Eco-Islands: Offshore Sustainable Manufacturing

Graduate Category

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ECO-ISLANDS: OFFSHORE SUSTAINABLE MANUFACTURING

1. THE VISION OF HIGH-TECH MANUFACTURING AT ECO-ISLANDS INC. IN YEAR 2035

Eco-Islands Inc. is a company with a goal to become the global leader in managing the waste especially plastics waste due to manufacturing such as plastic byproducts of manufacturing processes and plastic packing, and turning it into goods and services in an economically and environmentally positive business model by the year 2035. Operationally, this company will consist of a fleet of mother ships and surrounding drone ships situated in each of the five major oceans. The drones will collect the waste from land and reclaim the waste plastic floating in the ocean gyres, i.e., the naturally occurring ocean vortices, during traveling, bring them to the mother ships, and deliver to the shores surrounding each gyre the goods produced by the mother ships. The mother ships will utilize the gyres, supplemented by onboard solar and wind farms, to travel around the oceanic garbage patches and therefore have a net-zero energy cost and environmental impact for propulsion. The drones will run entirely on solar and wind energy. This system will basically act like a global oceanic conveyer belt for delivering reclaimed and reprocessed plastics back from the environment to the market. This system will eventually become the plastic recycling hub of choice owing to its net zero energy cost and a viable business model.

2. THE PROBLEM AND THE CHALLENGE: PLASTIC WASTE IN OUR OCEANS

2.1. THE WORLD OF 2035: THE THREAT FROM PLASTIC WASTE

It is the year 2035 and the major oceans including the major trade routes are littered with plastic. In each Atlantic hurricane season, tons of plastic get piled on the beaches. This is the result of 2.12 billion tons of waste plastic that has been dumped in the ocean [1,2] every year for the past half century. Consumers are very cognizant of the environmental impact of their use of plastics, hence there is a lot of economic value in manufacturing goods such that there is a net-zero impact on the environment. Moreover, customers shopping at the supermarket have recently launched the “plastic attack” movement wherein they dump the plastic packaging of the products right after checkout in order to shame the supermarkets for using excessive amounts of plastic as a packaging material. These “plastic attacks” have urged the supermarkets to minimize the plastic used in packaging their products.

The Earth is set to cross the climate danger threshold in the year 2036. With one year to reverse climate change, all the countries are in a race against time to keep the carbon dioxide levels to below 405 parts per million [3]. If this level is reached, there will be an irreparable damage to the planet we call home. If we fail in this endeavor, the global temperatures will rise by up to 3 degrees Celsius, which means the great port cities of the world like Miami, Rio de Janeiro, Shanghai, Osaka will be completely submerged under water by 2100 [4]. The world of 2035 is facing such dire and irreversible environmental catastrophe that the consequences that producing new, virgin plastic has been banned by most governments around the world since it produces greenhouse gases such as carbon dioxide, methane, nitrous oxide, perfluorocarbons and Sulphur hexafluoride [5].

However, plastic is still in high demand because of the excellent properties and cost advantages. Most of the plastic waste are produced as byproducts of the manufacturing process and packaging process. Since we barely could not avoid using plastics currently, by reclaiming the plastic waste to make consumer products from it in a way that does not produce greenhouse gases prove to be a major advantage to the global community. By 2035 Eco-Islands Inc. will have its infrastructure of mother and drone ships in all five ocean plastic gyres, making it the leading manufacturer and supplier of recycled plastic in the world.

2.2. THE OCEAN TRASH PROBLEM

Humans produce huge amounts of plastic waste every year, a lot of which finds its way to the ocean. Because of the high cost of transportation and recycling process, only 10% of plastic waste is recycled, but about 2.12 billion tons is simply dumped [1]. Consequently, 1.4 billion tons of trash, much of it plastic, ends up in the oceans every year [2]. The waste in the ocean consists of paper, wood, metal and other manufactured materials in addition to plastics. However, 60%-80% of the trash is composed of plastic

[6]. From the beginnings of the use of plastic to the year 2017, a total of 9.1 billion tons of plastics has been produced. Out of this 9.1 billion tons, 30% is still in use, 9% is recycled and 12% incinerated [7]. The rest is simply discarded to become environmental burden for the planet. At the current rate, 10 billion tons of plastic will be discarded and much of it will end up in the ocean by 2035. Figure 1 and Figure 2 show the locations, sizes, and travel patterns of the oceanic garbage patches as of 2017. Unless stopped, these sizes will grow manyfolds by 2035.

