Grenoble INP, Pagora, International school of paper, print media and biomaterials

Valorization of plastic waste in Algeria

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Introduction:

Plastic materials have played a major role in society during the last century and are expected to do so in the future as well. The worldwide production of different plastics was close to 350 million tons in 2017. During their lifetime, plastics have been a substitute for other types of materials such as metals and ceramics, due to for example its low weight, ease of processing, corrosion resistance against most chemicals and its low cost. However, the biodegradability of many plastics is practically none, making waste management important to prevent them from accumulating in nature. The plastic waste in marine environments is expected to increase and is of high concern because of its effect on the oceans and wildlife. Moreover, most plastics are currently produced from fossil resources which is not sustainable. The waste management hierarchy is a way to order different steps of waste handling, and from most preferred to least preferred option they are: reduce, reuse, recycle, recover and landfill. Today, a large part of plastic waste is incinerated or landfilled. Landfilling means that the material is not utilized in any way. While incineration utilizes the energy bound in the material, it means the loss of a material that could be put to higher value if recycled. Another drawback is the generation of greenhouse gas emissions. There are thus good reasons to minimize the use of these methods. Directive (EU) 2018/852, amending directive 94/62/EC on packaging and packaging waste, states new targets for the recycling of packaging waste; 50 % of the plastics should be recycled by the year 2025, and 55 % by 2030. The member states are responsible for taking the necessary measures to attain the targets.

Recycling of plastics can be categorized into mechanical and chemical recycling. Mechanical recycling simply means remolding the plastic into new products, preserving its chemical structure. This is a simple and efficient method, but it cannot be repeated indefinitely as the material degrades slightly over each cycle. Moreover, it requires high purity in the feedstock in order to achieve a material of good quality. Meanwhile, chemical recycling can convert the plastics into the compounds from which they are originally made, thus enabling a sustainable life cycle, and it can handle a feedstock consisting of a mixture of different plastics. Both pyrolysis and gasification are examples of thermo-chemical processes which can be utilized for chemical recycling of the aforementioned feedstock. Pyrolysis provides the opportunity to crack plastic polymers into their monomers, allowing repolymerization into new plastics in a more efficient and straight forward process than gasification. However, pyrolysis is less flexible towards mixtures of plastics and other materials.

Pyrolysis is defined as a thermochemical process, where long-chain polymer molecules are broken down into smaller and less complex molecules, by means of heat and pressure, in a temperature range of 400 to 800°C, and in the absence of O2. The three main products are oil (liquid), char (solid) and permanent gases, which yield and quality depend mainly on the heating rate, process temperature, residence time, waste composition and particle size.

The liquid oil produced is an intermediate product of great value for the industry, mainly for refineries, where it can be integrated as a raw material for the synthesis of liquid fuels, for example, gasoline and diesel.


The global surge in waste generation demands innovative solutions to mitigate environmental impact and harness untapped energy resources
REDUCE
THE USE OF PLASTIC OR OTHER WASTE .
PYROLYSIS, A THERMOCHEMICAL CONVERSION PROCESS, PRESENTS A PROMISING AVENUE FOR THE TRANSFORMATION OF ORGANIC WASTE MATERIALS INTO VALUABLE LIQUID FUELS
BY HARNESSING PYROLYSIS FOR THIS PURPOSE, WE CONTRIBUTE TO A GREENER, MORE EFFICIENT PARADIGM FOR WASTE PROCESSING AND RESOURCE CONSERVATION.
PYROLYSIS PROCESS
CHAR
GAS
GLASS
PAPER
PLASTIC
BOTTLES
TURN ORGANIC WASTE INTO OIL.

Chapter 01: Literature Review

I.1. Definition and Characteristics of Plastic

I.1.1. Definition

Plastics are defined as any synthetic or semi-synthetic polymer with thermoplastic or thermoset properties, which may be synthesized from hydrocarbon or biomass raw materials.

In other words, plastics are made of synthetic polymers of high molecular mass, which are usually produced through the polymerization of monomers derived from oil gas, or coal.

I.1.2. Characteristics of Plastic

I.1.2.1. Chemical Characteristics

Chemical Characteristics Plastic materials are made up of identical sequences (or polymers) of carbon molecules. Their main properties include flexibility, corrosion resistance, shock resistance, and water resistance, as well as air impermeability.

Two groups of plastic materials are distinguished:

Thermoplastics: can be repeatedly softened and hardened by cooling, which means they can be reused multiple times.

Thermosets: these plastics harden permanently after being heated. Once manufactured, they are not deformable under the effect of heat; thus, due to their high melting point, they are mainly used to withstand high temperatures.

I.1.2.2. Physical Characteristics

The physical characteristics of most plastics' present high resistance to aging and minimal biodegradation. Indeed, they become very slowly brittle, fragmenting into small particles (micro-plastics). They are ubiquitous and their persistence leads to their accumulation in the environment.

I.2. Production and Use of Plastic Worldwide

The worldwide production of plastics has seen a significant increase over the years. In 1950, the world produced just two million tons of plastic, while in 2021, the production reached a staggering 390.7 million metric tons

. It is estimated that 8300 million metric tons of virgin plastics have been produced to date, with approximately 6300 million metric tons produced as of 2015. The production of plastic has sharply increased, with the expectation that it will further increase to about 600 billion tons in 2025. Plastics are used for various applications, including packaging, construction, and the automotive industries, with packaging accounting for the largest share at 44%. The increase in plastic production has raised concerns about environmental pollution, particularly when plastic waste is mismanaged, leading to its leakage into the environment

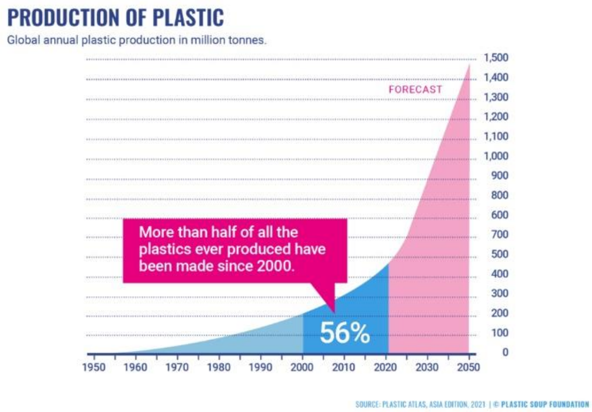
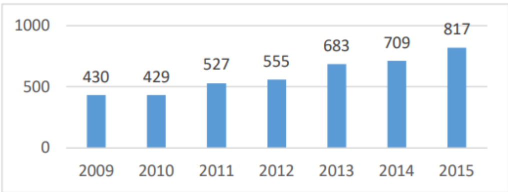


Figure 1. Global annual plastic production in million tons.

