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INGENIERO INDUSTRIAL - RAMA MECÁNICA

ECONOMIC FEASIBILITY OF ENERGY RECOVERY FROM PLASTIC WASTE

Autor: Juan Abascal Alonso
Director: Maryam Ghodrat

Madrid
Enero 2017

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ECONOMIC FEASIBILITY OF ENERGY RECOVERY FROM PLASTIC WASTE

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Madrid, on 23 of JANUARY, 2018

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Juan

Fdo.: (Nombre del alumno) Juan Abascal Alonso   Fecha: 23 / 01 / 18

Autorizada la entrega del proyecto

EL DIRECTOR DEL PROYECTO

Fdo.: (Nombre del Director) Maryam Ghodrat   Fecha: 10 / 1 / 18

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Autor: Abascal Alonso, Juan.

Director: Ghodrat, Maryam.

Entidad Colaboradora: ICAI – Universidad Pontificia Comillas.

RESUMEN DEL PROYECTO

Introducción

El objetivo del proyecto es evaluar la viabilidad económica de la construcción de una planta de tratamiento de residuos plásticos para producir energía. El principal es el estudio de la generación de valor añadido aprovechando el poder calorífico de los polímeros que conforman los plásticos sintéticos. Aprovechando este proyecto, se establece una recomendación a las autoridades con el fin de mejorar la gestión de los residuos de tal forma que se reduzcan las cantidades depositadas en los vertederos. La viabilidad se estudia a través de un análisis de coste/ingreso según los capitales aportados y recibidos. Durante el análisis se reproducen tanto los costes de la inversión inicial, así como los asumidos a lo largo del periodo de operación. Al final del análisis se estudian diversos escenarios con el fin de hacer el análisis más adaptable menos estático ante una única situación.

El "Estado del Arte" persigue la obtención de información sobre las tecnologías y procedimientos que ya se han utilizado para tratar plásticos residuales en distintas plantas alrededor del mundo prestando especial atención a los servicios en Australia. Esto servirá para definir las mejores estrategias a la hora de tratar los residuos en la planta. La información sobre las cantidades de residuos generadas, las tecnologías y sus beneficios e inconvenientes, la contaminación y demás condiciones, son imprescindibles para demostrar por qué el tema elegido tiene gran impacto en la actualidad.

En Australia, a lo largo del periodo 2014-2015, 64 millones de toneladas de basura fueron producidas, el equivalente a 2.7 toneladas per cápita. En cuanto a los plásticos, 107 kg per cápita fueron generados, lo que supone un 4% de toda la producción, ascendiendo a 2.5 millones de toneladas (Department of the Environment and Energy, 2016). En la siguiente figura se indican los distintos porcentajes de Residuos Sólidos Municipales. Entre los Plásticos se incluyen los explicados en la figura inmediatamente inferior.

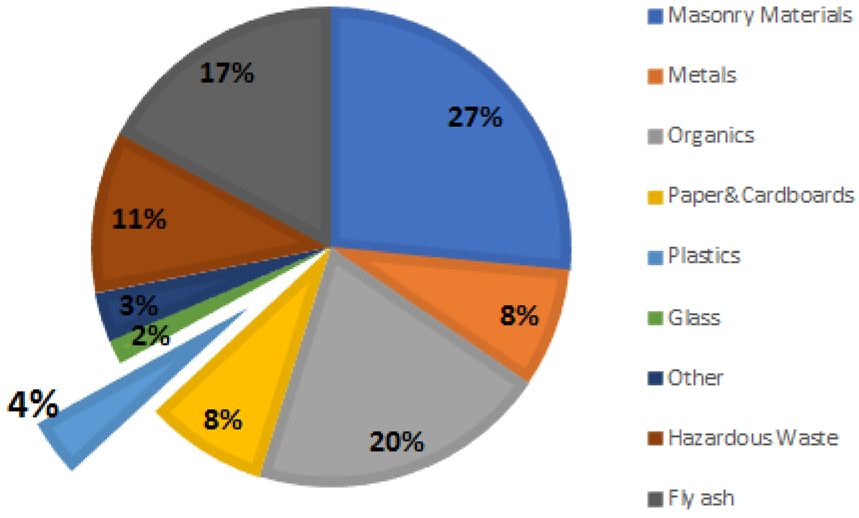

Figure 1: Producción de Residuos según la categoría del material en Australia 2014-2015. Fuente: Australian National Waste Report 2016.

Centrando el Proyecto en las tecnologías que ofrecen un mayor beneficio económico, teniendo en cuenta aspectos medioambientales y sociales, el "Estado del Arte" será más exhaustivo en los tratamientos térmicos dominantes en la gestión de los residuos plásticos. Los pros y contras de estas tecnologías han sido estudiados en detalle para poder elegir la mejor tecnología disponible a la hora de desarrollar el montaje de la planta.

Symbol	Acronym	Full name and uses
1	PET	Polyethylene terephthalate - Fizzy drink bottles and frozen ready meal packages.
2	HDPE	High-density polyethylene - Milk and washing-up liquid bottles
3	PVC	Polyvinyl chloride - Food trays, cling film, bottles for squash, mineral water and shampoo.
4	LDPE	Low density polyethylene - Carrier bags and bin liners.
5	PP	Polypropylene - Margarine tubs, microwave-able meal trays.
6	PS	Polystyrene - Yoghurt pots, foam meat or fish trays, hamburger boxes and egg cartons, vending cups, plastic cutlery, protective packaging for electronic goods and toys.
7	Other	Any other plastics that do not fall into any of the above categories. For example melamine, often used in plastic plates and cups.

Figure 2: Tipos de plásticos y sus principales usos (Pinterest, 2017).

A continuación, se detallan las distintas metodologías existentes para tratar plásticos residuales, evitando así depositarlos en los vertederos. Cada una de estas metodologías cuenta con diferentes técnicas aplicables, dentro de una gran variedad de procesos industriales.

How to manage Plastic Waste

There are many different ways which are separated into four groups:

1. **Re-extrusion:** primary recycling to create products of similar material
2. **Mechanical**: cutting/shredding, contaminant separation, floating, milling, washing and drying, agglutination, extrusion and quenching.
3. **Chemical:** thermo-chemical treatments to produce fuels or petrochemical feedstock.
4. **Energy recovery:** burning waste to produce energy in form of heat, steam and electricity.

Figure 3: Gestión del plástico residual (Al-Salem, 2009)

Metodología

Una vez determinado el tratamiento más eficiente según la información recogida, el proyecto continúa identificando la tecnología que se va a aplicar, así como el esquema que se va a crear para la planta. Dentro del propio esquema se organizarán las entradas y salidas que serán computables a la hora de realizar el análisis económico. La parte más importante del proyecto es la recogida de información relativa a los precios de las tecnologías y de la implantación del propio sistema. El coste de los dispositivos, los materiales de entrada y salida, la energía consumida, etcétera, son elementos fundamentales para estudiar la viabilidad. En cualquier caso, el proyectista ha determinado ciertos márgenes económicos de seguridad, aprovisionando costes por si hubiera errores en la obtención de la información.

Para producir los mayores beneficios económico-sociales posibles, la solución que se ha adoptado es la construcción de una planta que combine el proceso de pirólisis del plástico y posterior combustión de algunos de los elementos producidos. De esta forma se producirán distintas fuentes de energía como combustibles o calor, que podrán ser consumidos en el interior de las instalaciones o vendidos a terceros.

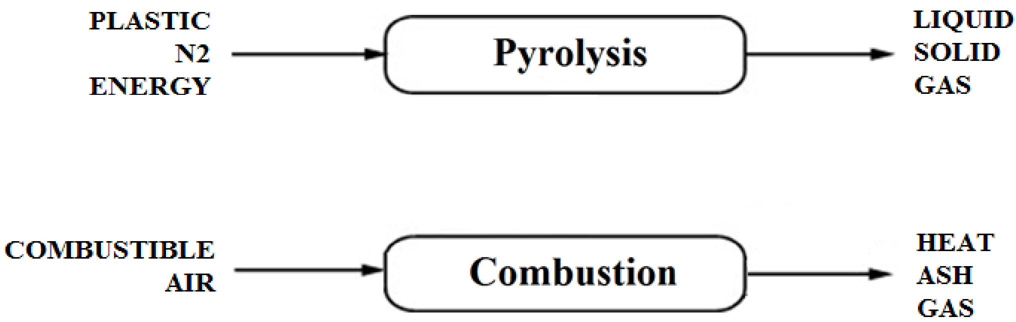

Figure 4: Entradas y salidas del Sistema

Como resultado, el proyectista ha diseñado el siguiente esquema:

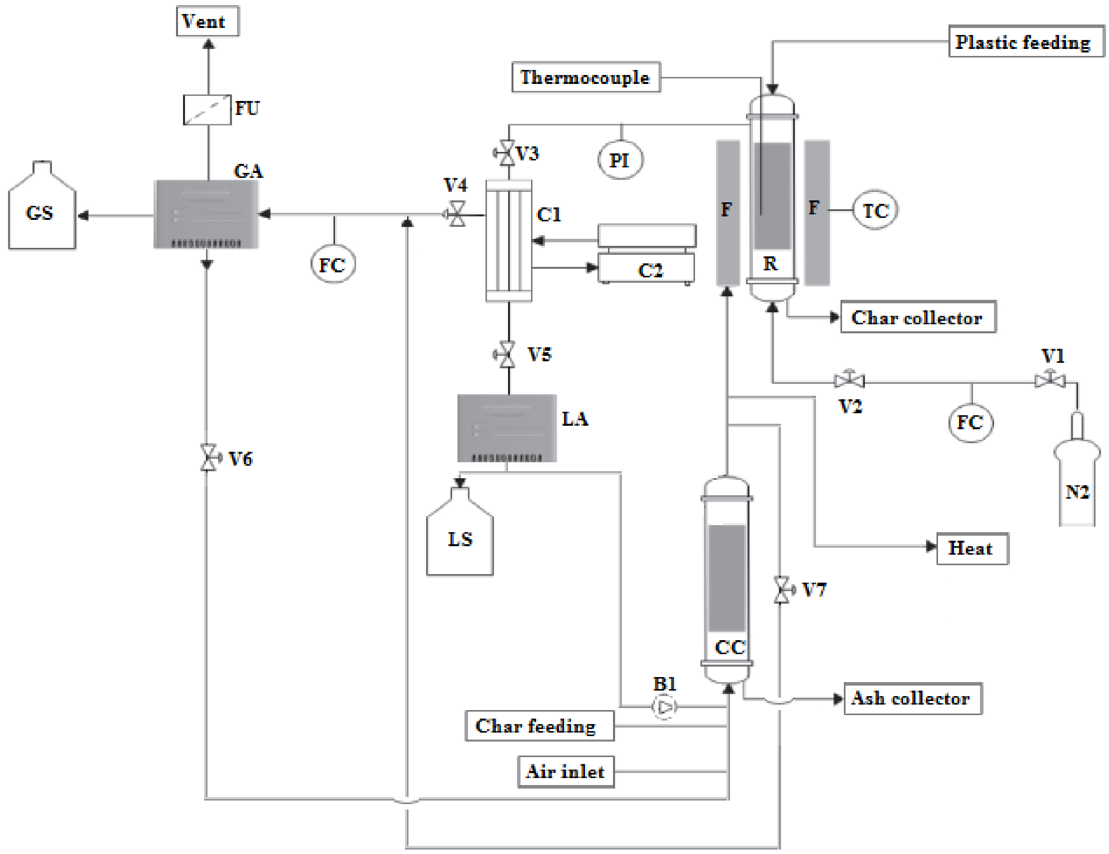

Figure 5: Esquema de la planta.

Donde:

- N2: Tanque de nitrógeno
- V: Válvula
- FC: Regulador de flujo
- TC: Regulador de temperatura
- F: Horno
- R: Reactor de pirólisis
- PI: Manómetro
- C1: Condensador
- C2: Refrigerador
- GA: Analizador de gas
- FU: Unidad de filtrado
- GS: Tanque de almacenamiento de gas
- LA: Analizador de líquido
- B: Bomba
- CC: Cámara de combustion

A estos elementos, se le añadiría una torre de destilación dentro del propio almacén que ofrece la posibilidad de tratar parte del líquido que no alcance los criterios de calidad requeridos. Este dispositivo trataría el fuel-oil obtenido para producir fluidos de mayor poder calorífico.

Para realizar el estudio económico, el proyectista separa los costes en dos categorías:

- Inversión inicial: terrenos, construcción, equipos, etc.
- Costes de operación: costes laborales, mantenimiento, cargas sociales, materiales, depreciación, etc.

Los ingresos procederán del valor añadido generado en los productos, principalmente de los combustibles líquidos producidos. Por otro lado, si fuera posible, las cenizas podrían ser vendidas a la industria del asfalto o del metal (interesados en el alto contenido en carbono). Para poder cuantificar estos beneficios en un análisis más dinámico, se han realizado distintos escenarios respecto al NPV producido.

Resultados

Una vez encontrado el modelo que mejor se ajusta a las necesidades del proyecto, la memoria termina con la evaluación económica. El análisis del coste/ingreso refleja distintos parámetros como el Valor Actual Neto, el periodo de retorno, un estudio de los flujos de caja, la Tasa Interna de Retorno, etc.

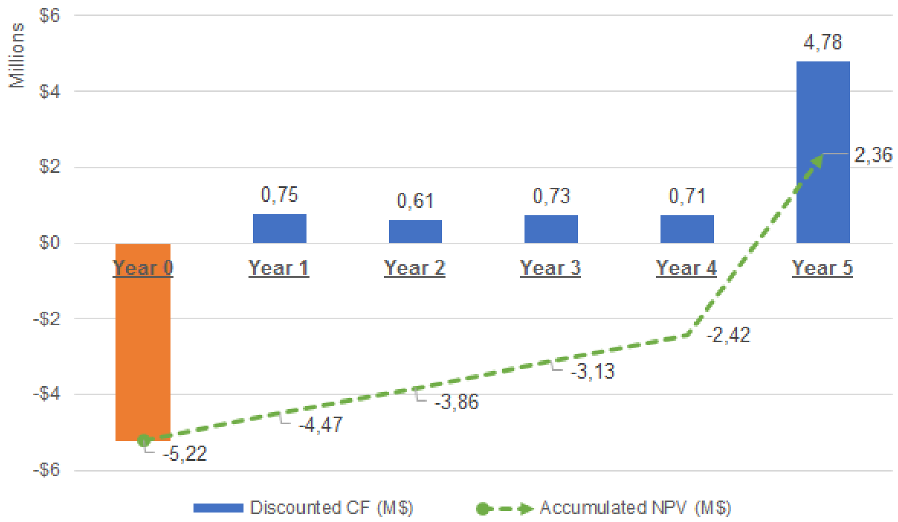

Figure 6: Flujos de caja Ajustado y Acumulado a lo largo del proyecto (5 años).

Discount Rate	NPV
1,9%	2.359.687
5%	1.494.379
10%	363.016
11,91%	0
15%	-518.821

Figure 7: Valor Actual Neto

Para terminar con los resultados económicos, se ofrece un análisis de sensibilidad en el cual se enfrentan distintos precios de venta del producto (siendo $1, equivalente a una venta del 100% en el precio unitario), así como los costes a los que hay que hacer frente por las distintas partidas.

	$ 0,80	$ 0,90	$ 1,00	$ 1,10	$ 1,20	$ 1,30
$ 0,52	$ 1.734.040	$ 2.643.838	$ 3.553.635	$ 4.463.433	$ 5.373.231	$ 6.283.029
$ 0,59	$ 1.137.066	$ 2.046.863	$ 2.956.661	$ 3.866.459	$ 4.776.257	$ 5.686.054
$ 0,65	$ 540.092	$ 1.449.889	**$ 2.359.687**	$ 3.269.485	$ 4.179.283	$ 5.089.080
$ 0,72	-$ 56.883	$ 852.915	$ 1.762.713	$ 2.672.511	$ 3.582.308	$ 4.492.106
$ 0,79	-$ 653.857	$ 255.941	$ 1.165.739	$ 2.075.536	$ 2.985.334	$ 3.895.132
$ 0,85	-$ 1.250.831	-$ 341.033	$ 568.764	$ 1.478.562	$ 2.388.360	$ 3.298.158

Figure 8: Análisis de sensibilidad para el Valor Actual Neto obtenido.

Conclusiones

La conclusión de este proyecto es que la construcción de la planta de tratamiento de pirólisis más combustión es un proceso económicamente viable. Convertir 40 toneladas de residuos a energía es posible gracias al proceso pirolítico mejorado con la cámara de combustión. La torre de destilación permite al inversor convertir fuel-oil en diésel, creando productos con un mayor mercado, disminuyendo el riesgo y permitiendo nuevas fuentes de ingreso si hubiera que adaptarse a variaciones del mercado.

El VAN muestra que la inversión se puede recuperar con grandes tasas de retorno y en poco tiempo. De todas formas, el proyectista recomendaría un análisis más profundo dada la incertidumbre en los precios de las unidades compradas y vendidas al ser este un mercado altamente volátil. Es ahí cuando el análisis de sensibilidad cobra mayor importancia al prever que un estudio estático de la viabilidad no es determinista.

El TIR demuestra que esta inversión es más rentable que aquéllas que no alcancen los 11.9 céntimos por dólar invertido. Dada la inversión en un país como Australia, el riesgo se reduce porque se trata de una economía estable con una tasa de inflación inferior al 2%.

Otro aspecto económico importante es que la mayor inversión se produce en la adquisición del terreno, activo que podríamos considerar no depreciable a lo largo de la duración del proyecto y que, en un principio, podría incluso recuperar la tasa de inflación del país.

Además, aunque los costes aumentasen debido a distintos imprevistos, el análisis de sensibilidad demuestra que hay espacio suficiente para abordar esas subidas de los costes. Esto es válido en el sentido contrario, aunque los precios de las unidades vendidas decrecieran, hay margen suficiente para soportar esas caídas.

Por otro lado, la cámara de combustión reduce la dependencia energética de la instalación, generando suficiente calor para alimentar tanto al reactor pirolítico como a la torre de destilación. Esto es una fuerte ventaja respecto a otros proyectos del sector de la gestión de residuos.

El proyectista concluye que, por todo lo explicado anteriormente, antes de proceder a la ejecución del proyecto, sería recomendable realizar un estudio previo del material que va a ser inyectado para analizar su composición y la calidad de los productos generados. Como estos proyectos son escalables, el estudio podría ser realizado por una persona en el laboratorio o contratado a una de las empresas con las que el proyectista ha contactado (ver Anexos). En este último caso, Waste Tire Oil ha ofrecido un estudio previo a la instalación con un presupuesto aproximado de $15,000.

Referencias

Department of the Environment and Energy, 2016. Australia National Waste Report 2016, s.l.: Department of the Environment and Energy.

Pinterest, 2017. Pinterest. [Online]
Available at: https://www.pinterest.co.uk/conpak/videos-on-plastic-types/
[Accessed 15 9 2017].

ECONOMIC FEASIBILITY OF ENERGY RECOVERY FROM PLASTIC WASTE

ABSTRACT

Introduction

The aim of this project is to evaluate the economic feasibility of setting up a plant that recovers energy from plastic waste. The main goal of the project is to evaluate the potential calorific value of plastic waste to utilise it as a source of energy, creating value-added materials from waste. Furthermore, make a recommendation for the authorities to manage the environmental burden of waste plastic and to reduce the amount of this solid waste sent into the landfills. The evaluation will be proceeded with analysing the economic viability of the plant´s setup through a cost/benefit study of capitals incomes and outcomes. This analysis will include the incomes and expenses of the initial investment as well as during operational period. Some scenarios will be evaluated before concluding the thesis.

The literature survey aimed to review in-used technologies that have been implemented to treat plastic waste all over the world, with specific focus on Australia. This allows the projector to assess different strategies to deal with various solid wastes such as paper, cardboard, wood or plastic. Data is to demonstrate that the topic is an important area to develop research, so it will be introduced in depth information about the generation rate of solid waste both in Australia and worldwide, the reuse strategies, the thermal treatment methodologies, the possible contamination resulted from each treatment methods.

In Australia, during 2014-2015, 64 million tonnes of waste, which is equivalent to 2.7 tonnes of waste per capita has been produced. In terms of plastic waste generation, 107 kg per capita were produced in the same period, overall 2.5 million tonnes, 4% of the whole generation (Department of the Environment and Energy, 2016). Figure illustrates the different sectors of the MSW from Australia. Plastics include: Polyethylene (PET), High-density polyethylene (HDEP), Polyvinyl chloride (PVC), Low-density polyethylene (LDPE), Polypropylene (PP), Polystyrene (PS) and Other.

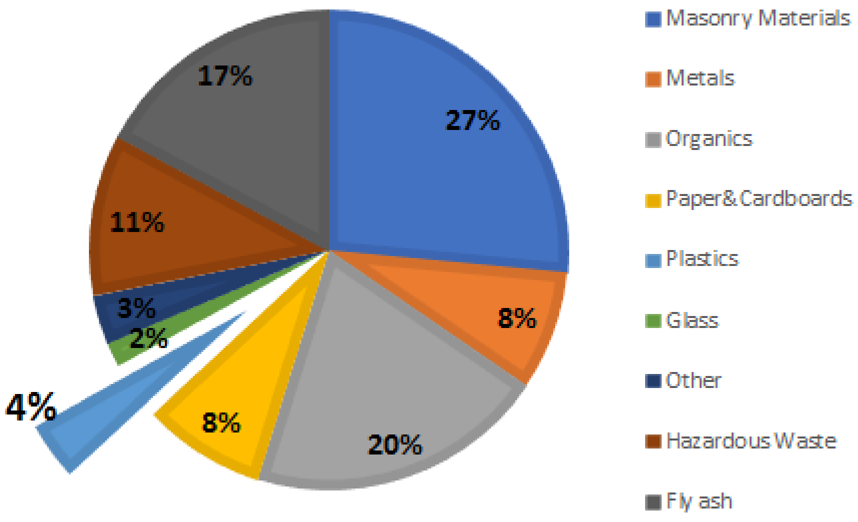

Figure 9: Waste generation by material category in Australia 2014-2015. Source: Australian National Waste Report 2016.

The focus of the project is to explore and evaluate the potential technologies which have maximum economic output taking the social and environmental aspects into the account. A comprehensive literature survey has been done on the dominant thermal treatment of waste plastic. The major obstacles in the plastic waste treatment has also been explored and analyzed. The key objective of this chapter is to select the best available technology and to compare its benefits and disadvantages.

Symbol	Acronym	Full name and uses
1	PET	Polyethylene terephthalate - Fizzy drink bottles and frozen ready meal packages.
2	HDPE	High-density polyethylene - Milk and washing-up liquid bottles
3	PVC	Polyvinyl chloride - Food trays, cling film, bottles for squash, mineral water and shampoo.
4	LDPE	Low density polyethylene - Carrier bags and bin liners.
5	PP	Polypropylene - Margarine tubs, microwave-able meal trays.
6	PS	Polystyrene - Yoghurt pots, foam meat or fish trays, hamburger boxes and egg cartons, vending cups, plastic cutlery, protective packaging for electronic goods and toys.
7	Other	Any other plastics that do not fall into any of the above categories. For example melamine, often used in plastic plates and cups.

Figure 10: Types of plastics and their uses (Pinterest, 2017).

There are different methods to treat plastic waste in order to avoid the disposal into landfills:

How to manage Plastic Waste

There are many different ways which are separated into four groups:

1. **Re-extrusion**: primary recycling to create products of similar material
2. **Mechanical**: cutting/shredding, contaminant separation, floating, milling, washing and drying, agglutination, extrusion and quenching.
3. **Chemical:** thermo-chemical treatments to produce fuels or petrochemical feedstock.
4. **Energy recovery:** burning waste to produce energy in form of heat, steam and electricity.

Figure 11: How to manage Plastic Waste. (Al-Salem, 2009)

Methodology

Once the most effective treatment methodology for plastic waste is selected, the project continues with identifying the best available technology and its flow chart. Flow chart design involves the inputs and outputs that enable the conversion from waste into energy.

Gathering the required data to define the cost involved in setting up the plant is the key part of this step. The cost of the devices, the material input and outputs streams for each step to calculate the material cost, determine the energy consumption to state the cost of utilities, the waste water treatment (if required) subsidiary, etc.

To produce the highest efficient in terms of economic and social impact, the decided solution is a pyrolysis plus combustion plant to generate fuel and other sources of energy such as heat to be consumed inside and outside the plant.

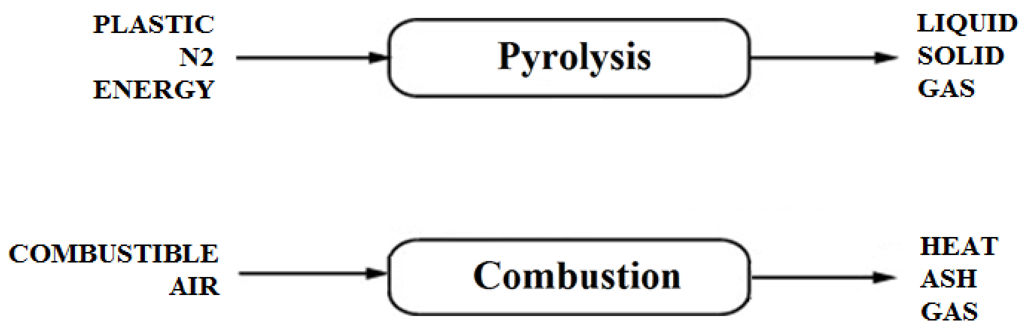

Figure 12: Inputs and outputs of the system

Furthermore, the scheme of the plant would be:

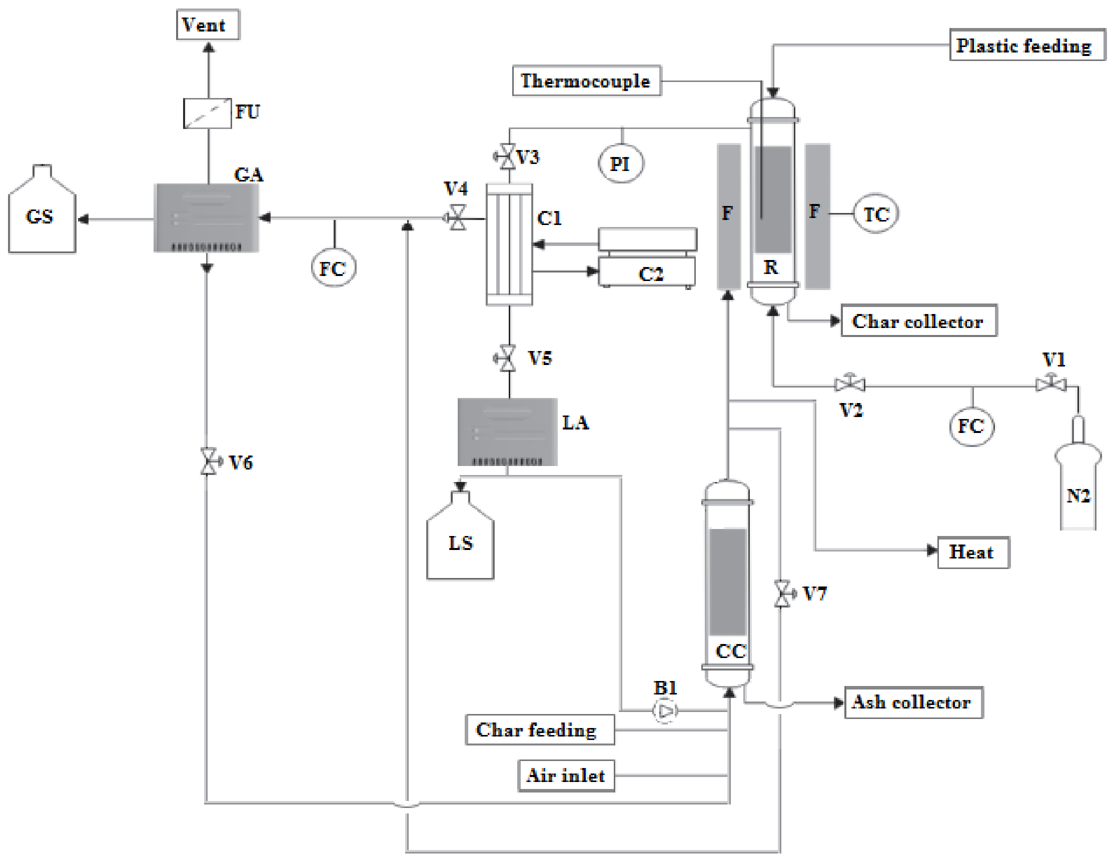

Figure 13: Scheme of the plant.