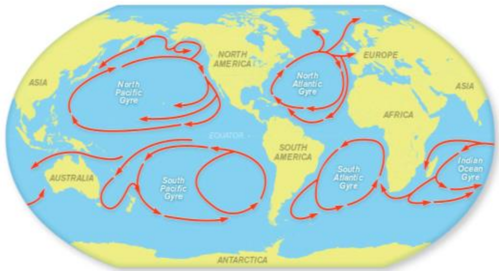

Figure 1: Paths of Swirling Plastic in the Oceans [8]

Figure 2: The Five Oceanic Garbage Patches [9]

There are approximately 5.25 trillion pieces of plastic debris in the ocean and 92% of them are micro plastics [10]. The biggest garbage patch is the Great Pacific Garbage Patch located in the North Pacific Gyre. It was first noted in the late 1980s and estimated to be twice the size of Texas and has been reported to be growing rapidly, as shown in Figure 3 and Figure 4.

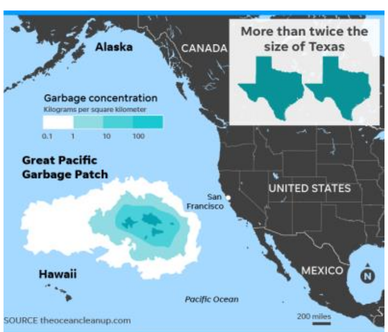

Figure 3: The size of the Great Pacific Garbage Patch [11]

Figure 4: A Boat on the Great Pacific Garbage Patch [12]

2.3. IMPACTS FROM THE INCREASING OCEAN TRASH

Humans polluting the oceans with plastic does not only harm the marine ecosystem, but also humans. Ocean trash contains many types and sizes of plastic. Most of these release a variety of toxins that are harmful to life in the presence of seawater and sunlight. Using the natural hierarchy of the marine food chain, toxins that are first consumed by smaller animals travel up to their predators, even if those predators do not consume plastic directly, and finally end up in humans through seafood consumption [13]. This phenomenon, called bioaccumulation, is shown schematically in Figure 5.

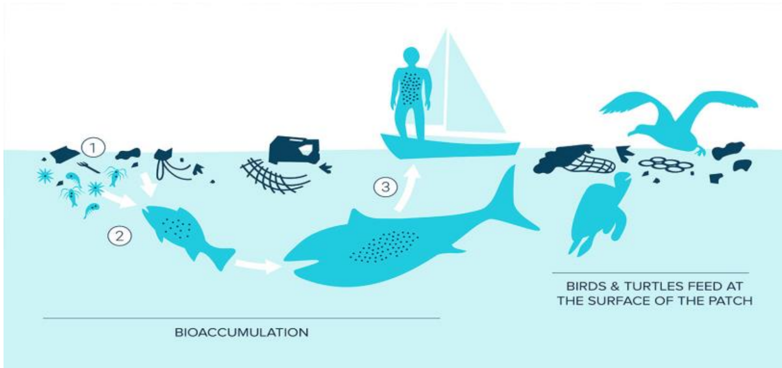

Figure 5: Bioaccumulation of plastic-based toxins in the ecosystem [14]

2.3.1. IMPACT ON MARINE WILDLIFE

Studies indicate that at least 690 marine species have encountered ocean trash and 92% of these are with plastic. At least 17% of the species listed on the IUCN (International Union for Conservation of Nature) Red list as near threatened or above, and at least 10% of the species had ingested microplastics [15]. Marine wildlife is harmed by plastic as following [13]:

1) Large plastic items in ocean trash can choke or entangle turtles, birds, dolphins, sharks, fish and other life. For instance, Figure 6 and Figure 7 show turtles stuck in plastic trash.

