Course name: Thesis (Final Course Project)

Project name: Pyrolysis of plastics for the production of sustainable alternative fuels for the marine sector

By: Sina Keyhani

Abstract:

Large quantities of marine litter exist in marine environment. This litter poses a serious threat to the environment and human health, but they can be an interesting source for pyrolysis process to produce fuel for shipping sector. Shipping sector itself is shown to be transitioning towards cleaner fuels, especially in terms of sulfur content which fit the resulting oil from pyrolysis process.

The study examines the composition and distribution of marine litter across different environments, identifying beach and floating marine litter as the most suitable options for pyrolysis process. While seafloor litter can also be used, it requires the removal of large non-plastic foreign materials and addressing challenges posed by PA and PVC.

A literature review showed that several experimental studies were performed on marine litter pyrolysis, after careful analysis of these studies, the most comprehensive one was selected as a reference study, Furthermore, to show the variability of marine litter, several feedstock scenarios were formed, and heat and mass balance calculations were done on each of them.

Based on the results of theoretical calculations, an industrial unit was designed and economic and LCA of the process was performed. The results showed that while economically unfeasible in current scale, which is considered small, the process shows great scalability. Moreover, the process generates an order of magnitude less emission than incineration.

Assessment of Marine Litter:

Sea	Type of sampling	Density (item/km²)	Description	Source
Eastern Med. Sea	Surface observation	232±325	Plastic pieces were dominant then bags and bottles.	[33]
Central Med. Near Malta	Surface observation	1321±688	91% were plastics and 4% woods. Mostly plastic fragments.	[34]
Adriatic Sea	Surface observation	251±601	91.4% were plastics. Mostly packaging materials. Bags and plastic pieces were dominant.	[110]
Black Sea	Surface observation	93.6±128.3	96% were plastic made. Mostly plastic pieces.	[49]
Central Adriatic sea	Surface observation	175.3±180.6	95% were made from plastics, and the rest were wood and paper.	[79]
Baltic and North Sea	Bottom Trawl	16.8 (NS), 5.07 (BS)	Plastics consisted 80% of items caught.	[58]
Baltic and North Sea	Bottom Trawl	70.7 (NS), 9.6 (BS)	Plastic was found in 91.3% of all samples.	[54]
Antalya Bay, East Med. Sea	Bottom Trawl	13.3-651.1	Plastic is the most abundant, but weightwise rubber is the most abundant material.	[74]

Marine litter density based on item for several European Sea.

Sea	Type of sampling	Density (kg/km²)	Description	Source
Northern and central Adriatic Sea	Bottom Trawl	82 ± 34	Plastics are 80% in terms of number, and 62% in terms of weight, dominant waste.	[82]
Greek gulf, East Med.	Bottom Trawl	6.7-47.4	Plastic was the dominant item (56%).	[60]
Southern Black Sea	Bottom Trawl	80.68 ± 48.06	Number-wise, plastics were the most dominant waste type (69.03%). Weight-wise, it was 16.37%. 62.01% of the overall weight was for rubber which only had 2% of items.	[38]
Catalan Coast, NW Med. Sea	Bottom Trawl	–	Plastic removal rate 0.74 ± 0.11 kg, accounting for 64.2% of marine litter in nets. Wood was second with 21.5%.	[9]

Marine litter density based on weight for several European Sea.

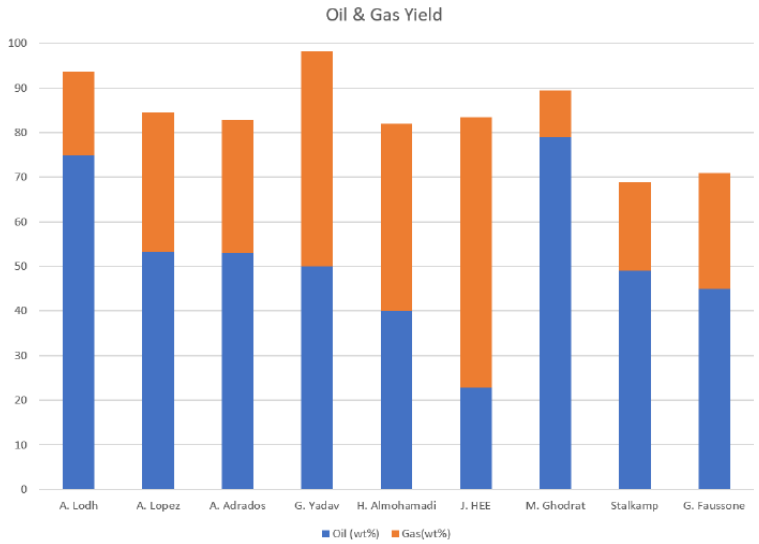
Location	Percent by number	Percent by weight
Europe	91%	64%
Mediterranean	81%	53%
Black Sea	80%	57%