Where:

- N2: Nitrogen tank
- V: Valve
- FC: Flow controller
- TC: Temperature controller
- F: Furnace
- R: Pyrolysis reactor
- PI: Pressure indicator
- C1: Condenser
- C2: Chiller
- GA: Gas analyser
- FU: Filter unit
- GS: Gas storage tank
- LA: Liquid analyser
- B: Pump
- CC: Combustion chamber

A distillation device is included inside the warehouse to treat part of the liquid output that does not reach the required level. This machine would treat oil to manufacture products of higher calorific value after separating the compounds of the oil in the input.

In order to perform de economic analysis, the projector separates into investment and operational costs. Therefore, the project will deal with:

- Capital Investment cost: equipment and devices, construction costs, land usage, preparation funds, loan interests, risk management, etc.
- Operational: raw material cost, energy consumption, labour & staff salaries, maintenance, depreciation costs, etc.

The benefits come from different outputs such as the energy created (value-added materials) and, if possible, the ash sold to concrete or asphalt manufacturers as well as the steel industry (interested on the carbon content of plastic residues). These benefits are considered different scenarios requiring sensitivity and uncertainty analysis. This information will lead the project to the final economic analysis to demonstrate the profitability or not of the setup.

Results

Once identified the cost model which best fits the case, the project finishes with the economic evaluation. The cost/benefit analysis will include capital cost, operational cost, payback period, cash flow analysis (internal rate of return (IRR) and net present value (NPV).

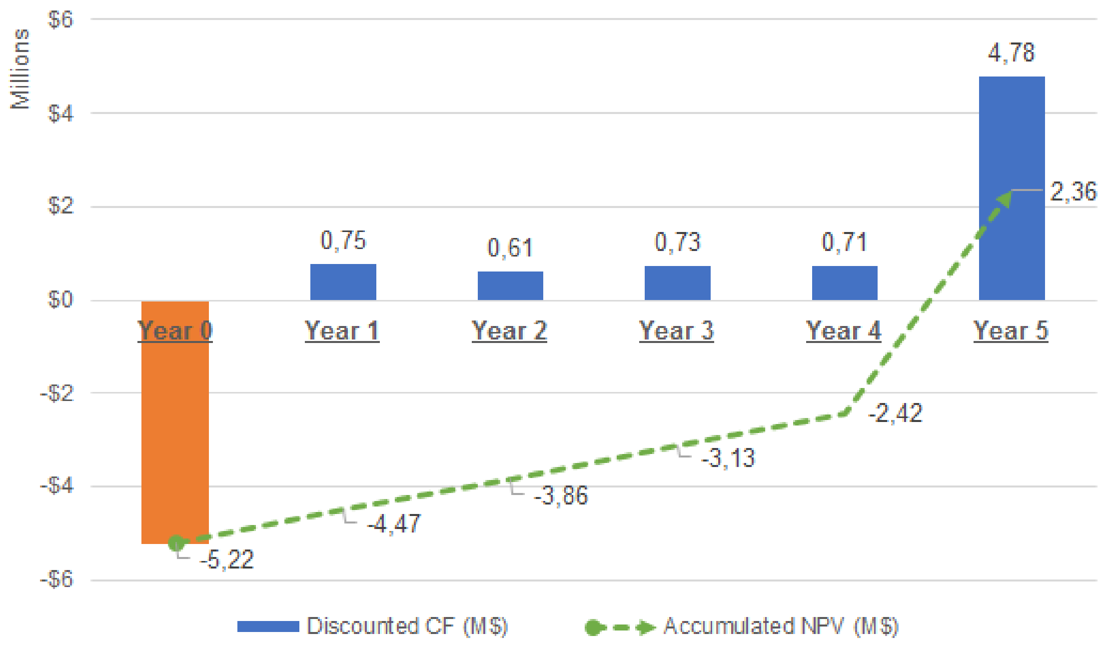

Figure 14: Discounted and Accumulative CF for the project (5 years).

Discount Rate	NPV
1,9%	2.359.687
5%	1.494.379
10%	363.016
11,91%	0
15%	-518.821

Figure 15: NPV

To end up with the economic chapter, the uncertainty analysis and the sensitivity analysis of different scenarios will be carried out to compare the profitability of different considered scenarios.

	$ 0,80	$ 0,90	$ 1,00	$ 1,10	$ 1,20	$ 1,30
$ 0,52	$ 1.734.040	$ 2.643.838	$ 3.553.635	$ 4.463.433	$ 5.373.231	$ 6.283.029
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$ 0,85	-$ 1.250.831	-$ 341.033	$ 568.764	$ 1.478.562	$ 2.388.360	$ 3.298.158

Figure 16: Sensitivity analysis for the resulting NPV.

Conclusions

The conclusion of the project is that the setup of the pyrolysis plus combustion plant is economically feasible. Converting 40 tons of waste into energy is possible thanks to the pyrolysis process which, in this case, is improved with the addition of the combustion chamber. The distillation equipment enables the investor to convert fuel oil into diesel, creating value-added products that has a bigger market than the other generated. In fact, diesel production represents the smallest proportion of products.

The NPV shows that the investment would be soon returned with large rates of return. However, since the costs and prices of units sold are not hundred percent reliable, being these highly volatile in the market, a deeper analysis is required. Hence, the sensitivity analysis gives the projector some idea of how the NPV may vary in different scenarios.

The IRR shows that this investment is more profitable than others if those give a return lower than 11.9 cents per dollar invested. Australia is a country that, if everything stays as its been running recently, will remain stable for the next years; therefore, the inflation rate should never reach 11.9%, hence, it is a good idea to invest in this project in terms of economic profits.

Another point to the project is that the highest investment comes from the purchase of the land, which is an asset that should not depreciate in the next five years, returning the investment after subtracting the discount rate for the accumulated years.

In addition, there is enough room to still being profitable despite the possibility of increasing the variable costs due to unforeseen costs. This statement is also valid in the case that the price or the production sold decreases. The certainty of this security comes from the sensitivity analysis and the impact of both reduction of revenues or increase of costs.

Moreover, the combustion section feeds enough heat for the operation of the pyrolysis chamber and the distillation equipment. This means that the facility would not require utilities such as electricity, important factor in some other economic analysis or business plans in the waste management industry.

Sensitivity analysis allows the projector to evaluate the impact of some inherent changes in the data gathered throughout the study.

However, before setting up this project, the projector would recommend performing a previous study of the material that would be fed into the facility to analyze its composition, as well as the outputs and their quality. Since these types of projects are scalable, the study could be done by someone himself or by one of the companies that the projector has already contacted. In this case, Waste Tire Oil, has offered a previous study for the setup with an approximate budget of $15,000.

References

Department of the Environment and Energy, 2016. Australia National Waste Report 2016, s.l.: Department of the Environment and Energy.

Pinterest, 2017. Pinterest. [Online]
Available at: https://www.pinterest.co.uk/conpak/videos-on-plastic-types/
[Accessed 15 9 2017].

Contents

Figures

Tables

Abbreviations

MSW: Municipal Solid Waste

PSW: Plastic Solid Waste

NPV: Net Present Value

NWC: Net Working Capital

NSW: State of New South Wales Australia

IRR: Internal Rate Return of the project

CF: Cash Flow

Introduction

Plastics come from materials found in the nature such as oil, natural gas, minerals, coal and plants. To replace materials such as ivory and tortoise shell, during the 1800s, the interest of producing plastics lead to heat with chemicals a substance found in plants and trees, cellulose, to elaborate the first synthetic plastics. Nowadays the raw materials for plastics come from many different places but most of them are produced through the hydrocarbons available in oil, natural gas and coal. Thus, plastics are polymers, reason why many plastics begin with “poly” such as polystyrene, polypropylene and polyethylene. These polymers are made of chains of carbon and hydrogen and, sometimes, oxygen, sulphur, nitrogen, fluorine, chlorine, silicon or phosphorous (American Chemistry Council, 2011). Due to their hydrocarbon nature, plastic´s calorific value is high compared to other materials, sometimes reaching values close to oils or diesel fuels.

First industrial scale production of plastics (synthetic polymers) took place in the 1940s. Ever since, production, consumption and waste generation of plastic solid waste (PSW) has increased significantly. Plastics are indispensable in our daily life. Their characteristics make them useful in a wide range of industrial and domestic applications, due to their durability, light weight, a fast rate of production, design flexibility, energy efficiency, etc. Consequently, recycling of PSW has become main point of many studies in the past decades. These researches have been also forced by vicissitudes in regulatory and environmental concerns. (Al-Salem, et al., 2009).

The waste generated is found in the final stream of municipal solid waste (MSW), reaching up to 3.5 million tonnes per day in the urban populations, which means 1.2 kg per capita per day and their projections for 2025 predict 6 million tonnes per day, an average of 1.4 kg per capita (World Bank, 2011). In 1990, the average was 0.7 kg per day per capita (Beede & Bloom, 1995). European Union countries generate over 250 million tonnes of municipal solid waste every year, with a 3% annual growth. In the United States, the plastic solid waste found in the MSW has increased from 11% during 2002 (USEPA, 2002) to 12.1% in 2007 (USEPA, 2007). Figure 1 shows the different sectors of the US and UK municipal solid waste proportions.

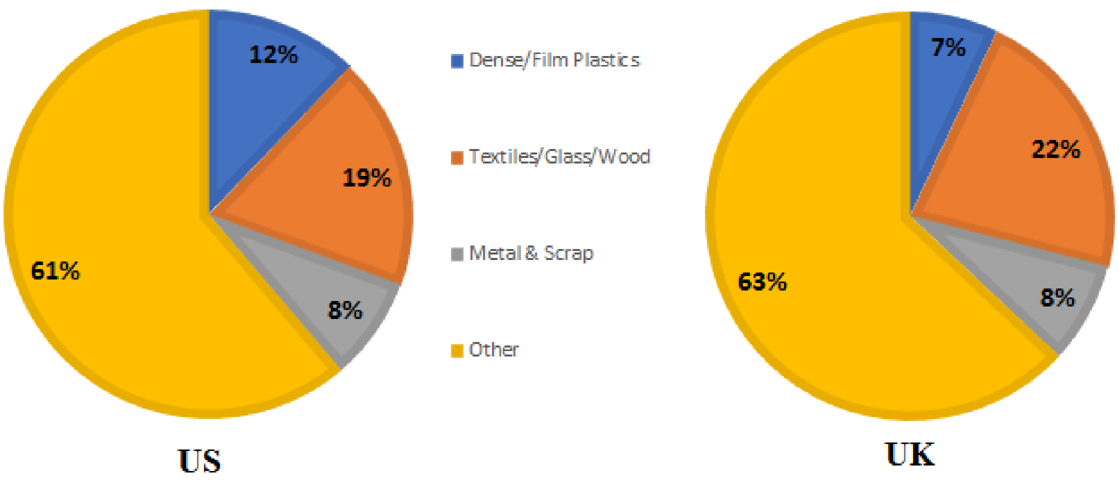


Figure 17: Dense and film plastic fraction in MSW in the US (left) and the UK (right). Source: USEPA (2008) and Parfitt (2002).

In Australia, during 2014-2015, 64 million tonnes of waste, which is equivalent to 2.7 tonnes of waste per capita has been produced. In terms of plastic waste generation, 107 kg per capita were produced in the same period, overall 2.5 million tonnes, 4% of the whole generation (Department of the Environment and Energy, 2016). Figure 2 illustrates the different sectors of the MSW from Australia. Plastics include: Polyethylene (PET), High-density polyethylene (HDEP), Polyvinyl chloride (PVC), Low-density polyethylene (LDPE), Polypropylene (PP), Polystyrene (PS) and Other.

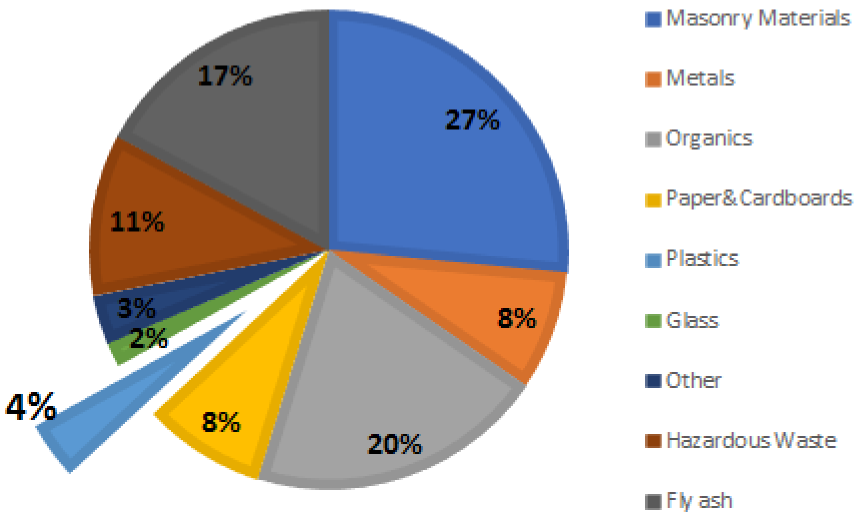
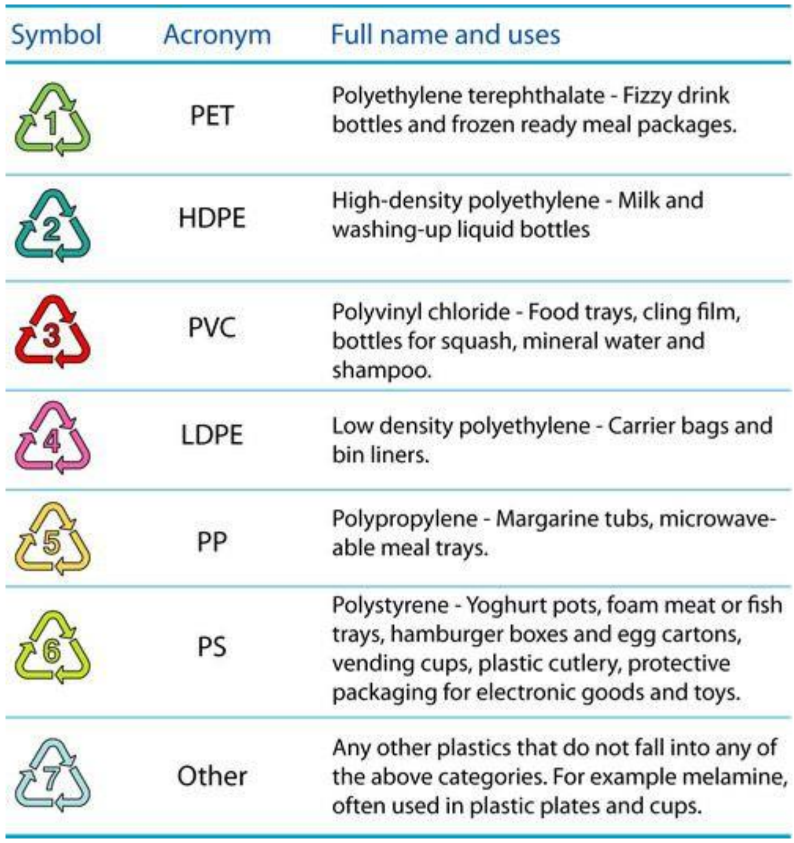


Figure 18: Waste generation by material category in Australia 2014-2015. Source: Australian National Waste Report 2016.

Almost 80% of the plastic consumption comes from thermoplastics, used for many different applications such as packaging (the most found in the MSW, 37.2% of all consumed in Europe and 35% worldwide (Clark & Hardy, 2004)) or textile fibres and coatings (Dewil, et al., 2006).

The different types of plastics are distinguished by the label within the product:



Symbol	Acronym	Full name and uses
1	PET	Polyethylene terephthalate - Fizzy drink bottles and frozen ready meal packages.
2	HDPE	High-density polyethylene - Milk and washing-up liquid bottles
3	PVC	Polyvinyl chloride - Food trays, cling film, bottles for squash, mineral water and shampoo.
4	LDPE	Low density polyethylene - Carrier bags and bin liners.
5	PP	Polypropylene - Margarine tubs, microwave-able meal trays.
6	PS	Polystyrene - Yoghurt pots, foam meat or fish trays, hamburger boxes and egg cartons, vending cups, plastic cutlery, protective packaging for electronic goods and toys.
7	Other	Any other plastics that do not fall into any of the above categories. For example melamine, often used in plastic plates and cups.

Figure 19: Types of plastics and their uses (Pinterest, 2017).

Waste generation is highly correlated to economic development, the degree of industrialization, local climate and society habits. Normally, the greater amount of solid waste produced is found where the higher gross domestic product and rate of urbanization are. When the income level increases, the urbanization and industrialization is higher, thus, living standards increase and consumption of goods and other services consequently increases, as it happens with the waste generated. Furthermore, urban residents produce about twice as much waste as their rural counterparts (World Bank, 2011).

INCOME LEVEL	WASTE GENERATION PER CAPITA (KG/CAPITA/DAY)		
	Lower Boundary	Upper Boundary	Average
HIGH	0.70	14	2.1
UPPER MIDDLE	0.11	5.5	1.2
LOWER MIDDLE	0.16	5.3	0.79
LOWER	0.09	4.3	0.60

Table 1: Current Waste Generation Per Capita by Income Level (World Bank, 2011).

According to World Bank estimates of gross national income per capita for 2005, the countries are separated into four income levels: High $10,725 or above; Upper middle: $3,466-10,725; Lower middle: $876-3,465; and Lower: $875 or less. Low income countries generate the least solid waste per capita while the high-income produce the most. This classification may be inaccurate since the separation is country-wide and in many countries the average wealth could be completely different from average wealth of urban populations. An example could be India and China, they have unreasonably high urban waste generation rates per capita compared to their overall economic status as they have large relatively poor rural residents, fact that leads to a dilution of the national figures. It is possible to say that only the prosperity of urban population is important in projecting MSW rates (World Bank, 2011).

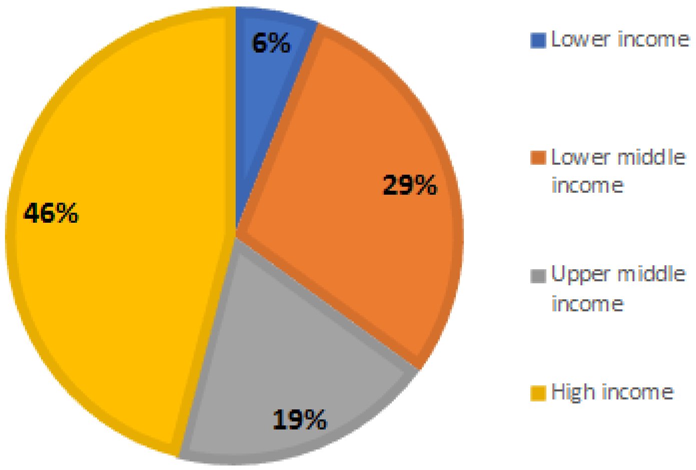


Figure 20: Waste Generation by Income (World Bank, 2011).

To sum up, the Low-income countries generate between 0.6 – 1.0 kg per capita per day and represent the 6% of the world; middle-income produce 0.8 – 1.5 kg per capita per day and represent 48%; High-income cause between 1.1 – 4.5 kg per capita per day and signify 46%.

Improvements in technology enable to improve the efficiency of the process to reduce waste, and these improvements are highly related to wealthy countries. Developed countries care more about environment than those who are still developing and, higher disposal costs help to greater environmental awareness. In fact, it is said that “When the time we put on our time grows faster than the price of material goods, the production of waste is promoted” (Department of the Environment and Energy, 2016). Figure 5 illustrates the Australian economic activity by state and territory.

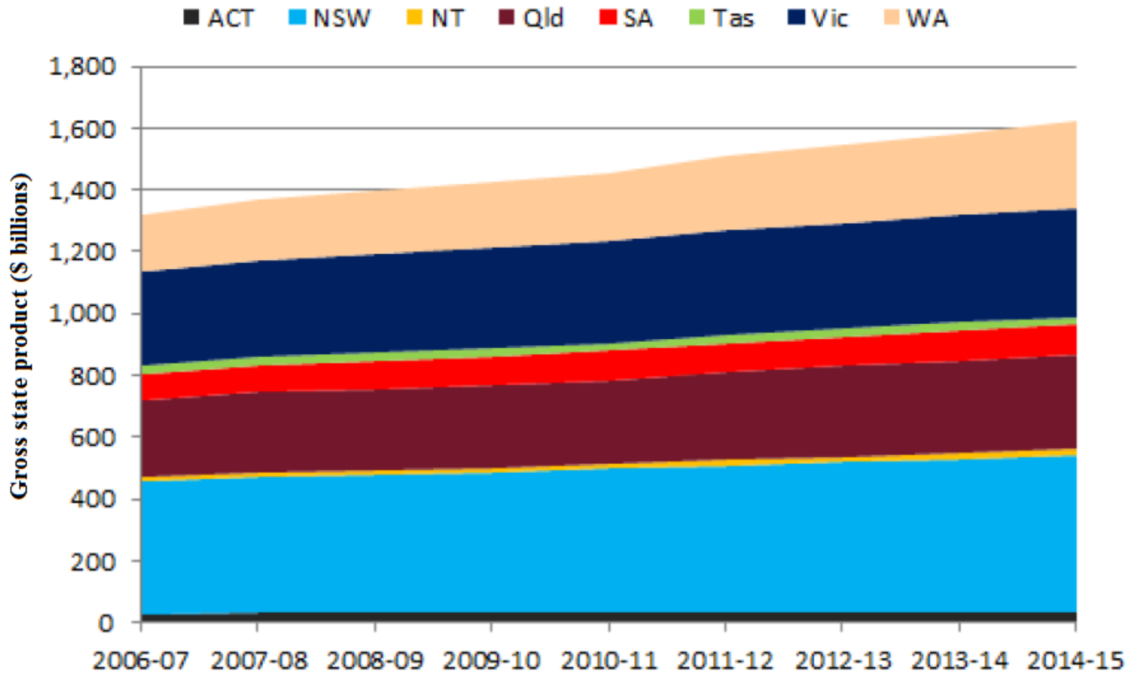


Figure 21: Australian economic activity by state and territory 2006-2015 (ANWR, 2016).

According to the Australian National Waste Report of 2016, overall population grew from 20.6 to 23.6 million in nine years (from 2006 to 2015), increasing by 14%, averaging 1.5% per year. New South Wales, Victoria and Queensland, represent more than 75% of Australia´s population. Since the higher proportion of urban population means the higher amount of municipal solid waste, Australia will face the problem of waste management due to its increase of population in recent years. Figure 5 represents the population by states and years.

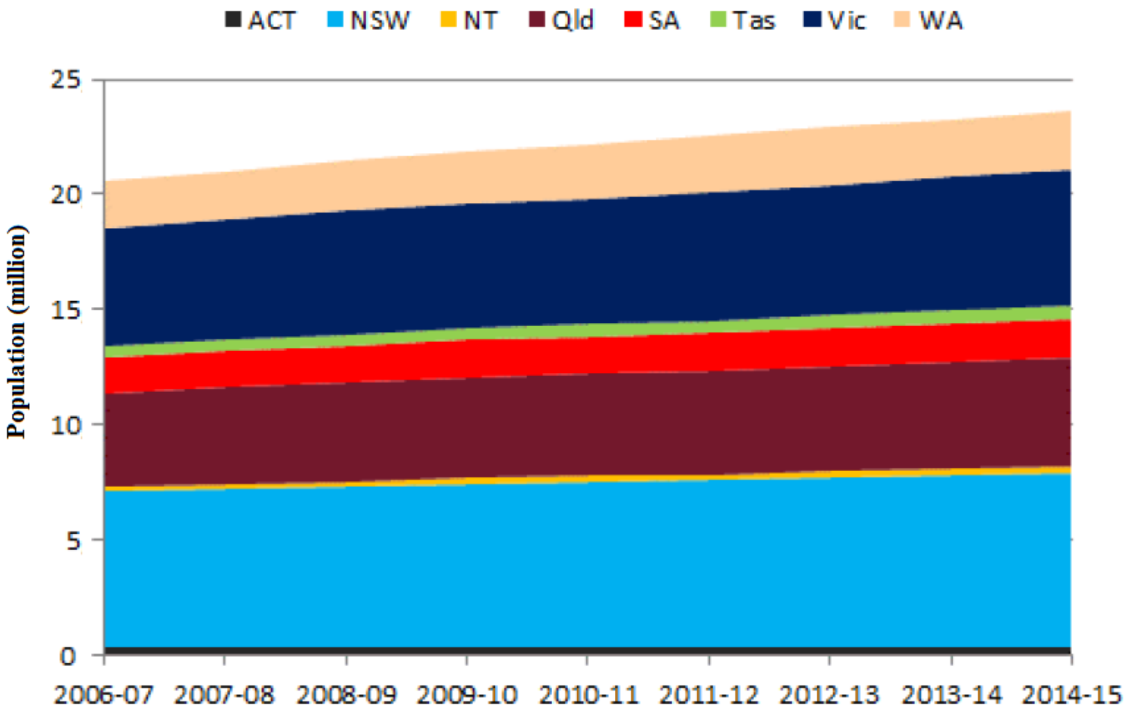


Figure 22: Population of States in Australia 2006-2015 (ANWR, 2016).

Recently, considerations about alternative options for Plastic Solid Waste (PSW) disposal have been forced due to the increment of cost and decrement of space in landfills. After years of research, studies and tests, numerous economically and environmentally feasible methods have been discovered to treat, recycle or recover energy from PSW. For example, during 2002, the reuse technologies led to produce different parts of textiles from 388,000 tonnes of polyethylene, almost 97.5% of this was reused from polyethylene castoff objects (Gobi, 2002). Some other examples of scrap reused shows that fully recycled products have been successfully manufactured in different appliances. The environmental concerns have forced the industry of plastic to meet the present needs of today without compromising the future requirements.

Literature Survey

Plastic Solid Waste (PSW) treatments can be separated into four major groups: re-extrusion, mechanical, chemical and energy recovery. Each of these techniques provides advantages that makes it unique for specific characteristics such as location, appliances or needs. While mechanical treatment includes physical techniques, chemical recycling involves a treatment that produces feedstock for the chemical industry. Partial or complete oxidation of the material is required in energy recovery techniques producing heat, steam or electricity beside the emissions and ash disposed.

