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Eco-friendly carbon synthesis from waste PET bottles to reduce plastic pollution and its environmental impact: a review

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***Abstract*—Plastics are inexpensive and durable. Plastics are becoming increasingly popular, but most of them are non-biodegradable, posing a significant environmental threat. Each year, India produces around 270 lakh tonnes of waste plas- tic., providing a significant potential resource. Waste plastic is currently a cause of environmental concern. We can lessen plastic waste by re-purposing it as a resource. The synthesis of carbon and fuel is a novel technique to the thermal recovery of plastics waste in order to produce higher-value products. Chemical recycling is now an appealing approach for minimizing the rapid rise of plastic disposal of solid waste issues.**

Plastics is just crude oil, which is processed, and this can be reversed. Plastic pyrolysis (Pyro - Heat, Lysis – breakdown) is a very effective process where plastic is exposed to high temper- atures in oxygen free environment. Reuse, mechanical/chemical recycling, and energy recovery are only a few of the waste plastic management strategies that have been developed. The variety of plastic composition makes sorting, cleaning, and separating expensive. High levels of impurities and additives in mixed plastic diminish homogeneity and usability. Using pyrolysis to convert plastic wastes to fuel is a conventional method for disposing of them. Plastic is hard to break down; a catalyst is needed (Flyash, Zeolite etc). The products of pyrolysis process will be 80% oil,15% gas & 5% Carbon black. After hydro processing the oil, it can be formulated to diesel. The Activated carbon can be used in preparation of carbon reinforced composites with higher order properties.

***Index Terms*—Pyrolysis, Catalyst, Carbon**

Abbreviations: PVDC - Poly Vinylidene Chloride, PET - Polyethylene Terephthalate, PVC - Poly Vinyl Chloride, PU - Poly Urethane, PVA - Poly Vinyl Alcohol, HDPE - High Density Polyethylene, LDPE - Low Density Polyethylene, PP - Poly Propylene, PF - Phenol Formaldehyde, PS - Polystyrene

I. INTRODUCTION

According to the findings, pyrolysis helps create sustainable fuels and manages old waste plastics. Plastics are manufac- tured more than 330 million tonnes per year worldwide, with India producing 60 million tonnes per year. Plastic's life span in the automobile, consumer, and household industries may vary by less than one year to over 50 years. Many of the plastics will wind up in India's 27 million tonnes of annual garbage plastic. The most frequent plastics in urban solid waste are HDPE, PS, LDPE, PVC, PP and PET. HDPE and LPDE are polyethylene polymers with different branching and cross-linking. LDPE's branching and cross-linking restrict polymer chains from packing securely, resulting in a lower density plastic. Those thermoplastics are pyrolyzed to form gas and oil/wax, with hydrocarbon makeup dependent on polymer structure. If present waste management patterns continue, 26 billion metric tonnes of pure plastics and 12 billion metric tonnes of rubbish plastics will be produced by 2050. Most of the waste plastics are PE and PP. Plastic litter degrades in the marine world, resulting in microplastics and nano plastics, which have negative consequences for coastal and terrestrial environments. One of the most pressing and convincing issues in the developing world is waste plastic pollution. Pyrolysis is the heating of plastic without oxygen. Plastic does not oxidize since there is no oxygen present; rather, it degrades. Reactors, condensers, and collection tanks are all part of the system. At high temperatures, volatile vapors are generated in reactors and then condensed to liquid in heat exchangers before being collected in collecting tanks. The volatile fumes generated in the reactor are carried to the condenser by gases such as

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nitro- gen or hydrogen. The pyrolysis process has shown to be oneof the most effective ways for converting plastic waste since the final product may be utilized to generate energy directly, and the conversion produces no harmful contaminants.

[1.1] Environmental problems related to mishandling of waste plastics:

Plastics can't biodegrade. It takes 300-500 years to biode- grade, therefore improper management might cause environmental concerns. For example:

- Plastic litter degrades city beauty, clogs drains, and pol-lutes public spaces.
- Incinerating trash, particularly plastics, may release harm-ful fumes into the air.
- Plastics in landfill trash cause problems.
- Lack of recycling facility causes environmental unhy-giene.