Otherwise, one general observation is that plastics are imported at higher amounts in primary form than as finished products. This implies that the rates of plastic processing and production activities using imported primary polymers are high in many countries of Africa. For Algeria, the data provided by the National Center for Informatics and Statistics of the Algerian Customs (CNIS) show imports worth 2.174 billion USD of plastics, of which USD 1.904 billion of raw products destined for the plastic industry with a rate of 87.58% and USD 269 million of finished plastic products.



Source : Adapted from, EUROMAP

Figure 2.Algerian's plastic import per Kt

I.3. Types of Plastic and Their Composition (Classification)

I.3.1. Polyethylene Terephthalate (PET)

Polyethylene terephthalate (PET) is also one of our most used plastics. It is a thermoplastic polymer belonging to the polyester family. PET is synthesized from ethylene glycol and terephthalic acid. PET has excellent thermal, mechanical, and chemical resistance. It is characterized by good strength, hardness, stiffness, and ductility. PET is the most recyclable kind of plastic, having the number "1" as a recycling symbol. It has the molecular formula $(C10H8O4)n$ and a density of 1.397g/cm3. PET is flexible, colorless, and semi-crystalline in its natural state.

I.3.2. High-Density Polyethylene (HDPE)

High-density Polyethylene (HDPE) HDPE is a linear structural compound with no or very little branching and a density ranging from 0.941 to 0.967 g/cm3. HDPE is formed using a low-pressure process (10-80 bar) and temperature (70-300 °C). HDPE is mainly produced by slurry polymerization or gas phase. The longer the main chain, the more atoms there are, and thus the higher the molecular weight. The physical and chemical properties of the final product are determined by the molecular weight, degree of branching, and distribution of molecules. Linear polyethylene is much stronger than branched polyethylene. Due to its high degree of crystallinity (70-90%), HDPE is opaque, rigid, and has high tensile strength. Therefore, it is commonly used in the production of milk bottles, detergent bottles, organic solvent bottles, pipes (water pipes, chemical-resistant pipes, gas distribution pipes, etc.) HDPE is the third most common type of plastic found in municipal solid waste and contributes to around 12.9% of the total plastic waste.

I.3.3. Polyvinyl Chloride (PVC)

Polyvinyl chloride (PVC) is a widely used thermoplastic manufactured from 57% chlorine and 43% carbon. PVC is produced from the polymerization of vinyl chloride monomer (VCM). PVC is used in pipes, medical appliances, wire cables, etc. It is characterized by its high-strength properties. Furthermore, the high chlorine content of PVC makes it fire resistant and thus ideal for electrical insulation. It is the world's third most used plastic after PE and PP and accounts for 9.6% of worldwide used plastic.

I.3.4. Low-Density Polyethylene (LDPE)

Low-density Polyethylene (LDPE) Some of the carbons in polyethylene have long chains or branches of polyethylene attached to them instead of hydrogen atoms. LDPE has a higher degree of short and long side-chain branching compared to HDPE. When compared to high-density polyethylene, branched or low-density polyethylene is less expensive, easier to manufacture, and has greater flexibility. Until 1950, the only polyethylene produced was low-density polyethylene density (LDPE) via free radical polymerization at very high pressures (1000-3000 bar) and moderate temperatures (147-297 °C). Due to the transfer of intermolecular and intramolecular chains during polymerization, this high-pressure polymerization produced polyethylene with many connections. LDPE has more branching and a density ranging from 0.910 to 0.925 g/cm3, resulting in a lower intermolecular force. This reduces tensile strength, melting point, crystallinity, and hardness. LDPE is made up of 4,000 to 40,000 carbon atoms with numerous short branches. Because the lateral branch makes the structure less crystalline, LDPE is easier to mold, semi-rigid, and has higher ductility than HDPE. Furthermore, due to its lower crystallinity (30-50%), this type of plastic is translucent rather than opaque. LDPE has high water resistance and is used in plastic bags, packaging, garbage bags, and other products. Because these items are commonplace in our lives, they have become the second most common plastic in municipal solid waste, accounting for approximately 17.4% of total global plastic waste.

I.3.5. Polypropylene (PP)

Polypropylene (PP) Polypropylene, like polyethylene, is a polyolefin with a methyl group attached to one of the main chain's two carbons, with the formula (-CH2-CH(CH3)-)n. As illustrated in fig. 1.5, polypropylene is synthesized by radical polymerization of propylene [(CH2=CH-CH3)] monomers using Ziegler Natta polymerization in the presence of metallocene catalysts. Upon polymerization, polypropylene can form three basic chain structures based on the position of the methyl group: isotactic, atactic, and syndiotactic.

I.3.6. Polystyrene (PS)

Polystyrene (PS) Polystyrene is a long hydrocarbon chain with a phenyl group attached to one of the main chain's two carbons. Polystyrene is produced through free radical vinyl polymerization of the monomer styrene (C8H8), is a low-cost, clear, hard, and brittle plastic with a melting point of around 240 °C. It is a transparent thermoplastic that is available as standard solid plastics as well as rigid foam materials. The solid plastic form of polystyrene is commonly used in medical device applications (test tubes, Petri dishes, etc.) and is commonly used in our daily lives in food packaging (dairy, fishery), electrical and electronic equipment, building insulation, eyeglass frames, CD cases, etc... Polystyrene plastic's wide range of applications resulted in it accounting for 6.1% of plastic production in 2020.

I.4. Plastic Waste

The total quantity of plastic waste generated is significantly less than the number of plastics produced. This is attributable to applications in which plastic meets a long-term need and has therefore not yet entered the waste streams in large quantities.

The majority of plastic waste comes from post-use sources. Post-use waste in OECD countries is primarily found in solid urban residues (RUS) and is also generated by distribution, construction and demolition, the automotive industry, electronic agriculture, and electrical sectors.