The priorities are: continue developing recovery and recycling technologies, establish feasible markets, more investment in infrastructure and participation by governments, industries and consumers (Scheirs, 1998). Integrated waste management is essential to scheme the production and life-cycles of plastics and into the PSW to reduce the amount of plastic synthesized from non-renewable resources which is approximately 90%. Although recycling is considered a sustainable way to handle PSW, the way to improve sustainability in the use of energy and resources is through integrated waste management. Figure 6 shows the scheme of Integrated Waste Management, illustrating the process followed to reduce the amount of waste disposed into landfills and, therefore, reducing the emissions of greenhouse gas and CO_2.

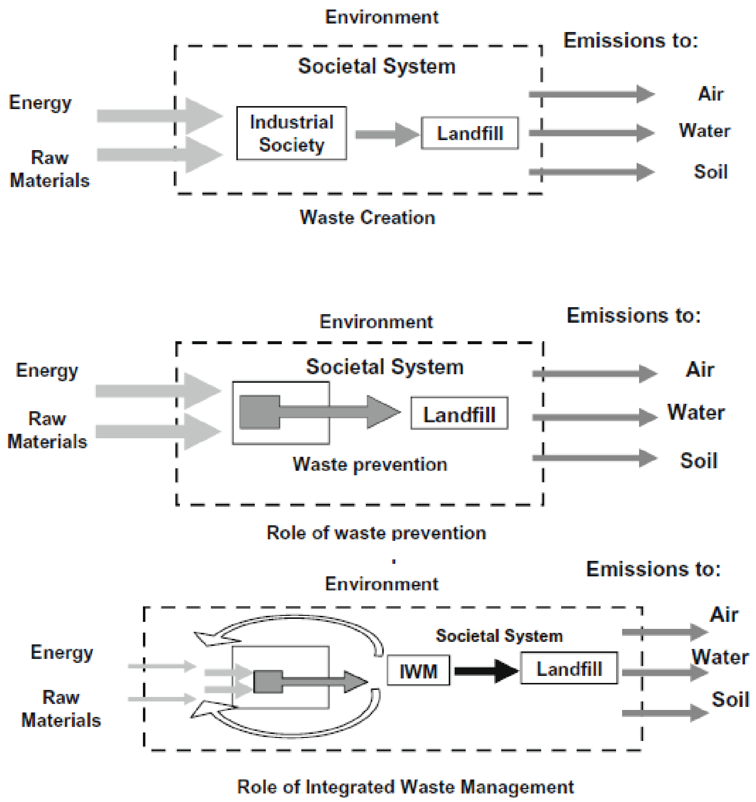


Figure 23: Integrated Waste Management schemes (Kirkby et al., 2004).

The aim of integrated waste management is to control the waste production from the different processes to, at minimal environmental impact, meet the requirements of the society. Thus, activating capacities of waste prevention, re-use and recycling is the main goal. Whilst, technical and economic viability and commercial feasibility should be considered in every step of the recycling chain (Frisch, 1999).

Since synthetic plastic comes from crude oil which is refined, the hydrocarbon content of the plastics may be recovered to use as feedstock for new petrochemicals. The different methods to manage plastic solid waste in order to reduce the amount disposed into landfills are illustrated in Figure 7:

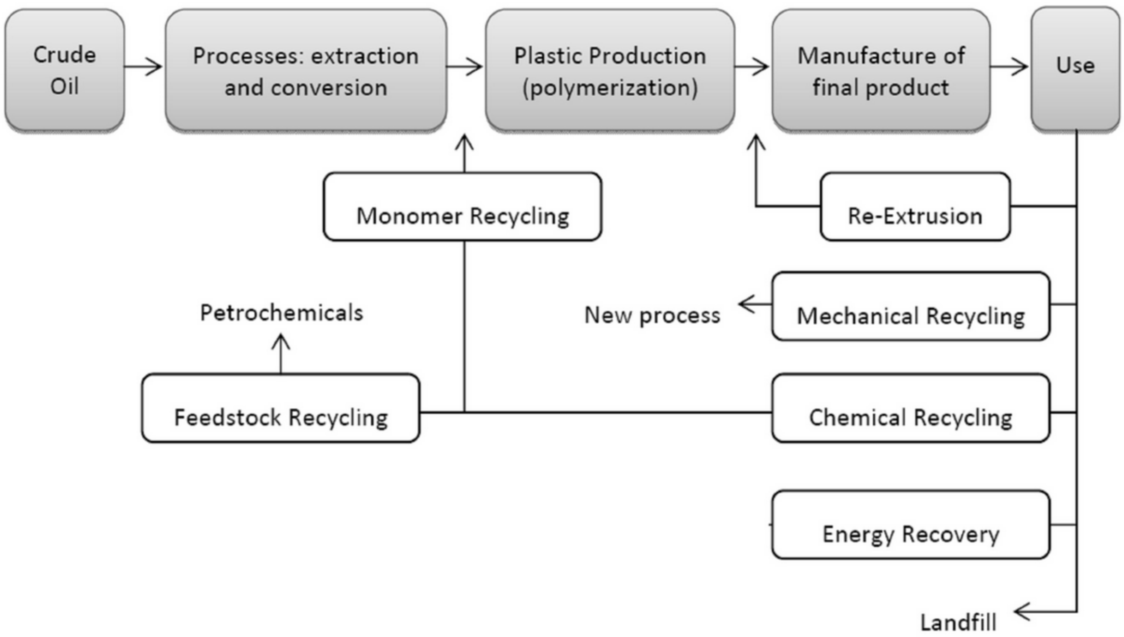


Figure 24: Process from Crude Oil to Plastic Waste management (Brems, 2013).

Reusing, sorting, primary recycling

This method is based on the issue that some plastic objects end up in the MSW a short time after acquisition which sometimes it is after a single use, for example the food packaging. Both recycling and reusing have become popular solutions to reduce the amount of PSW in MSW, but, since reusing requires fewer energy and resources, is preferable.

Approximately, plastic production consumes 4 to 8% of global oil generation (Perdon, 2004), thus, reusing plastics leads to numerous advantages such as reducing oil consumption, reducing the energy utilised to produce plastics, decreasing the amount of municipal solid waste. Thus, reduction of emissions of gas generated during each of the processes above, means decreasing the amount of carbon-dioxide, sulphur-dioxides and nitrogen-oxides.

Separating and sorting PSW is the first step to reuse it. Quick and accurate identification of the composition of every item followed by manual or automated sorting is essential for the success of the whole process. These methods depend on the size, weight, colour and coating; recently, density sorting has been improved and implemented because, since most plastics have close densities (ρ_{HDPE} = 0.941, ρ_{MDPE} = 0.935, ρ_{LDPE} = 0.920, ρ_{LLDPE} = 0.925, ρ_{PP} = 0.96 g/cm^3), the division becomes difficult even for machines. Hydro cyclones may be used to enhance substantial wettability applying centrifugal force. Some plastics, normally those from electronic devices, require a heavy medium sorting which is costlier and may lead to contamination of the resulting plastic due to the addition of a modifier mixed in water or using tetrabromoethane (Kang, 2005).

Triboelectric separation allows to differentiate between two plastic materials by basically rubbing them against each other so one becomes positively charged whilst the other negative or neutral. The procedure rotates a drum to mix the particles and enabling the charging. This method suits for particles with sizes up to 4 mm (Xiao, 1999). Another technique is using high-speed acceleration delaminating waste which is separated by air, sieves and electrostatics and identified through X-ray fluorescent spectroscopy.

The most challenging step in recycling plastic waste is removing paint on the plastics and recovering plastic properties altered due to coating and the stress created in the material. Abrasion, cryogenic, grinding or solvent stripping are methods to liberate coatings and paints from the plastics (Kang, 2005); some plastics can handle high-temperature methods. Since none of these methods is completely reliable, processing properties must be controlled to ensure that degradation does not appear decreasing the resale value of the new products.

Re-extrusion, also known as primary recycling, introduces scrap, complex or single-polymer plastic parts into the cycle to produce materials of similar composition. It is a rare method because requires semi-clean waste which is difficult to find out in the final step of the MSW stream. In some factories, manufactured products that do not reach quality standards are reintroduced in the process as raw material. According to some researchers, PSW from industry is the most recycled by this method; for example, 95% of the 250,000 tonnes of process scrap is primary recycled (Parfitt, 2002).

Mechanical recycling

Secondary recycling, also known as mechanical recycling, covers the methods that process PSW to manufacture plastics materials through mechanical techniques. Thus, single-polymer plastics are the only items that can be recycled because its structure is simple and the more complex and contaminated the plastic, the more difficult to reintroduce mechanically. There are three essential steps in the process to create high quality products: separate, wash and prepare plastic solid waste to manage clear, clean and homogenous materials (Mastellone, 1999).

Degradation and heterogeneity are the important disadvantages of these methods. Chemical reactions that establish polymer chains construction are, in theory, reversible, thus heat or energy supply may lead to photo oxidation and, consequently, mechanical stresses appear. Therefore, it is a viable solution for cases such as rigid plastics or foams if the second use handles the issues mentioned before. Sometimes, industrial plastic waste suits the use as raw material for new purposes, due to its high quantity, the clear distribution of scrap and the low amount of dirt. Daily, many products are manufactured through mechanical recycling methods: plastic bags, tubes, drains, blinds, etc.

According to Aznar, who defined the most general scheme, the steps to be follow in mechanical recycling are:

1. Shred: creating small parts by cutting large sized materials.

2. Separate contaminants: typically using a cyclone, different inputs of scum are cleared and separated from plastic.
3. Float: thanks to its differences in density, small parts are separated in the floating tank.
4. Mill
5. Wash and dry: usually with water and sometimes with other chemicals to ensure perfect cleaning.
6. Agglutination: products of same characteristics are gathered to store or continue processing.
7. Extrusion: to produce the new plastics.
8. Quench: cool the product with water to granulate and sell it.

Depending on the type of polymer, plastic solid waste goes through a wide range of schemes exposed by researchers such as Kowalska (PP, LDPE and PVC), Strapasson (PP and LDPE) or Meran (LDPE, HDPE and PP).

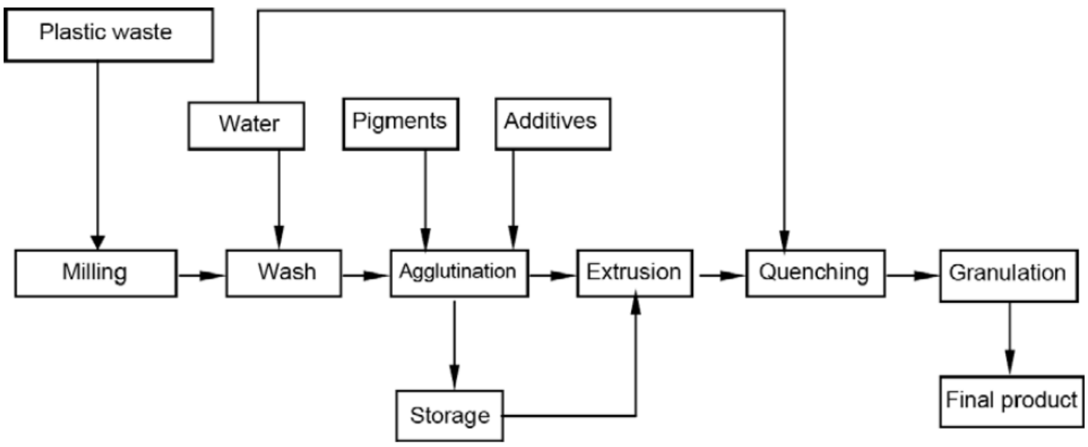


Figure 25: Steps of the mechanical recycling (Aznar, 2006).

Extrusion is not the only technique utilized to create new products. Injection, blow, vacuum and inflation moulding use heated molten to mould manufactured items such as buckets, pallets, PET bottles, cups, trays or shopping bags.

Chemical recycling

Covers technology methods that convert plastic materials into smaller molecules, typically gases or liquids, that are used as feedstock for the generation of new plastics or petrochemicals. The chemical structure of the polymer is altered to create a new chain of hydro carbons with high value yield and low waste. Some of the processes under the category of chemical recycling are pyrolysis, liquid-gas hydrogenation, gasification and some others that reduce agent in blast ovens. There is also another division into catalytic and non-catalytic cracking methods to treat plastic solid waste into fuel fractions.

Depending on the type of polymer, the method becomes more or less efficient. Polyethylene teraphthalate, known as PET, and some polyamides are advantageous for this treatment because it is easily depolymerised. For example, Polyethylene, is useful to produce gasoline.

When Al-Salem tested the thermal cracking response of high density polyethylene, he realized that it cracks forming liquids, gases, waxes and aromatics and char. Another research, developed by Martin-Gullon, showed that the polyethylene teraphthalate trailed a pseudo mechanism of pyrolysis plus combustion with the resulting char following a new reaction to generate gases. (Mastellone, 1999)

Recycling polymers is viable since its content of hydro carbon chains makes it worth it to produce value added products from plastic solid waste through thermal degradation methods such as smelting by coke oven or blast furnace and liquefaction. An advantage is that, both simple and complex polymers may be recycled to generate monomer units or a mixture which contains different components for its later use as fuels. Even contaminated or heterogeneous polymers can be raw material in these methods, saving energy and money in methods that must separate and treat the inputs.

The process of heating plastic solid waste within controlled temperatures and without catalysts is known as Thermolysis. It can be separated into pyrolysis (advanced thermochemical) consisting in thermal cracking performed in an inert atmosphere, gasification (leading to CO_2 or CO through a sub-stoichiometric presence of air) and hydrogenation. These processes lead to the generation of different molecules, combustible fluids and energy while reducing space required for landfilling municipal solid waste (Mastral, 2007). Figure 9 illustrates the methods into where Thermolysis is separated and its production.

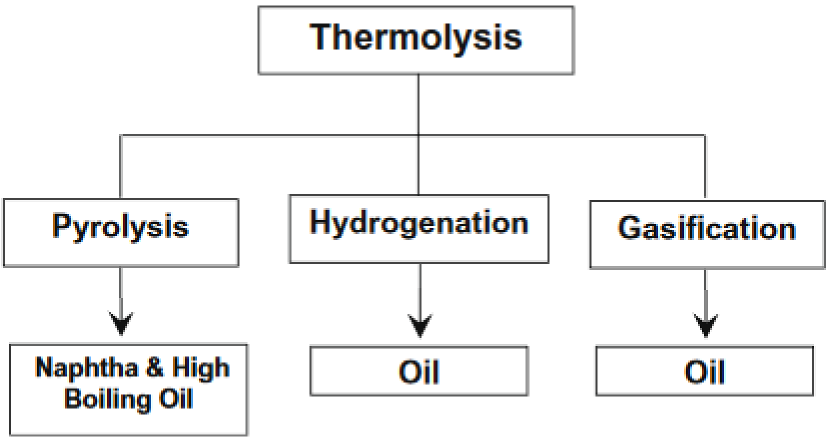


Figure 26: Thermolysis techniques (Mastellone, 1999).

Pyrolysis

Particularly, pyrolysis allows to produce clean energy via a high calorific value fluid from waste thanks to an advanced conversion technique. The fluid comes from the hydrocarbon chain available in the plastic and it is suitable in wide range applications such as gas engines, boiler applications or petrochemicals usages. Depending on the content of hydrocarbon in the disposed material heated, the calorific value could be 22-30 MJ/m^3 where the biomass generates the lower limit and other waste, such as synthetic materials, produce higher calorific values. Furthermore, amounts of carbon may be found in the solid char disposed whilst other mineral particles from the original feedstock. Thus, this solid char can be used in other thermal process or even reutilized to make the most recovering its content of carbon.

The main advantages of pyrolysis are:

- Operational advantages: does not require flue gas clean up because, typically, it is treated before its utilisation. Furthermore, the char produced after the process could be further utilised to produce fuel and becoming feedstock in other processes.
- Environmental advantages: pyrolytic processes reduce greenhouse gas and CO_2 emissions while providing solutions to the amount disposed into landfills.
- Financial profits: creating high calorific value products that could be sold in the fuel market, generating value-added products from waste, becoming sources of energy and heat.

On the other hand, some other disadvantages appear when studying pyrolysis. The most common ones are related to the treatment of the final product to generate the fuel desired and when handling the char generated during the process.

To improve the efficiency of waste incineration processes, some researchers (Smolders, Baeyens or Vand de Velden) recommend the separation of pyrolysis from other processes such as combustion of waste, especially in industrial scale plants of energy recovery.

The main pyrolysis techniques are:

- PYROPLEQ® process: The mixture of both pyrolysis and combustion implies temperatures between 450 and 500 ^{o}C in the rotary kiln during pyrolysis while 1200 ^{o}C are reached in combustion. The gas exhausted during combustion heats the pyrolysis drum to save energy. May be used feeding plastic but it is also useful for some other types of municipal solid waste (Modern Power Systems, 2014).

- Akzo process: originate in Netherlands, it is proven to be successful for the treatment of PSW bases its production of energy by a circulating fluidised bed system, with two reactors and further combustion. It is relatively fast and absorbs up to 30kg/h of plastic. Typically used for high PVC content, handles different inputs of plastic and mixtures of synthetic components. The composition of the outputs depends on the inputs and the raw material but usually consists of CO, H_2, HCl, CH_4 and other hydrocarbons plus char and fly ash (Tukker, 1999).

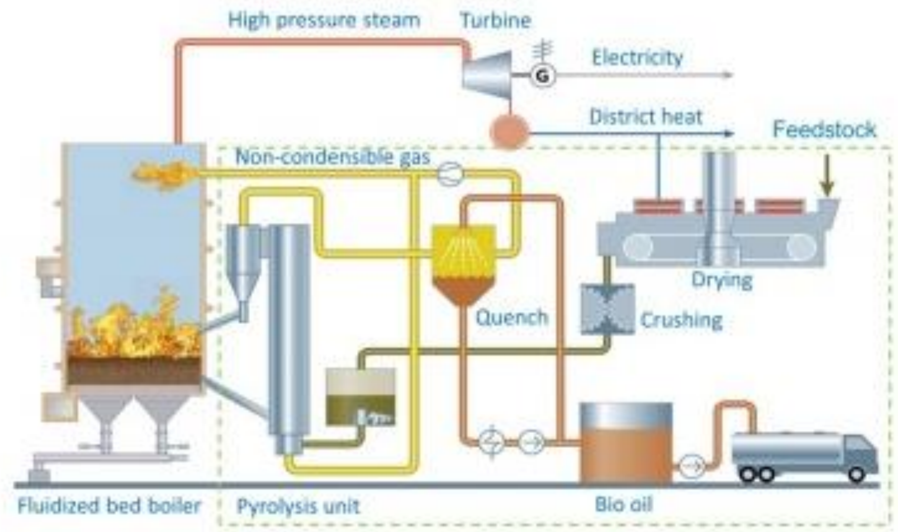


Figure 27: Pyrolysis and Combustion processes to produce energy and feedstock for Petrochemical purposes (Valmet,2017).

- ConTherm® method: TECH-Nip supplies rotary kilns that process plastic solid waste, typically automotive residues, up to 100 kilo tonnes per year at temperatures of 500 – 550 ºC for about 1 hour. After this process, the gas is combusted in a pulverised coal fired boiler. The outputs of the process are separated and sorted to reuse metals and other valuable materials (Malkow, 2004) (Trade, 2014).

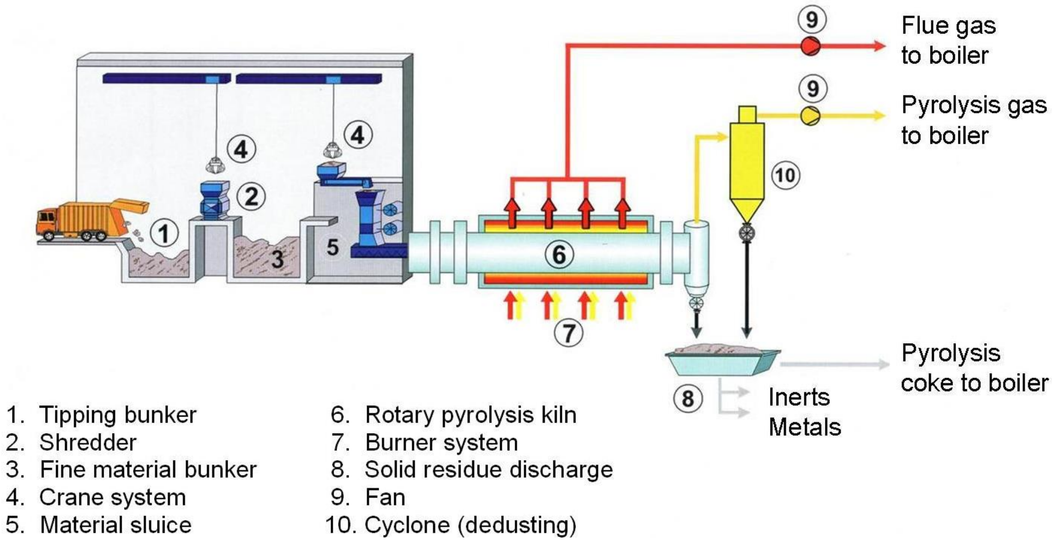


Figure 28: Schema of the ConTherm Pyrolysis Plant in Hamm, Germany (Techtrade.de,2017).

- NRC process: fed with PVC waste, pyrolysis with metal extraction techniques procure to avoid generation of HCl and create calcium chloride instead. Furthermore, coke, organic condensate and heavy metals are the outputs of the process (Malkow, 2004).

- PKA process: mixes pyrolysis and gasification at a relatively high temperature (around 550 ºC) during 45 – 60 minutes, after separating the scrap from municipal solid waste to feed the rotary kiln. Fuel generated is rich in hydrocarbon, but the char produced has metal content as well as high moisture, therefore, another treatment is required to use the output as a fuel. Otherwise, the char could be use as feedstock for other industrial processes such as concrete production (Malkow, 2004). Figure below illustrates the separation between pyrolysis and gasification in PKA process.

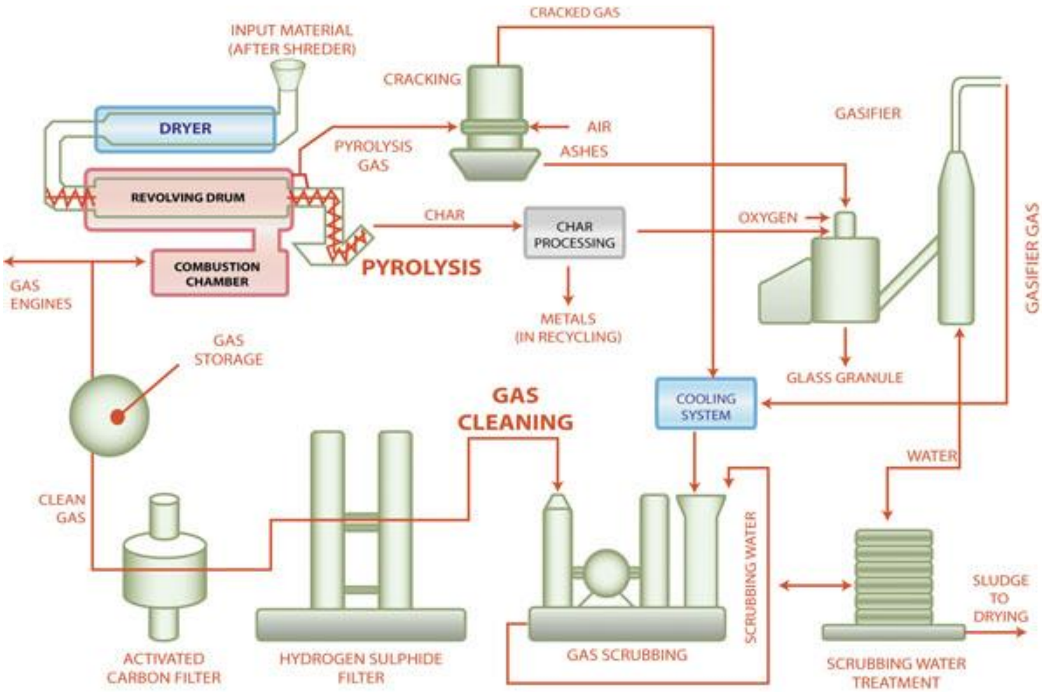


Figure 29: PKA process (Vamvuka, 2011).

- PyroMelt process: first introduced by "ML Entsorgungs und Energieanlagen GmbH", German company that combines combustion and pyrolysis after feeding plastic from hazardous waste as well as automotive solid waste. The gas resulted from pyrolysis is combusted and the char also combusted with oil in a melt furnace (Juniper, 2005).

- BP polymer cracking process: treating over 25 kilo tonnes per year, the first plant was set up in Scotland after some trials during 1998. At a 500 ^oC in an inert atmosphere, a fluidized bed reactor heats plastic (which has been previously reduced in size). The thermal cracking of the plastic produces a vapor which leaves the reactor with gas, leading to HCl production. The lime absorber neutralizes the HCl by putting in contact with hot gas with an absorbent (ECVM, 1997). After the process, the resulting output contains 85% of the weight of the plastic fed as hydrocarbon liquid and 15% as gas with high content of monomers (mostly C_2H_4 and C_3H_6) and other hydrocarbons suitable as feedstock for other processes. Nevertheless, CH_4 is also generated and its amount surrounds 15% of the gas produced. The total solid of the output is around 20% of the total solid fed as input (Brophy, 1997).

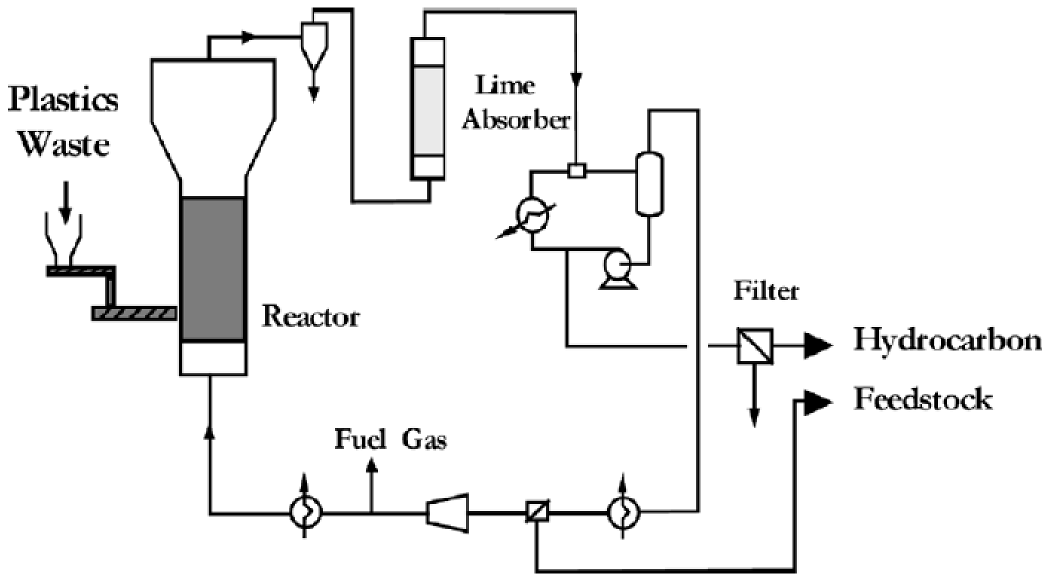


Figure 30: BP polymer cracking process (Tükker, 1999).

- BASF process: is one of the main schemes in pyrolysis methods. Began in Germany with a trial plan prepared for 15 kilo tonnes per year back in 1994. Before the treatment, as it is done in some other technologies, plastic solid waste is separated from other scraps such as metals and other materials. Through different stages of melting and reduction, the petrochemicals are collected apart from the HCl that results from the presence of chlorine in the input (especially if it is made of PVC). Some other products, in lower amounts, appear after the thermal cracking: $CaCl_2$ or NaCl (Kremer, 1999).