Figure 6: A turtle stuck in a plastic six-pack holder as a juvenile [16]

Figure 7: A sea turtle entangled in a ghost net [15]

2) Microplastics, nanoplastics and other small trash enter food webs because they are ingested by filter feeders and small fish, which soak up toxins that leach from the particles or adsorb onto them. Figure 8, 9 and 10 show examples of marine life that ate plastic trash.

Figure 8: Turtle eat plastic [17]

Figure 9: Albatross chick, showing a belly full of plastic trash [18]

Figure 10: Plastic found in Rainbow Runner fish guts [17]

2.3.2. IMPACT ON THE HUMAN SOCIETY

The ocean trash affects the human foodchain and the economy [14]:

1) Once the trash enters the wildlife especially marine food web, it is possible that the toxins soaked up by marine animals will pass to the food web that includes humans.
2) The cost of beach cleanups and the financial loss incurred by fisheries is dramatically high.
3) Shipping routes need to circumnavigate the garbage patches, which increases cost.

2.4. CHALLENGE AND OPPORTUNITY

While the high cost of transportation and recycling of the trash and the trash in the ocean present tremendous challenges, it also presents Eco-Islands Inc. with the opportunity to move the company offshore and clean up the ocean while building a sustainable business model. There are four primary reasons why we believe that there is an opportunity in this endeavor: a) ample raw material available at no cost, since there are 5.4 billion tons of plastics discarded while are still reusable and this number keeps increasing, b) shipping and transportation cost will be reduced by using the waste as energy, c) moving the company offshore will reduce the land use and storage costs, and will help to collect the waste in the ocean, d) the current technology is mature enough or will be mature enough by 2035 to recycle plastic waste in a viable fashion. While the first reason is evident from discussion in section 2.2, the state of the art of technology is elaborated on below to justify this futuristic opportunity.

2.4.1. MOTHER-DRONE FLEET

1. *Factory on Ship*

Oil platforms are traditional example of manufacturing plants on sea. However, they are often mounted on structures founded on the seabed and rarely move from one location to another. A floating production storage and offloading (FPSO) unit is a vessel used by the oil platform for production and processing of hydrocarbons, for the storage of the oil, and for transportation of the product. Ships can be manufactured large enough to transport large and precision equipment even a complete plant in working conditions. The world's largest FPSO, Egina FPSO, which departed Samsung Heavy Industries in 2017, is 330 meters long and 61 meters wide (Figure 11). The world's largest container ship, OOCL Hong Kong, can carry over 191,422 tons of cargo (Figure 12). This ship is 400 meters long and 59 meters wide, providing over 20000 square meters on the deck, which is more than about 3 soccer fields [20]. Given this practically unlimited capacity of ships that could be built, it is reasonable to assume that Eco-Islands Inc.'s factories could be housed on ships of similar size or that larger ships could be built, if necessary, for this purpose.

Figure 11: Egina FPSO [19] **Figure 12: OOCL Hong Kong [20]**

2. Energy

Renewable energy sources, such as wind and solar energy, can be used to drive ships. For example, SkySails Marine has developed the SkySails propulsion system that harnesses wind energy for propelling cargo ships. It consists of a large foil kite, an electronic control system for the kite, and a system to retract the kite, which allows modern cargo ships using the wind as a source of power [21]. Other traditional sailboats also prove the feasibility of powering a ship using wind. The first hydrogen powered vessel, Energy Observer, was launched in April 2017. It is equipped with two vertical axis wind turbines, a smart traction kite that can convert the electric motors into hydrogenators, and 130 m^2 bifacial thermoformed solar panels, operates with a mix of renewable energies: wind, solar and hydrogen produced from seawater (Figure 13). It is reasonable to hope that these technologies will be advanced further along by 2035 to provide the necessary sustainable and pollution-free power sources necessary to propel the fleet of Eco-Islands Inc.