I.5. Influences and Dangers of Plastics

The combustion of plastic waste has a harmful impact on the environment and human health. To mitigate these negative effects, it is advisable to equip oneself with a gas mask to avoid inhalation, glasses to avoid eye contact, and gowns to avoid skin contact. It is also recommended to carry out combustion in ventilated places or to provide a system for the recovery and treatment of fumes.

Waste management in Algeria is currently carried out through four methods: direct management by municipalities, public industrial and commercial establishments, public procurement contracts with companies, and public service delegation: - In the case of direct management, the municipality assumes complete control of waste removal and disposal services. This method is the most widely used among Algerian municipalities. - An alternative method of managing waste removal and disposal is through the establishment of Public Administrative Institutions (EPAs) and Public Industrial and Commercial Institutions (EPICs). However, this method is not widely used in Algeria. A decree was issued in the late 2000s outlining the procedures for establishing EPICs, and by 2020, 62 EPICs had been established in the country.

In fact, waste management is a significant challenge in Algeria and other developing countries due to high levels of waste production. In Algeria, the amount of waste collected is only a small fraction of the total waste produced, and there are no reliable statistics on the quantities of waste collected or produced. It is estimated that the overall amount of waste generated in Algeria will almost double over the next 17 years, increasing from 34 million tons (0.8 kg/inhabitant) currently to 73 million tons (1.23 kg/inhabitant) by 2035. In most developing countries, the simplest way to dispose of household waste is through controlled or uncontrolled landfills. A significant portion of household waste, including plastics, is still disposed of in this manner. This method is the most convenient option for disposing of these residues.

II. Chapter 2: technical part: pyrolysis process

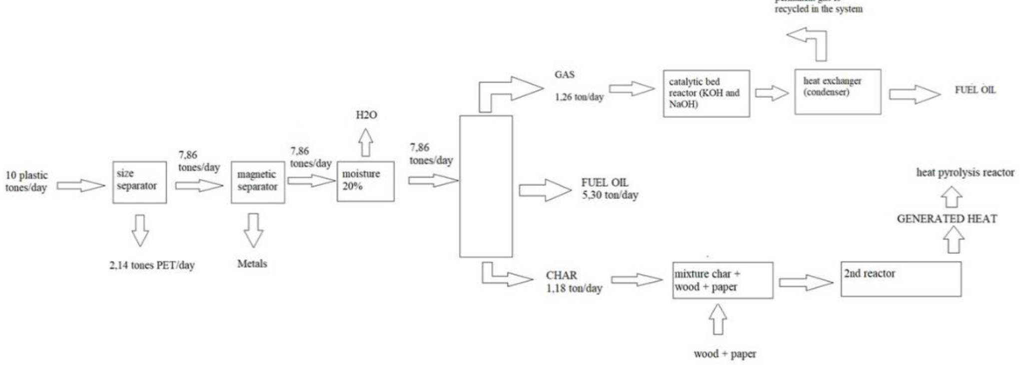


Figure 3. Process of converting plastic into fuel oil

II.1.Pyrolysis of mixed plastics

From the literature review, the pyrolysis reaction consists of three progressive steps: initiation, propagation, and termination. Initiation reaction cracks the large polymer molecules into free radicals. The free radicals and the molecular species can be further cracked into smaller radicals and molecules during the propagation reactions.

Pyrolysis is a thermal cracking reaction of the large molecular weight polymer carbon chains under an oxygen free environment and produces small molecular weight molecules. Traditional treatments for post-consumed plastics were landfills or incineration. However, landfill of the post-consumed plastics has potential problems because of limited land resource and high durability of plastics. Incomplete incineration may generate poisonous substances and causes serious health problems. Other methods like gasification and bioconversion are mainly used for organic materials. HDPE, LDPE, PP and PS are all hydrocarbons consisting entirely of carbon and hydrogen, which are similar to hydrocarbon fuels such as liquefied petroleum gas (LPG), petrol and diesel.

Some cracking occurs at the ends of the molecules or the free radicals, which is end chain cracking. Some polymers have reactive functional side group on their molecular backbones. The functional groups will break off the backbone, which is chain strip cracking. Chain strip cracking is the dominant cracking reaction during polystyrene pyrolysis. The activation energy and the energy requirement for the pyrolysis are dependent on the reaction process and the distribution of the final products.

The economic feasibility of a pyrolysis-based process will depend on how it is designed, as well as the scale of the plant. While a larger scale reduces specific investment costs, larger investments are more difficult to get in place, and shipping plastics over long distances requires more administration and increases operational costs. It is therefore of interest to investigate how a pyrolysis process can be designed to handle different types of plastic waste efficiently, and how large the plant would have to be to achieve economic feasibility. A plant for treating mixed plastics has the potential benefits of reducing or even eliminating the costs for sorting the waste, and a high amount of feed per uptake area. While PMMA constitutes less than one percent of the EU plastics market.

Figure 4. Pyrolysis process scheme.

II.2.Modeling of the Pyrolysis Plants

Simulating complete plastics pyrolysis plant allows investigation of the technological feasibility and limitations of the plant before its economic aspects are examined, and generates accurate material and energy balances for detailed and accurate estimation of the costs of utility and other materials required for its economic analysis. Also, the effects of process parameters, such as temperature and pressure, can be studied and optimized.

Material and energy balances were arbitrarily based on, 10 ton/day waste plastics. Waste plastics were composed as it shows in figure 5: 24% polyethylene terephthalate (PET), 14% polypropylene (PP), 6% high-density polyethylene (HDPE), 54% plastics bags, 1% polyvinyl chloride (PVC) and 1% polystyrene (PS). The values found on literature of the municipal waste on Algeria are the ones represented on table 1.

Developing conceptual flow sheets for the plants was the first step in developing their models. Chemical components and related thermodynamic models, together with unit operations and their operating and input conditions, were selected and specified. Then, the various units of the two plants were simulated in the sequences of their flow sheets, with the output of a unit serving as an input to the succeeding unit, until synthesis and test-running of the complex plants were achieved.

II.3.PLASTIC PRETREATMENT

Literature values were extracted from the total municipal waste of Algeria, where 15% of the waste consists of plastic. The corresponding percentage over 100 was calculated. Figure 5 shows the composition of plastic in the municipal waste of Algeria.