[1.2] Plastics' adverse effects on nature include thefollowing:

- Biodegradability is affected by the total amount of dif- ferent atom groups that are linked to the benzene ringof organic compounds. And thus, increase in plastic pollution.
- Rather of biodegrading, plastic trash undergoes photodegradation, resulting in plastic dusts that may enter the food chain and create serious health problems for Earth's inhabitants.
- Hydrocarbons are the primary components of plastics, which are further enriched with antioxidants, colourants and other stabilisers for added protection.
- However, these compounds are environmentally unfavor-able when plastic goods are used and disposed.
- In the burning of plastics, NOX, COX, and SOX are released along with particulate matter and dioxins, furans, and other hazards, all of which contribute to pollution of the air, acid rain, and climate change.
- Toxic contamination of groundwater due to plastics in landfills.

Raw plastic materials and their composition are listed in the table below.

TABLE I
CONTENT AND KIND OF PLASTIC [27].

Type of plastics	Contents
PP, PS, PE (HDPE, LDPE)	Hydro carbons
PF, PET, PVA	Hydro carbons with oxygen
PVCD, PVC	Hydrocarbons with chlorine
PU, Nylon (polyamide)	Hydrocarbons with nitrogen
Hydrocarbons with sulfur	Polyphenylene sulfide

[1.3]Plastics by Type: SPI (Society of the Plastics Industry,Inc.) established its resin identity tagging system in 1988 atthe request of recyclers throughout the nation.

The following are examples of the seven plastics:

- Polyethylene Terephthalate (PETE or PET)
- Polyvinyl Chloride (PVC)
- High-Density Polyethylene (HDPE)
- Polypropylene (PP)
- Low-Density Polyethylene (LDPE)
- Polystyrene or Styrofoam (PS)
- Miscellaneous plastics (includes: Fiberglass, acrylic,acrylonitrile butadiene, polycarbonate, polylactide, styrene, and nylon)

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Fig. 1. Plastic types

Generally, plastics may be divided into two categories:

• **Thermoplastics:** PET, HDPE, LDPE, PP, PVC, and PS are all examples of thermoplastics, which soften when heated and may be moulded into the required form.

• **Thermosets:** Sheet moulding compounds (SMC), FRP,bakelite, etc. are thermosets/thermosetting polymers that hardenon heating but cannot be remoulded or recycled. [28]**[1.4] Technologies for Recycling Plastics:** Plastic recycling reducespollution, boosts efficiency, and saves energy. Thereare many technologies, which contain the following features:

- **Mechanical Recycling:** Plastic trash is recycled into useful products

Fig. 2. Examples of various Plastics [28]

- **Chemical Reuse:** Gasification and Blast Furnaces
- **Incineration:** Waste polymer-to-energy conversion.
- **Pyrolysis:** It is the process of converting waste polymers into liquid fuels.

[1.5] Pyrolysis: It is thermal decomposition without oxy- gen. Insufficient oxygen hinders COX, NOX, and SOX syn- thesis. It breaks down huge hydrocarbon chains, but it's heat- and time-intensive, high residual content, low octane.

[1.6] Catalytic Pryolysis: Pyrolysis of plastics waste using a catalyst decreases pyrolysis temperature and reaction time, improves waste-to-fuel conversion rate, enhances fuel yield, and improves diesel and petrol fuel quality by improving petrol octane and reducing diesel pour point. Silica, alumina, HZSM-5, zeolite-Y, mordenite, zeolite-β, MCM-41 are used as catalysts. Acidified catalysts (HZSM-5, zeolite-Y, mordenite, etc.) are more efficient than amorphous alumina silicate[27]. Mordenite's larger pores produce large product molecules,
whereas HZSM-5's smaller pores produce little ones.