Figure 13: Energy Observer [23]

3. Autonomous Navigation

With the development of autonomous navigation technology, self-driving ships are now possible. A prototype of autonomous Unmanned Surface Vehicle (USV) named Sea Hunter was launched in 2016 by Vigor Industrial (Figure 14). It is 40 meters long and has a top speed of 50 km/h. It is powered by two diesel engines and can travel at sea for months at a time [24]. The operation time will get longer when it was powered by other renewable energy instead or diesel. Meanwhile, Massachusetts-based Autonomous Marine System is already using unmanned sailing drones. This drone, called Datamarans, is a wing-sail surface drone providing a platform for devices that can be operated continuously in ocean for long durations without human intervention or fuel, esp. to collect ocean data [25]. By extrapolating the current technology trends for autonomous navigation, it is reasonable to assume that USVs with the capability to transport cargo and collect ocean trash will be possible in a scale needed for the size and the mother-drone operating model of Eco-Islands Inc. by 2035.

Figure 14: Sea Hunter [24]

2.4.2. TRACKING OCEAN WASTE

In order to be able to locate trash efficiently the drone ships must be able to track the location and amount of trash. Global Positioning System (GPS) was developed and launched in 1978 by the United States Air Force. It is a geolocation system that works in even for marine applications like the one in question. While at sea, accurate position, speed, and heading are needed to ensure the vessel reaches its destination in the safest, most economical and timely fashion that conditions will permit. It can also be used for underwater surveying, buoy placements, hazard location and mapping. An enhancement to the basic GPS signal known as Differential GPS (DGPS) provides much higher precision and increased safety in its coverage areas for maritime operations. GPS information is embedded within a system known as the Automatic Identification System (AIS) transmission. The AIS, which is endorsed by the International Maritime Organization, is used for vessel traffic control around busy seaways. [26]

Some headway has already been made to accurately map the amount and movement of plastic waste in the ocean [27 - 30]. An International Whaling Commission report [30] states that while there are some gaps in our knowledge of the debris, there is accurate date available on the presence of plastic gyres in the major oceans of the world. Since oceans are not steady, a onetime map of the plastic waste floating in the ocean will not suffice. Hence, a profile of the drift trajectories is a must in order to track the plastic waste in real time. One such technique is the NOAA drifter program [31]. It maps the trajectories into a grid of create six transition matrices representing the probabilities of moving from one cell to any other cell in a two-month period. This simulates the seasonal ocean circulation variability. Each two-month iteration of time updated the probability of transport to any other cell. This model can be applied to each of the plastic gyres identified.

2.4.3. CONVERT PLASTIC INTO SYNTHETIC FUEL

A recent research proposed a method that using pyrolysis to convert non-recycled plastics into synthetic crude oil, and the crude oil can be further refined and made into valuable products for everyday use like gasoline [32]. This is a first great step towards using the waste plastic as an energy resource.

2.4.4. OPPORTUNITY TO CREATE ENVIRONMENTAL IMPACT AND AWARENESS

The ocean trash problem is serious, and our oceans need to be clean as soon as possible. By cleaning up those ocean trash especially plastic in oceans, the ecological environment of world oceans will restore. Marine animals will return to their habitats, get healthy, and the food chain will be cleaner.

2.4.5. OPPORTUNITY TO OFFSET GLOBAL PLASTIC PRODUCTION BY REUSE

About 300 million tons of plastic is produced globally each year, and only 9% is recycled. That is a huge waste, that the used plastic can be reused or remanufactured. By remanufacturing the plastic waste to clean plastic, the amount of the global new plastic production will be dramatically reduced but still reach the global plastic requirements, which will save raw materials, energy and our environment and have the potential to generate more than $1 trillion a year [33].

3. THE SOLUTION AND MODE OF OPERATION

The Eco-Islands Inc. operating model will consist of a fleet of five mother ships floating around the five main garbage patches of the world's oceans, several child ships (drones) traveling around the garbage patches between mother ships and between mother ships and land, and several autonomous underwater vehicles (AUVs) traveling around mother ships under water to collect ocean trash from the seabed, as shown in Figure 15. The main purpose of a mother ship is to store and process the ocean trash and plastic waste that the drones bring in. The main purpose of a drone is to transport the trash from the land and collect the floating ocean trash from the patches during travelling, transport the trash to its mother ship, and carry reprocessed plastic products to sea-ports for returning them to the economy. The number of drones and AUVs may vary between mother ships based on the size of the garbage patch and the travel distance of the drones.