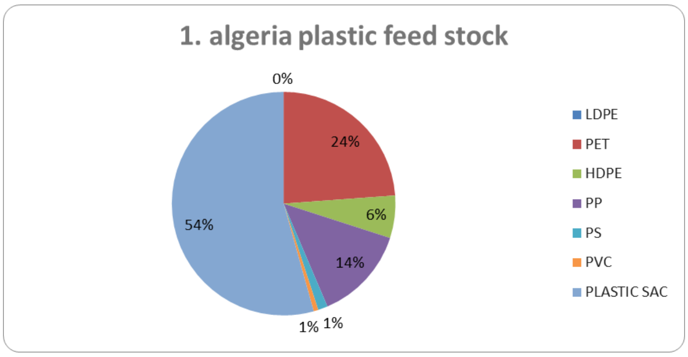


Figure 5. Municipal waste plastic production incoming to the pretreatment

To determine the value of plastic bags, the assumption was made that 90% of plastic bags are made of LDPE and 10% of HDPE

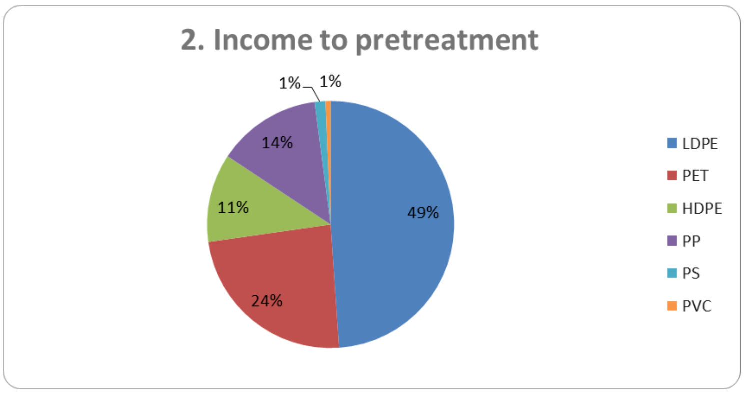


Figure 6. Plastic distribution incoming to the pretreatment after assumption

Table 1.Income to the pretreatment process

Algeria plastic feed stock			income to the process (%)	income to the process (t/d)
	over 15%	over 100%	LDPE assumption	mass tones/day
	Literature values	calculated		

PLASTIC SAC	8,14	54,34	0	0
LDPE	0	0,00	48,91	4,891
PET	3,57	23,83	23,83	2,383
HDPE	0,92	6,14	11,58	1,158
PP	2,04	13,62	13,62	1,362
PS	0,21	1,40	1,40	0,140
PVC	0,1	0,67	0,67	0,067
Total	14,98	100,00	100	10

II.4.PET elimination

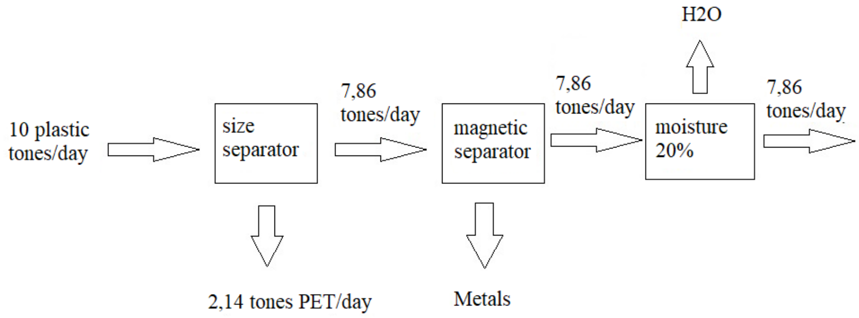


Figure 7.. Pretreatment process line

The aim of the pretreatment of plastics is to separate the PET bottles which has significant bigger size than the rest of plastic, the metals compounds to avoid corrosion and problems in the tower, and to mixture the plastics and ensure the moisture is below 20% before incoming to the pyrolysis tower.

With the aim of simplify the study, the maximum mass flow expected to come from pretreatment will be the maximum mass flow without PET.

For the sizing of the machines, the calculations have also been simplified regarding metals, assuming that there is no presence of metals in the mixture. In case there is any presence of metals, the sizing of the machines will remain the same because the metals will be eliminated before entering the pyrolysis tower.

Table 2.Mass balance after PET reduction

Plastics	pet reduced to 1,5-2%	Pretreatment	
	new percentage	eliminates 90% pet 90% metals	mass flow in tones/day
LDPE	48,91	62,97	4,89
PET	1,50	1,93	0,24
HDPE	11,58	14,90	1,16
PP	13,62	17,53	1,36

PS	1,40	1,80	0,14
PVC	0,67	0,86	0,07
Total	77,67	100	7,86
outcoming pet	22,33		2,145
total incoming (tones)	10,00	tones/day	
PET Mec. Recycled	2,14	tones/day	

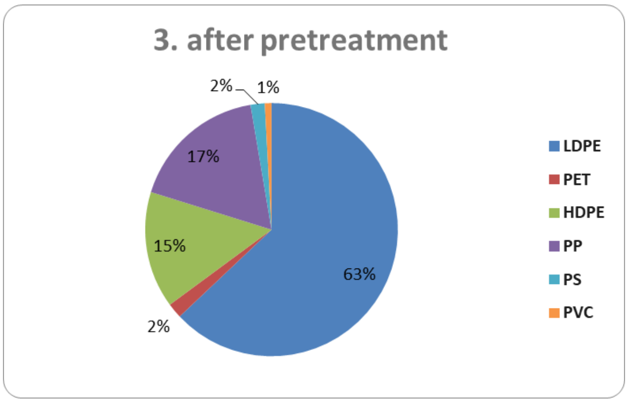


Figure 8. Plastic composition after pretreatment and incoming to pyrolysis tower.

After pretreatment the main plastics incoming to the pyrolysis tower will be LDPE, HDPE and PP. PVC, PS and PET have very low percentage over the other components of the mixture.

II.5.Pyrolysis tower

To calculate the pyrolysis yield tower, it's been used the literature of the BEINTEC Company, *BEINTEC Inovações Tecnológicas*, based in RS/Brazil, personal communication, 2020. The pretreatment of our process has been adjusted as similar as the one used in this company.

After the pre-treatment of the plastic solid waste (PSW), the fixed-bed pyrolysis reactor with a capacity of $8m^3$ is loaded with pre-treated PSW, and then heated at a rate of 2°C/min until it reaches a reaction temperature between 270 and 350°C. This temperature range is typical for pyrolysis processes and is necessary to break down the long-chain polymer molecules in the plastic waste into smaller organic molecules or monomers. The pyrolysis process is then maintained at the established temperature for 6 hours, the retention time of the pyrolysis gases is 90 minutes. Each batch operation cycle lasts an average of 9 hours.