[1.7] Plastic to fuel (PTF) methods provide two distinct advantages:

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(1) Creating a lucrative product from non-recyclable plas- tics.
(2) Producing a dependable supply of alternate fuels froma plentiful, free or low-cost feedstock.

[1.8] Stages in pyrolysis to turn discarded plastic into fuel sources:

• **Isolation and Pretreatment:** Plastic garbage (only HD, LD, PP, and multilayer packaging, with the exception of PVC)is separated from the rest of the garbage and then givena preliminary treatment. The pre-treatment might consist of anything as simple as size reduction or something as involved as extensive cleaning and the elimination of moisture.

• **Conversion:** The transformation of plastic into gas is accomplished using pyrolytic processes. Waste polymers are subjected to high temperatures inside of an enclosed reactor vessel in order to facilitate their transformation into a vapour. As a consequence of the use of the catalyst, the pyrolysis takes less energy and more branched hydrocarbons are produced. The procedure is economically feasible and contributes to the reduction of air pollution by reusing the gas produced during the operation as fuel.

• **Distillation:** The gas is gathered in a condensation cham- ber and transformed into liquid fuel. The oil possesses qualities similar to LDO and may be utilised as a safe substitute toLDO in industry, therefore preserving the already diminishing natural resources.

• **Acid removal process:** Acids that generated during the decomposition must be eliminated since they are harmful to plastic fuel systems and engines that will consume thegasoline.

• **Separation / final blending / refining:** Depending on the intended usage.

Fuel production estimates may change, and yields will vary from different batches based on the quality of the feedstock used. The production of gasoline will decrease as contaminantsand non-resin components increase. A greater concentration ofPS, PP, and LLDPE will increase yield.

Output	Percentage of Overall Output
Char	Ranges on average from 2% -13% (one system claims negligible amounts of char when the system is run on a continuous feed vs a batch feed)
Natural gas	Ranges average from 8% to 10%
Fuel/Oil	Ranges average from 80% - 90%
One gallon (3.78 liters) of oil = 138,095 BTUs (40 kWh) One pound (0.45 Kg) of mixed plastic = 15,500 BTUs (when incinerated) (4.5 kWh)	

Fig. 3. Percentage of Overall Output in Plastic to Fuel (Pyrolytic Conversion [28]

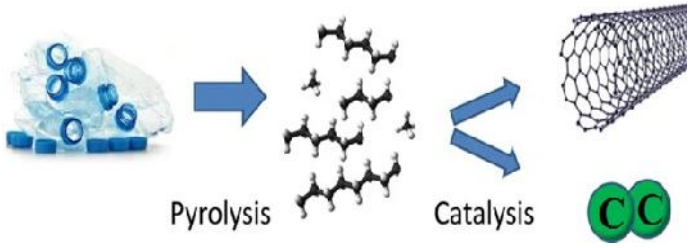

Fig. 4. Graphical representation of the common pyrolysis process [27]

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II. LITERATURE REVIEW

Dequan Chen et.al [1] In his experiment, waste PC andPET were pyrolyzed at 1200, 1400, and 1600 °C. PC-HCand PET-HC carbon anodes showed improved sodium storage. PC-HC and PET-HC provide 327 and 342 $mAhg^{-}1$ at 20$mAg^{-}1$, achieving 84.7 and 86.1 percent ICE, respectively. After 140 cycles at 100 $mAg^{-}1$, neither kind of HC shows significant capacity loss. His discovery proposes a simple,environmentally-friendly way to repurpose discarded plastics and shows that PC and PET may be used to make high-performance HC.

Paul T. Williamsn [2] In his article, he explored the two- stage pyrolysis-catalysis of waste plastics in connection toreactor structure, process parameters, and the usage and de- velopment of alternative catalysts to create hydrogen and/or carbon nanotubes.