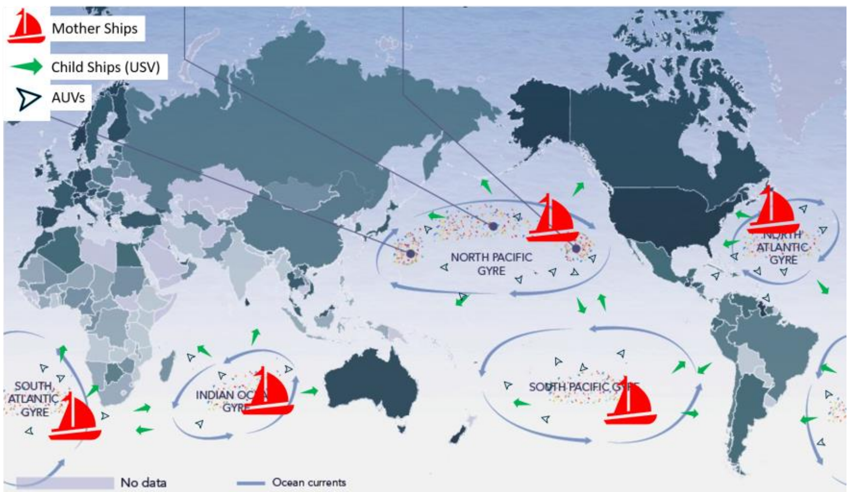

Figure 15: The Mother-Drone Fleet Operation Model of Eco-Islands, Inc.

Each mother ship will contain plants and facilities to collect the ocean trash brought in by the drones from its garbage patch, store the trash, sort and separate plastic and other trash, and remanufacture the trash to clean plastic raw materials such as beads and sheets, or even completed products.

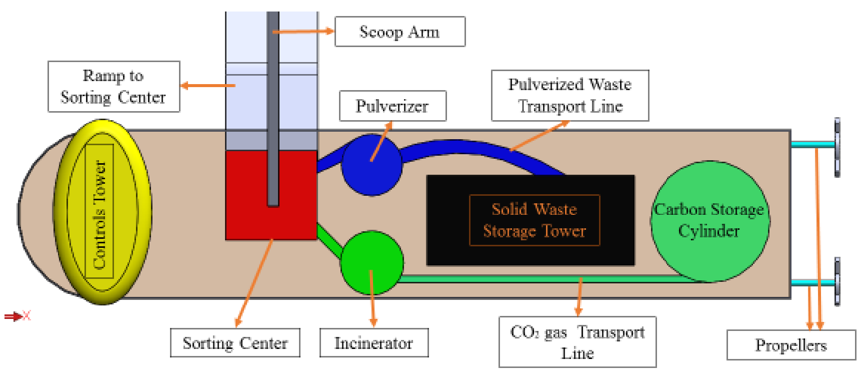

Figure 16: Schematic of the Drone Ships

Figure 16 is a schematic of a drone ship's process plant. The purpose is to collect, sort, and preprocess the plastic trash to the point of pulverized solids and carbon dioxide that could be transferred to the mother ship for remanufacturing. The amounts of pulverized plastic and CO_2 stored on board are crucial. Hence two sensors—a weight sensor to sense the amount of plastic and a pressure sensor to read the amount of gas—are included. Accordingly, the power of the boat will be adjusted. Once the storage units are full, the boat will return to the mother ship to unload the waste.

On board the mother ship, the collected plastic and CO_2 will be converted into end remanufactured plastic raw materials or products. Several ideas for products include the followings:

1. Convert ocean plastic to raw material such as beads or sheets of plastic
2. Convert ocean plastic to fiber and then use the fiber to make cloth, bags, or cables
3. Convert ocean plastic to fiber needed as raw material for plastic 3D printing
4. Convert ocean plastic to fuel-grade hydrogen that could drive the ships or sold outside
5. Convert plastic to synthetic fuel
6. Convert ocean trash, which is hard to sort, to structural blocks for buildings and structures
7. Build floating islands using ocean trash that could be used for recreational purpose or hurricane rescue and relief

4. ASSESSMENT OF THE SOLUTION

In order to roughly evaluate the solution mathematically, several assumptions should be made:

Assumption 1: The average price of post-consumer plastic is $132.3 per ton [34].