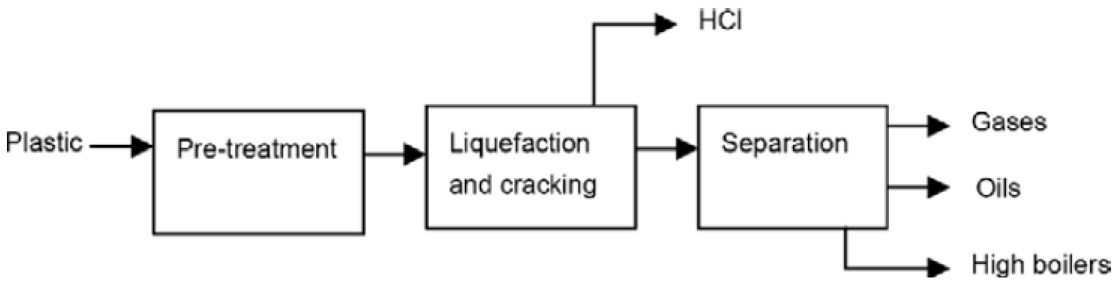


Figure 31: BASF Process (Kremer, 1999).

- NKT process: after separating plastics from other disposed material, a low-pressure reactor, at 2-3 bars and 375 ^{o}C, processes the feed modifying the hydrocarbon chain of the original polymer. This process does not emit any dioxins or chlorine, but a small quantity of carbon-dioxide may be produce while neutralising hydrogen chloride with the lime absorber. All the streams, if not used as products, are recycled in the system in order to produce energy or heat.

- Noell – KRC process: a rotary kiln reactor heats plastic at approximately 550 ^{o}C, converting 25% of the inputs into oil. Gasification occurs at 1400 – 2000 ^{o}C and 2 – 50 bars. Produces medium calorific value gas apart from the hot gas which is used to heat the kiln. It is one of the most applied techniques in the pyrolysis processes (Jaeger, 2000).

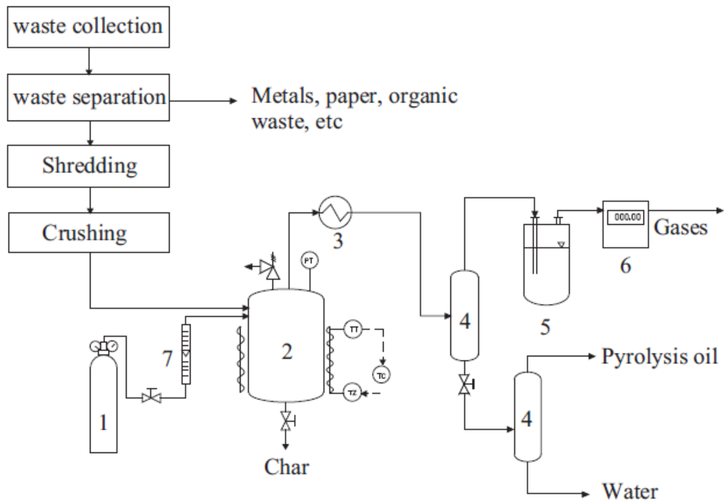
- Serpac technology: two chambers are interconnected, one conical and the other cylindrical, both inclined and rotatory. Combines pyrolysis at 600 – 700 ^{o}C, gasification on presence of air at 800 ^{o}C and then combustion of that air approximately 1100 – 1200 ^{o}C (Malkow, 2004).

- Microwave assisted process: is a particular way of pyrolysis. Its ability to quickly and directly heat materials makes it interesting for pyrolysis if the fed material absorbs microwave. Since plastic is not-dielectric, carbon must be used in the chamber in order to absorb the microwaves, therefore increasing its temperature and, consequently, heating the plastic inside (Aishwarya, 2016).

Figure 32: Experimental setup of the microwave assisted pyrolysis procedure (Asihwarya, 2016).

- Many other processes are listed as pyrolysis (or pyrolysis plus other technique) such as: EDDITH process, Siemens Schwel-Brenn technology, Mitsui R21, Takuma SBV, Thermoselect process, Von Roll RCP technology, Compact Power Process, Honghoo technology and CNRS thermos-chemical convertor (Dezhen, 2014).

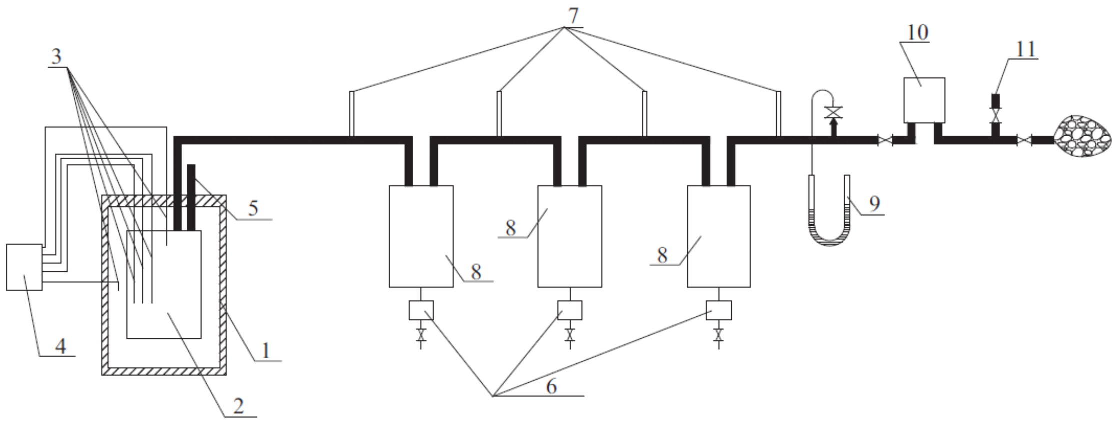
Furthermore, the pyrolysis schemes could be presented as follows:



Fixed-bed reactor and pyrolysis system (1-N_2 bottle; 2-reactor; 3-heat exchanger; 4-separation unit, 5-water trap; 6-gas flow meter; 7-rotameter)

Figure 33: Fixed-bed reactor and pyrolysis system (Mikolczi, 2013).

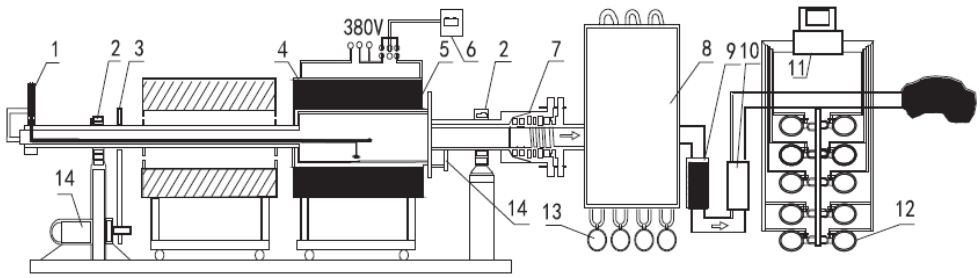
The N_2 is used to ensure that the heating occurs in an inert atmosphere, without oxygen, avoiding combustion of the feed. The vapor is separated into gas and liquids, resulting products that are suitable as feedstock for further petrochemical processes or to reuse as energy source to heat the reactor.



Fixed bed pyrolysis system (1-furnace; 2-pyrolysis reactor; 3-thermocouple; 4-temperature controller; 5-N_2 pipe; 6-liquid gathering tank; 7-thermometer; 8-condenser; 9-pressure gauge; 10-sampling vent)

Figure 34: Fixed bed pyrolysis system (Wang, 2005).

The furnace heats the chamber, also heated through thermocouples, and the vapor is cooled and condensed to extract the value-added products such as liquid oil or gas.



Rotary kiln pyrolysis system (1-thermometer; 2-bearing; 3-gear transmission; 4-electrical furnace; 5-rotary kiln; 6-temperature controller; 7-seal; 8-two-steps condenser; 9-filter; 10-accumulative flowmeter; 11-computer; 12-gas sampling device; 13-feed and discharge opening; 14-speed adjustable electrical machinery)

Figure 35: Rotary kiln pyrolysis system (Li, 2000).

The electrical furnace heats the rotary cylindric kiln where the plastic vaporizes for further condensation to produce petrochemical fluids.

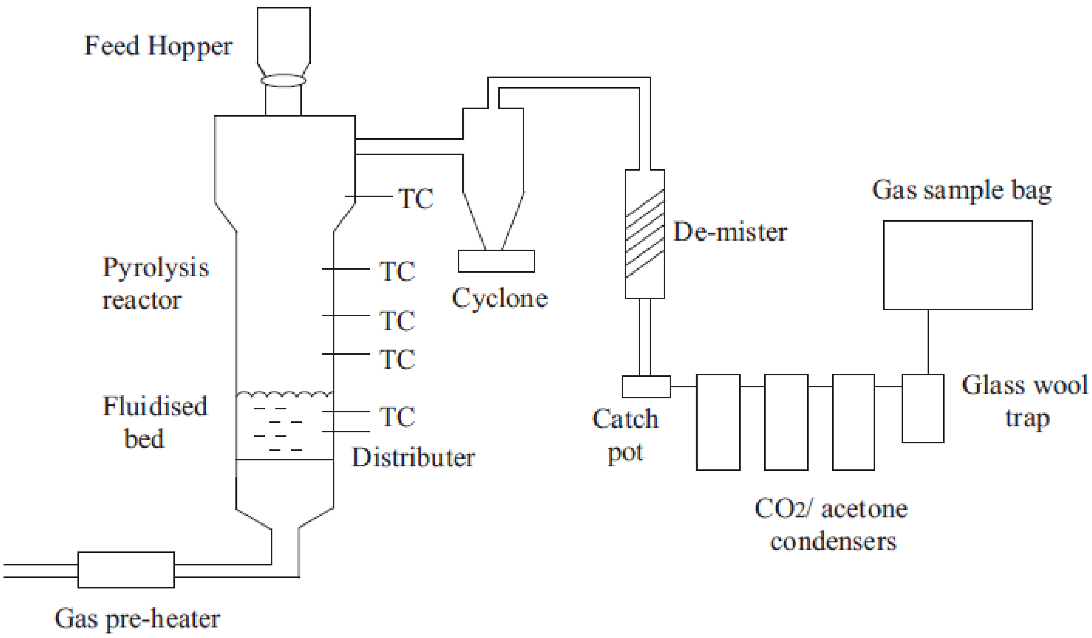


Figure 36: Fluidised-bed pyrolysis system (Williams, 1999).

As seen in most of the schemes, pre-treatment of the feedstock is important to heat the plastic before entering the reactor. This lead the engineers to design the system showed below:

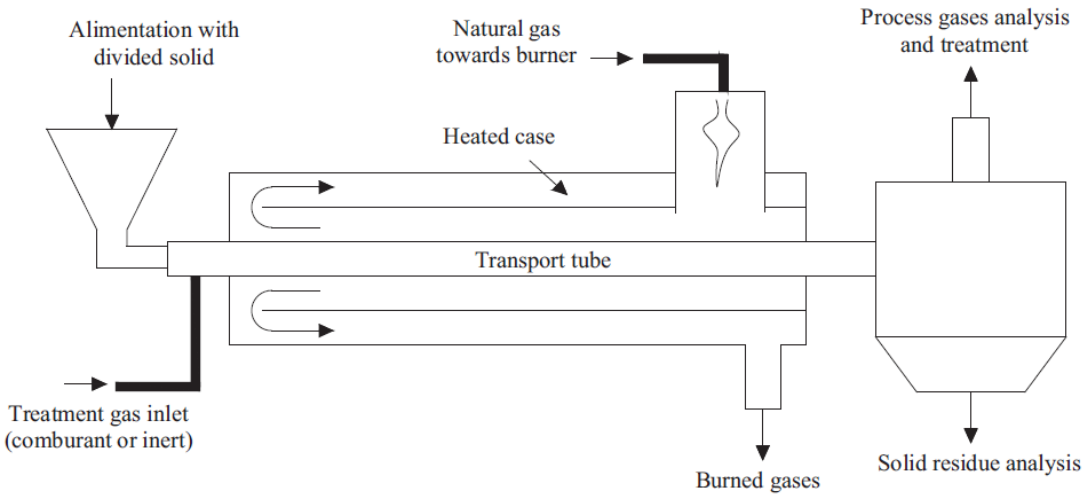


Figure 37: Functional scheme of the transport tube thermochemical convertor (Dezhen, 2014).

Summarizing the different techniques, the table illustrates the methods and their reactor types:

Reactor type	Running experiences	Requirements on material preparation	Capacity	Maintenance requirement	Flexibility to operation parameters' change	Application recommendation
Fixed-bed reactor	Running in batch, only in laboratory researches	Almost no requirements except for energy-saving purpose	Small, may not exceed several tons per day	Low, but batch by batch operation demanding manual labour	Excellent flexibility	Not recommended for industrial application
Rotary kiln	Most common	Not rigid	Large, up to 150,000 tpa	Low to moderate	Good flexibility	Recommended but efficiency should be improved; multi-sectional reactor suggested
Fluidised-bed reactor	Only for laboratory researches, no practical experiences for MSW	Very rigid	Large theoretically	Highest	Very limited to size change; good flexibility to temperature, etc.	Heating system should be improved before application to MSW pyrolysis
Tubular reactor	A few	Rigid	Moderate, up to 50,000 tpa	Moderate to high	Limited to size and temperature change	Recommended, especially the multi-sectional tubular reactor

Figure 38: Different reactors in PSW pyrolysis (Dezhen, 2014).

As conclusion, the pyrolysis technique to convert waste-to-energy is increasing in demand recently as a plastic solid waste treatment. As seen in the chapter, most pyrolysis facilities combine pyrolysis with other sections such as combustion or gasification. To reduce the emissions, every section should treat its exhausted gas with gas scrubbing devices. The output products include solid, liquid and gas, generating char and coal, oil and waxes and a wide range of gas.

The yield of each product highly depends on the parameters of the process, being feedstock characteristics, temperature and exposed time the most determinant. The gas yields from different plastics fed are diverse and increase while increasing the temperature of operation; the average calorific value surrounds 15 MJ N m^{-3} in most cases if the temperature is 600 ^{o}C or above, thus, the gas generated is a potential sellable product. Liquids have not potential qualities to be sold if the pyrolysis is fed with municipal solid waste, whilst oil and many other petrochemical feedstocks are manufactured when the reactor is fed with PSW. The char is of high calorific value, hence, a potential solid fuel resource. It is essential to control the composition of the raw materials to supervise the emissions, the heavy materials, the heavy metals and organic pollutants (Dezhen, 2014).

To improve the quality of the products of pyrolysis facilities, some other devices should be developed to treat the process, generating higher levels of efficiency and a more environmentally beneficial process.

The essential steps of the pyrolysis of PSW method include (Patni, et al., 2013):

1. Evenly heating the plastic to a narrow temperature range without excessive temperature variations.

2. Purging oxygen from pyrolysis chamber.

3. Managing the carbonaceous char by-product before it acts as a thermal insulator and lowers the heat transfer to the plastic.

4. Careful condensation and fractionation of the pyrolysis vapours to produce distillate of good quality and consistency.

Being the advantages (Patni, et al., 2013):

a) Volume of the waste is significantly reduced (< 50 - 90%).

b) Solid, liquid, and gaseous fuel can be produced from the waste.

c) Storable/transportable fuel or chemical feedstock is obtained.

d) Environmental problem is reduced.

e) Desirable process as energy is obtained from renewable sources like municipal solid waste or sewage sludge.

f) The capital cost is low.

Gasification

Gasification produces fuels or combustible gases out of waste. To simplify and reduce the costs of the process, air is used as the gasification agent instead of O_2. The biggest disadvantage is the presence of N_2, which is inert and, consequently, produces a reduction in the calorific value of the fuels generated. To reduce the proportion of N_2, steam could be introduced in a stoichiometric ratio. Considerable amounts of char are produced whilst gasification, therefore, further treatment or burning is required. Some facilities use expensive pure O_2, while others require large amounts of expensive materials such as limestone, coke and generate much sludge from which metals cannot be separated (Al-Salem, et al., 2009).

The ideal process of gasification for PSW has high calorific value gas as output, has completely combusted the char, low values of easy metal product which are easily separated from the ash and should not include any additional devices for water/air pollution prevention.

Gasification of solid waste has been studied since the 1970s (Hasegawa, 1974), however, obtaining high calorific value gas from PSW was demonstrated for PVC, PP and PET in more recent researchers (Borgianni & Filippis, 2002) (Xiao, 2007) (Matsunami, et al., 1999). The pursue to use as much waste as possible to treat in gasification process and the need for alternative sources of fuels has encouraged the researchers to find techniques of co-gasification of PSW with other types of waste, bio mass for example.

Some technologies of gasification are Waste Gas Technology UK Limited (WGT), Texaco Gasification (which is, by far, the most common and well-known technologies), SVZ process (appropriate for severely contaminated PSW or other wastes), Akzo Nobel (a process for mixed PSW gasification) (Al-Salem, et al., 2009).

As shown in this chapter, both pyrolysis and gasification generate products in three different phases: solid, liquid and gas; represented by char (5-25%), tars (10-45%) and gas (Aznar, 2006). The first step of the cracking process yields hydrocarbons in the range of C_{20}-C_{50}. Then, these hydrocarbons are, once again, cracked to obtain lighter products as propene and ethene, that, at high temperatures are unstable, reacting to form benzene, toluene and other aromatic compounds. Whilst increasing the temperature, the plastic cracks into lighter compounds and H_2, CO, CO_2 and CH_4. At elevated temperatures, around 850 degrees and above, the pyrolysis yields are mostly aromatics, C_2H_4 and CH_4 (Mastral, 2003).

The biggest disadvantage of plastic pyrolysis and gasification techniques is the strict control required to supervise the chloride content of the raw material fed and the risk of bad fluidization due to particle agglomeration (Kaminsky, 1995).

Catalytic process of pyrolysis produces larger amounts of liquid and fuel oil, reaching conversions up to 70-80% in weight and with similar characteristics as the conventional diesel fuel. These characteristics are the “high heating value (HHV) of 38–45.86 MJ/kg, a density of 0.77–0.84 g/cm^3, a viscosity of 1.74–2.5 mm^2/s, a kinematic viscosity of 1.1–2.27 cSt, a pour point of (−9) to (−67) °C, a boiling point of 68–352 °C, and a flash point of 26.1–48 °C. Thus, the liquid oil from catalytic pyrolysis is of higher quality and can be used in several energy-related applications such as electricity generation, transport fuel and heating source”. In fact, it faces some limitations such as high parasitic energy demand, catalyst costs and less reuse of the catalyst (Miandad, et al., 2016).

To conclude, both gasification and pyrolysis can be utilized in industry but should be researched and developed to produce more efficient end-products. Improvements include scale-up and detail analysis of the products manufactured, those that may be sold in a market that, nowadays, is still growing.

There are some other chemical recycling techniques, hydrogenation, for example, is the process of addition of diatomic hydrogen through a chemical reaction by unit operation (March, 1992). The most used hydrogenation technology is the Veba process, based upon the coal liquefaction technology, converting coal into gas oil and naphtha.

Energy recovery

This technique implies burning waste to produce energy in form of heat, steam and electricity. This is only considered a sensible way of waste handling when the material recovery procedures are not economically feasible (Al-Salem, et al., 2009).

Since plastic materials partially derive from oil, its calorific value when burned is high. In the table below, it is shown the calorific value of some major plastics as well as the same characteristic of some oils and municipal solid waste mixture:

ITEM	CALORIFIC VALUE (MJ KG^{-1})
POLYETHYLENE	43.3 – 46.5
POLYPROPYLENE	46.5
POLYSTYRENE	41-9
KEROSENE	46.5
GAS OIL	45.2
HEAVY OIL	42.5
PETROLEUM	42.3
HOUSEHOLD MSW MIXTURE	31.8

Table 2: Calorific value of some plastics compared with common fuels (Mastellone, 1999).

The incineration process is assumed to decrease the volume of the waste by 90-99%, reducing the amount of plastic solid waste disposed in the landfills. Incineration also reduce the emissions of chlorofluorocarbons (CFCs), however, nowadays still being complicated avoiding the presence flame-retardants in the combustion process.

The biggest concerns about incineration are associated with the emissions of numerous pollutants such as carbon dioxide, sulfates and nitrates. Moreover, some volatile organic compounds, fumes, heavy metals, etc. are also disposed to the environment after incineration. Some other substances produced after the incineration of PVC, PET, PS and PE have been identified as carcinogenic.

To deal with these issues, capture and removal of flue gases in combustion process is essential and could be achieved through different solutions such as: addition of ammonia to the combustion chamber, cooling the flue gas, neutralizing the acid generated or activated carbon filtration and/or addition (Yassin, et al., 2005). Hence, PSW could be considered as a renewable energy source under certain constrains of feed preparations (Al-Salem, et al., 2009).

There are different techniques to perform the energy recovery process, some examples are: grate technology (co-incineration by direct one stage combustion process of waste), fluidized bed and two stage incineration or rotary and cement kiln combustion. They have difference in the optimal materials for the input as well as the energy recovered throughout the process.

Conclusion Literature Survey

The different technologies explained in this chapter have contributed greatly to the eco-image of waste management and, in this case, particularly to PSW handling. In one way or another, these methodologies have reduced the amount of PSW disposed into landfills and the dependence of the crude oil since, the first two techniques prevent from utilizing more oil to produce plastic and the last two produce energy that otherwise may be manufactured through the burning of fuel.

Re-using plastics mean reducing single-life materials and, sometimes, could be integrated in the process of recycling through scrap re-extrusion. This process faces some limitations such as the type of polymer contained in the plastic that should suit and have conditions similar to the ones of the recycled plastic in order to reduce the energy consumption of the process. Therefore, for a practical application of mechanical treatment, the raw materials to be recycle should have similar properties of commercial grade plastics.

The most sustainable solution is the tertiary treatment that, not only recovers valuable petrochemicals as feedstock but providing in the process a recycling way and producing energy in form of heat, steam, etc. Energy recovery is based on the origin of plastics. These materials derive from oil and recovering energy sometimes produce amounts comparable to other energy sources.

There are many ways of reducing the amount of PSW at the same time that it is reduced the dependence on fossil fuels, resulting in a better conservation of natural resources, achieving an integrated waste management solution. Thus, it has been demonstrated that there are many technologies available to prevent the usage of landfills, being particularly important to consider recycling and energy recovery methods in plastic manufacturing and converting facilities.

Australia: legislation and opportunities

"Facilities that turn urban waste into energy are a major investment opportunity in the Australian energy from waste sector. With around 23 million tons of urban waste sent to landfill around the country each year, there is a significant opportunity for energy from waste to play a role in generating renewable energy and diverting waste from landfill" (Clean Energy Finance Corporation, 2016).

The levies imposed by the different states to landfilling help to make energy from waste projects more economically viable. A significant source of revenue for energy from waste projects is earning money for receiving solid waste. This charge highly depends on the costs of other disposal alternatives. However, some countries export solid waste to other places and sell the materials to recycle and further treat them to manufacture new products. This is the case of Australia and China. China is a country that is known to buy waste from other countries and use it to reduce the amount of new raw material as input of different factories all over various industries. Australia, in fact, exports waste material and, in 2011-2012, the total exports were 4.4 million tons valued at $2,407 million (Australian Bureau of Statistics, 2013).

States that charge landfill levies promote and effective way of pricing the environmental and social externalities of waste disposal. In New South Wales and Western Australia there have been different project announcements valuating over $1.5 billion.

Some organizations, such as the Clean Energy Finance Corporation, support project developers and investors, waste company's managers and stakeholders and councils that are willing to set up facilities to convert waste to energy and are looking for finance.

New South Wales, where the project would be set up, specify a hierarchy for waste management that, from most to least preferable, states this (NSW Environment Protection Authority, 2017):

- Avoid and reduce waste
- Reuse waste
- Recycle waste
- Recover energy from waste
- Treat waste
- Dispose waste

The waste policies in New South Wales postulate a list of energy from waste fuels that are eligible for consent. The scope of the policy statement covers facilities with treatments of combustion, thermal oxidation, thermal or plasma gasification and pyrolysis. These facilities that use waste must meet some criteria, particularly:

- Ensure that they use only residual waste from genuine resource recovery operation.
- Does not undermine higher-priority waste management options, such as avoidance, re-use or recycling.
- Capture at least 25% of the thermal energy as electricity or an equivalent level of recovery.
- Use current international best practice emissions controls, monitoring and management.

- Use proven and well-understood technologies.
- A maximum residual waste allowed for energy recovery depending on the material fed.

All the requirements are explained in the "*NSW Energy from Waste Policy Statement*" (NSW Environment Protection Authority, 2015).

In the same state, the waste levy is $135.70 per ton for metropolitan and residential areas and $78.20 per ton in regional areas, increasing year by year this price with the consumer price index. In other states such as Western Australia, Victoria and South Australia, the levies for landfilling are lower, thus, setting up the plant in NSW would be a great idea since the plastic solid waste disposal is much more expensive and less profitable than the conversion into energy (Clean Energy Finance Corporation, 2016).

However, energy from waste projects need reliable waste volumes to be considered. Huge and secure waste streams are also decidedly pertinent, being more likely to have the substantial domestic and industrial waste volumes required to supply the factory. Moreover, air quality and emissions management are essential for been accepted as a waste-to-energy facility. Being environmental friendly, supporting human health, controlling that the local air quality is not disturbed by the factory is critical for Government and community acceptance.

The states are concerned that these projects create jobs in some different important areas such as environmental monitoring, commissioning and procurement, operation and maintenance, manufacturing, transport, delivering and so on. As per the CEFC, the major energy from waste projects announced recently have been:

PROJECT	REPORTED COST ($M)	WASTE CAPACITY (1,000 TONS PER YEAR)
NEW ENERGY PORT HEDLAND, WA	150	100
NEW ENERGY EAST ROCKINGHAM, WA	180	225
PHOENIX ENERGY KWINANA, WA	400	400
EMRC RESOURCE RECOVERY FACILITY PERTH, WA	NA	150
DIAL-A-DUMP EASTERN CREEK, NSW	700	1300
OMEGA ENERGY HUNTER RESOURCE & ENERGY RECOVERY FACILITY WESTON NSW	NA	150
BORAL BERRIMA, NSW	NA	100

Table 3: Announced major energy from waste projects in Australia (Clean Energy Finance Corporation, 2016).

The conclusion is that NSW is the place to locate the project for its policies in terms of landfilling levies, supports to waste to energy facilities and the viability of some other related projects (which are not particularly rivals since they will feed the facility with MSW instead of PSW).

This, combined with the fact that NSW is the state with higher population, ensures that the opportunities of the project would be much better in this state than in the rest of the country, receiving plastic solid waste without any charge.

Flow chart: pyrolysis & combustion

In order to make the most of the plant, as it has been explained in previous chapters, the projector has decided to use pyrolysis plus combustion. Pyrolysis allows to generate liquid, gases and char. The liquids which are already useful for further uses in petrochemical appliances would be sold. Those which require treatment would be further distillate to be sellable as diesel and other petrochemicals. The gases will be burnt inside the facility, in the combustion chamber, to meet the criteria imposed by the NSW Government that requires the waste-to-energy plants to recover a percentage of the outputs as electricity or heat. The char could be sold for other industrial purposes or burnt inside the combustion chamber.

