Techno-economic assessment of pyrolysis of rubber and plastic wastes

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April 19th 2022

Introduction

In 2020, 29 million tonnes of plastics waste have been disposed of (Plastics Europe), this number does not match the plastic production because most of it has a life span of <1 year. The management comprises 35% is sent to recycling, 42% is used in energy recovery and 23% is sent to landfills. More action is taken by the European Union to lead the plastic economy towards a circular system. To achieve this goal zero plastic should be sent to landfills so the recycling collection system needs to be improved and new recycling technologies need to be developed and affordable for industries.

The situation is similar for end-of-life tires (ELTs); each year 290 million tires are disposed of in the USA and about 3.1 million tires in Europe (European Tyre and Rubber Manufacturers' Association) and mismanagement leads to the accumulation of these wastes in landfill or in the open environment. Recycling is the biggest treatment route (46%), and it consists mainly of granulation and application in steel mills and foundries. It is understandable that recycling cannot tackle the disposal problem alone. Energy recovery poses environmental problems because of SOx, NOx, VOC, PAHs, dioxins, and other harmful compounds emissions.

The thermochemical process like gasification and pyrolysis seems to be an environmental safety route to follow, they allow waste valorization by generating added-value products.

Objectives

- Evaluation of pyrolytic conversion of virgin plastic and rubber waste under different operating conditions and setups in laboratory-scale reactors
- Identification of the best configuration to maximize gas production and optimize monomers and hydrogen production
- Perform a techno-economic evaluation of the pyrolysis of plastic and rubber wastes and critically compare the results, with the aim to assess the economic sustainability of the scale-up of the considered processes. Both routes have been scaled up to 2500 kg h-1 of the treated material and the economic sustainability of different technical scenarios has been evaluated.

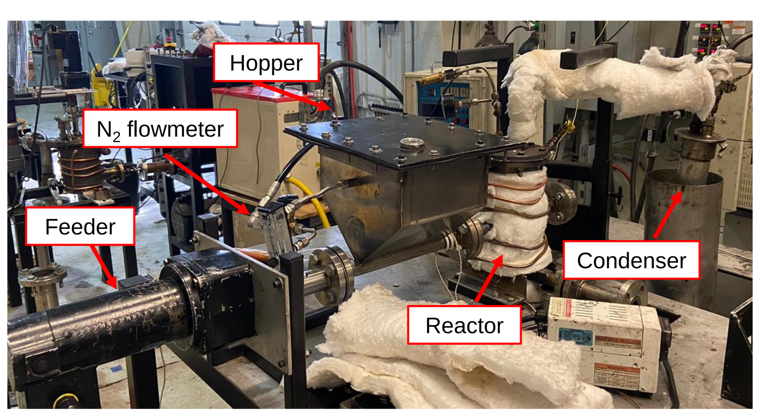
Methodology

- Virgin HDPE and LDPE were provided by **Nova Chemicals**

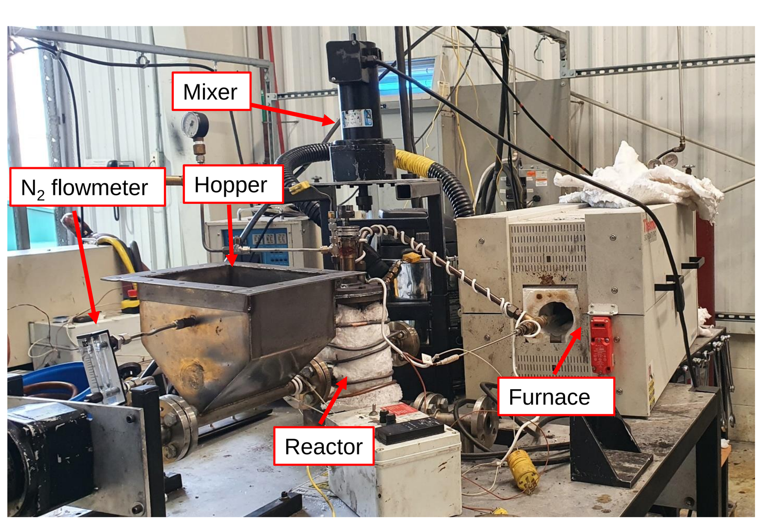

HDPE


LDPE

- **Single stage pyrolysis** in mechanically fluidized bed reactor (**MFR**), feeding rate of 0.72 kg h^{-1}, temperature 550°C, nitrogen flow 1 L min^{-1}