Assumption 2: The ocean surface current velocity is 3 km per hr. [35]

Assumption 3: The garbage patch is circular, and the size is 1,599,996 km^2 [36]. The radius is about 714 km, and the perimeter is about 4,483 km.

Assumption 4: Each mother ship connects to land in eight directions by drones. Each direction has four drones for transporting plastic waste from land and collecting ocean trash on its way. Three drones will be sent into the garbage patch to collect the ocean trash. Thus, there are 32 drones per mother ship.

Assumption 5: The ocean is a circle with diameter 15,187km (distance between US and Australia). This simplification is needed only to use average distances from mother ships to the shores.

Assumption 6: Using the Sea Hunter as the model of drones. Thus, the drone is 40 meters long and 3.6 meters wide, providing 102 tons capability for carrying the ocean trash and plastic waste. The velocity of the drone is 50 km/hr.

Assumption 7: All operations using energy from solar, wind, seawater, and plastic.

Assumption 8: The average power consumption for processing plastic is 2.87 KW·hr/kg [37].

Assumption 9: The solar panel has an input rate of about 1 kw/m^2 [38], using the most efficient solar panel with 44.5% efficiency [39].

4.1. ECONOMIC ASSESSMENT

Under above assumptions, the mother ship will spend 62 days to travel once around a gyre. The distance from garbage patch to land is *15187/2 – 714 =* ***6,879.5 km****,* and thus the drone needs *6,879.5/50 = 137.59 hr. ≈* ***5.7 days*** to travel one way from mother ship to land. Thus, the mother ship will get *8 × 102 =* ***816 tons*** plastics every three days from drones traveling to land, and will get *3 × 108 =* ***306 tons*** every day from the drones in the garbage patch. Therefore, each mother ship will get about 578 tons plastics per day, and there will be totally about 2890 tons plastic waste collected and processed per day by the Eco-Island Inc. In that case, the Eco-Island will generate around **$382,347** from remanufacturing the waste plastic per day.

4.2. ENVIRONMENTAL ASSESSMENT

There will be *35 × 5 =* ***175*** **drones** on oceans to collect and clean the ocean trash. Based on the speed of the drone and using 5 meters width tools to collect the ocean trash, the total area the Eco-Island Inc. can clean is about *175 × 50 × 5 =* ***43,750 m²*** per day.

4.3. ENERGY ASSESSMENT

For each mother ship, to process 578 tons (578,000 kg) plastics, the energy consumption is *578,000*2.87 =* ***1,658,860 KW·hr.*** The energy output rate of solar panel is about *1kw/m² * 44.5% =* ***445kw/m²***. To reach the energy requirement 1,658,860 KW·hr, with 5 hr. direct sunlight, about

*(1658,860/5)/445 = 745.555 =**746 m²*** solar panels are needed. The mother ship can easily hold that much solar panel.

5. ANTICIPATED IMPACT IN 50 YEARS

Eco Islands Inc. can have a great impact in the upcoming half and complete century. This impact is economic, environmental, and technological. Eco Islands has the potential to completely eliminate the need for the production of virgin plastic. All the Earth's need for plastics can be met by perpetual recycling. This means that the amount of plastic present on planet Earth will never increase, except for applications that need virgin plastic. Once Eco Islands Inc. is fully operational in all the ocean gyres, it will save 1,658,860 KW·hr of energy that is annually used to produce plastics. It is important to keep in mind that this energy is now not just being saved, but being generated by renewable and eco-friendly sources of energy like wind and solar energy. In addition to the processing cost. Eco Islands Inc. will save energy cost in terms of global transformation of plastic. With the cleaning rate of 43,750 m^2/day, the world oceans will be cleaned within 50 years and the continue to be kept clean.

6. VISION FOR PARTNERSHIPS AND INVESTMENTS NEEDED BY ECO-ISLANDS INC.

In order to make Eco Islands Inc. a reality there are advances in technology and industrial partnerships that are required.