Jingbo Jia et.al [3], His research intends to generate inex- pensive antimonial atomic number 28 catalysts (Ni/La, Ni/Mg,and Ni/Sr) via in-place growth. MSI's effect on atomic number 28 catalyst properties and chemical activity was studied. Yield, structure, shape, and quality of produced carbon products werealso evaluated. Carbon products were synthesised from LDPE and PP using in-line contact action, chemical change, and chemical action. In the first step, LDPE/PP was converted into transformation gas, and after condensation, the non- condensable gas was introduced into a chemical action reactorto synthesis carbon products over Ni-based catalysts. Tem- perature and feedstock type affect transformation products. The non-condensable transition gas from LDPE/PP before CNTs production was examined using GC-FID-TCD. The detectable gases mostly comprised C_1eC_5 hydrocarbons and small amounts of CO, CO_2 and H_2. LDPE and PP have somewhat differing hydrocarbon chain compositions. LDPE's prime 5 hydrocarbons were ethylene > methane > propylene > ethane > 1-butene with (39.38%) >(34.67%) >(12.01%) > (7.35%) >(1.85%) respectively, while for PP, the order was: methane > ethylene > propylene > ethane > i-butylene with (34.25%) >(22.43%) >(21.12%) >(8.30%)> (7.96%) respectively. Because the top 5 hydrocarbons covered 94%of hydrocarbons, their conversions were emphasised during CNT synthesis. LDPE and PP yielded 114% and 110% after improving reaction conditions. This work showed how to build and develop efficient catalysts for turning polymers into CNTs.
Katharina Heilos et. al [4] His study describes the quality levels of carbon fiber-reinforced plastics (rCFRP) manufac-tured from rCF nonwovens utilising industrial manufacturingtechniques. The line's carbon fibre nonwovens are suited forCFRP constructions. High formability, enough power, and tun-able MD/CD ratio make them ideal for advanced composites.
His thesis demonstrates a potential commercial approach for recycling carbon fibres.

Marcus A. Hunt et. al [5] Patterned, continuous carbon fibres with adjustable surface geometries and properties were manufactured via modular manufacturing. This method can easily design and produce fibres with specified surface shapes,with adjusted filament diameter down to the submicron scale, and tune porosity via diffusion-controlled precursor function- alization.

According to their findings, Yuliusman et. al[6], the car- bonization yielded 21.47 percent, whereas physical activity yielded 62%. Yield was 13.3%. Increasing CO_2 flow increases activated carbon's surface area. 200 ml/min CO_2 flow was ideal. Increasing activation time may enhance activated car- bon's surface area. Activation lasts 240 minutes. When CO_2 gas flow rate was 200 ml/min and activation period was 240 minutes, 1591.72 m^2/g was produced. Activated carbon also contains oxygen, iron, and copper.

Esfandiari Ali et. al [7]The activated carbon investigated in this research was generated from PET wastes in N_2 and CO_2 atmospheres. This study explored an improved method for making high-surface activated carbon. In addition, commercial activated carbon qualities were examined.

[8] Porous amorphous carbon (activated carbon) is a popularindustrial material. Activated carbon has a 3000 m^2/g surface area. Charcoal, pet coke, diesel oil, old tyres, coconut shell, wood, and agricultural wastes are used to make activated carbon. Activated carbon is made from coal and coconut shell. Physical and chemical activation are two methods. Physical activation is done using CO, dry air, and steam (H_2O), which adsorb on the carbon surface. In chemical activation,the carbon precursor is impregnated with chemical activating chemicals such as LiOH, H_3BO_3, NaOH, Na_2CO_3, Na_2S, KOH, KCl, K_2CO_3, $CaCl_2$, $AlCl_3$, MgCl, $ZnCl_3$, $FeCl_3$, $FeSO_4$, RbOH, HCl, H_3PO_4, H_2SO_4, HNO_3, H_2O, etc., and heated (pyrolyzed) in an iner Activation and heat treatment(pyrolysis) may be done in one or numerous phases. These processes have 300–3000 m^2/g surface