- **Double stage pyrolysis** in mechanically fluidized bed reactor (**MFR**) coupled with a **furnace**, feeding rate of 0.72 kg h^{-1}, temperatures: reactor 480-550°C, furnace 800-850°C, nitrogen flow 1-10 L min^{-1}



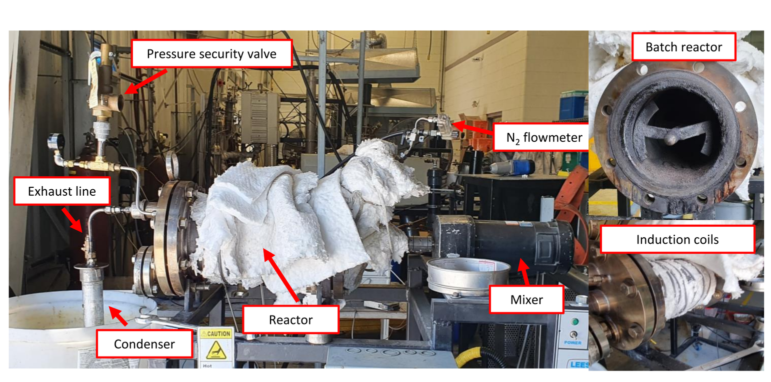
- Commercial gardening **rubber**


Rubber

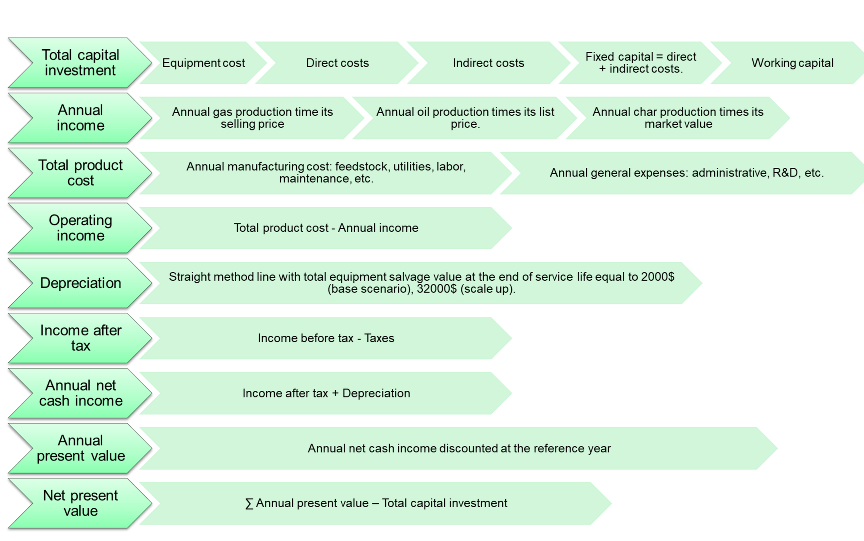

Liquid nitrogen


Result

- **Batch pyrolysis** in a mechanically fluidized horizontal unit (HU), 1 kg of processed material per experiment, reactor temperature 400-500°C, nitrogen flow 1 L min^{-1}



- **Techno-economic analysis** development method
- The techno-economic assessment has been carried out for HDPE and LDPE pyrolysis in both single-stage and double stage configurations
- For rubber pyrolysis it has been supposed that the results obtained with the batch process are replicable in a continuous process
- The scale-up scenarios are based on the production of plastic wastes (15000 tonnes per year) in the city of London, Ontario, Canada
- Scenarios 2, 3, and 4 are sensitivity analyses to identify the main parameters affecting the overall economic sustainability and profitability of the plant
- Scenarios 5 and 6 are theoretical cases assessing hydrogen and ethylene production respectively to highlight future research needs