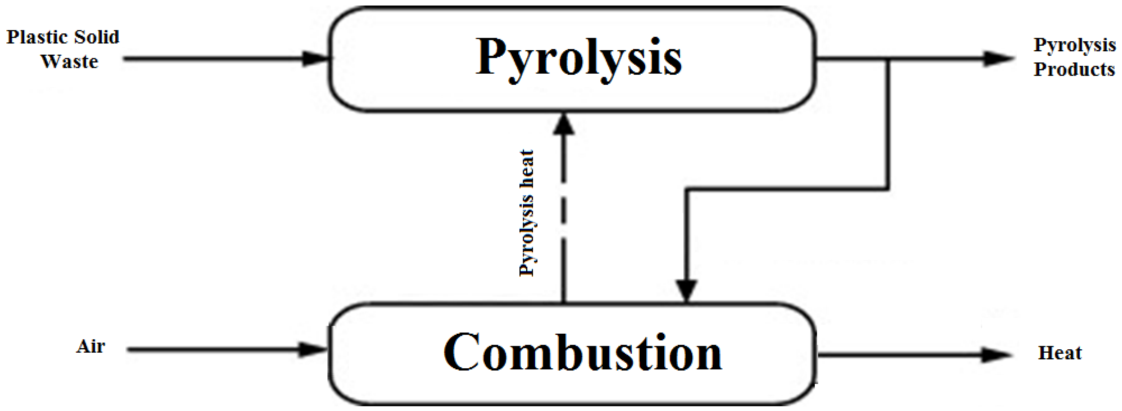


Figure 39: Flow chart for the energy recovery plant

Adding combustion to the process requires higher investment but ensures that all the products are worth it. Combustion makes the system more flexible in terms of inputs and outputs characteristics, recovers energy and prevent further treatment of some low-value outputs burning them in the chamber.

Below, it is shown the flow chart explained with its different devices and technologies:

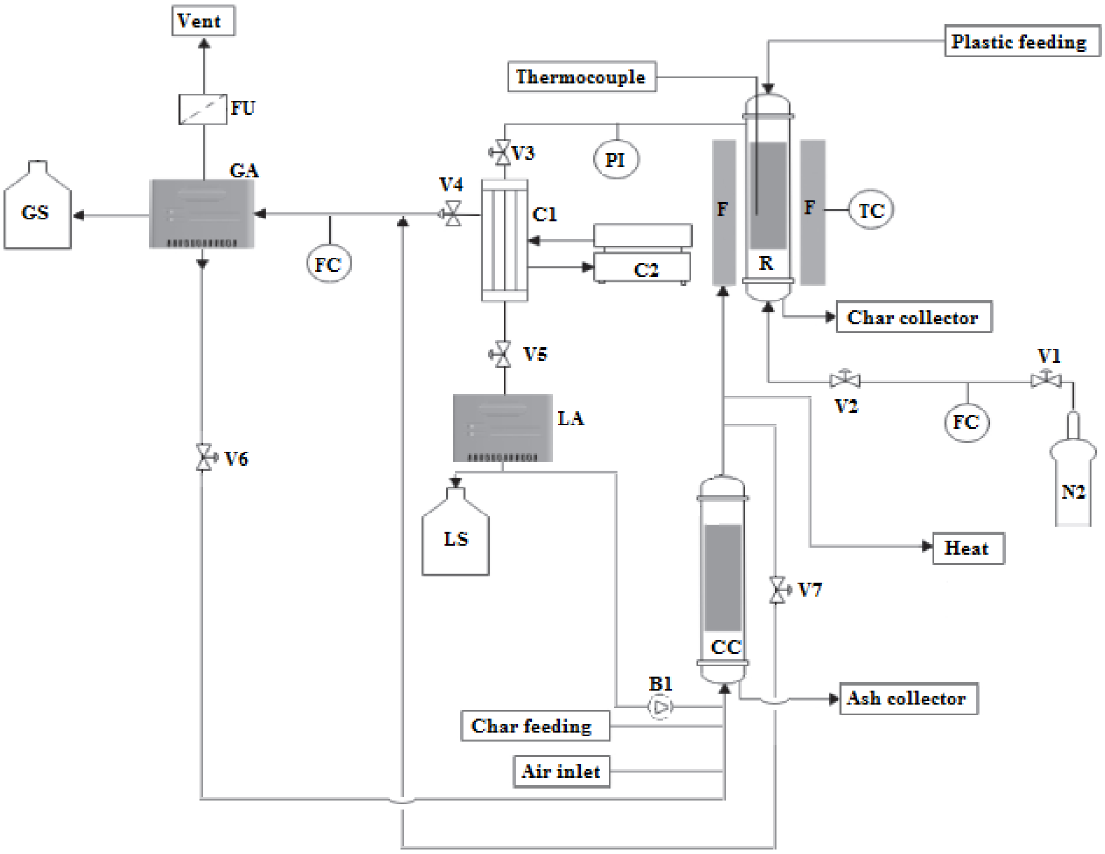


Figure 40: Scheme of the plant.

Where:

- N2: Nitrogen tank
- V: Valve
- FC: Flow controller
- TC: Temperature controller
- F: Furnace
- R: Pyrolysis reactor
- PI: Pressure indicator
- C1: Condenser
- C2: Chiller
- GA: Gas analyser
- FU: Filter unit
- GS: Gas storage tank
- LA: Liquid analyser
- B: Pump
- CC: Combustion chamber

A distillation device is included inside the warehouse to treat part of the liquid output that does not reach the required level. This machine would treat oil to manufacture products of higher calorific value after separating the compounds of the oil in the input.

Explaining the process, the plastic solid waste is fed in the pyrolysis reactor where, thanks to the usage of N_2, the atmosphere is inert, preventing the raw material from combustion. Heating the reactor with the thermocouple or with the heat recovered from the combustion chamber, the plastic vaporizes and goes through the condenser. The chiller provides refrigeration so the vapor is separated into liquid and gas. Both liquid and gas are analysed so, if their characteristics are feasible for further sell as value-added products, the plant storages the output. Some of the oil products would be treated in the distillation device to convert them into diesel and other compounds. No further treatments are performed in the plant to ensure better characteristics, thus, those products which are not sold as consumable could be either exhaled (prior filter of harmful particles) or burnt in the combustion chamber.

The combustion chamber burns char and gases from pyrolysis reactor which are neither sold or treated, producing thermal energy to heat the reactor and the distillation machine. In case that some heat is left over, the operator could consider adding a steam device to produce energy from the extra heat.

The inputs and outputs of the process are shown below:

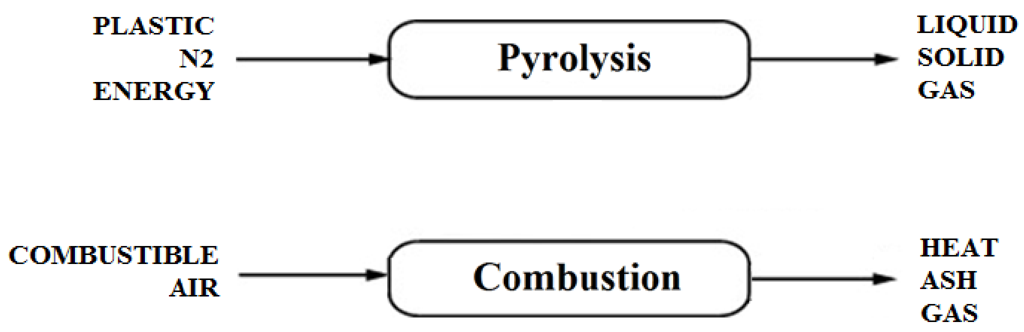


Figure 41: Inputs and outputs of the system

Location

The pyrolysis plus incineration plant will be set up in Chullora, 15 km away from Sydney to the west. It is established there because it is close to an industrial area where some companies related to plastic products manufacture are. Some examples could be Pirelli, Bridgestone, Volkswagen, Portavin Integrated Wine Services, NEPEAN Building and Infrastructure and some others.

Figure 42: Chullora, west Sydney (Google Maps, 2017).

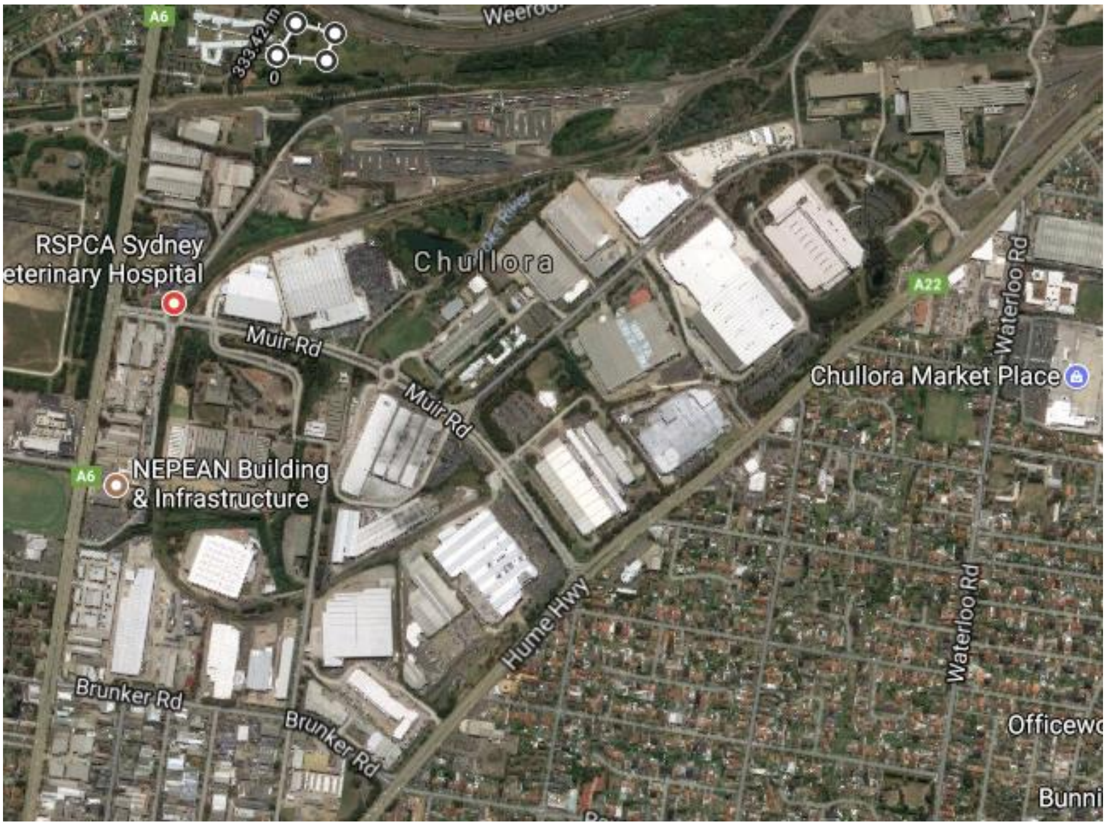


Figure 43: Industrial area of Chullora (Google Maps, 2017).

The smallholding selected is:

Figure 44: Smallholding of the plant (Google Maps, 2017).

The area must be remodeled to install the warehouse, office, parking and all the required areas for setting up the business. Therefore, not only buying the smallholding but work the area for further concreting, construct the foundations and building the warehouse and office.

Figure 45: Area remodeled for office and warehouse. (Google Maps, 2017)

In addition, a road must be built to access the facility:

Figure 46: Road to be built to access the facilities (Google Maps, 2017).

The pictures of the area show that there is no need to move huge amounts of soil to build the foundations of the factory. This reduces the cost of setting up the land to build the base of the premises.

Figure 47: Picture of the smallholding

Economic analysis methodology

The economics of the process depends on the value of the products recovered which is a function of associated petrochemical market prices that are characterized by their high volatility (Ghodrat, et al., 2016). Considering this fact, it has been decided to study the historical trend of prices from a determined period.

An input/output model has been generated to analyze the economic feasibility of the setup. Both costs and revenues for each unit operation and every other parameter that modifies the profits have been studied and quantified. The total processing incomes and costs can be appraised after estimating each unit operation of the process of recovering energy in form of petrochemicals out of plastic solid waste. Furthermore, the sensitivity analysis was used to study the variability of the model due to the unpredictability of the key input values.

To create the economic model for the PSW to energy plant defined above, it was utilized the technical cost modelling (TCM) that was firstly introduced by Rosato and Rosato (1989) in "Blow modelling handbook" and then modified and further used by Schoenung (1995) and Kang and Schoenung. According to these researchers, the model has two main components known as input and outputs. The variables that are specified in the model are the inputs, whilst outputs are the results of the modelling and comprises revenues and costs estimations. The initial step involves reviewing the basic unit operations, as well as the process options identified. Secondly, baseline costs are evaluated, and the key parameters calculated for each of every unit operation. Third stage of the model application is to establish a functional relationship with the process parameters, which may be used afterwards calculating the costs. The final step requires adding the key costs consequent from the process and the final cost is calculated by the sum of all the unit operation costs. Incomes work the same as costs, adding each unit to the count (Ghodrat, et al., 2016).

The Figure below shows the cost and revenue flows considered in the PSW to energy process studied in this thesis. The costs include setting up the land and foundations, building, equipment, energy, labor, materials and maintenance. The incomes are illustrated as arrows inwards the box representing the process. These revenues come from selling products generated in the plant, mainly oil and gas. Some industries also accept char for further treatment in concrete manufacture or asphalt production for example.

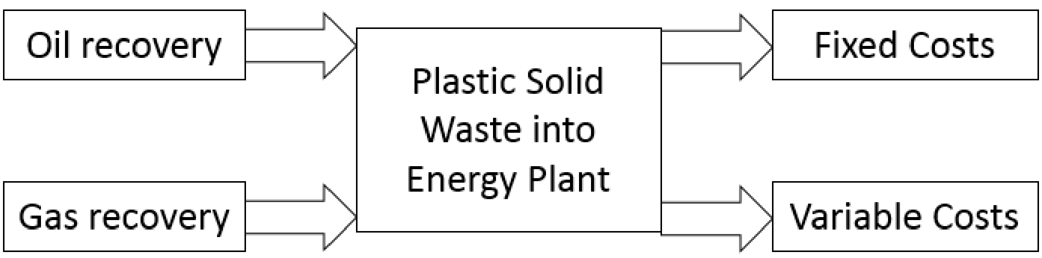


Figure 48: Model of the flow costs and revenues in a PSW to energy plant.

Where the fixed costs include land, foundations, building and equipment; and variable costs are defined by labor costs, energy, material and maintenance.

The capital costs estimates were based on a combination of price list from vendors and literature data. The values obtained in the literature have been scaled through the capacity power-law expression:

$$cost_2 / cost_1 = (capacity_2 / capacity_1)^{m}$$, with "*m*" varying from 0.48 to 0.87.

For every currency exchange, the factors were selected on October the 10th of 2017 (XE, 2017):

AUD	**USD**	**EUR**
1	0.778429	0.658815
1.28456	1	0.845459
1.51788	1.18155	1

Table 4: Currency exchanges of the 10th of October of 2017 (XE, 2017).

Economic parameter	**Basis**
Cost year for analysis	2017
Plant financing by equity/debt	100% (from the investor) / 0%
Internal rate of return*	10%
Term for debt financing**	25 years
Interest rate for debt financing	10%
Plant life/analysis period depreciation method	20 years (5 years studied) / 7 years
Income tax rate***	27.5% < $10 million sales >30%
Plant construction cost schedule	1 year
Plant salvage value	$100.00 + Land
Start-up period	1 year
Revenue and cost during start up	Revenue = 50% normal year
	Variable costs = 100% normal year
	Fixed costs = 100% normal year
Inflation rate**	1.9%
On stream percentage	90% (7884 h/year)

*According to: (Royal Society of Chemistry, 2017)

** According to: (Trading Economics, 2017)

***According to: (Australian Taxation Office, 2017)

Table 5: Economic parameters of the project.

The products that would be generated are proportions in weight of the material fed to the pyrolysis reactor: 51% oil, 28% carbon black, 11% steel wire and 10% exhaust gas (Waste Tire Oil, 2017). Some other machines generate higher amounts of oil working at higher temperatures than this device, however, those machines cannot be fed with waste tires. The assumption that will be done is that every product that is not oil will be further burnt in the combustion chamber, feeding heat to the pyrolysis reactor and the distillation equipment.

Costs

The total amount of PSW treated in this facility would be 40 tons per day. This includes tires from companies close to the area and plastic solid waste from the industrial sector and landfills.

The smallholding that would be bought is large enough to build the facilities and have spare space in case the company considers further developments inside the area. From the 6,500 square meters, 4,200 would be holding the area available to build after the foundations and the concreting. Inside this area, the parking zones are important for the trucks to load up and down the material. The exceeded area is designed to prevent problems such as full storage in the warehouse, problems with the trucks or the disposal of useless materials. The warehouse is designed to shelter the machinery as well as the raw materials, the resources and the final products.

Furthermore, the office is built to establish the company and its headquarters. Not many employees are required, thus, 150 square meters is the final decision. The green area is developed in the rest of the area which is not in use.

Resulting this area:

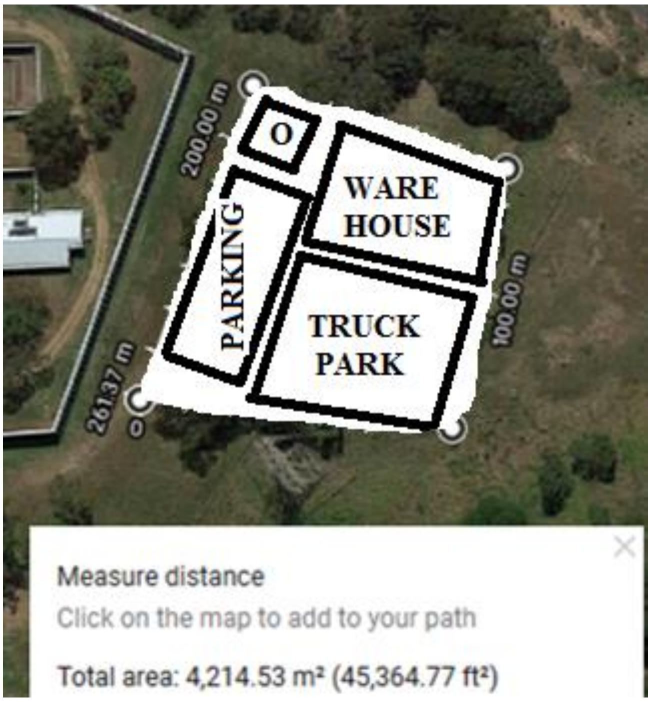


Figure 49: Constructed area (Google Maps, 2017).

*Being "O" the area for the office.

Costs of Investment

According to the sources, the prices of each process are explained below:

SITE & PREPARATION	M^2	AUD/M^2	TOTAL AUD	SOURCE
SMALLHOLDING	6,500	446	2,899,000	(m3 Property, 2016)
REMODELING	4,200	70	294,000	(Home Improvements Pages, 2017)
WAREHOUSE	1,200	562	674,400	(BMTQS, 2006)
OFFICE	150	1,274	191,100	(BMTQS, 2006)
GREEN AREA	950	25	23,750	(Said Ali Hassam, 2016)
			4,082,250	

Table 6: Cost of lands and construction.

There is no need to pay royalty costs because there is not an extraction of a mineral or a natural resource.

When analyzing the costs of the equipment, it should be considered different types of equipment: waste receiving, thermal pyrolysis unit plus combustion unit and miscellaneous equipment. Some costs have been obtained from other researchers and scaled through the capacity power-low expression. The costs have been studied considering 40 tones treated per day in the factory. This equipment will face depreciation in the NPV analysis.

Table below shows the costs of waste receiving machinery.

WASTE RECEIVING	QTY	AUD/QTY	TOTAL AUD	SOURCE
TRUCK SCALE, 80 TONS	1	50,000	50,000	(Said Ali Hassam, 2016)
CONVEYOR	2	7,500	15,000	(Bastian, 2013)
LOADERS, 5 TONS	2	30,000	60,000	(Alibaba, 2017)
TIPPER TRUCK	2	50,000	100,000	(Truck Sales, 2017)
STORAGE CONTAINERS, 1 M^3	30	200	6,000	(Said Ali Hassam, 2016)
			231,000	

Table 7: Equipment costs. Waste receiving machinery.

The tipper truck has a weight capacity of 35,000 kg; hence, it is necessary to have 2 working 8 hours a day during weekdays to feed the plant with 40,000 kg/day and distribute the products.

Both the cost of the thermal pyrolysis unit and the cost of the incineration unit are not hundred percent reliable since the companies do not usually show their flow charts and costs in their websites. Therefore, it will be included a safety factor of 115% to prevent unforeseen costs. The projector has contacted three different companies (Waste Tire Oil, 2017) (Agile Process, 2017)

(PACIFIC PYROLYSIS, 2017) to ask them for budget and schemes of the plant but they refused to give further information unless the projector chooses to purchase a pre-study of the plant.

The table below shows the costs related to the thermal pyrolysis unit, considering its size of 30x15 square meters and 40 tones treated per day (Waste Tire Oil, 2017) (Huayin Group, 2017).

PYROLYSIS & INCINERATION	QTY	AUD/QTY	TOTAL AUD	SOURCE
PYROLYSIS SECTION	1	120,561	120,561	(Waste Tire Oil, 2017) (Huayin Group, 2017)
INCINERATION SECTION	1	13,000	13,000	(Alibaba, 2017)
DESTILLATION EQUIPMENT	1	30,000	30,000	(Waste Tire Oil, 2017)
GAS ANALYZER	1	6,000	6,000	(Alibaba, 2017)
LIQUID ANALYZER	1	10,000	10,000	(Alibaba, 2017)
GAS FILTER	1	5,000	5,000	(Alibaba, 2017)
PIPES & ACCS	-	5,000	5,000	(Reliable, 2017)
GAS TANK	1	5,000	5,000	(Alibaba, 2017)
SAFETY FACTOR		15%	29,184	
TRANSPORTATION & CUSTOMS		10%	22,375	(Said Ali Hassam, 2016) Scaled.
			246,120	

Table 8: Equipment costs. Pyrolysis and Combustion units.

The cost of purchasing the pyrolysis section is difficult to obtain. The projector has written numerous companies and the average price for 30 tons per day plant is approximately $100.000. Therefore, with the capacity power-low expression:

Cost = \$100.000 x $(40 / 30)^{0.65}$ = \$120,561

Some other equipment and devices are required to build the plant. In the table below, it is illustrated the cost of each device:

MISCELLANEOUS EQUIPMENT	QTY	AUD/QTY	TOTAL AUD	SOURCE
WATER TREATMENT FACILITY	1	67,161	67,161	(Said Ali Hassam, 2016) Scaled*
GENERATOR	1	9,000	9,000	(Generators Online, 2017)
7.500 L CRUDE OIL STORAGE TANK (PL)	10	5,000	50,000	(Fuel Tank Shop, 2017)
SLUDGE STORAGE CONTAINER (PL)	1	10,000	10,000	(Alibaba, 2017)
AIR COMPRESSOR	1	2,000	2,000	(Sydney Tools, 2017)
NITROGEN GENERATING UNIT & TANK	1	6,000	6,000	(Paige, 2017)
			141,161	

Table 9: Equipment costs. Miscellaneous equipment.

Scaled*: Cost = $300.000 x (40 / 400)^{0.65} = $67,161.

Once studied the Site and Equipment costs, the next step involves the Project related costs:

PROJECT RELATED	TOTAL AUD
MANAGEMENT AND COMISSIONING	120,000
UNFORESEEN COSTS	100,000
OPERATING CAPITAL	10% sales = 300,000
	520,000

Table 10: Project related costs.

These costs include the investment that is required for the start-up period and will be added to the cash flow as the "Net Working Capital to start the project". For subsequent years, the net working capital will be defined as the 10% of the sales foreseen for that year.

Hence, the total Fixed Costs Investment is:

ITEM	AUD
SITE & PREPARATION	4,082,250
WASTE RECEIVING	231,000
PYROLYSIS & INCINERATION	246,120
MISCELLANEOUS & EQUIPMENT	141,161
PROJECT RELATED	520,000
	5,220,531

Table 11: Total Fixed Costs.

Variable costs

The different variable costs are shown below:

DESCRIPTION			
OPERATING LABOR	C_{OL}	Calculated in Table below	
UTILITIES (ENERGY)	C_u	Calculated in Table below	
MAINTENANCE AND REPAIR	C_m	0.069FCI (Fixed Capital Investment)	(Perry & Green, 1997) (Seider, et al., 2009)
LOCAL TAXES AND INSURANCE	$C_{T\&I}$	0.032FCI	(Perry & Green, 1997) (Seider, et al., 2009)
PLANT OVERHEAD	C_{po}	0.708 C_{OL} + 0.009FCI	(Perry & Green, 1997) (Seider, et al., 2009)
GENERAL OPERATING EXPENSES	C_{GOE}	0.31C_{OL}	(Perry & Green, 1997) (Seider, et al., 2009)

Table 12: Definition Variable Costs.

In order to reduce the amount of PSW, the projector assumes that the NSW Government will provide the plastic that otherwise would be thrown away and further disposed to the landfills. Furthermore, the company is established close to an industrial area to handle the plastic waste generated by companies like Pirelli, Bridgestone and some others. Therefore, the plastic fed to the plant comes from domestic use, industrial use and waste tires free of charge.

Operating Labor include the cost of the salaries of the employees:

TASK	PRICE / HOUR ($/H)	HOURS A YEAR (H/Y)	WAGE PER YEAR ($/Y)
SECRETARY ASSISTANT	24.26	2,086	50,606
4 X LABORER WEEKDAYS DAY	4 x 20.84	2,006	4 x 41,805
2 X LABORER WEEKDAYS NIGHT	2 x 31.26	2,006	2 x 62,707
12 X LABORER WEEKEND	12 x 35.43	914	12 x 32,383
2 X TRUCK DRIVER	2 x 25.11	2,086	2 x 52,379
			836,596

Table 13: Operating Labor Costs.

The secretary assistant would work in the office, taking care of the phone calls and dealing with customers and suppliers. The working hours are from 8 A.M. to 5 P.M. with one-hour break for lunch, working only during weekdays. The salary has been obtained from: Pay Scale (Pay Scale , 2017).

There would be 2 laborers in every turn of 8 hours from Monday to Sunday. Being the shifts:

- 6 A.M. – 2 P.M. (day shift): $20.84/h
- 2 P.M. – 10 P.M. (day shift): $20.84/h
- 10 P.M – 6 A.M. (night shift): $31,26/h

The turns during the weekend have different wages, during weekend the salary is homogenous, changing turns during the year. Holidays are paid as weekends (during 2017, 10 weekdays are holidays):

- Weekdays: (365 x 5 / 7) – 10 = 251
- Weekends: (365 x 2/7) + 10 = 114. $35,43/h. 2 people every turn every day means 12 people in 8-hour shifts.

The salaries are taken from Pay Scale Capital Human.

The truck driver works transporting inputs and outputs of the facility. Working 8 hours a day during weekdays.

The cost of utilities includes the price of the energy required to heat the pyrolysis reactor, the combustion chamber and the distillation equipment. The combustion chamber produces energy through burning char and gas disposed from the pyrolysis chamber that is not further sold.

These are the specifications for a 30 tons/day machine:

ITEM	CONSUMPTION
COAL (OR)	500kg/day
WOOD (OR)	800kg/day
NATURAL GAS (OR)	100-150kg/day
OIL (OR)	300-350kg/day
ELECTRICITY (OR)	244kwh/day
WATER (RECYCLED)	60 m^3 /month
TOTAL POWER	19kw
LAND AREA	35m*15m

Table 14: Consumption of the pyrolysis section (Waste Tire Oil, 2017)

With the capacity power-low expression we obtain the values required for a 40 tons capacity plant:

Gas = 150 kg/day x $(40 / 30)^{0.65}$ = 181 kg/day

Since the pyrolysis reactor generates 10% of gas, it produces 4,000 kg/day of gas.