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area.
Alireza Bazargan et. al.[9] Their study discussed on making porous carbon from plastic garbage. Their assessment is splitby precursor kind. First portion examines thermoplastics,second section covers PET (PET). This is since PET has beenemployed in the bulk of studies in this field. Because of thepoor carbon output, the manufacture of porous carbons fromplastic trash may be unfeasible. As a result, the authors pro-pose an alternative integrated method for future research,wherein during the process of converting polymers to gaseous andliquid chemicals, porous carbons are produced as a byproduct.Alireza Bazargan et.al. [10] & Chuanwei Zhuo[15] Plasticpolymers were used in their research as the carbonaceousfeed for carbon nanotubes (CNTs). Additionally, they usedcatalytic and thermal techniques in autoclaves, quartz tubereactors, muffle furnaces, fluidized beds, and other apparatusto manufacture multi-walled carbon nanotubes (MWCNTs)from plastic polymers. Concerning the elements that influenceproduction yields and quality, there is still a great deal that can be learned.

Mohammad Adibfar et.al. [11] Utilizing polymers as car- bonaceous feed for CNTs and catalytic and thermal proce- dures, they created MWCNTs from polymers using a variety of methods including fluidized beds and autoclaves as wellas quartz tube reactors and muffle furnaces. Research into the elements that influence production yields and quality is currently ongoing.

Recent findings show that transforming cheap waste prod- ucts into CNMs with a high value helps to advance efficiently processed materials & recycling technologies. Junjiao Deng et.al. [12] The goal of this study is to investigate green synthesis pathways for CNMs, with an emphasis on graphene & carbon nanotubes. This review identifies plastic trash that can be used to make CNMs, and then moves on to cover alternative CNT and graphene synthesis processes.

PET waste was employed in the physical activation proce- dure to make activated carbon, which was gasified using car- bon dioxide (CO_2) Ali Esfandiari et. al.[13]. On the adsorption capacity of activated carbon, the effects of temperature, , flow rate, heating rate and holding time during the carbonization and activation stages were examined. The Taguchi technique was used to develop preparation tests for the influence of thesecomponents.

For its availability and lower cost, PET plastic trash is an excellent raw material to produce activated carbon. Aside from plastic, PET possesses the necessary qualities as an activated carbon raw material for natural gas storage since it is durable as it contains a significant amount of carbon, around 62.5% wt. Carbonization occurs at a temperature of 400 degrees Celsius, after which a physical activation with CO_2 gas at a temperatureof 975 degrees Celsius is performed. The carbon dioxide flow rate and activation time are the variables that change during the as activation process. Yuliusman et.al.[14]

Noha A. El Essawy et.al. [16] Their study was successfulin creating and regulating the micro structure of a numberof different kinds of carbon nanoparticles obtained from PET waste by adjusting the preparation factors such as time, additives, and catalyst concentrations.

A.Joseph Berkmans et.al. [17] They present a unique tech- nique using rotating cathode arc discharge in a catalyst-free and solvent-free method for the production of nano channelledultrafine carbon tubes (NCUFCTs) and multiwalled carbon nanotubes (MWCNTs) from PET wastes.

Noha A. El Essawy et.al.[21] In their work, they described a solvent-free method that transforms PET bottle trash into carbon nanostructure materials by heat dissociation in a closedsystem under autogenic pressure with additives and/or cata- lysts that function as cluster nuclei for fullerenes and carbon nanotube. This study optimised preparation factors such as time, additives, and catalyst concentrations to produce and regulate the microstructure of carbon nano particles from PETwaste.

Material	Operating temperature	Yield		
		Liquid	Gas	Char/Residue
PS	450	80.8	13.1	6.1
HDPE	400	81.5	17.8	0.7
LDPE	400	81.4	16.6	2
PP	375	82	17.3	0.7
PS+PP	450	50	39.8	10.2
PS+PP+PE	450	38	40.6	21.4
PE+PP	500	34.2	8.1	57.7
LDPE + Sugarcane bagasse	500	52.75	12	35.25

Fig. 5. Temperature effects on plastic pyrolysis [27]

There is endangerment of different other species also with the growth of plastics in our landfills. The following figures are

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some such examples.