		Processed material (kg h^{-1})	Equipment cost	Gas composition	Methane recycle	Annual manufacturing cost		
						Operating labor	Utility type	Utility cost
Base scenario		0.72	Based on known data	As in experiments	No	8 hours shifts 24 hours per day 7 days a week Total 4.5 workers per day	Electricity	0.093 $/kWh
Scale up	Scenario 1	2500	0.6 power law	As given in scale up	No	8 hours shifts 24 hours per day 7 days a week Total 9 workers per day	Electricity	0.093 $/kWh
	Scenario 2				No		Electricity	0.043 $/kWh
	Scenario 3				No		Natural gas	2.91 $/MMBtu
	Scenario 4				Yes		Natural gas if n eeded	2.91 $/MMBtu
	Scenario 5			80% hydrogen 20% methane	Yes		Natural gas if n eeded	2.91 $/MMBtu
	Scenario 6			80% ethylene 20%methane	Yes		Natural gas if n eeded	2.91 $/MMBtu

Results

- Plastic pyrolysis
  - Solids yield is negligible
  - Higher temperatures result in greater gas production
  - The oil is mainly composed of diesel and gasoline-like fractions when double stage pyrolysis is used
  - For single-stage experiments waxes are obtained, while with double stage pyrolysis the oil presents low viscosity
  - Lowering temperature and residence time in the reactor maximizes hydrogen and ethylene production

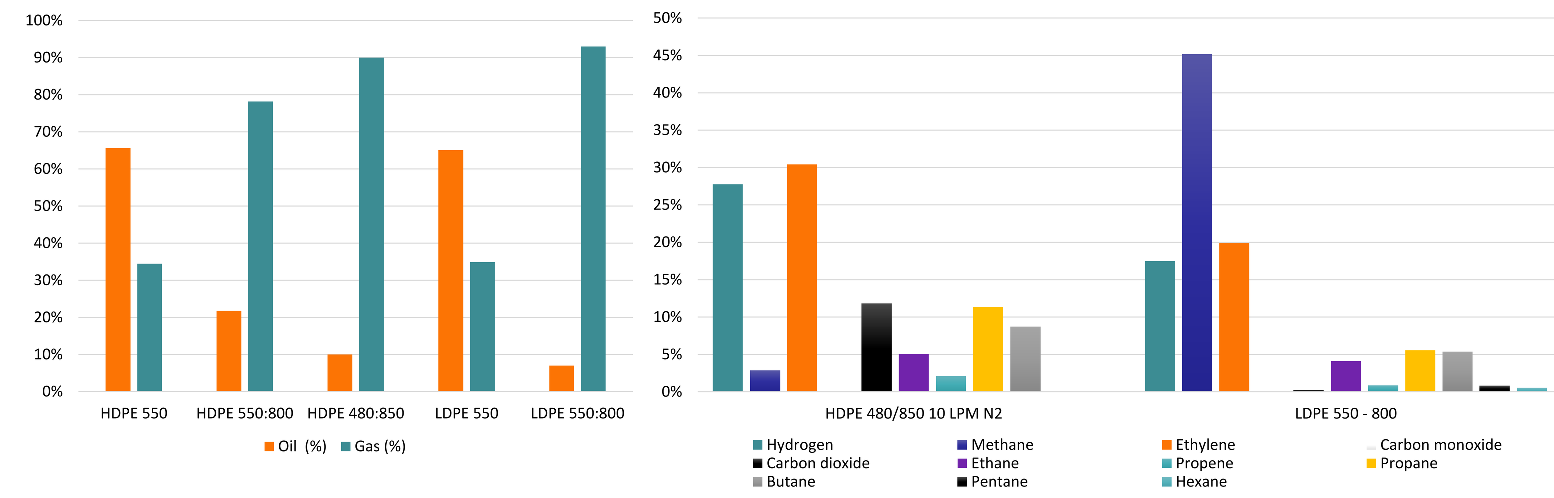


Fig.1 - HDPE and LDPE pyrolysis yield (left) and gas composition (right) for single and double stage configuration

- Rubber pyrolysis
  - Solids are the main product and are composed of 84.42 %wt of fixed carbon
  - A temperature of 500°C (runs 1,2, and 3) generates greater yields with respect to the lower temperature (400°C) in run 4
  - More than 100 compounds identified by GC-MS, most of these present a carbon number lower than 12
  - Oil is comparable with unrefined gasoline
  - The main components in the gas are hydrogen and methane