Percentage of plastic waste by number and weight in different locations.

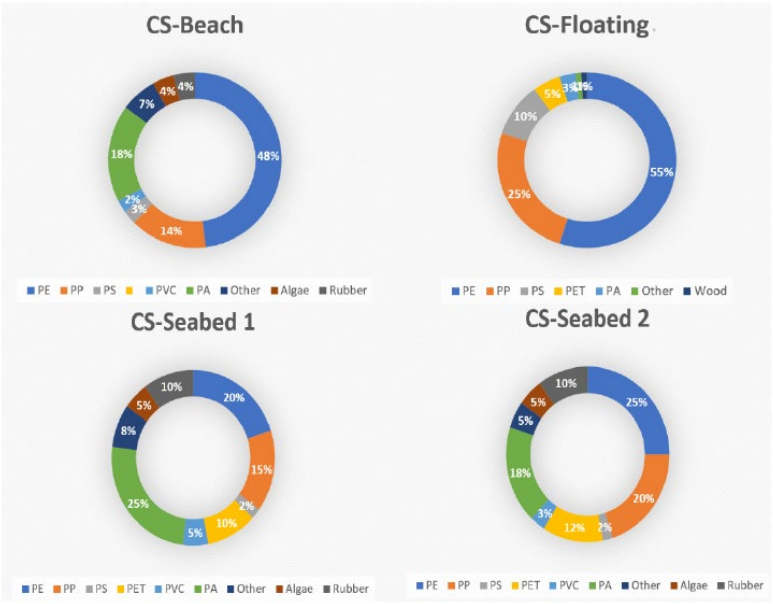
Location	HDPE	LDPE	PP	PS	PA	PVC	PET	Other
North Sea	46.08%	23.52%	20.67%	–	6.65%	–	0.95%	1.90%
Baltic Sea	14.29%	10.71%	21.43%	3.57%	21.43%	3.57%	17.86%	7.14%

Composition of seafloor plastics.

Theoretical Calculations:



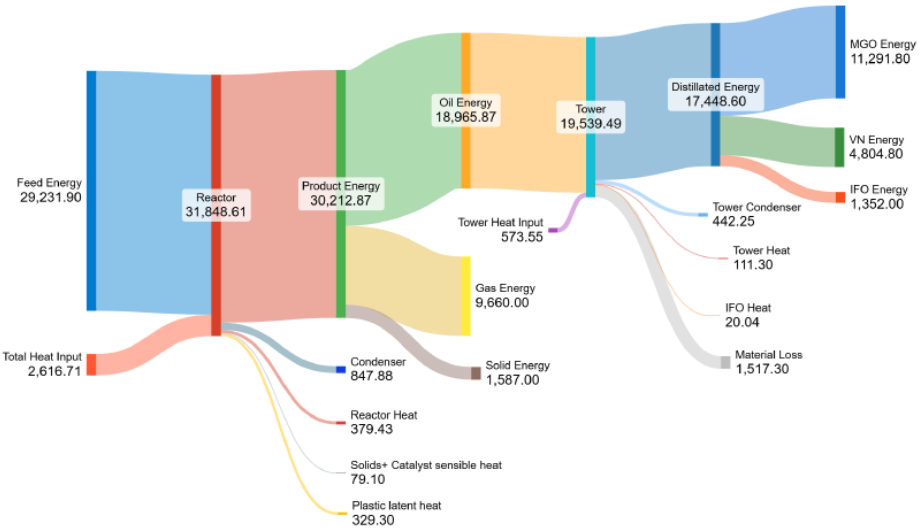
Comparison of plastic oil and gas yield from several pyrolysis experiments similar to marine litter pyrolysis.