FEEDSTOCKS AND OUTPUT WITH THERMAL DEPOLYMERIZATION (Note. Paper/cellulose contains at least 1% minerals, which was probably grouped under carbon solids.)				
Average Thermal Depolymerisation (TDP) Feedstock Outputs				
Feedstock	Oils	Gases	Solids (mostly carbon based	Water (Steam)
Plastic bottles	70%	16%	6%	8%
Medical waste	65%	10%	5%	20%
Tires	44%	10%	42%	4%
Sewage sludge	26%	9%	8%	57%
Paper (cellulose)	6%	43%	24%	20%

Fig. 6. Feedstocks and output with thermal depolymerization[27]

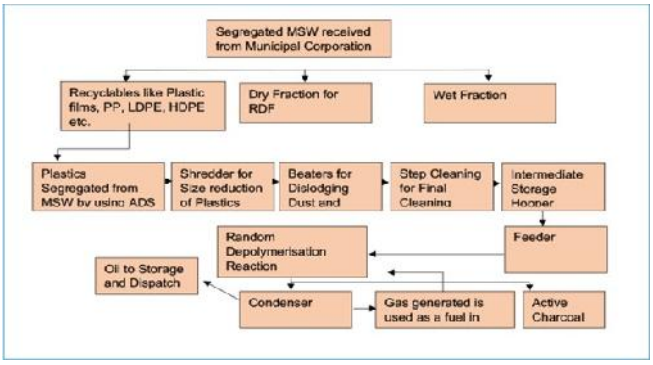

Fig. 7. Liquid RDF from waste plastic manufacturing flowchart [27]

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Fig. 8 Micro plastics found in dead bird body Source:https://www.nwf.org/Home/Magazines/National-Wildlife/2019/June-July/Conservation/Ocean-Plastic, Photo by Chris Jordan

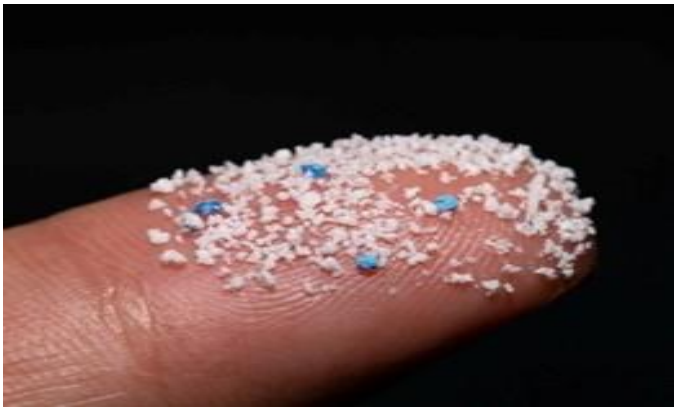

Fig. 9. A Greenpeace Philippines display after a sperm whale wasfound in Indonesia with 1000 plastic piece in its stomach, Source: https://www.basug.eu/yet-another-dead-whale-is-grave-reminder-of-our- massive-plastic-proble

Fig. 10. As per research done by consumerreports.org It is cal- culated that just by eating, drinking and breathing, people ingestat least 74,000 micro-plastic particles every year, another recent study commissioned by the World Wildlife Fund and conducted byRES. Source: https://www.istockphoto.com/photo/small-plastic-pellets-on-the-finger-micro-plastic-air-pollution-gm1170923784-324199999