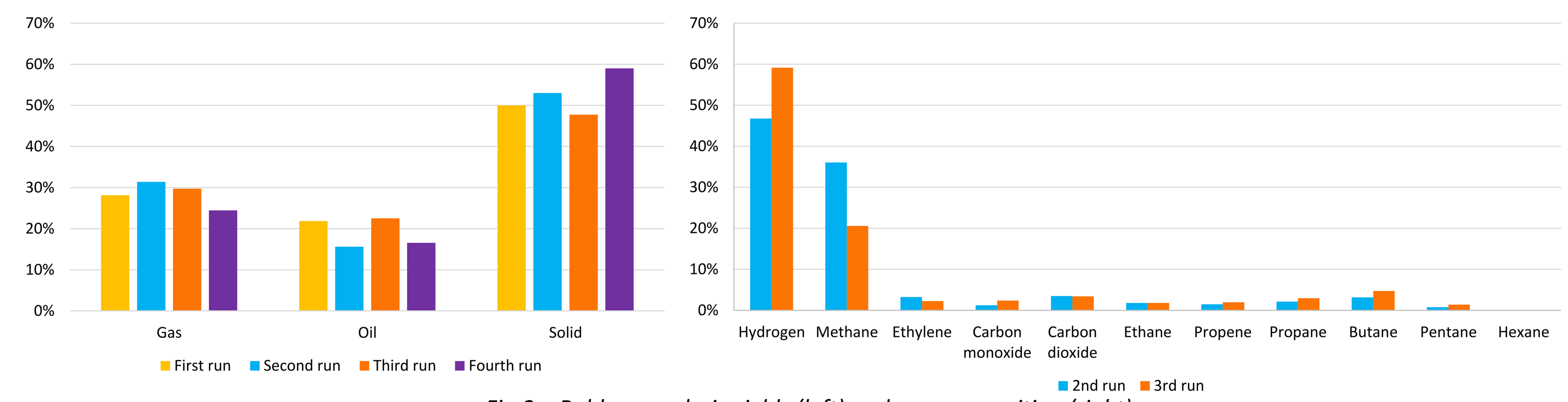


Fig.2 – Rubber pyrolysis yields (left) and gas composition (right)

- Techno-economic analysis of plastic pyrolysis
  - Base scenarios are not economically sustainable
  - Single stage pyrolysis is profitable but not sustainable
  - The best scale-up scenario for virgin LDPE is double stage pyrolysis at 550-800°C with **methane recycled** into the system for energy production: payback period **<6 years**
  - The best scale-up scenario for virgin HDPE is double stage pyrolysis at 480-850°C with **methane recycled** into the system for energy production: a payback period of **4.5 years**
  - Maximizing **hydrogen production** (scenario 5) results in the **most economically sustainable** and profitable case for both LDPE and HDPE: a payback period of **2-2.5 years** and a final revenue of 124 M$ and 148 M$, respectively

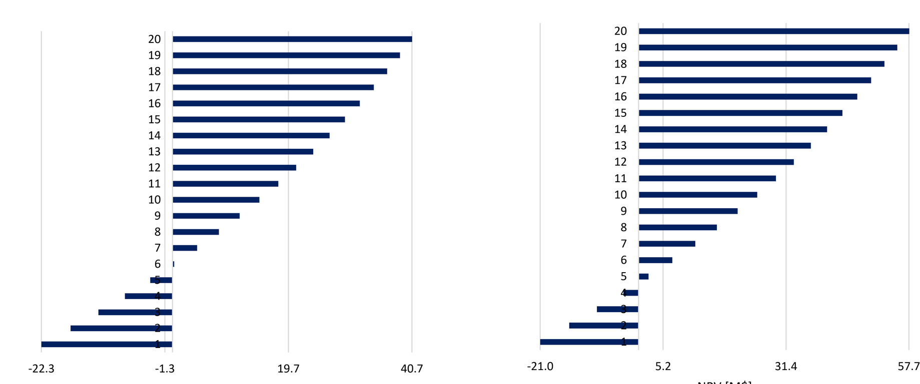


Fig. 3 – Net present value (NPV) of scenario 4 (methane recycle) for LDPE double stage pyrolysis (left) and HDPE double stage pyrolysis (right)