Feedstock Case Studies used for calculations.

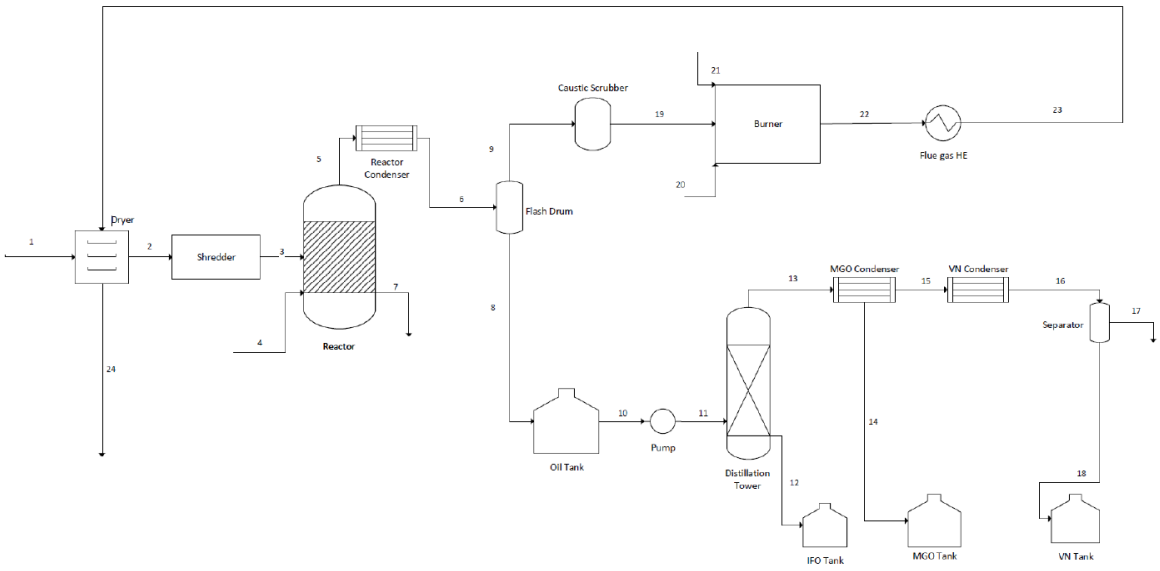
Streams	Beach (kg)	Floating (kg)	Seabed-1(kg)	Seabed-2(kg)
Marine Litter	1000	1000	1000	1000
Dolime	100	100	100	100
Volatiles	826	875	791	800
Gas	200	275	318	280
Solids	274	225	309	300
Pyro oil	626	600	473	520
IFO	43.94	44.76	30.74	33.8
MGO	341.54	348.24	238.86	262.6
VN	148.8	151.74	104.1	114.4
Water	37.56	0	61.5	67.6

Theoretical mass balance results.



Theoretical energy balance results.

Pyrolysis Plant with industrial considerations:



PFD of the pyrolysis process.

Energy	Beach (MJ)	Floating (MJ)	Seabed-1 (MJ)	Seabed-2 (MJ)
Pretreatment Energy	252	252	252	252
Real Input by NG	2616	2897.93	2437.85	2551.86
Real Input by Pyro gas	4659.42	3887.7	3646.52	1737.82
Real Total Input of Reactor	7275.42	6785.63	6084.37	4289.68
Reactor Condenser	926.36	945.2	814.8	847.88
Tower Heat Input	573.79	477.56	531.67	573.55
MGO Condenser	235.8	239.8	188.3	208
VN Condenser	200.2	99.8	217.6	241.1
Real Total Output of Burner	8262.33	7645.47	6964.26	5119.2
Recovered from Flue gas	544.8	3768.8	5324	6108
Remain in Flue gas	846.55	1123.68	1248.9	1118.97
Oil Energy	24840.05	25484.97	17251.65	18965.87
Gas Energy	6900	9487.5	10971	9660
Solid Energy	1132.06	1216.7	1364.82	1587

Energy balance results of industrial process.