Meanwhile, plastic waste polymer molecules are broken up into smaller organic molecules or monomers by the action of heat in an oxygen-free environment. During this process, volatilization, and fusion reactions occur.

To selectively promote specific reactions during pyrolysis and obtain higher yields of liquid products at low temperatures, catalysts are added to the PSW. However, the company chose not to publish which materials are used as catalysts within the pyrolysis reactor.

Table 3.. Pyrolysis tower conditions

T pyrolysis	270	ºC
	350	ºC

rate	2	ºC/min
residence time	6	Hours
gas ret. Time	90	Min

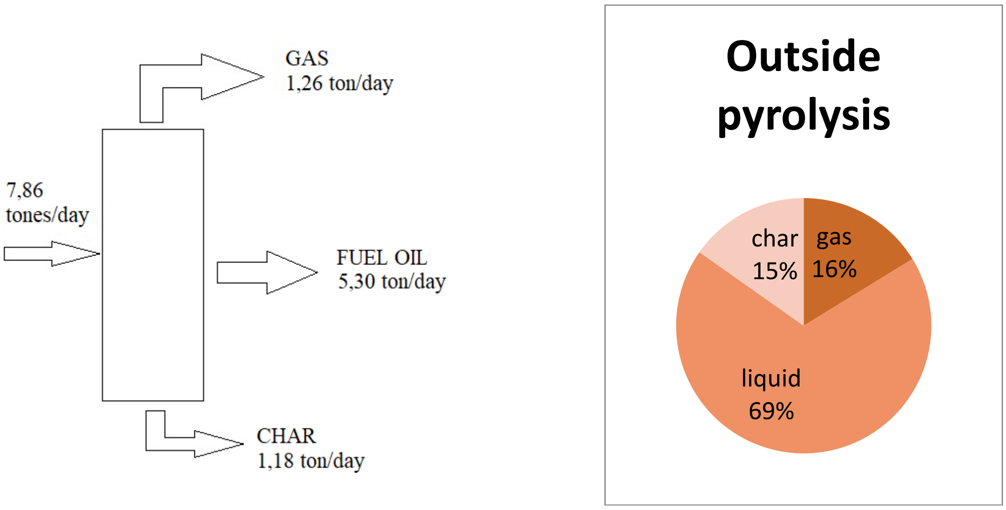


Figure 9. Pyrolysis scheme composition

Table 4. Outcome of pyrolysis tower

out pyrolysis ton/day	
gas (16%)	1,26
liquid (69%)	5,30
char (15%)	1,18
mass balance tones/day	
total	7,86

II.6.Fuel Oil

In Table 5 are shown the characteristics of the FO produced during the pyrolysis of PSW in the system under analysis. From an economic perspective, attention should be paid to the conversion rates of PSW to oil; BEINTEC pyrolysis process has a conversion factor of 0.72 for the ratio liters of oil/mass of PSW, and the efficiency of the oil purification system is 95 %, thus, for 10 ton of plastics are is produced 5,30 ton of oil.

Table 5. Characteristic of the FO produced

Lower heating value	46.5	MJ/kg FO
Density 20 °C	0.786 – 0.847	g/cm³
Viscosity 50°C	2.318	mm²/s cost
Viscosity 100°C	1.085	mm²/s cost

Sulphur content	1.785	mg/kg FO
a: Company, BEINTEC Inovações Tecnológicas, based in RS/Brazil, personal communication, 2020.		

The FO obtained through the thermochemical conversion of PSW in the BEINTEC technology has a lower heating value (LHV) of 46.5 MJ/kg.

This value is higher than market fuels such as diesel oil and gasoline that have LHV of 42 MJ/Kg and 43 MJ/kg, respectively.

II.7.Gas treatment

In the pyrolysis process, the gas generated will pass through a catalytic bed (KOH and NaOH) for the treatment of de-nitrogenization, de-chlorination, and desulphurization. As shown in figure 10.

The fusion of these materials occurs between the temperatures of 350°C to 400°C. Besides, most of the acid gas such as HCl, SO2, SO3, and H2S, are absorbed using inorganic acid H2SO4.

When the catalytic cracking, and purification process finishes, the gas is conducted through heat exchangers where it is condensed into a liquid mixture of light and heavy hydrocarbons.

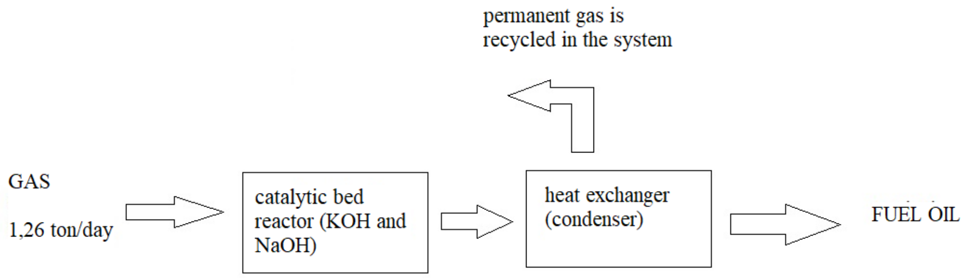


Figure 10. Gas treatment after pyrolysis tower

These oils are an essential intermediate energy carrier with a high added value that can be integrated into conventional refineries as a raw material for the synthesis of liquid fuels.

The permanent gas is used in the pyrolysis reactor as a purge gas, to prevent the entry of O2, and to promote the flow of the pyrolysis gas released during the process. The rest of the permanent gas is burned to generate part of the process heat for the pyrolysis reactor.

II.8.Char treatment

The char coming from the pyrolysis tower will follow another treatment. It is mixed with woody biomass and wastepaper, the blend produced is used in co-gasification in a second reactor to generate the heat required by the pyrolysis reactor. Thus, to ensure that the process is thermally self-sustaining.