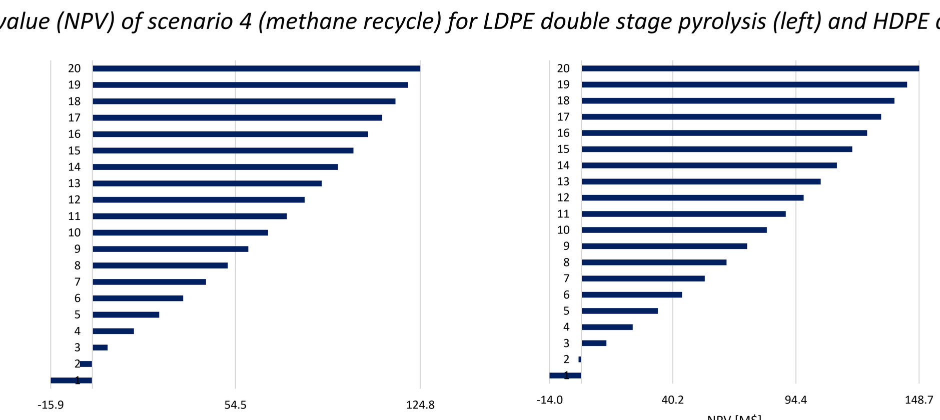


Fig. 4 – NPV of scenario 5 (theoretical hydrogen production) for LDPE double stage pyrolysis (left) and HDPE double stage pyrolysis (right)

- Techno-economic analysis of rubber pyrolysis
  - Base scenario is not profitable along the lifetime of the plant (20 years)
  - All the scale-up analyzed present PBP around **7-8 years**
  - **Methane recycling** (scenario 4) into the system for energy production results in the most economically sustainable configuration with a PBP of **7.5 years** and an end-of-life NPV of 23 M$
  - The theoretical case maximizing **hydrogen production** (scenario 5) can lower the payback period to **6.5 years**
  - Due to the composition of the rubber maximizing **ethylene production** (scenario 6) is **not profitable** not sustainable during the lifetime of the plant

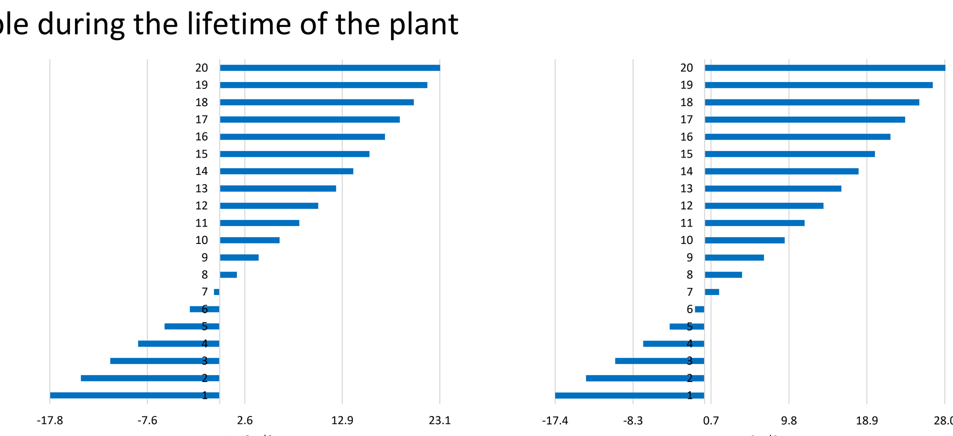


Fig. 5 – NPV of rubber pyrolysis for methane recycling (left) and hydrogen production (right)

Conclusion

Pyrolysis of plastic wastes and rubber is feasible and their products have marketable capacity. The gas fraction is composed of monomers and hydrogen which have the highest selling price and therefore hold great influence on the overall economic sustainability of the process. Both feedstocks show profitability and industrially acceptable payback periods when scaled up to 2500 kg h^{-1}. Moreover, the sensitivity analysis of the gas composition highlights that hydrogen production is the best case due to its high market value in today's economy.

Acknowledgments

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icfar
NSERC CRSNG
NOVA Chemicals