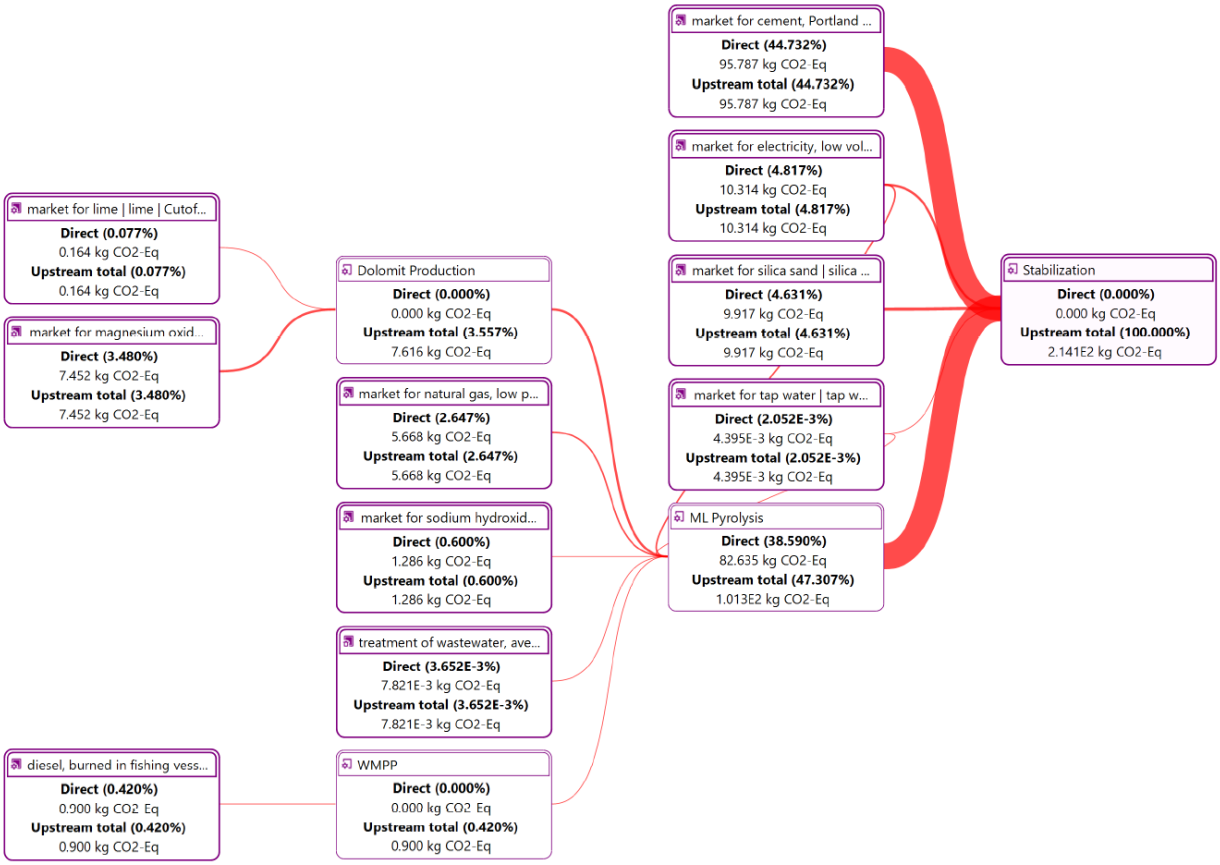
Economic and Environmental Analysis:

Parameters	Capacity (100 kg/cycle)	Capacity (1000 kg/cycle)
Direct and Indirect costs	503615.81	3490099.13
Contingency	75542.37	523514.87
Contractor fee	15108.47	104702.97
Aux. and Facilities	199443.49	876503.99
TOTAL CAPITAL ($)	**793710.15**	**4994820.97**
TOTAL CAPITAL (€)	**729459.31**	**4590490.21**

Capital costs calculations for two different capacities.

Parameters	Capacity (100 kg/cycle)	Capacity (1000 kg/cycle)
Capex (€)	729459.31	4590490.21
Annualized capital (€)	74297.04	467551.57
MGO Production (ton/year)	53.59	536.06
Gross COM (€)	1303313.3	2944541
Gross COM per ton feedstock (€)	7240.63	1635.8
Net COM (€)	1267282.3	2572129.2
Net COM per ton feedstock (€)	7040.45	1429
MGO Price (€/ton)	25034.13	5670

Economic Summary and minimum selling price of product for each capacity.



LCA Sankey diagram for 1000kg/ cycle capacity.