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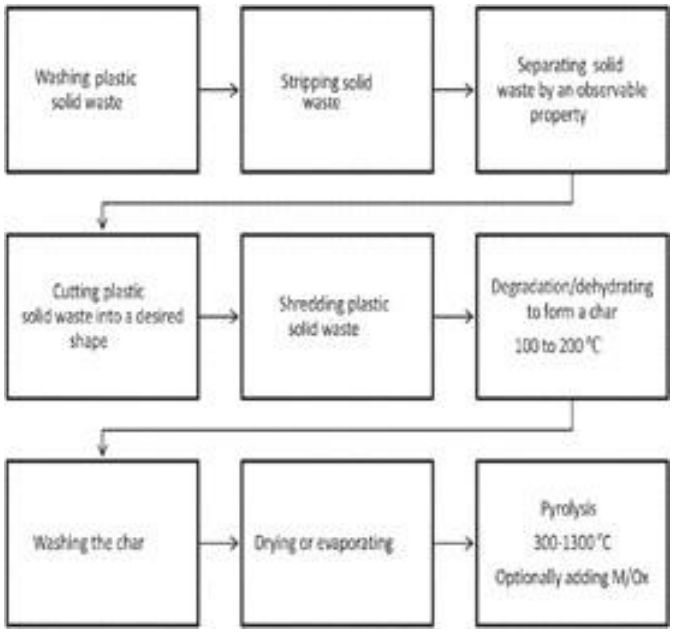

Fig. 11. Source: https://www.nytimes.com/2018/11/21/world/asia/whale- plastics-indonesia.html A sperm whale (Physeter macrocephalus) was stranded on Kapota Island, Wakatobi in a rotting condition (2018/11/21). The whale was in poor condition when it was found and its body parts were incomplete. The authorities cannot perform the necropsy to find out the cause of death of the whale 5.9 kg of plastic waste was found in the belly of this poor whale. Plastic waste, namely: hard plastic (19 pcs, 140 gr), plastic bottles (4 pcs,150 gr), plastic bags (25 pcs, 260 gr), flip flops (2 pcs, 270 gr), dominatedby raffia (3.26 kg) & plastic cups (115 pcs, 750 gr)

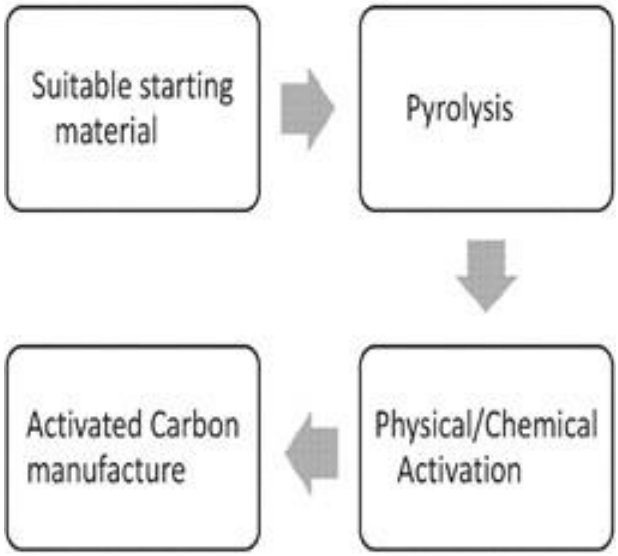

Fig. 12. A flowchart and representation of a process of activation [8]

Fig. 13. A flowchart and representation of a process of optional preparationand activation[8]

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III. CATALYST'S IMPACT

Many studies have been done on non-catalytic and catalyticpyrolyses of plastics, demonstrating that plastic waste maybe turned into valuable chemical feedstock. The results show that a variety of factors, including the polymer source (plastic type), catalysts utilized, catalyst size, catalyst to polymer ratio,reaction temperature, reaction duration, and reactor type, may influence product dispersion. The impact of different process factors is discussed further below. The catalyst employed in the pyrolysis of plastics certainly affects the result. Silica alumina, zeolites (beta, USY, ZSM-5, REY, clinoptilolite, etc.),and MCM-41 are the catalysts often used for plastic waste pyrolysis. Increasing acid sites increases polyolefin pyrolysis catalyst activity. Due to their high acid strength, zeolite-based catalysts yield more conversion.