6.1. TECHNOLOGY AND RESEARCH CHALLENGES

- **Self-driving cargo ship with trash collection ability:** In order for the drones to be able to collect trash autonomously and bring it back to the mother ship, research needs to be done on efficient collection methods, optimization of the path of travel back and to the mother ship and the ocean. Reliable docking mechanisms need to be put in place in order to make sure that smooth transfer of the plastic waste can be done from the drone to the mother ship.
- **New sorting method:** In addition to plastic debris, there is metal debris and micro plastics also floating in the ocean surface. When the drone ships collect these debris, they need to be able to sort through them in order to make sure that only plastics make their way to the mother ship. Currently these sorting methods have not been tested when installed on a drone ship.
- **Produce fuel from plastic:** Besides processing the plastic waste into clean plastic or new products, a new way of producing fuel from plastic will help more with recycling and to address the global fuel shortage. Recent research already shows that plastic can be converted into synthetic fuel, but further research on this topic is needed.
- **Lightweight plant and facility design:** Since the entire company of Eco-Islands Inc. will be set on boats, the weight of plants and facilities used for Eco-Islands Inc. should be as light as possible, which will reduce the cost.

6.2. INDUSTRIAL PARTNERSHIPS

- **Ship manufacturers:** Eco-Islands Inc. should partner with large ship manufactures to design and manufacture a ship that best support the plant and facilities for better manufacturing environment, and self-driving ship manufactures to design and manufacture drones and AUVs that provide abilities for travelling in the ocean and collecting the ocean trash.
- **GPS company:** Eco-Islands Inc. should partner with GPS service providing companies, like Google LLC, so that ocean trash could be mapped in real time and the fleet's path could be optimized.
- **Green energy equipment manufacturers:** Eco-Islands Inc. should partner with manufacturers who provide equipment for generating energy from solar, wind, seawater, since Eco-Islands Inc. will entirely use green energy.

- **Artificial Intelligence support:** AI system will be needed for operating those drones so that Eco-Islands Inc. should partner with AI support companies.

With the above partnerships and research investments, it is reasonable to expect that the infrastructure to make the operational model of Eco-Islands Inc. a reality could be established by year 2035. The prospect of disposing the manufacturing waste and cleaning the ocean of trash and relieving marine life of the damages of ocean pollution, combined with the economic prospect of returning the discarded plastic to the global economy with a minimal environmental footprint provides ample justification to investigate and invest into these research directions.

REFERENCES

[1] "http://www.theworldcounts.com/counters/shocking_environmental_facts_and_statistics/world_waste_facts" accessed on 15-May-2019

[2] "https://4ocean.com/blogs/blog" accessed on 15-May-2019

[3] Earth Will Cross the Climate Danger Threshold by 2036, "https://www.scientificamerican.com/article/earth-will-cross-the-climate-danger-threshold-by-2036/?redirect=1" accessed on 15-May-2019

[4] The Three Degree World: The Cities That Will Be Drowned by Global Warming, "https://www.theguardian.com/cities/ng-interactive/2017/nov/03/three-degree-world-cities-drowned-global-warming" accessed on 15-May-2019

[5] Greenhouse Gas Emissions from The Plastics Processing Industry, "https://www.nrcan.gc.ca/energy/efficiency/industry/technical-info/benchmarking/plastics/5211" accessed on 15-May-2019

[6] "http://www.oceanhealthindex.org/methodology/components/trash-pollution" accessed on 15-May-2019

[7] "http://www.latimes.com/science/sciencenow/la-sci-sn-plastic-trash-20170721-htmlstory.html" accessed on 15-May-2019

[8] "https://scienceworld.scholastic.com/issues/2016-17/041717/an-ocean-of-plastic.html" accessed on 15-May-2019

[9] "https://news.nationalgeographic.com/news/2015/01/150109-oceans-plastic-sea-trash-science-marine-debris/" accessed on 15-May-2019

[10] "https://www.youtube.com/watch?v=Bic7QEVRNe4" accessed on 15-May-2019

[11] "https://www.usatoday.com/story/tech/science/2018/03/22/great-pacific-garbage-patch-grows/446405002/" accessed on 15-May-2019