According to the sources, the natural gas is almost composed by methane, ethane and propane (Enbridge, 2017). As shown in the Figure below, methane and propane content of the gaseous products yields between 20-30% of the products, being 30% when the pyrolysis reactor works at 600°C.

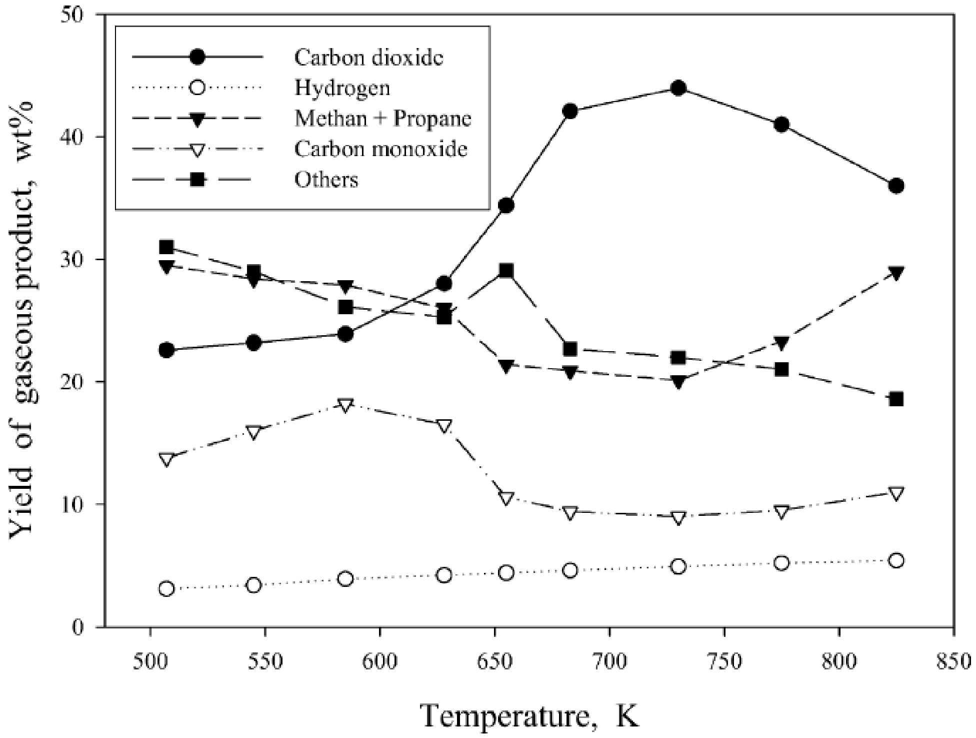


Figure 50: Yield of gaseous products of pyrolysis (Demirbas, 2004).

Therefore:

40 tones/day x 90% running time x 10% gas x 30% of methane & propane = 1,080 kg/day

With this amount of methane and propane, the heat required by the pyrolysis reactor and the distillation machine, is generated by the ignition of methane and propane in the combustion chamber. In the Appendix it is explained the theoretical estimation of this statement.

The combustion chamber would provide the energy required, burning char from the pyrolysis reactor and gas after separation in condenser. The distillation chamber is fed through the heat generated in the combustion chamber. Therefore, the utilities are reduced to the recycled water. The price of the recycled water is obtained thanks to the Independent Pricing and Regulatory Tribunal (IPART, 2007).

UTILITY	QUANTITY	PRICE	TOTAL AUD
PYROLYSIS SECTION	0	0	0
COMBUSTION CHAMBER	0	0	0
DISTILLATION CHAMBER	0	0	0
RECYCLED WATER	2 m^3/day	\$0.30/m^3	insignificant
			0

Table 15: Costs of utilities of the factory.

The maintenance and repair has been defined as 0.069 x FCI, excluding the land price (price of the smallholding) of the total amount, resulting:

0.069 x $2,321,531= **$160,186**

The local taxes and insurances have been defined as 0.032 x FCI, excluding the land price of the total amount, resulting:

0.032 x $2,321,531 = **$74,289**

The plant overhead has been defined as 0.708 x C_{OL} + 0.009 x FCI, excluding the land price of the total amount, resulting:

0.708 x $836,596 + 0.009 x $2,321,531 = **$613,204**

The general operating expenses have been defined as 0.31 x C_{OL}, resulting:

0.31 x $836,596 = **$259,344**

All the variable costs are shown in the table below:

ITEM	AUD
OPERATING LABOR	836,596
UTILITIES (ENERGY)	0
MAINTENANCE AND REPAIR	160,186
LOCAL TAXES AND INSURANCE	74,289
PLANT OVERHEAD	613,204
GENERAL OPERATING EXPENSES	259,344
	1,943,618

Table 16: Total variable costs per year.

Revenues

To estimate the incomes, it is essential to calculate the amount of product that can be sold:

51% of the material fed is converted into oil, which means:

365 days x 40 tons/day x 90% running time x 51% = 6,701,400 kg/year

With a density of 0.92 kg/l, the total volume of oil is:

6,701,400 kg/year x (1 / 0,92) l/kg = 7,284,130 l/year

Out of this, the conversion into diesel is limited to 1 ton per day because the machine supplied by "*Waste Tire Oil*" has that limited capacity.

365,000 kg/year x (1 / 0.92) l/kg x 90% running time = 357,065 l/year

Asumming 48% of conversion to diesel and 26% to fuel oil, 1 ton of oil destilled per day generates (U.S. Energy Information Administration, 2017):

357,065 l/year x 48% diesel = 171,391 l/year of diesel

357,065 l/year x 26% fuel oil = 92,837 l/year of fuel oil

The rest of the oil that is not converted into diesel is:

7,284,130 l/year - 357,065 l/year = 6,927,065 l/year

Out of this amount, 50% is fuel oil and 32% synthetic oil. The rest would be sold as heating oil (Syamsiro, et al., 2013). Therefore, the quantities are:

6,927,065 l/year x 50% fuel oil = 3,463,533 l/year of fuel oil

6,927,065 l/year x 32% synthetic oil = 2,216,660 l/year of synthetic oil

6,927,065 l/year x 18% heating oil = 1,246,872 l/year of heating oil

Once estimated the amount produced for each type of oil, the next step involves price for sale. The price for the heating oil and the fuel oil are assumed to be the same. For the synthetic oil it is supossed that has the same price as the crude oil. The prices are estimated evaluating the mean of the last 24 months of the data that is available at *Index Mundi* (Index Mundi, 2017). For each price it is discounted an excise of 10% that is withhold by the Government (Australian Institute of Petroleum, 2015):

PRODUCT	PRICE ($/L)	SALES PER YEAR (L/YEAR)	TOTAL AUD
DIESEL	0.46	171,391	78,840
FUEL OIL	0.44	3,556,370	1,564,803
HEATING OIL	0.44	1,246,872	548,624
SYNTHETIC OIL	0.35	2,216,660	775,831
			2,968,097

Table 17: Incomes of the oil produced.

The gases and the char generated by the pyrolysis section would be entirly used to feed the combustion chamber, recovering the energy to produce heat for the pyrolysis reactor and the destillation machine.

NPV, IRR and Sensitivity analysis

Once obtained the data for fixed costs, variable costs and revenues, the next step to be follow is calculate the NPV. The NPV is generated through an Excel File that will be shown in screenshots in the following pictures. (Excel produces "," where "." and vice versa).

		Year 1	Year 2	Year 3	Year 4	Year 5
Units sold per year:		1.484.049	2.968.097	2.968.097	2.968.097	2.968.097
Price per unit for Year 1:	$	1,00				
Price increase per year:		0%				
Inflation rate:		1,9%				
Tax rate:		27,5%				
Unit production cost for Year 1:	$	0,65				
Increase in unit cost per year:		0%				
NWC to start project:	$	520.000				
NWC for subsequent years (% of sales):		10%				
Depreciation rate:		14,29%	24,49%	17,49%	12,49%	8,92%
Cost of machine	$	618.281				
Cost of warehouse:	$	4.082.250				
Pretax salvage value:	$	100.000				

Figure 51: Excel File for NPV – 1.

The year 0 would be the start-up period for the construction and setup. Units sold per year represents the product of each output times its price for one year. Therefore, the units sold per year is shown as the total revenue. The first year, as explained above, the amount sold is the 50% of a normal business year. The price per unit represents the nominal product of units sold times its price. It could have been considered as a percentage of this product.

As an explanation, if for example the price of sales decreases a 10% but the amount that is sold remains constant, the price per unit would decrease to 0.9. If both price and production decrease a 10%, the price per unit would be 0.81.

The price does not increase year by year, the inflation rate is 1.9% (Trading Economics, 2017) and the tax rate is 27,5% for our business (Australian Taxation Office, 2017). The unit production cost is calculated dividing the variable costs by the total units sold (which in this case is the product of units multiplied by its price).

The NWC to start the project is the cost defined as the "Project Related" in the "Costs" chapter. The NWC for the subsequent years is estimated as the 10% of the sales, counting as provisions that are required by the end of one year to run the subsequent year. The cost of warehouse is defined as the cost of "Site and preparation" explained above. The land would be sold after the project and it does not suffer depreciation, it will only be discounted the "Inflation rate" which will be the same as the "Discount rate" to evaluate the cash flows of the project.

The depreciation refers to the cost allocated to a tangible asset over its useful life. According to BMT (BMT Tax Depreciation, 2017), in Australia, the assets from machinery of the industry of "Waste remediation and materials recovery services", miscellaneous equipment from

“Materials recovery facility assets” are depreciated between 5 and 10 years. The MACRS system, Modified Accelerated Cost Recovery System which is used in the United States, recovers the capitalized cost of tangible assets over a specified life by annual deductions. This method will be used as the way to depreciate the machinery assets for a 7 years life. There is a table in the Appendix that shows the depreciation rates for a given equipment life throughout its life.

The cost of the machine results from the addition of “Waste receiving”, “Pyrolysis & Incineration” and “Miscellaneous equipment”. These assets are facing depreciation throughout the project. The “Book value of the machine” represents the final value of those assets, the value that, if sold, is supposed to be the price of sale. The “Pretax salvage value” represents the real price receive after selling the assets when the project is over.

Depreciation table, sales revenue and costs of goods sold are detailed in the Figure below:

	Year 1	*Year 2*	*Year 3*	*Year 4*	*Year 5*
Depreciation	88.352	151.417	108.137	77.223	55.151
Accumulated depreciation	88.352	239.769	347.907	425.130	480.281
Book Value of machine	529.929	378.512	270.374	193.151	138.000
Price per unit	1,00	1,00	1,00	1,00	1,00
Sales revenue	1.484.049	2.968.097	2.968.097	2.968.097	2.968.097
Cost per unit	0,65	0,65	0,65	0,65	0,65
COGS (Operating Costs)	971.809	1.943.618	1.943.618	1.943.618	1.943.618

Figure 52: Excel File for NPV – 2.

The machine will have a salvage value at the end of the project, but it must be considered the tax that must be paid. The tax to be paid is calculated through the product of the tax rate time the subtraction of the “Pretax salvage value” minus the “Book Value”, obtaining the “Taxes on sale”. “Pretax salvage value” minus “Taxes on sale” results in the “After-tax salvage value”:

Tax Rate x (Pretax SV – Book V) = Taxes on sale = 27.5% x ($100,000 – $138,000) = -$10,450.

Pretax SV – Taxes on sale = After-tax SV = $100,000 – (-$10,450) = $110,450.

Pretax salvage value	100.000
Taxes on sale	(10.450)
Aftertax salvage value	110.450

Figure 53: Excel File for NPV – 3.

The change in net working capital for each year is the beginning net working capital for each year minus the net working capital investment at the end of the year. So, the change in net working capital each year is:

	Year 1	Year 2	Year 3	Year 4	Year 5
Net working capital					
Beginning NWC	520.000	148.405	296.810	296.810	296.810
End of year NWC	148.405	296.810	296.810	296.810	0
NWC cash flow	371.595	-148.405	0	0	296.810

Figure 54: Excel File for NPV – 4.

Now it is can be calculated the pro forma income statement for each year, which will be:

	Year 1	Year 2	Year 3	Year 4	Year 5
Sales revenue	1.484.049	2.968.097	2.968.097	2.968.097	2.968.097
COGS (Operating Costs)	971.809	1.943.618	1.943.618	1.943.618	1.943.618
Depreciation	88.352	151.417	108.137	77.223	55.151
EBIT	423.887	873.062	916.342	947.256	969.328
Taxes at 27,5 percent	116.569	240.092	251.994	260.495	266.565
Net income	307.318	632.970	664.348	686.760	702.763

Figure 55: Excel File for NPV – 5.

With this, the incremental cash flows each year, NPV for different interest rates, and IRR for the project are:

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Sales revenue		1.484.049	2.968.097	2.968.097	2.968.097	2.968.097
COGS (Operating Costs)		971.809	1.943.618	1.943.618	1.943.618	1.943.618
Taxes		116.569	240.092	251.994	260.495	266.565
Cash flow from operations (Sales - Cost - Taxes)		395.671	784.387	772.485	763.984	757.914
Cash flow from operations (NI + Depreciation)		395.671	784.387	772.485	763.984	757.914
Cash flow from operations (EBIT+Dep-Tax)		395.671	784.387	772.485	763.984	757.914
Machine	-618.281					110.450
Deposits	-4.082.250					4.082.250
Net Capital Spending	-4.700.531	0	0	0	0	4.192.700
Change in NWC	-520.000	371.595	-148.405	0	0	296.810
Total cash flow of project	-5.220.531	767.266	635.982	772.485	763.984	5.247.424

Discount Rate	NPV
1,9%	2.359.687
5%	1.494.379
10%	363.016
11,91%	0
15%	-518.821

Figure 56: Excel File for NPV – 6.

Where the cash flow of the project is calculated as:

$$CF = \sum_0^n \frac{CF_n}{(1+r)^n}$$

Being:

CF = Cash flow of the project

n = each year of the project [0,1,2,3,4,5]

CF_n = Cash flow for the year *n*

r = discount rate [1.9%]

Resulting the *CF* for the given *r*: **$2,359,687**

The *IRR* is the discount rate that makes the *CF* equals to *0*. Resulting the *IRR* = **11.91%**

The operating cash flow margin is:

(Cash flow from operating activities) / (Net Sales in 5 years) x 100 =

= ($3,474,440 / $13,356,438) x 100 = **26%**

This shows that the plant is efficient converting sales to cash and also indicates high quality earnings from the proposed plant

The ROI, return on investment, is:

(Gains from investment – Cost of investment) / (Cost of investment) x 100 =

($8,187,140 - $5,220,531) / ($5,220,531) x 100 = **57%**

In fact, the ROI does not consider the discount rate, thus, a much accurate estimation could be calculating the NPV of the money earned divided by the cost of investment:

(NPV of Gains from Investment – Cost of investment) / (Cost of investment) x 100 =

($7,580,218 - $5,220,531) / ($5,220,531) x 100 = **45%**

To make it easier to understand, it will be shown the cash flow diagram for the project:

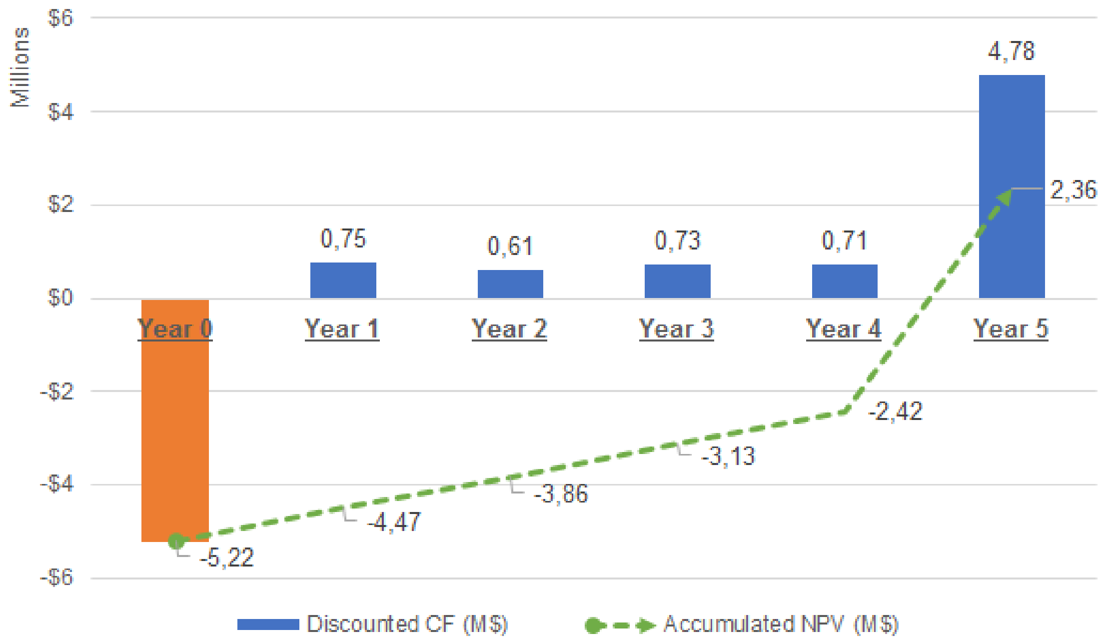


Figure 57: Discounted and Accumulative CF for the project.

The payback period in this case is: **5 years**

Being this payback period really short, indicating that the investment is highly desirable.

After the evaluation of the cash flow, the next step involves considering different scenarios for the price of sales, unit production and variable costs. This is estimated through the sensitivity analysis. This has special interest because the inherent uncertainties in some key parameters, since the costs and prices are both highly volatile and not hundred percent reliable, varying according short periods of time and different sources. The sensitivity analysis evaluates the impact that variations would have in the NPV of recovering energy out of PSW.

The sensitivity analysis is performed by changing the price of unit sold (blue, columns) and the cost of unit sold (red, rows). As explained before, the price of unit sold represents a product of the items times their prices, being $1 the nominal value. Increasing and decreasing this value means changing the production, the price or a combination of both. It will be changed by adding 10%, 20% and 30%; and subtracting 10% and 20%. The cost of unit sold represent the proportion of variable costs out of the total revenues. Changing this quantity means being more or less efficient. As it is done with the price per unit sold, it will be changed by adding 10%, 20% and 30%; and subtracting 10% and 20%.

Here it is shown the combination of different scenarios and their resulting NPV:

	$ 0,80	$ 0,90	$ 1,00	$ 1,10	$ 1,20	$ 1,30
$ 0,52	$ 1.734.040	$ 2.643.838	$ 3.553.635	$ 4.463.433	$ 5.373.231	$ 6.283.029
$ 0,59	$ 1.137.066	$ 2.046.863	$ 2.956.661	$ 3.866.459	$ 4.776.257	$ 5.686.054
$ 0,65	$ 540.092	$ 1.449.889	**$ 2.359.687**	$ 3.269.485	$ 4.179.283	$ 5.089.080
$ 0,72	-$ 56.883	$ 852.915	$ 1.762.713	$ 2.672.511	$ 3.582.308	$ 4.492.106
$ 0,79	-$ 653.857	$ 255.941	$ 1.165.739	$ 2.075.536	$ 2.985.334	$ 3.895.132
$ 0,85	-$ 1.250.831	-$ 341.033	$ 568.764	$ 1.478.562	$ 2.388.360	$ 3.298.158

Figure 58: Sensitivity analysis for the resulting NPV.

The cell filled in yellow represents the nominal NPV calculated in the project. Those green-shadowed cells mean profits over zero and those red-shadowed represent losses in the investment.

Obviously, if the price of unit sold increases, the profit increases and vice versa. The opposite happens with the costs of unit sold, whilst decreasing means lower costs and larger profits, an increase, consequently, implies higher costs and lower profits. It is particularly interesting the worst value of the table, -$ 1,250,831; meaning that, in the worst-case scenario analyzed, the investor would lose 24% of the total capital investment at the very beginning of the project.

Since this sensitivity analysis covers from the worst-case scenario to the best-case scenario, both pessimistic and optimistic perceptions and the range between them are considered. In 32 out of the 36 cases studied, the investor would make money from the project.

Furthermore, an analysis may be done to study what happens if the price of unit sold decreases. There are two different approaches to deal with this problem:

1. Increasing the production even if this implies spending more in variable costs:

	$ 0,80	$ 0,90	$ 1,00	$ 1,10	$ 1,20	$ 1,30
$ 0,52	$ 1.734.040	$ 2.643.838	$ 3.553.635	$ 4.463.433	$ 5.373.231	$ 6.283.029
$ 0,59	$ 1.137.066	$ 2.046.863	$ 2.956.661	$ 3.866.459	$ 4.776.257	$ 5.686.054
$ 0,65	$ 540.092	$ 1.449.889	**$ 2.359.687**	$ 3.269.485	$ 4.179.283	$ 5.089.080
$ 0,72	-$ 56.883	$ 852.915	$ 1.762.713	$ 2.672.511	$ 3.582.308	$ 4.492.106
$ 0,79	-$ 653.857	$ 255.941	$ 1.165.739	$ 2.075.536	$ 2.985.334	$ 3.895.132
$ 0,85	-$ 1.250.831	-$ 341.033	$ 568.764	$ 1.478.562	$ 2.388.360	$ 3.298.158

Figure 59: Sensitivity analysis: Recommendation 1.

2. Reducing the variable costs by increasing the efficiency of the assets:

	$ 0,80	$ 0,90	$ 1,00	$ 1,10	$ 1,20	$ 1,30
$ 0,52	$ 1.734.040	$ 2.643.838	$ 3.553.635	$ 4.463.433	$ 5.373.231	$ 6.283.029
$ 0,59	$ 1.137.066	$ 2.046.863	$ 2.956.661	$ 3.866.459	$ 4.776.257	$ 5.686.054
$ 0,65	$ 540.092	$ 1.449.889	**$ 2.359.687**	$ 3.269.485	$ 4.179.283	$ 5.089.080
$ 0,72	-$ 56.883	$ 852.915	$ 1.762.713	$ 2.672.511	$ 3.582.308	$ 4.492.106
$ 0,79	-$ 653.857	$ 255.941	$ 1.165.739	$ 2.075.536	$ 2.985.334	$ 3.895.132
$ 0,85	-$ 1.250.831	-$ 341.033	$ 568.764	$ 1.478.562	$ 2.388.360	$ 3.298.158

Figure 60: Sensitivity analysis: Recommendation 2.

In both cases, the investor would tackle the problem, reaching profitable solutions.

Another case of study, if the plant is running as expected, it would be a good idea considering spending more in new or more efficient machines or hiring more employees to meet the production requirements. This case could be represented as:

	$ 0,80	$ 0,90	$ 1,00	$ 1,10	$ 1,20	$ 1,30
$ 0,52	$ 1.734.040	$ 2.643.838	$ 3.553.635	$ 4.463.433	$ 5.373.231	$ 6.283.029
$ 0,59	$ 1.137.066	$ 2.046.863	$ 2.956.661	$ 3.866.459	$ 4.776.257	$ 5.686.054
$ 0,65	$ 540.092	$ 1.449.889	**$ 2.359.687**	$ 3.269.485	$ 4.179.283	$ 5.089.080
$ 0,72	-$ 56.883	$ 852.915	$ 1.762.713	$ 2.672.511	$ 3.582.308	$ 4.492.106
$ 0,79	-$ 653.857	$ 255.941	$ 1.165.739	$ 2.075.536	$ 2.985.334	$ 3.895.132
$ 0,85	-$ 1.250.831	-$ 341.033	$ 568.764	$ 1.478.562	$ 2.388.360	$ 3.298.158

Figure 61: Sensitivity analysis. Recommendation 3.

Even if, for unforeseen reasons or costs that have not been considered in this study, the variable cost increases, the manager could maintain the production of the machine:

	$ 0,80	$ 0,90	$ 1,00	$ 1,10	$ 1,20	$ 1,30
$ 0,52	$ 1.734.040	$ 2.643.838	$ 3.553.635	$ 4.463.433	$ 5.373.231	$ 6.283.029
$ 0,59	$ 1.137.066	$ 2.046.863	$ 2.956.661	$ 3.866.459	$ 4.776.257	$ 5.686.054
$ 0,65	$ 540.092	$ 1.449.889	**$ 2.359.687**	$ 3.269.485	$ 4.179.283	$ 5.089.080
$ 0,72	-$ 56.883	$ 852.915	$ 1.762.713	$ 2.672.511	$ 3.582.308	$ 4.492.106
$ 0,79	-$ 653.857	$ 255.941	$ 1.165.739	$ 2.075.536	$ 2.985.334	$ 3.895.132
$ 0,85	-$ 1.250.831	-$ 341.033	$ 568.764	$ 1.478.562	$ 2.388.360	$ 3.298.158

Figure 62: Sensitivity analysis. Recommendation 4.

If, for any reason, this happens while the price of goods sold decrease (due to market factors which are external from the plant), the manager could have two solutions:

1. Invest more in variable costs, purchasing machines for example, to produce higher amounts of sellable goods:

	$ 0,80	$ 0,90	$ 1,00	$ 1,10	$ 1,20	$ 1,30
$ 0,52	$ 1.734.040	$ 2.643.838	$ 3.553.635	$ 4.463.433	$ 5.373.231	$ 6.283.029
$ 0,59	$ 1.137.066	$ 2.046.863	$ 2.956.661	$ 3.866.459	$ 4.776.257	$ 5.686.054
$ 0,65	$ 540.092	$ 1.449.889	$ 2.359.687	$ 3.269.485	$ 4.179.283	$ 5.089.080
$ 0,72	-$ 56.883	$ 852.915	$ 1.762.713	$ 2.672.511	$ 3.582.308	$ 4.492.106
$ 0,79	-$ 653.857	$ 255.941	$ 1.165.739	$ 2.075.536	$ 2.985.334	$ 3.895.132
$ 0,85	-$ 1.250.831	-$ 341.033	$ 568.764	$ 1.478.562	$ 2.388.360	$ 3.298.158

Figure 63: Sensitivity analysis. Recommendation 5.

2. Decrease the variable costs by increasing the efficiency of the assets:

	$ 0,80	$ 0,90	$ 1,00	$ 1,10	$ 1,20	$ 1,30
$ 0,52	$ 1.734.040	$ 2.643.838	$ 3.553.635	$ 4.463.433	$ 5.373.231	$ 6.283.029
$ 0,59	$ 1.137.066	$ 2.046.863	$ 2.956.661	$ 3.866.459	$ 4.776.257	$ 5.686.054
$ 0,65	$ 540.092	$ 1.449.889	$ 2.359.687	$ 3.269.485	$ 4.179.283	$ 5.089.080
$ 0,72	-$ 56.883	$ 852.915	$ 1.762.713	$ 2.672.511	$ 3.582.308	$ 4.492.106
$ 0,79	-$ 653.857	$ 255.941	$ 1.165.739	$ 2.075.536	$ 2.985.334	$ 3.895.132
$ 0,85	-$ 1.250.831	-$ 341.033	$ 568.764	$ 1.478.562	$ 2.388.360	$ 3.298.158

Figure 64: Sensitivity analysis. Recommendation 6.

As explained before, in the worst-case scenario, the investor would only lose 24% of the investment. (In fact, this numbers are studied at a certain moment and are static, reader should consider them as an estimation and knowing that circumstances may vary throughout the project).

Hence, the purpose of this section was to contribute to an improved insight in the key factors that determine the economic feasibility of PSW processing to produce energy, given as much certainty as possible.