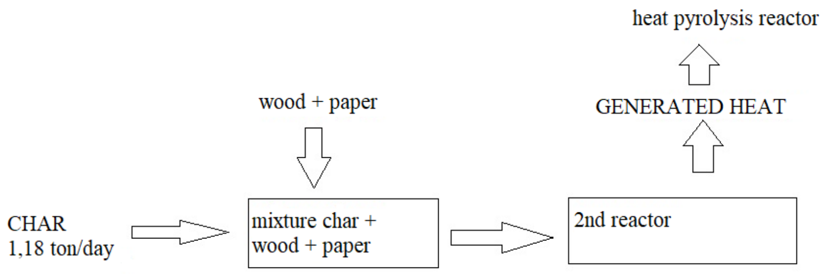


Figure 11. Scheme of char treatment after pyrolysis

In slow plastic pyrolysis, the main product is oil, while non-condensable gas and char are by products.

II.9.Machines and prices of the project

In order to determine the pricing of the machines involved in the process and their installation costs, a company that processes 10 tons per day of plastic waste has been identified (BLJ-16 BESTON Pyrolysis). The mass balance of this project has been adjusted to the volume of BESTON company. The costs of the pretreatment machines and the pyrolysis tower have been taken from this company's prices, and the post-treatment of gas and char has been researched, along with some machines that meet the functional demand and the required flow for the process. The list of machines and prices is shown in the table 7.

On the post treatment of char 1.16 tons/day had to be treated. In gas 1,26 ton/day. It's been divided this mas in 24 hours and then multiplied by 15 hours of working plant process. The results of these calculations are shown in table 6.

Table 6.. Calculation to determine the number of machines post treatments post treatment

	Gas	Char
tones/day	1,26	1,16
tones/hours	0,0525	0,048333333
working 15 hours	15	15
tones each hour	0,7875	0,725
kg each hour	787,5	725
capacity of reactor (L)	200	200
number reactors	3,9375	3,625
Real number of reactors	4	4
as L is not kg, we estimate one more	5	5
kg entrance/each reactor	157,5	145

III.Chapter 3: Economical part

III.1. Project Scope Definition:

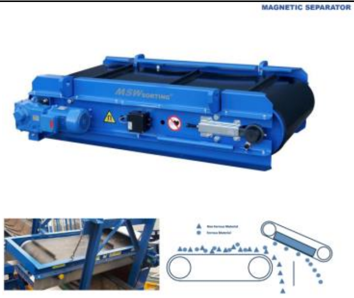
The proposed pyrolysis plant is designed to process a variety of plastic waste materials, including LDPE, HDPE, PP and PS. The plant is scaled to handle an input of 10 tons of plastic waste per day. This scale was chosen based on factors such as the availability of plastic waste, market demand for pyrolysis products, and available resources. The daily throughput of 10 tons allows for a significant amount of waste to be processed, while still being manageable for a new operation. This scale of operation is expected to produce a substantial quantity of valuable end products such as oil, char, and syngas, contributing to the economic viability of the project. As the operation matures and efficiencies are realized, there may be opportunities to scale up the operation to process even greater quantities of plastic waste.

III.2. Capital Expenditure (CAPEX) Estimation:

III.2.1. Infrastructure costs

Table 7. Machines involved in the process

machine	capacity	price	
1. chain plate feeder	10 ton/day	-	
2. feeder waste distributor		-	
3. bag opener		-	
4. tromell screen (will separate the PET)		-	

5. magnetic separator		-	
6. waste shredder (will grind the plastics)		-	
7. pyrolysis tower		-	
BLJ-16 BESTON PYROLYSIS		Total =89000	
8. mixer with wood (char treatment 1) 5000L GMP Quality Machine Factory Blender Homogenizing Mixer	5000	3500	
9. Thermal Reactor (char treatment 1) FS 3000L Stainless steel multi-function reactor	3000	10000	

10. catalytic bed reactor (gas treatment 1) 5000L High Pressure Stainless Steel Fluidized Bed Reactor	200	1650*5=8250	
11. condenser (gas treatment 2) Refrigeration Industry Customized Shell and Tube Heat Exchanger Condenser Heat Exchanger Tube Bundle	200	1800*5=9000	

The detailed breakdown below presents the fixed investment costs associated with equipment, transportation, installation, materials, license, and workshop requirements. Each item includes information on the unit, unit price, quantity, and the resulting amount. The total fixed investment cost for this segment is calculated to be $259,100.

The majority of the equipment will be procured from Beston Company.

Table 8.. Capital Expenditure Estimation for pyrolysis process

	Item	Details	unit	unit price	quantity	amount	total amount
fixed investment cost	Equipment	BLJ-16 (beston)	Set	89000	1	89000	
		Char treatment	Set	13500	1	13500	
		gas treatment	Set	17250	1	17250	
	Transportation	Sea freight	Set	64600	1	64600	
		from port to site	Set	3000	1	3000	
	custom tax	15%	Set	13350	1	13350	

		Tech Salary	Day	50	50	2500	
		round trip	Ea	3000	2	6000	
		Visa	Ea	750	1	750	
	installation	Local welder	Day	30	100	3000	
		Local plumber	Day	30	20	600	
		local labor	Day	23	50	1150	
		crane forklift	Day	130	30	3900	
	Materials	installation material	Set	4000	1	4000	
	License		Ea	1500	1	1500	
	Workshop	500	m^2	70	500	35000	
							259100

III.3. Operational Expenditure (OPEX) Estimation:

This section outlines the estimated ongoing operating costs associated with the day-to-day running of the plant. The table below breaks down the various components, including raw materials, water, electricity, fuel, labor, maintenance, and depreciation over an 8-year period. Each item specifies the unit, unit price, quantity, and the resulting amount. The total operating cost for this segment is calculated to be $2105.06.

Table 9. operational cost Estimation

	Raw materials	Waste plastic	Ton	180	10	1800	
	water		m3	0,3	3	0,9	
	Electricity		KW/H	0,035	864	30,24	
	Fuel	Natural gas	Liter	0,004	240	0,96	
	Labor		People	20	4	80	
	maintenance		Day	85	1	85	
	Depreciation (8 years)	8	Day	108	1	107,9583333	
operating cost							2105,058333

III.4. Revenue Estimation:

The economic viability of the project is crucial for its success. In this section, we delve into the revenue estimation, outlining the anticipated returns from the end products. The table below provides a breakdown of the expected revenue generated from the sale of pyrolysis oil and char. It's important to note that the gas produced is utilized internally for heating within the process, and therefore, its value is not calculated as a separate revenue item. The quantities, unit prices, and total amounts for each product are detailed, resulting in a total estimated revenue of $3428.

