE, PA, ABS, etc. (see Figure 3 - Bioplastics vs Oil-based Plastics degradability[48]) in order for companies meet their green claims requirement, while not completely abandoning the oil-based plastic.

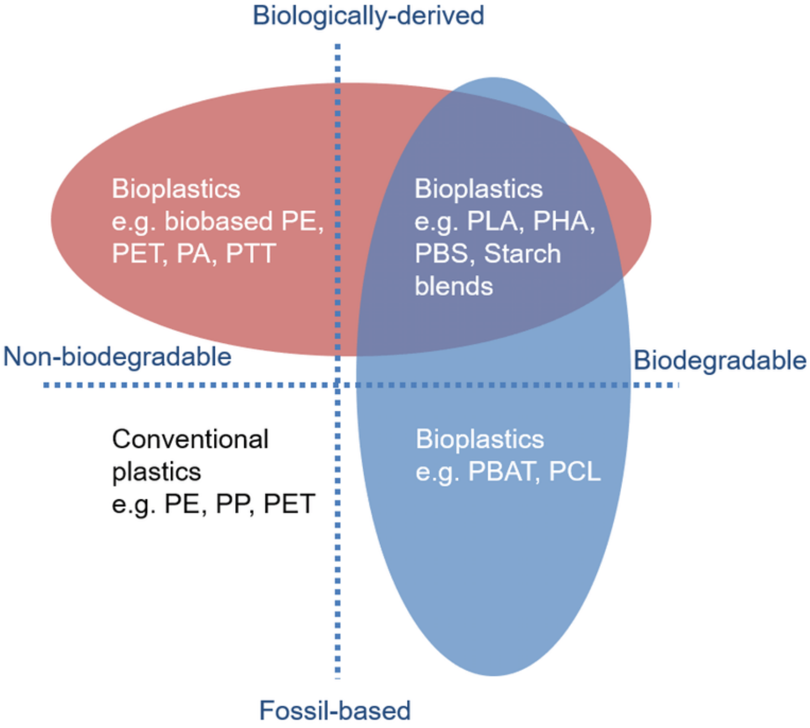

Figure 3 - Bioplastics vs Oil-based Plastics degradability

Parts that are made from a blend of oil-based plastics and PLA based bioplastics can be reused and recycled. The process that that is currently in development would break down the PLA in the blended compound, then extract (isolate) the PLA and recycle that back to virgin material. The remainder of the blended compound is the oil-based plastics. This portion can be sent to recyclers as a standalone basic material. This critical advantage would incentivize scarp dealers to look for parts, which are either made exclusively out of PLA or have PLA polymer blended within them.

Conclusion:

As new technologies are developed, it is critical for the shipping industry to demand suppliers to provide full LCA for the components used in these new technologies, as not to create additional carbon emission as a mere substitution to another carbon footprint in need to be mitigated.

As more and more plastics are selected for lightweighting, batteries, electronic systems and other technologies, each plastic type by itself contributes to a massive impact on the carbon emissions during each part production and at the end of life disposal.

Alternative plastic materials are available and should be encouraged to be used. Given the large volumes the shipping industry needs for each vessel, they can demand suppliers to incorporate the right materials into their technologies, thus reducing the carbon footprint not only in the operation, but also during the ship production and recycling stages.

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[37] Calculation based on Tesla solar panel: 8kg/m^2 x 31,000m^2 = 248,000 kg = 248 Tons

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