Conclusion

The conclusion of the project is that the setup of the pyrolysis plus combustion plant is economically feasible. Converting 40 tons of waste into energy is possible thanks to the pyrolysis process which, in this case, is improved with the addition of the combustion chamber. The distillation equipment enables the investor to convert fuel oil into diesel, creating value-added products that has a bigger market than the other generated. In fact, diesel production represents the smallest proportion of products.

The NPV shows that the investment would be soon returned with large rates of return. However, since the costs and prices of units sold are not hundred percent reliable, being these highly volatile in the market, a deeper analysis is required. Hence, the sensitivity analysis gives the projector some idea of how the NPV may vary in different scenarios.

The IRR shows that this investment is more profitable than others if those give a return lower than 11.9 cents per dollar invested. Australia is a country that, if everything stays as its been running recently, will remain stable for the next years; therefore, the inflation rate should never reach 11.9%, hence, it is a good idea to invest in this project in terms of economic profits.

Another point to the project is that the highest investment comes from the purchase of the land, which is an asset that should not depreciate in the next five years, returning the investment after subtracting the discount rate for the accumulated years.

In addition, there is enough room to still being profitable despite the possibility of increasing the variable costs due to unforeseen costs. This statement is also valid in the case that the price or the production sold decreases. The certainty of this security comes from the sensitivity analysis and the impact of both reduction of revenues or increase of costs.

Moreover, the combustion section feeds enough heat for the operation of the pyrolysis chamber and the distillation equipment. This means that the facility would not require utilities such as electricity, important factor in some other economic analysis or business plans in the waste management industry.

Sensitivity analysis allows the projector to evaluate the impact of some inherent changes in the data gathered throughout the study.

However, before setting up this project, the projector would recommend performing a previous study of the material that would be fed into the facility to analyze its composition, as well as the outputs and their quality. Since these types of projects are scalable, the study could be done by someone himself or by one of the companies that the projector has already contacted. In this case, *Waste Tire Oil,* has offered a previous study for the setup with an approximate budget of $15,000.

NPV, IRR and Sensitivity analysis (25years)

Once obtained the data for fixed costs, variable costs and revenues, the next step to be follow is calculate the NPV. The NPV is generated through an Excel File that will be shown in screenshots in the following pictures. (Excel produces "," where "." and vice versa).

		Year 1	*Year 2*	*Year 3*	*Year 4*	*Year 5*	*Year 6*
Units sold per year:		1.484.049	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097
Price per unit for Year 1:	$	1,00					
Price increase per year:		0%					
Inflation rate:		1,9%					
Tax rate:		27,5%					
Unit production cost for Year 1:	$	0,65					
Increase in unit cost per year:		0%					
NWC to start project:	$	520.000					
NWC for subsequent years (% of sa		10%					
Depreciation rate:		3,75%	7,22%	6,68%	6,18%	5,71%	5,28%
Cost of machine	$	618.281					
Cost of warehouse:	$	4.082.250					
Pretax salvage value:	$	-					

Year 7	*Year 8*	*Year 9*	*Year 10*	*Year 11*	*Year 12*	*Year 13*	*Year 14*	*Year 15*
2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097
4,89%	4,52%	4,46%	4,46%	4,46%	4,46%	4,46%	4,46%	4,46%

Year 16	*Year 17*	*Year 18*	*Year 19*	*Year 20*	*Year 21*	*Year 22*	*Year 23*	*Year 24*	*Year 25*
2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097
4,46%	4,46%	4,46%	4,46%	4,46%	2,23%				

Figure 65: Excel File for NPV – 1.

The year 0 would be the start-up period for the construction and setup. Units sold per year represents the product of each output times its price for one year. Therefore, the units sold per year is shown as the total revenue. The first year, as explained above, the amount sold is the

50% of a normal business year. The price per unit represents the nominal product of units sold times its price. It could have been considered as a percentage of this product.

As an explanation, if for example the price of sales decreases a 10% but the amount that is sold remains constant, the price per unit would decrease to 0.9. If both price and production decrease a 10%, the price per unit would be 0.81.

The price does not increase year by year, the inflation rate is 1.9% (Trading Economics, 2017) and the tax rate is 27,5% for our business (Australian Taxation Office, 2017). The unit production cost is calculated dividing the variable costs by the total units sold (which in this case is the product of units multiplied by its price).

The NWC to start the project is the cost defined as the “Project Related” in the “Costs” chapter. The NWC for the subsequent years is estimated as the 10% of the sales, counting as provisions that are required by the end of one year to run the subsequent year. The cost of warehouse is defined as the cost of “Site and preparation” explained above. The land would be sold after the project and it does not suffer depreciation, it will only be discounted the “Inflation rate” which will be the same as the “Discount rate” to evaluate the cash flows of the project.

The depreciation refers to the cost allocated to a tangible asset over its useful life. In this case, the machinery will be depreciated in 20 years. The MACRS system, Modified Accelerated Cost Recovery System which is used in the United States, recovers the capitalized cost of tangible assets over a specified life by annual deductions. This method will be used as the way to depreciate the machinery assets for a 20 years life. There is a table in the Appendix that shows the depreciation rates for a given equipment life throughout its life.

The cost of the machine results from the addition of “Waste receiving”, “Pyrolysis & Incineration” and “Miscellaneous equipment”. These assets are facing depreciation throughout the project. The “Book value of the machine” represents the final value of those assets, the value that, if sold, is supposed to be the price of sale. The “Pretax salvage value” represents the real price receive after selling the assets when the project is over.

Depreciation table, sales revenue and costs of goods sold are detailed in the Figure below:

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Depreciation	23.186	44.632	41.285	38.188	35.324	32.675
Accumulated depreciation	23.186	67.818	109.102	147.291	182.615	215.290
Book Value of machine	595.095	550.463	509.179	470.990	435.666	402.991
Price per unit	1,00	1,00	1,00	1,00	1,00	1,00
Sales revenue	1.484.049	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097
Cost per unit	0,65	0,65	0,65	0,65	0,65	0,65
COGS (Operating Costs)	971.809	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618

Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
30.224	27.957	27.585	27.585	27.585	27.585	27.585	27.585	27.585
245.514	273.472	301.057	328.641	356.226	383.811	411.396	438.980	466.565
372.767	344.809	317.224	289.640	262.055	234.470	206.885	179.301	151.716
1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097
0,65	0,65	0,65	0,65	0,65	0,65	0,65	0,65	0,65
1.943.618	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618

Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24	Year 25
27.585	27.585	27.585	27.585	27.585	13.792	0	0	0	0
494.150	521.734	549.319	576.904	604.489	618.281	618.281	618.281	618.281	618.281
124.131	96.547	68.962	41.377	13.792	0	0	0	0	0
1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097
0,65	0,65	0,65	0,65	0,65	0,65	0,65	0,65	0,65	0,65
1.943.618	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618

Figure 66: Excel File for NPV – 2.

It will be considered that the machine has 0 salvage value. Therefore, the machine wouldn´t be sold and no “Taxes on sale” would be paid (or received).

The change in net working capital for each year is the beginning net working capital for each year minus the net working capital investment at the end of the year. So, the change in net working capital each year is:

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Net working capital						
Beginning NWC	520.000	148.405	296.810	296.810	296.810	296.810
End of year NWC	148.405	296.810	296.810	296.810	296.810	296.810
NWC cash flow	371.595	-148.405	0	0	0	0

	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Beginning NWC	296.810	296.810	296.810	296.810	296.810	296.810	296.810	296.810	296.810
End of year NWC	296.810	296.810	296.810	296.810	296.810	296.810	296.810	296.810	296.810
NWC cash flow	0	0	0	0	0	0	0	0	0

	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24	Year 25
Beginning NWC	296.810	296.810	296.810	296.810	296.810	296.810	296.810	296.810	296.810	296.810
End of year NWC	296.810	296.810	296.810	296.810	296.810	296.810	296.810	296.810	296.810	0
NWC cash flow	0	0	0	0	0	0	0	0	0	296.810

Figure 67: Excel File for NPV – 4.

Now it is can be calculated the pro forma income statement for each year, which will be:

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Sales revenue	1.484.049	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097
COGS (Operating Costs)	971.809	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618
Depreciation	23.186	44.632	41.285	38.188	35.324	32.675
EBIT	489.054	979.847	983.194	986.291	989.155	991.804
Taxes at 27,5 percent	134.490	269.458	270.378	271.230	272.018	272.746
Net income	354.564	710.389	712.816	715.061	717.137	719.058

	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Sales revenue	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097
COGS (Operating Costs)	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618
Depreciation	30.224	27.957	27.585	27.585	27.585	27.585	27.585	27.585	27.585
EBIT	994.255	996.521	996.894	996.894	996.894	996.894	996.894	996.894	996.894
Taxes at 27,5 percent	273.420	274.043	274.146	274.146	274.146	274.146	274.146	274.146	274.146
Net income	720.835	722.478	722.748	722.748	722.748	722.748	722.748	722.748	722.748

	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24	Year 25
Sales revenue	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097
COGS (Operating Costs)	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618
Depreciation	27.585	27.585	27.585	27.585	27.585	13.792	0	0	0	0
EBIT	996.894	996.894	996.894	996.894	996.894	1.010.687	1.024.479	1.024.479	1.024.479	1.024.479
Taxes at 27,5 percent	274.146	274.146	274.146	274.146	274.146	277.939	281.732	281.732	281.732	281.732
Net income	722.748	722.748	722.748	722.748	722.748	732.748	742.747	742.747	742.747	742.747

Figure 68: Excel File for NPV – 5.

With this, the incremental cash flows each year, NPV for different interest rates, and IRR for the project are:

	Year 0	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year 5*	*Year 6*
Sales revenue		1.484.049	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097
COGS (Operating Costs)		971.809	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618
Taxes		134.490	269.458	270.378	271.230	272.018	272.746
Cash flow from operations (Sales - Cost - Taxes)		377.750	755.021	754.101	753.249	752.461	751.733
Cash flow from operations (NI + Depreciation)		377.750	755.021	754.101	753.249	752.461	751.733
Cash flow from operations (EBIT+Dep-Tax)		377.750	755.021	754.101	753.249	752.461	751.733
Machine	-618.281						
Deposits	-4.082.250						
Net Capital Spending	-4.700.531	0	0	0	0	0	0
Change in NWC	-520.000	371.595	-148.405	0	0	0	0
Total cash flow of project	-5.220.531	749.345	606.616	754.101	753.249	752.461	751.733

	Year 7	*Year 8*	*Year 9*	*Year 10*	*Year 11*	*Year 12*	*Year 13*	*Year 14*	*Year 15*
Sales revenue	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097
COGS (Operating Costs)	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618
Taxes	273.420	274.043	274.146	274.146	274.146	274.146	274.146	274.146	274.146
Cash flow from operations (Sales - Cost - Taxes)	751.059	750.436	750.333	750.333	750.333	750.333	750.333	750.333	750.333
Cash flow from operations (NI + Depreciation)	751.059	750.436	750.333	750.333	750.333	750.333	750.333	750.333	750.333
Cash flow from operations (EBIT+Dep-Tax)	751.059	750.436	750.333	750.333	750.333	750.333	750.333	750.333	750.333
Machine									
Deposits									
Net Capital Spending	0	0	0	0	0	0	0	0	0
Change in NWC	0	0	0	0	0	0	0	0	0
Total cash flow of project	751.059	750.436	750.333	750.333	750.333	750.333	750.333	750.333	750.333

	Year 16	*Year 17*	*Year 18*	*Year 19*	*Year 20*	*Year 21*	*Year 22*	*Year 23*	*Year 24*	*Year 25*
Sales revenue	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097	2.968.097
COGS (Operating Costs)	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618	1.943.618
Taxes	274.146	274.146	274.146	274.146	274.146	277.939	281.732	281.732	281.732	281.732
Cash flow from operations (Sales - Cost - Taxes)	750.333	750.333	750.333	750.333	750.333	746.540	742.747	742.747	742.747	742.747
Cash flow from operations (NI + Depreciation)	750.333	750.333	750.333	750.333	750.333	746.540	742.747	742.747	742.747	742.747
Cash flow from operations (EBIT+Dep-Tax)	750.333	750.333	750.333	750.333	750.333	746.540	742.747	742.747	742.747	742.747
Machine										0
Deposits										4.082.250
Net Capital Spending	0	0	0	0	0	0	0	0	0	4.082.250
Change in NWC	0	0	0	0	0	0	0	0	0	296.810
Total cash flow of project	750.333	750.333	750.333	750.333	750.333	746.540	742.747	742.747	742.747	5.121.807

Figure 69: Excel File for NPV – 6.

Discount Rate	NPV
1,9%	12.186.182
5%	6.514.408
10%	1.878.362
13,99%	0
15%	-342.009

Table 18: NPV & IRR - 25 years - Different discount rates

Where the cash flow of the project is calculated as:

$$CF = \sum_0^n \frac{CF_n}{(1+r)^n}$$

Being:

CF = Cash flow of the project

n = each year of the project [0, 1, 2…24, 25]

CF_n = Cash flow for the year *n*

r = discount rate [1.9%]

Resulting the *CF* for the given *r*: **$12,186,182**

The *IRR* is the discount rate that makes the *CF* equals to *0*. Resulting the *IRR* = **13.99%**

The operating cash flow margin is:

(Cash flow from operating activities) / (Net Sales in 25 years) x 100 =

= ($18,367,335 / $72,718,385) x 100 = **25.3%**

This shows that the plant is efficient converting sales to cash and also indicates high quality earnings from the proposed plant.

The ROI, return on investment, is:

(Gains from investment – Cost of investment) / (Cost of investment) x 100 =

($22,969,585 - $5,220,531) / ($22,969,585) x 100 = **340%**

In fact, the ROI does not consider the discount rate, thus, a much accurate estimation could be calculating the NPV of the money earned divided by the cost of investment:

(NPV of Gains from Investment – Cost of investment) / (Cost of investment) x 100 =

($17,406,713 - $5,220,531) / ($5,220,531) x 100 = **233%**

To make it easier to understand, it will be shown the cash flow diagram for the project:

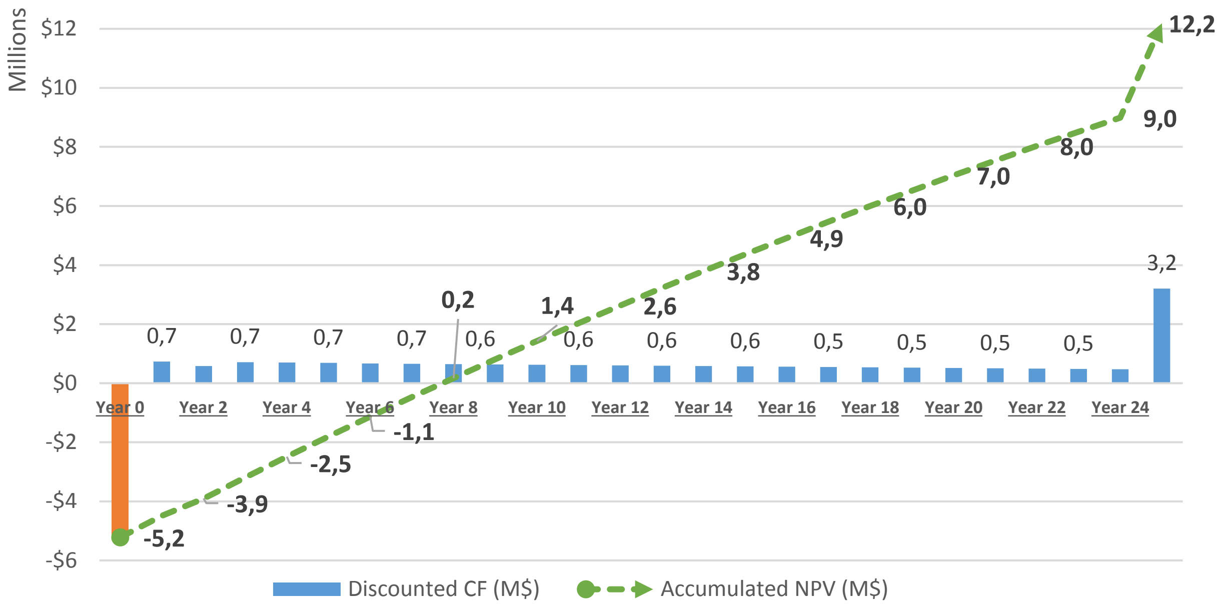


Figure 70: Discounted and Accumulative CF for the project.

The payback period in this case is: **8 years**

Being this payback period really short, indicating that the investment is highly desirable.

After the evaluation of the cash flow, the next step involves considering different scenarios for the price of sales, unit production and variable costs. This is estimated through the sensitivity analysis. This has special interest because the inherent uncertainties in some key parameters, since the costs and prices are both highly volatile and not hundred percent reliable, varying according short periods of time and different sources. The sensitivity analysis evaluates the impact that variations would have in the NPV of recovering energy out of PSW.

The sensitivity analysis is performed by changing the price of unit sold (blue, columns) and the cost of unit sold (red, rows). As explained before, the price of unit sold represents a product of the items times their prices, being $1 the nominal value. Increasing and decreasing this value means changing the production, the price or a combination of both. It will be changed by adding 10%, 20% and 30%; and subtracting 10% and 20%. The cost of unit sold represent the proportion of variable costs out of the total revenues. Changing this quantity means being more or less efficient. As it is done with the price per unit sold, it will be changed by adding 10%, 20% and 30%; and subtracting 10% and 20%.

Here it is shown the combination of different scenarios and their resulting NPV:

	$ 0,80	$ 0,90	$ 1,00	$ 1,10	$ 1,20	$ 1,30
$ 0,52	$ 9.345.167	$13.480.200	$17.615.233	$21.750.266	$25.885.300	$30.020.333
$ 0,59	$ 6.630.642	$10.765.675	$14.900.708	$19.035.741	$23.170.774	$27.305.807
$ 0,65	$ 3.916.116	$ 8.051.149	**$12.186.182**	$16.321.216	$20.456.249	$24.591.282
$ 0,72	$ 1.201.591	$ 5.336.624	$ 9.471.657	$13.606.690	$17.741.723	$21.876.757
$ 0,79	-$ 1.512.935	$ 2.622.098	$ 6.757.132	$10.892.165	$15.027.198	$19.162.231
$ 0,85	-$ 4.227.460	-$ 92.427	$ 4.042.606	$ 8.177.639	$12.312.673	$16.447.706

Figure 71: Sensitivity analysis for the resulting NPV.

The cell filled in yellow represents the nominal NPV calculated in the project. Those green-shadowed cells mean profits over zero and those red-shadowed represent losses in the investment.

Obviously, if the price of unit sold increases, the profit increases and vice versa. The opposite happens with the costs of unit sold, whilst decreasing means lower costs and larger profits, an increase, consequently, implies higher costs and lower profits.

Since this sensitivity analysis covers from the worst-case scenario to the best-case scenario, both pessimistic and optimistic perceptions and the range between them are considered. In 34 out of the 36 cases studied, the investor would make money from the project.

Furthermore, an analysis may be done to study what happens if the price of unit sold decreases. There are two different approaches to deal with this problem:

1. Increasing the production even if this implies spending more in variable costs:

	$ 0,80	$ 0,90	$ 1,00	$ 1,10	$ 1,20	$ 1,30
$ 0,52	$ 9.345.167	$13.480.200	$17.615.233	$21.750.266	$25.885.300	$30.020.333
$ 0,59	$ 6.630.642	$10.765.675	$14.900.708	$19.035.741	$23.170.774	$27.305.807
$ 0,65	$ 3.916.116	$ 8.051.149	**$12.186.182**	$16.321.216	$20.456.249	$24.591.282
$ 0,72	$ 1.201.591	$ 5.336.624	$ 9.471.657	$13.606.690	$17.741.723	$21.876.757
$ 0,79	-$ 1.512.935	$ 2.622.098	$ 6.757.132	$10.892.165	$15.027.198	$19.162.231
$ 0,85	-$ 4.227.460	-$ 92.427	$ 4.042.606	$ 8.177.639	$12.312.673	$16.447.706

Figure 72: Sensitivity analysis: Recommendation 1.

2. Reducing the variable costs by increasing the efficiency of the assets:

	$ 0,80	$ 0,90	$ 1,00	$ 1,10	$ 1,20	$ 1,30
$ 0,52	$ 9.345.167	$13.480.200	$17.615.233	$21.750.266	$25.885.300	$30.020.333
$ 0,59	$ 6.630.642	$10.765.675	$14.900.708	$19.035.741	$23.170.774	$27.305.807
$ 0,65	$ 3.916.116	$ 8.051.149	**$12.186.182**	$16.321.216	$20.456.249	$24.591.282
$ 0,72	$ 1.201.591	$ 5.336.624	$ 9.471.657	$13.606.690	$17.741.723	$21.876.757
$ 0,79	-$ 1.512.935	$ 2.622.098	$ 6.757.132	$10.892.165	$15.027.198	$19.162.231
$ 0,85	-$ 4.227.460	-$ 92.427	$ 4.042.606	$ 8.177.639	$12.312.673	$16.447.706

Figure 73: Sensitivity analysis: Recommendation 2.

In both cases, the investor would tackle the problem, reaching profitable solutions.

Another case of study, if the plant is running as expected, it would be a good idea considering spending more in new or more efficient machines or hiring more employees to meet the production requirements. This case could be represented as:

	$ 0,80	$ 0,90	$ 1,00	$ 1,10	$ 1,20	$ 1,30
$ 0,52	$ 9.345.167	$13.480.200	$17.615.233	$21.750.266	$25.885.300	$30.020.333
$ 0,59	$ 6.630.642	$10.765.675	$14.900.708	$19.035.741	$23.170.774	$27.305.807
$ 0,65	$ 3.916.116	$ 8.051.149	**$12.186.182**	$16.321.216	$20.456.249	$24.591.282
$ 0,72	$ 1.201.591	$ 5.336.624	$ 9.471.657	$13.606.690	$17.741.723	$21.876.757
$ 0,79	-$ 1.512.935	$ 2.622.098	$ 6.757.132	$10.892.165	$15.027.198	$19.162.231
$ 0,85	-$ 4.227.460	-$ 92.427	$ 4.042.606	$ 8.177.639	$12.312.673	$16.447.706

Figure 74: Sensitivity analysis. Recommendation 3.

Even if, for unforeseen reasons or costs that have not been considered in this study, the variable cost increases, the manager could maintain the production of the machine:

	$ 0,80	$ 0,90	$ 1,00	$ 1,10	$ 1,20	$ 1,30
$ 0,52	$ 9.345.167	$13.480.200	$17.615.233	$21.750.266	$25.885.300	$30.020.333
$ 0,59	$ 6.630.642	$10.765.675	$14.900.708	$19.035.741	$23.170.774	$27.305.807
$ 0,65	$ 3.916.116	$ 8.051.149	**$12.186.182**	$16.321.216	$20.456.249	$24.591.282
$ 0,72	$ 1.201.591	$ 5.336.624	$ 9.471.657	$13.606.690	$17.741.723	$21.876.757
$ 0,79	-$ 1.512.935	$ 2.622.098	$ 6.757.132	$10.892.165	$15.027.198	$19.162.231
$ 0,85	-$ 4.227.460	-$ 92.427	$ 4.042.606	$ 8.177.639	$12.312.673	$16.447.706

Figure 75: Sensitivity analysis. Recommendation 4.

If, for any reason, this happens while the price of goods sold decrease (due to market factors which are external from the plant), the manager could have two solutions:

3. Invest more in variable costs, purchasing machines for example, to produce higher amounts of sellable goods:

	$ 0,80	$ 0,90	$ 1,00	$ 1,10	$ 1,20	$ 1,30
$ 0,52	$ 9.345.167	$13.480.200	$17.615.233	$21.750.266	$25.885.300	$30.020.333
$ 0,59	$ 6.630.642	$10.765.675	$14.900.708	$19.035.741	$23.170.774	$27.305.807
$ 0,65	$ 3.916.116	$ 8.051.149	$12.186.182	$16.321.216	$20.456.249	$24.591.282
$ 0,72	$ 1.201.591	$ 5.336.624	$ 9.471.657	$13.606.690	$17.741.723	$21.876.757
$ 0,79	-$ 1.512.935	$ 2.622.098	$ 6.757.132	$10.892.165	$15.027.198	$19.162.231
$ 0,85	-$ 4.227.460	-$ 92.427	$ 4.042.606	$ 8.177.639	$12.312.673	$16.447.706

Figure 76: Sensitivity analysis. Recommendation 5.

4. Decrease the variable costs by increasing the efficiency of the assets:

	$ 0,80	$ 0,90	$ 1,00	$ 1,10	$ 1,20	$ 1,30
$ 0,52	$ 9.345.167	$13.480.200	$17.615.233	$21.750.266	$25.885.300	$30.020.333
$ 0,59	$ 6.630.642	$10.765.675	$14.900.708	$19.035.741	$23.170.774	$27.305.807
$ 0,65	$ 3.916.116	$ 8.051.149	$12.186.182	$16.321.216	$20.456.249	$24.591.282
$ 0,72	$ 1.201.591	$ 5.336.624	$ 9.471.657	$13.606.690	$17.741.723	$21.876.757
$ 0,79	-$ 1.512.935	$ 2.622.098	$ 6.757.132	$10.892.165	$15.027.198	$19.162.231
$ 0,85	-$ 4.227.460	-$ 92.427	$ 4.042.606	$ 8.177.639	$12.312.673	$16.447.706

Figure 77: Sensitivity analysis. Recommendation 6.

Even if we consider an increase of 1% every year in the “Cost per unit” to pay unforeseen costs such as investments in machinery (maintenance, spare parts, etc.), the NPV, depending on different “Inflation rates”, is shown in the table below:

Discount Rate	NPV
1,9%	8.879.218
5%	4.487.507
10%	865.311
12,05%	0
15%	-906.281

Table 19: NPV Increase of Cost per unit

This numbers are studied at a certain moment and are static, reader should consider them as an estimation and knowing that circumstances may vary throughout the project.

Hence, the purpose of this section was to contribute to an improved insight in the key factors that determine the economic feasibility of PSW processing to produce energy, given as much certainty as possible.

Appendix

I. Distillation tower

The distillation tower uses oil and other inputs to generate finished petroleum products. In the case of study, the tower would be fed with oil that has been produced by the pyrolysis reactor and the final product would be mainly diesel and fuel oil.

The tower has been designed to treat one tone of oil per day for a service life of seven years with the subsequent method (Waste Tire Oil, 2017):

1. Prepare waste oil.
2. Heating for distillation
3. Cooling
4. Chemical process for cleaning distillation oil
5. Collect final diesel product

The main characteristic of the output is that it can be used directly for diesel oil generators, trucks, vans, etc.