[12] L.Lebreton, B.Slat, et al., 2018, "Evidence that the Great Pacific Garbage Patch Is Rapidly Accumulating Plastic", *Science Reports*, "https://www.nature.com/articles/s41598-018-22939-w"

[13] "http://www.oceanhealthindex.org/news/Making_Least_Most_Marine_Trash" accessed on 15-May-2019

[14] "https://www.theoceancleanup.com/great-pacific-garbage-patch.html#footnote-2" accessed on 15-May-2019

[15] S.C. Gall and R.C. Thompson, 2015, "The Impact of Debris on Marine Life", *Marine Pollution Bulletin*, "https://www.sciencedirect.com/science/article/pii/S0025326X14008571?via%3Dihub"

[16] "https://www.thedodo.com/turtle-six-pack-unstoppable-1166240209.html" accessed on 15-May-2019

[17] "http://plastic-pollution.org/" accessed on 15-May-2019

[18] "https://www.geolounge.com/ocean-garbage-patches/" accessed on 15-May-2019

[19] "http://gcaptain.com/worlds-largest-fpso-departs-samsung-heavy-industries/" accessed on 15-May-2019

[20] "https://www.marinetraffic.com/en/ais/details/ships/shipid:4910459/mmsi:477333500/imo:977 6171/vessel:OOCL_HONG_KONG" accessed on 15-May-2019

[21] "https://www.skysails.info/en/skysails-marine/skysails-propulsion-for-cargo-ships/" accessed on 15-May-2019

[22] "http://www.energy-observer.org/en/#hydrogene" accessed on 15-May-2019

[23] "http://www.euronews.com/2017/01/16/sun-and-wind-to-power-energy-observer-catamaran-on-six-year-circumnavigation" accessed on 15-May-2019

[24] "https://www.cnbc.com/2018/02/16/the-sea-hunter-autonomous-ship-could-be-the-future-of-military-warfare.html" accessed on 15-May-2019

[25] "http://www.automarinesys.com/" accessed on 15-May-2019

[26] GPS, "https://www.gps.gov/" accessed on 15-May-2019

[27] Mapping Plastic Waste, "https://www.ecowatch.com/first-of-its-kind-map-details-extent-of-plastic-in-five-ocean-gyres-1881935191.html" accessed on 15-May-2019

[28] Law, Kara Lavender, et al.,2014, "Distribution of surface plastic debris in the eastern Pacific Ocean from an 11-year data set." *Environmental science & technology* 48.9 (2014): 4732-4738.
[29] Reisser, Julia, et al., 2013, "Marine plastic pollution in waters around Australia: characteristics, concentrations, and pathways." *PloS one* 8.11 (2013): e80466.
[30] Baulch, Sarah, and Mark P. Simmonds, 2015, "An update on research into marine debris and cetaceans." *IWC Scientific Committee, San Diego, California* (2015).
[31] Sherman, Peter, and Erik Van Sebille, 2016, "Modeling marine surface microplastic transport to assess optimal removal locations." *Environmental Research Letters* 11.1 (2016): 014006.
[32] "https://www.rdmag.com/article/2015/09/non-recycled-plastics-new-energy-resource" accessed on 15-May-2019
[33] "https://www.rdmag.com/article/2015/09/non-recycled-plastics-new-energy-resource" accessed on 15-May-2019
[34] "https://resource-recycling.com/plastics/2017/12/13/latest-recovered-plastics-pricing/" accessed on 15-May-2019
[35] "http://oceanmotion.org/html/background/wind-driven-surface.htm" accessed on 15-May-2019
[36] "https://earther.com/just-how-big-is-the-great-pacific-garbage-patch-1825116026" accessed on 15-May-2019
[37] Low Energy Plastics Processing, 2006, "http://www.tangram.co.uk/TI-Energy-Low%20Energy%20Plastics%20Processing%20(e).pdf" accessed on 15-May-2019
[38] "https://www.quora.com/How-much-solar-energy-is-generated-per-square-metre" accessed on 15-May-2019
[39] "https://www.weforum.org/agenda/2017/08/this-is-the-most-efficient-solar-panel-ever-made" accessed on 15-May-2019