[3.1] Effect of Catalyst Contact Mode Liquid and vapour phase contact are two techniques to add catalyst to the pyrolysis reactor. In liquid phase contact, the catalyst andpolymer are combined and heated to reaction temperature. In vapour phase interaction, the polymer is thermolyzed to produce the volatile portion. When the hydrocarbon vapour travels over the catalyst, it is degraded to get the required product distribution. The two procedures don't significantly affect product yield.[25]

[3.2] Effect of Polymer-to-catalyst ratio With more cata- lyst, effectiveness does not increase proportionally. Increased catalyst amount improves conversion up to a certain limit, however increasing the catalyst % has no meaningful effect. Research suggests a 4:1 polymer-to-catalyst ratio. According to the literature, a lower catalyst ratio results in the same degradation, but at a greater reaction temperature. Catalyst ratio and temperature must be optimised for cost-effective operation.[25]

[3.3] Temperature effects Catalytic pyrolysis at high tem- peratures or heating rates increases bond breakdown and creates smaller molecules. Temperature increases conversion, and with increased conversion, gaseous products are generated while liquid output is small or negligible. Catalysts have a lower impact on liquid yield and product dispersion when the temperature is higher.[25]

[3.4] Effect of Flow Rate of Nitrogen Gas The nitrogen flow rate often was increased to eliminate volatile main prod- ucts and reduce secondary reactions. This boosts yield. Studies suggest that increasing carrier gas flow rate may enhance condenser evaporation. This disproves liquid yield. The ideal flow rate is 10 mL/min, according to research. [25]

Sr. no.	Catalyst	Pore size (nm)	Commercial name
1	USY	0.74	H-Ultrastabilised, Y-zeolite
2	ZSM-5	0.55 × 0.51	H-ZSM-5 zeolite
3	MOR	0.65 × 0.70	H-Mordenite
4	ASA	3.15	Syncłyst 25 (silica-alumina)
5	MCM-41	4.2–5.2	—
6	SAHA	3.28	Amorphous silica-alumina
7	FCC-R1	—	Equilibrium catalyst
8	Silicalite	0.55 × 0.51	Synthesized in house

Fig. 14. List of catalysts in use [21, 22, & 23]

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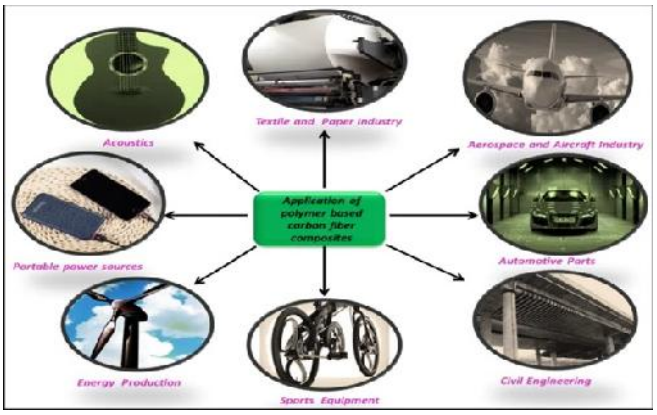

Fig. 15. Applications of carbon fibre-based composites [30]

IV. Conclusions and Discussions:

The disposal of waste plastics in an environmentally friendlymanner is a hot topic right now. Carbon nanotubes have specific features that make them high-value materials. Huge quantity of plastic trash generated may be processed using properly

developed technique to create fossil fuel alternatives. If facilities and funding are provided, the approach is superior (ecologically and economically). It has been revealed that plas-tic trash may be converted into hydrocarbon fuel, which wouldbe a cheap, pollution-free alternative to petroleum. It would also reduce crude oil imports and plastic garbage. Settingcriteria for post-consumer recycled plastics and implementing more complicated pyrolysis procedures for waste plastics arethe two biggest challenges, according to the latest study. Wasteplastics from small and medium-sized businesses and mixed waste streams must be accommodated by the pyrolysis reactor.Analysis would reduce capital investment and operating costs,improving the process's economic viability.

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