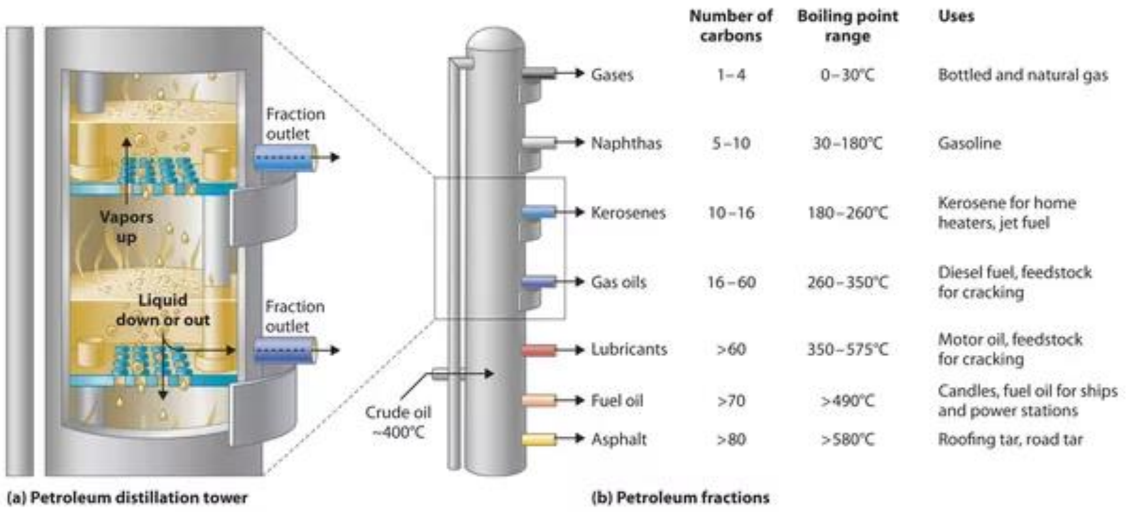


Figure 78: Distillation tower (Quora, 2015).

II. Estimation of utilities

One of the biggest concerns of this plant is to recover the energy that remains in the products which are not feasible to sell.

In this case, the projector explains what happens with 100 grams of plastic that are fed in the pyrolysis reactor. The process would be:

1. 100 grams of plastic at 20ºC enter in the pyrolysis reactor.
2. The heat in the chamber is transferred into the plastic.
3. The plastic reaches 600ºC as a vapor.
4. The vapor leaves the reactor and goes through the condenser.

The total heat required to vaporize the plastic will be estimated as:

- Increasing de temperature of 100g of plastic by 580ºC.
- Changing the phase two times, vaporizing the plastic.

Since there is much information about the heat required to increase the temperature and vaporize the plastic, the assumptions will be:

- The specific heat of the plastic remains constant throughout the process.
- Two phase changes equal to vaporizing the plastic.
- Both changes of phase have the same latent heat consumption.

According to the sources (Universidad de Alicante, 2015):

POLYMER	SPECIFIC HEAT (KJ/KG/ºC)	FUSION LATENT HEAT (KJ/KG)
HDPE	2.3	209
PP	1.93	100
PS	1.34	-
PVC	1.00	-
PMMA	1.47	-
ABS	1.47	-
NAILON 6,6	1.67	130

Table 20: Specific and Latent heat of plastics (Universidad de Alicante, 2015)

An average of the Specific heat is 1.59 kJ/kg/ºC and an average of the Fusion latent heat is 146.3 kJ/kg. Meaning this that the heat required to increase the temperature and change two phases of 100g of plastic is:

$$(1.59\ kJ/kg/^{o}C \times 0.1kg \times 580^{o}C) + (2 \times 146.3\ kJ/kg \times 0.1kg) = 121kJ$$

The calorific value of the methane is 50,000 kJ/kg (National Council of Educationa Research and Training, 2014).

Being the amount of methane required:

$121kJ / 50,000kJ/kg = 2.43$ grams of methane, 2.43% of the plastic amount.

For 40,000 kg of plastic a day, the theoretical methane required would be:

2.43% of methane x 40,000kg/day = 972 kg of methane / day

The distillation machine would be assumed to work the same way but increasing the temperature of 100g of oil by 1000^{o}C and with one phase changing. Therefore, the values of specific heat and latent heat are reused:

$$(1.59\ kJ/kg/^{o}C \times 0.1kg \times 1000^{o}C) + (146.3\ kJ/kg \times 0.1kg) = 110kJ$$

This heat requires methane to be burnt in this amount:

110kJ / 50,000kJ/kg = 2.2 grams of methane, 2.2% of the oil amount.

For 1,000 kg of oil per day:

2.2% of methane x 1,000kg/day = 22 kg of methane / day

Adding both amounts of methane, it is required 994 kg of methane per day. Since the production of methane is 1,080 kg/day, theoretically, there is enough methane to feed heat for both devices.

The efficiency of the burning should be at least:

994 kg / 1080 kg = 92%

Which is really high for a combustion chamber (Department of Energy and Mines). However, there is excess of burning products in the outputs of the pyrolysis reactor such as char and coal that may be burnt to reach the utility requirements.

III. MACRS table for depreciation

The MACRS table is a system used to depreciate the cost of the assets throughout their lifetime. It is commonly useful for engineering projects and it is the recommended way from some countries such as the U.S.

The table below shows how should be depreciated an asset depending on its life and on the operating year of the asset.

	Equipment Life (Years)					
Year	3	5	7	10	15	20
1	33,33%	20,00%	14,29%	10,00%	5,00%	3,75%
2	44,44%	32,00%	24,49%	18,00%	9,50%	7,22%
3	14,81%	19,20%	17,49%	14,40%	8,55%	6,68%
4	7,41%	11,52%	12,49%	11,52%	7,70%	6,18%
5		11,52%	8,92%	9,22%	6,93%	5,71%
6		5,76%	8,92%	7,37%	6,23%	5,28%
7			8,92%	6,55%	5,90%	4,89%
8			4,46%	6,55%	5,90%	4,52%
9				6,55%	5,90%	4,46%
10				6,55%	5,90%	4,46%
11				3,28%	5,90%	4,46%
12					5,90%	4,46%
13					5,90%	4,46%
14					5,90%	4,46%
15					5,90%	4,46%
16					2,95%	4,46%
17						4,46%
18						4,46%
19						4,46%
20						4,46%
21						2,23%

Figure 79: Depreciation table according to MACRS system

IV. Real Feasibility Study

ISO 9001:2015 Certified

Proposal for Pyrolysis Plant Feasibility Study

Pyrocrat Systems LLP

J103, 1st floor,

Railway Station Commercial Complex, Sector 11, C.B.D. Belapur,

Navi Mumbai, PIN: 400 614

sales@pyrocrat.com | +91 99306 55477 | www.pyrolysisplant.com

PYROCRAT

Cover Letter

Pyrocrat Systems LLP is pleased to submit the proposal for Pyrolysis Plant Feasibility Study.

Pyrocrat has over a decade of extensive experience and expertise in field of technology development, equipment designing, manufacturing, supplying, installing, commissioning and providing after sales support pyrolysis plant. With absolute capacity and credentials, we are confident to take up the work.

We shall be glad to provide any clarification and or additional information where is prompted during the evaluation of this proposal.

Regards,

Amit Sharma
Manager - Business Development & corporate Communications
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Sector 11, C.B.D. Belapur,Navi Mumbai, PIN: 400 614
www.pyrocratsystems.com | www.pyrolysisplant.com | www.mswplant.com

Executive Summary

A feasibility study is designed to provide an overview of the primary issues related to a business idea. The purpose is to identify any "make or break" issues that would prevent your business from being successful in the marketplace. In other words, a feasibility study quantifies prerequisite necessary for the business idea to make sense.

Feasibility Study is an assessment of the practicality of a proposed Pyrolysis Plant. Pyrocrat's experience and expertise in field of pyrolysis can help you compile the detailed Feasibility Study of the following:

- Raw Material Suitability & Profitability
- 'Mass & Energy Balance' for various raw materials
- Finished products: Quality, Yield (% output), Expected Selling Cost
  - Pyrolysis Oil
  - Carbon Black
- Optimum Plant Capacity
- Calculations of Working Capital
  - Manufacturing Cost Breakup
  - Manpower Cost
  - Operation and Maintenance Cost
- Total Capital Investment
  - Requirement of additional equipments if any
  - Shredder
  - Raw material handling plant

This Feasibility Study can help investor clearly understand the techno-commercial viability of the proposed pyrolysis project. Post feasibility study, Pyrocrat's recommendations can help you recovered the cost of feasibility study within 2 to 6 months of Pyrolysis plant operation by avoiding financial risks due to avoidable issues like:

★ Bad raw material quality
★ Environmental non-compliance
★ Substandard quality of finished products

Recommendations shall also include :

★ Identifying possible catalyst for each of raw material
★ Additional machines like shredder or oil storage etc

Feasibility Study uncover possible opportunities for business development which easily helps investor recover the cost of Feasibility Study .

Feasibility Study Proposal:

BASIC	INTERMEDIATE	ADVANCED	Technical Scope of Work	Cost per Raw Material Sample: INR	Cost per Raw Material Sample: US$	Helps in Determining
✓	✓	✓	1. Raw Material Testing a. Pyrolysis Oil Yield b. Carbon Yield c. Water Yield d. Gas Yield e. Mass Balance f. Interpretation of the laboratory tests and Recommendations	10,000	200	Raw Material Suitability
	✓	✓	2. Raw Material Quality Assessment a. Moisture Content b. Ash Content c. Calorific Value d. Elemental Analysis (C, H, O, N, Cl, S) e. Visual Inspection for particle	40,000	700	Raw Material Purchase Cost

			size and foreign materials like metal, stone, soil. f. Interpretation of the laboratory tests and Recommendations			
			3. Oil Quality Analysis a. Appearance b. Calorific Value c. Density d. Viscosity @ 20°C and 40°C e. Sulphur Content f. Flash Point g. Pour Point h. Cetane Index i. Tar Content j. Water and Sediments k. Cloud Point l. Corrosion Strip Test m. Hydrocarbons (Aromatics, Olefins, Aromatics) n. Boiling Range o. Interpretation of the laboratory tests and Recommendations	45,000	800	Oil Selling Cost
			4. Carbon Quality a. Elemental Analysis (C, H, O, N, Cl, S, Metals and Silicones) b. Ash content c. Calorific Value d. Sieve size distribution e. Iodine Number f. Interpretation of the laboratory tests and Recommendations	30,000	500	Carbon Selling Cost
			5. Opportunities of manufacturing high value products like: a. Petrol, Diesel, Kerosene,	200,000	3000	Possibility of manufacturing high value

			Naphtha b. Wax c. Transformer oil d. Resin Manufacturing e. Activated carbon f. Waste to energy (Electricity)			products
			6. Detailed Report with Recommendations a. Possibility of manufacturing high Value Products i. Petrochemicals ii. Additives iii. Distilled products iv. Activated carbon v. Recommendations b. Interpretation of the laboratory tests c. Financial Feasibility for Pre Decided Capacity d. Comparison of Pyrolysis Oil with Diesel, Gasoline, Naptha etc e. Inputs for preparation of bankable project report	200,000	3,000	Action plan for Project Planning
			7. Market Analysis a. Market Analysis by Visits and Interactions i. Discussion with Raw material supplier ii. Discussion with Oil buyers iii. Discussion with Carbon black buyers b. Discussion with Pollution Control Board or Environment Protection Agency c. Interpretation of the laboratory tests and	200,000 for 3 days visit plus 15,000 per day	3500 for 3 days plus 250 per day	Understanding Business Variables

			Recommendations			
			Total:	INR 725,000	US$ 11,700	

Milestones

1. Order confirmation with Advance

   Customer confirms the Purchase order with 50% Advance

2. Testing and Draft Report against additional 30% Payment

   Pyrocrat completes the feasibility study and submits draft report against 30% payment

3. Submission of final report against balance 20% payment

   Pyrocrat submits the final report against payment. Pyrocrat team makes a techno-economic feasibility study presentation based on the findings of study.

Standard Terms

1. Delivery Period:

	Basic	Intermediate	Advanced
Delivery Period in Days	2	10	20

   From the date of receipt of Purchase order, advance and receipt of Raw Material Samples. Raw material samples will not be received by Pyrocrat unless Purchase order and Advance is received by Pyrocrat.

2. Payment Schedule

   a. 50% advance

b. Additional 30% against Proforma Invoice for Draft Report

c. Balance 20% plus taxes against Proforma Invoice for final report

3. All prices Ex- Navi Mumbai, India. Travelling, hotel, food, logistics and courier expenses extra at actual. Prices valid upto December 2017.

4. Taxes & Duties: Extra at actual

5. Jurisdiction: Navi Mumbai

6. Limitation of Liability:

   In no event Pyrocrat Systems LLP or its employees shall be liable for any consequential loss or damage arising out of or connected with this feasibility study in any way whatsoever.

7. Bank Details:

   Account Name: Pyrocrat Systems LLP
   Bank Name: State Bank of India
   Current Account Number: 33506186928
   Branch: Konkan Bhavan, C.B.D.-Belapur, Navi Mumbai
   RTGS & IFSC Code: SBIN0006240
   MICR Code: 400002109
   Swift Code: SBININBB362

Bibliography

Agile Process, 2017. *Pyrolysis Plant.* [Online]
Available at: http://pyrolysisplant.com/
[Accessed 10 09 2017].

Aishwarya, K., 2016. *Microwave Assisted Pyrolysis of Plastic Waste,* Kozhikode, Kerala: RAEREST 2016.

Alibaba, 2017. *Alibaba.* [Online]
Available at: https://www.alibaba.com/showroom/5-ton-wheel-loader.html
[Accessed 11 10 2017].

Alibaba, 2017. *Alibaba.* [Online]
Available at: https://www.alibaba.com/showroom/industrial-combustion-chamber.html
[Accessed 10 10 2017].

Alibaba, 2017. *Alibaba.* [Online]
Available at: https://www.alibaba.com/product-detail/2017-new-hot-sell-industrial-column_60637715756.html?spm=a2700.7724838.2017115.21.1ac80c56wSYfkC&s=p
[Accessed 10 10 2017].

Alibaba, 2017. *Alibaba.* [Online]
Available at: https://www.alibaba.com/product-detail/LAB-High-Performance-Liquid-Chromatography_60516615010.html?spm=a2700.7724838.2017115.29.66f95c4eQtMMAW
[Accessed 10 10 2017].

Alibaba, 2017. *Alibaba.* [Online]
Available at: https://spanish.alibaba.com/product-detail/air-filter-for-gas-oil-industry-60421614310.html?spm=a2700.8698675.29.304.5a7059f58DGMNq&s=p
[Accessed 16 10 2017].

Alibaba, 2017. *Alibaba.* [Online]
Available at: https://www.alibaba.com/product-detail/Horizontal-Industrial-Gas-Storage-Bottle-Holder_60421050037.html?spm=a2700.7724838.2017115.1.6e62e16fBXTFeG&s=p
[Accessed 10 10 2017].

Alibaba, 2017. *Alibaba.* [Online]
Available at:
https://www.alibaba.com/trade/search?fsb=y&IndexArea=product_en&CatId=&SearchText=sludge+storage+tank
[Accessed 10 10 2017].

Al-Salem, S., Letteri, P. & Baeyens, J., 2009. *Recycling and recovery routes of plastic solid waste,* London: University College London.

American Chemistry Council, 2011. *Plastics make it possible.* [Online]
Available at: https://www.plasticsmakeitpossible.com/about-plastics/types-of-plastics/what-are-plastics/

Australian Bureau of Statistics, 2013. *Australial Bureau of Statistics.* [Online]
Available at:
http://www.abs.gov.au/ausstats/abs@.nsf/Products/4602.0.55.005~2013~Main+Features~Au

stralia%27s+International+Trade+in+Waste?OpenDocument
[Accessed 27 10 2017].

Australian Institute of Petroleum, 2015. *Biofuels Factsheet,* Canberra: AIP.

Australian Taxation Office, 2017. *Australian Taxation Office.* [Online]
Available at: https://www.ato.gov.au/Business/Small-business-entity-concessions/Concessions/Income-tax-concessions/Small-business-company-tax-rate/
[Accessed 18 10 2017].

Aznar, M., 2006. *Plastic waste elimination by co-gasification with coal and biomass in fludized bed with aire in pilot plant.,* s.l.: Fuel Processing Technology.

Bastian, B., 2013. *bastiansolutions.com.* [Online]
Available at: https://www.bastiansolutions.com/blog/index.php/2013/08/08/how-much-does-conveyor-cost/#.Wd2QlHZLfIU
[Accessed 11 10 2017].

Beede, D. & Bloom, D., 1995. *Economics of the generation and management of municipal solid waste,* s.l.: NBER Working Papers 5116. National Bureau of Economic Research, Inc.

BMT Tax Depreciation, 2017. *BMT Tax Depreciation.* [Online]
Available at: https://www.bmtqs.com.au/depreciation-rate-finder
[Accessed 23 10 2017].

BMTQS, 2006. *BMTQS.* [Online]
Available at: https://www.bmtqs.com.au/Documents/publications/mav18.pdf
[Accessed 4 October 2017].

Borgianni, C. & Filippis, P., 2002. *Gasification process of wastes containing PVC,* s.l.: s.n.

Brophy, K., 1997. *Polymer cracking for feedstock recycling of mixed plastic wastes. ,* Cambridge: s.n.

Clark, J. & Hardy, J., 2004. *Towards sustainable chemical manufacturing: polylactic add - a sustainable polymer,* s.l.: Wiley.

Clean Energy Finance Corporation, 2016. *Energy from waste in Australia: a state-by-state update,* s.l.: CEFC.

Demirbas, A., 2004. *Pyrolysis of municipal plastic wastes for recovery of gasoline-range hydrocarbons.,* Konya, Turkey: Department of Chemical Engineering, Selcuk University.

Department of Energy and Mines, n.d. *Combustion.* [Online]
Available at: http://www.cdts.espol.edu.ec/documentos/apuntes%20de%20combustion.pdf
[Accessed 19 10 2017].

Department of the Environment and Energy, 2016. *Australia National Waste Report 2016,* s.l.: Department of the Environment and Energy.

Dewil, R., Everaert, K. & Baeyens, J., 2006. *The European plastic waste issue: trends and toppers in its sustainable re-use. ,* Prague: 17th International Congress of Chemical and Process Engineering.

Dezhen, C., 2014. *Pyrolysis technologies for municipal solid waste: A review,* Shanghai: s.n.

Enbridge, 2017. *Chemical Composition of Natural Gas,* Victoria: Embridge.

Frisch, K., 1999. *Advances in Plastic Recycling,* s.l.: Technomic Publishing.

Fuel Tank Shop, 2017. *Fuel Tank Shop.* [Online]
Available at: https://www.fueltankshop.co.uk/7500-litre-diesel-tank-harlequin-7500fs/p4883
[Accessed 10 10 2017].

Generators Online, 2017. *Generators Online.* [Online]
Available at: https://www.generatorsonline.com.au/kubota-j310-10kva-three-phase-diesel-generator?gclid=CjwKCAjw3_HOBRBaEiwAvLBbokqF1eJ2ALnvw-yNAZL078YKdLlLHBDvXi-F7_3SsMAMUWNPkZ73ihoCKUQQAvD_BwE
[Accessed 10 10 2017].

Ghodrat, M., Rhamdhani, M., Brooks, G. & Masood, S., 2016. Techno economic analysis of electronic waste processing through black copper smelting route. *Journal of Cleaner Production,* Volume 126, pp. 178-190.

Gobi, 2002. *New forecast for Polypropylene, Polystyrene and Polyurethane,* s.l.: s.n.

Google Maps, 2017. *Google Maps.* [Online]
[Accessed 2017].

Hasegawa, M., 1974. *Gasification of solid waste in a fluidized with circulating sand. ,* s.l.: s.n.

Home Improvements Pages, 2017. *homeimprovementpages.* [Online]
Available at:
https://www.homeimprovementpages.com.au/article/how_much_does_concreting_cost
[Accessed 4 October 2017].

Huayin Group, 2017. *Huayin Energy.* [Online]
Available at: http://huayinrecycling.com/index.php/home/index/service_detail/id/4
[Accessed 18 10 2017].

Index Mundi, 2017. *Index Mundi.* [Online]
Available at: http://www.indexmundi.com/commodities/?commodity=heating-oil&months=360&currency=aud
[Accessed 25 10 2017].

IPART, 2007. *Pricing arrangements for recycled water and sewer mining,* Sydney: Independent Pricing and Regulatory Tribunal.

Jaeger, M., 2000. *The Noell Conversion Process - a gasification process for the pollutant-free disposal of sewage sludge and the recovery of energy and materials,* s.l.: s.n.

Kaminsky, W., 1995. Olefins from polyolefins and mixed plastics by pyrolysis.. *Journal of Analytical and Applied Pyrolysis,* Volume 32, pp. 19-27.

Kang, H., 2005. *Electronic waste recycling: a review of U.S. infrastructure and technology options.,* s.l.: s.n.

m3 Property, 2016. *m3 Property.* [Online]
Available at: http://www.m3property.com.au/wp-content/uploads/2016/08/Sydney-Industrial-market-August-2016-update.pdf
[Accessed 4 October 2017].

Malkow, P., 2004. *Novel and innovative pyrolysis and gasification technologies for energy efficient and environmentally sound municipal solid waste disposal,* s.l.: s.n.

March, J., 1992. *Advanced Organic Chemistry: Reactions, Mechanisims, and Structure,,* U.S.: John Wiley & sons.

Mastellone, M., 1999. *Thermal treatments of plastic wastes by means of fluidized bed reactors. ,* Napoles: s.n.

Mastral, F., 2003. Fluidized bed thermal degradation products of HDPE in an inert atmosphere and in air-nitrogen mixtures.. *Journal of Analytical and Applied Pyrolysis,* Volume 80, pp. 427-439.

Mastral, J., 2007. *Therotical prediction of product distribution of the pyrolysis of high density polyethylene,* s.l.: s.n.

Matsunami, J., Yoshida, S. & Yokota, O., 1999. *Gasification of waste tyre and plastic (PET) by solar thermochemical process for solar energy utilization,* s.l.: Solar Enery 65.

Miandad, R. et al., 2016. Catalytic pyrolysis of plastic waste: A review. *Process Safety and Environmental Protection,* Volume 102, pp. 822-836.

Modern Power Systems, 2014. *Modern Power Systems.* [Online]
Available at: http://www.modernpowersystems.com/features/feature pyrolysis-penetrates-power-from-waste-market/
[Accessed 2014].

National Council of Educationa Research and Training, 2014. *Combustion and Flame.* s.l.:NCERT.

NSW Environment Protection Authority, 2015. *NSW Energy from Waste Policy Statement,* Sydney: NSW Environment Protection Authority.

NSW Environment Protection Authority, 2017. *NSW Environment Protection Authority.* [Online]
Available at: https://www.epa.nsw.gov.au/
[Accessed 27 10 2017].

PACIFIC PYROLYSIS, 2017. *PACIFIC PYROLYSIS.* [Online]
Available at: http://pacificpyrolysis.com/
[Accessed 09 09 2017].

Paige, 2017. *Paige.* [Online]
Available at:
https://www.alibaba.com/trade/search?fsb=y&IndexArea=product_en&CatId=&SearchText=nitrogen+generator
[Accessed 10 10 2017].

Parfitt, J., 2002. *Analysis household waste composition and factors driving waste increases. ,* London: Government Cabinet Office.

Patni, N., Shah, P., Agarwal, S. & Singhal, P., 2013. *Alternate Strategies for Conversion of Waste Plastic to Fuels,* Ahmedabad, Gujarat, India: Departament of Chemical Engineering, Institute of Technology, Nirma University.

Pay Scale , 2017. *Pay Scale Human Capital.* [Online]
Available at: https://www.payscale.com/research/AU/Job=Secretary/Hourly_Rate
[Accessed 22 10 2017].

Perdon, S., 2004. *Sustainable development in practice: case studies for engineers and scientists. ,* s.l.: Wiley.

Perry, R. & Green, D., 1997. *Perry´s Chemical Engineers´Handbook. Seventh Ed. ,* New York: McGraw-Hill.

Pinterest, 2017. *Pinterest.* [Online]
Available at: https://www.pinterest.co.uk/conpak/videos-on-plastic-types/
[Accessed 15 9 2017].

Quora, 2015. *Quora.* [Online]
Available at: https://www.quora.com/Chemical-Engineering-Why-in-a-normal-distillation-column-does-temperature-and-pressure-gradient-exist-from-bottom-to-top
[Accessed 27 10 2017].

Reliable, 2017. *Reliable Pipes & Tubes.* [Online]
Available at: http://www.reliablepipestubes.com/blog/price-pricelist-carbon-steel-pipe-seamless-pipe-welded-pipe/
[Accessed 10 10 2017].

Royal Society of Chemistry, 2017. *Pyrolysis of Biomass: Advances in Science and Technology,* s.l.: The Royal Society of Chemistry.

Said Ali Hassam, E., 2016. *Techno-Economical Feasibility Study of Waste-to-Energy Using Pyrolysis Technology for Jeddah Municipal Solid Waste,* Jeddah, Saudi Arabia: Department of Industrial Engineering, King Abdulaziz University.

Scheirs, J., 1998. *Polymer Recycling: Science, Technology and Application,* s.l.: Wiley-Blackwell.

Seider, W., Seader, J. & Lewin, D., 2009. *Products & Process Design Principles: Synthesis, Analysis and Evaluation, Third ed.,* New Yor: John Wiley & sons.

Syamsiro, M. et al., 2013. *Fuel Oil Production from Municiapl Plastic Wasters in Sequential Pyrolysis and Catalytic Reforming Reactors,* Indonesia: Conference and Exhibition Indonesia Renewbable Energy & Energy Conservation.

Sydney Tools, 2017. *Sydney Tools.* [Online]
Available at: https://sydneytools.com.au/chicago-hush150-silenced-150l-air-compressor?fee=4&fep=7445&gclid=EAIaIQobChMI8p6noY301gIVSh9oCh0yngVPEAYYAyABEgK2iPD_BwE
[Accessed 16 10 2017].

Trading Economics, 2017. *Trading Economics.* [Online]
Available at: https://tradingeconomics.com/australia/inflation-cpi
[Accessed 22 10 2017].

Truck Sales, 2017. *trucksales.* [Online]
Available at:
https://www.trucksales.com.au/buy/results/?q=((Service%3D%5Btrucksales%5D%26Category%3D%5BTrucks%5D)%26State%3D%5BNew%20South%20Wales%5D)
[Accessed 11 10 2017].

U.S. Energy Information Administration, 2017. *EIA U.S. Government.* [Online]
Available at: https://www.eia.gov/tools/faqs/faq.php?id=327&t=9
[Accessed 22 10 2017].

Universidad de Alicante, 2015. *Universidad de Alicante.* [Online]
Available at: http://iq.ua.es/TPO/
[Accessed 18 10 2017].

USEPA, 2002. *Municipal Solid Waste un the United States: 2000. Facts and Figures. Executive Summary. ,* s.l.: Office of solid waste management and emergency response.

USEPA, 2007. *Municipal Solid Waste in the United States: 2007. Facts and Figures. Executive Summary,* s.l.: Office of solid waste management and emergency response..

Waste Tire Oil, 2017. *Waste Tire Oil.* [Online]
Available at:
http://www.wastetireoil.com/Pyrolysis_plant/Pyrolysis_Plant/waste_plastic_pyrolysis_machine_177.html
[Accessed 11 10 2017].

Waste Tire Oil, 2017. *Waste Tire Oil.* [Online]
Available at:
http://www.wastetireoil.com/Pyrolysis_plant/Waste_oil_distillation/oil_distillation_refining_plant_124.html
[Accessed 15 10 2017].

World Bank, 2011. *Urban Development Series - Waste Generation,* s.l.: s.n.

XE, 2017. *XE.* [Online]
Available at:
http://www.xe.com/currencyconverter/convert/?Amount=1&From=USD&To=EUR
[Accessed 10 10 2017].

Xiao, C., 1999. *Electrostatic separation and recovery from mixed plastics.,* Michigan: s.n.

Xiao, R., 2007. *Air gasification of polypropylene plastic waste in fluidized bed gasifier,* s.l.: Energy Conversion Management.

Yassin, L., Lettierim, P. & Simons, S., 2005. *Energy recovery from thermal processing of waste: a review.,* s.l.: Engineering Sustainability.