Table 10.. Revenue Estimation for Pyrolysis Oil Production

End product	Pyrolysis oil		KG	5,8	530	3074	
	char		Kg	3	118	354	
	Gas			0	126	0	
							3428

III.5. Financial Analysis:

To assess the profitability of the project, a financial analysis has been conducted, taking into account the daily, monthly, and yearly income. The daily income is calculated as the difference between the total operating cost and the total amount of benefits. Subsequently, the applicable taxes (17%) are deducted from the daily income to derive the net income. The final values are then extrapolated to represent the income per working day (25 days per month) and per year (300 days). The table below presents a comprehensive overview of the financial analysis, offering insights into the project's profitability.

Table 11.Net daily, monthly and yearly income

Taxes	17%						
Daily income		working day					1098,041583$
Monthly		25 days					27451,03958$
yearly income		300 days					329412,475$

Before delving into the financial analysis metrics, it's important to note that the calculations take into account variations in the pricing of pyrolysis oil. The selling price of pyrolysis oil is assumed to increase by 4% each year, reflecting potential market fluctuations. Additionally, technician salaries are considered to rise by 1.3% annually to changing economic conditions over the **8-year** period and are based on a discount rate of 10%.

Table 12.the financial analysis metrics

year	Cash flow	Cumulative Cash Flow	initial investment	Discounted cash flow	Remaining Investment	
1	329412,48	329412,475	259100	299465,886	70312,475	

2	360025,62	689438,0994	259100	297541,8383	430338,0994	
3	391863,4	1081301,496	259100	294412,77	822201,4964	
4	424974,78	1506276,276	259100	290263,492	1247176,276	
5	459410,72	1965686,993	259100	285257,91	1706586,993	
6	495224,19	2460911,187	259100	279541,147	2201811,187	
7	532470,31	2993381,5	259100	273241,464	2734281,5	
8	571206,38	3564587,882	259100	266471,993	3305487,882	
Payback period					Before1 year	236 days
NPV						2027096,5$
IRR						136%

Net present value (NPV)

$$NPV=\sum \frac{CFt}{(1+r)^t}$$

The positive Net Present Value (NPV) of $2027096.5 indicates that the plastic waste pyrolysis project in Algeria is not only financially viable but also has the potential to generate significant returns. A positive NPV suggests that the project's expected earnings, when discounted at the specified rate, exceed the initial investment, making it an appealing investment opportunity.

The Internal Rate of Return (IRR) at 136% is high. This signifies that the project is expected to yield substantial returns on the initial investment. An IRR of 136% is well above typical rates of return and further strengthens the attractiveness of the investment.

Payback period: The cumulative cash flow for the first year surpassing the initial investment implies a quick payback period. In fact, the project is projected to pay back the initial investment before the completion of the first year, specifically within 236 days of work. This rapid payback period is a positive indicator of the project's financial efficiency and strong cash flow generation.

III.6. Risk Analysis:

In the pursuit of successful project management, a comprehensive understanding and anticipation of potential risks and uncertainties are paramount. This risk analysis aims to systematically identify and evaluate the various challenges associated with our project, spanning aspects such as changes in waste supply, fluctuations in product demand, and shifts in the regulatory environment. By scrutinizing these potential risks, we can develop proactive strategies to navigate and mitigate their impacts. The subsequent table, Table 13, provides a detailed overview of identified risks, their impact levels, and proposed mitigation measures. Through this analysis, we aim to fortify our project against adversities, ensuring a resilient and successful execution.

Table 13.the potential risks

Assumptions	Impact Level	Risk	Mitigation
Supply of Plastic Waste	Very High	Low	Diversified supply sources, long-term contracts, and continuous monitoring of recycling trends can help mitigate the impact.
Market Demand for End Products	Moderate to Low	High	Regular market analysis, exploration of new applications, and strategic partnerships can help manage the impact of fluctuating market demand.
Raw Material Price Variability	Low	moderate	| Utilizing forward contracts, diversifying sources, and ongoing analysis of international markets can help mitigate the impact of price variability. |
Regulatory Risks	Low to moderate	Low	A dedicated team to monitor regulatory changes, proactive engagement with authorities, and adherence to environmental best practices can help manage regulatory risks.
Technological Risks	Moderate to Low	Low	Selecting proven technologies, rigorous preventive maintenance programs, and continuous staff training can help mitigate potential technological risks.
Geopolitical Risks	Very High to high	high	Very High to Low | Continuous monitoring of political and economic developments, diversification of energy and raw material sources, and proactive engagement with local authorities can help manage geopolitical risks.
Financial Risks	Very High	Low	Establishing contingency budgets, using financial instruments to hedge against exchange risks, and regular review of financial performance can help mitigate potential financial risks.
Commercialization Risks	Moderate to Low	moderate	Developing a robust marketing strategy, identifying potential buyers in advance, and establishing long-term sales contracts can help manage commercialization risks.

III.7. Sensitivity Analysis of Cost Variables on Profitability

In this section, we conduct a sensitivity analysis focusing on key cost variables to understand their impact on the overall profitability of the project. By varying the values associated with the cost of plastic waste, quantity of oil sold, and cost of oil, we assess the corresponding effects on profitability. Each scenario is meticulously examined, shedding light on both low and high-profit impacts. This sensitivity analysis provides valuable insights into the project's vulnerability to changes in these critical cost factors, emphasizing the need for strategic management and mitigation strategies to optimize profitability under varying conditions.

Table 14.Sensitivity Analysis of Cost Variables on Profitability

Variable	Base value	low Profit	Impact	high Profit	Impact
Cost Plastic waste	$180,00	$ 280		$ 100	
Profitability	$329412,48	$ 80 412,48	-75,6%	$ 528 612,48	60,5%
Quantity sells of oil	Initial quantity 530 Ton	50%		100%	
Profitability	$329412,48	$-53 300,53	-116,2%	$ 329412,48	0
Cost of oil		90%		130%	
Profitability	$ 32412,48	$ 252 869,88	-23,2%	$ 559 040,28	69,7%

Cost Plastic Waste:

Base Value: $180.00. Low Profit Impact: Increasing the cost to $280 results in a $100 decrease in profit. High Profit Impact: Decreasing the cost to $100 leads to a 60.5% rise in profitability.

Quantity Sells of Oil:

Initial Quantity: 530 tons. Low Profit Impact: A 50% decrease negatively impacts profitability. High Profit Impact: A 100% increase positively impacts profitability, bringing it back to the base value.

Cost of Oil:

Low Profit Impact: A 90% increase results in a $252,869.88 decrease in profit. High Profit Impact: A 130% increase significantly reduces profitability, with a high impact of 69.7%.

Profitability: Base Value: $329,412.48. Low Profit Impact: An $80,412.48 increase leads to a 75.6% decrease in profitability. High Profit Impact: A $528,612.48 increase results in a 60.5% rise in profitability.

Profitability (Quantity Sells of Oil):

Low Profit Impact: A $53,300.53 decrease significantly negatively impacts profitability.

High Profit Impact: A $329,412.48 increase brings profitability back to the base value.

Profitability (Cost of Oil): Low Profit Impact: A $252,869.88 increase leads to a 23.2% decrease in profitability. High Profit Impact: A $559,040.28 increase results in a 69.7% rise in profitability.

From the provided information, the Cost of Oil (Scenario 3) has the most significant impact on profitability, with a 69.7% increase when the cost of oil rises by 130%. This suggests that managing and controlling the cost of oil is crucial for maintaining or improving profitability in this analysis.

III.8. Comparison between market energy and pyrolysis price

III.8.1. Petroleum and liquid fuels energy

The price of crude oil in Algeria varied over the years. In the second quarter of 2022, the average price of crude oil in Algeria was $117.8 per barrel .

. In December 2022, the export price of crude oil was reported at $103.7 per barrel, showing an increase from the previous year.

Figure 12.Price of crude oil in 28 January

Table 15.. Comparison between crude and pyrolysis oil price's

	weight (kg)	Prix	price of pyrolysis oil
barrel	136	83,72	
Ton	1000	615,55	580

- Our pyrolysis oil price stands at $580, presenting a competitive alternative to the current crude oil market, which is priced at $615.
- This $35 price difference positions our product as a cost-effective and sustainable option for potential customers.
- Current market trends indicate an increasing demand for eco-friendly solutions, aligning with the sustainability aspect of our pyrolysis oil.
- Environmental awareness and regulatory measures may further enhance the market reception of our product.
- Develop an adaptable business plan that considers market dynamics, allowing us to make informed decisions and stay competitive in the evolving landscape.

III.9. Proposing Pyrolysis Integration for Plastic Waste Management in Sonatrach's Oil Refinery

The project aims to propose the integration of pyrolysis technology for waste plastic management to Sonatrach, a major petroleum company. Pyrolysis involves converting plastic waste into valuable products, aligning with global sustainability goals. The benefits include environmental responsibility, resource recovery, corporate social responsibility, and enhanced market positioning. The proposal emphasizes the economic, environmental, and social advantages, making a compelling case for collaboration and showcasing Sonatrach as a pioneer in sustainable waste management.

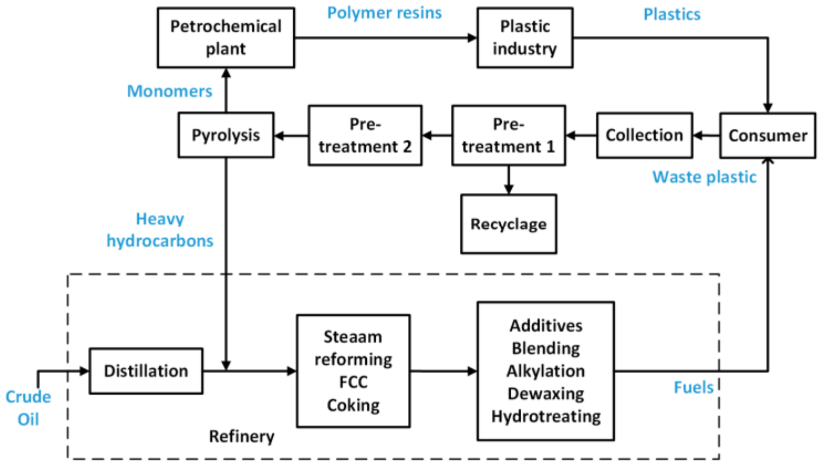


Figure 13..integration of a plastic waste pyrolysis plant with an oil refinery

The integration of a pyrolysis plant for plastic waste into an oil refinery involves incorporating polyolefin pyrolysis waxes into various refining processes. These processes include fluid catalytic cracking (FCC) units, catalytic upgrading of pyrolysis liquids, hydro processing, dewaxing, fuel properties enhancement, and char upgrading. The goal is to recover raw materials and obtain fuels from plastic waste. The upgraded liquids, obtained through catalytic processes, can include gasoline-like, diesel-like, and waxy fractions. The integration also involves directing monomers and light hydrocarbons to petrochemical plants for new polymer resin production. Overall, this recycling configuration enables the valorization of different plastic waste types, contributing to sustainability and minimizing the landfilled fraction.

Conclusions

The valorization of plastic waste through pyrolysis technology in Algeria presents a promising and financially viable venture. The financial analysis reveals positive indicators such as a favorable Net Present Value (NPV), a high Internal Rate of Return (IRR), and an impressively quick payback period of 236 days, underscoring the project's financial efficiency and potential for robust returns on investment over the 8-year period. Additionally, the project's positive financial outlook and alignment with global sustainability goals position it as a strategic initiative. The proposal to integrate pyrolysis technology into Sonatrach's oil refinery not only addresses plastic waste management but also reinforces Sonatrach's commitment to environmental responsibility, resource recovery, and corporate social responsibility. This project stands to contribute significantly to both the company's success and the broader goals of environmental sustainability in Algeria

The benefits of plastic waste valorization through pyrolysis technology include reduced petroleum use, energy conservation, CO_2 emission reduction, and reduced landfill use. Recycling plastic waste can reduce petroleum use by up to 40%, save significant energy, lead to a reduction in CO_2 emissions and other greenhouse gases, and decrease the amount of plastic in landfills, resulting in less emission of landfill gases and reduced environmental damage.

While there are challenges and limitations to the current tools and methods used for recovering plastic waste, such as the difficulty in recycling all types of plastic using current technology, pyrolysis technology still offers a promising solution for plastic waste management and environmental sustainability.

In conclusion, the integration of pyrolysis technology for plastic waste valorization in Algeria not only presents a sound financial opportunity but also contributes to environmental responsibility and sustainability, making it a strategic initiative for both Sonatrach and the broader goals of environmental sustainability in the country.

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