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Techno-Economic Assessment of Hydrogen Production from Plastic Waste using Aspen HYSYS

Ayda Dastneshan[1], Jamshid Behin [1,2] *, Amarjeet Bassi[2]

[1] Faculty of Petroleum and Chemical Engineering, Razi University, Kermanshah, Iran
[2] Department of Chemical and Biochemical Engineering, Western University, London, N6G 0N1, ON, Canada

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ABSTRACT

The rapid growth in global demand for clean and sustainable energy has intensified the need for efficient hydrogen (H_2) production technologies. The thermochemical recycling of plastic waste has emerged as a promising approach, offering both environmental benefits and a generation of high-purity, low-carbon H_2. This study evaluates the technical and economic feasibility of H_2 production from diverse plastic waste streams using Aspen HYSYS and the Aspen Economic Analyzer. The process integrates the pyrolysis of polymers, removal of chlorine, and steam reforming. Feedstocks (200×10^3 t/y) include polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS), polyethylene terephthalate (PET), and mixed industrial and municipal waste from packaging (PKG), medical (MED), automotive (AUT), municipal solid waste (MSW), construction (CON), and textile (TEX) sectors. H_2 production yield strongly depends on the composition of the feedstock, ranging from 0.14 to 0.31 t H_2/t feed. PET with the lowest H/C ratio, exhibits the lowest yield, whereas PE and PP achieve the highest yields, albeit with the incomplete conversion of carbon to CO. Oxygenated polymers, such as PET, generate the highest CO_2 emissions (~1.4 t/t feed). The economic analysis indicates that PE and MED are the most cost-effective feedstocks, with gross margins of 62 and 66% and annual net profits of 232×10^{6} and 223×10^{6} USD respectively.

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1. Introduction

The global demand for clean and renewable energy has surged in recent years, driven by rapid economic growth and industrial expansion, which have constrained per capita access to energy and excerbated inflationary

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*Corresponding author: Behin@razi.ac.ir

pressures [1]. In this context, hydrogen (H_2) has emerged as a promising clean energy carrier with substantial potential to reduce reliance on fossil fuels and support the transition toward a low-carbon energy economy [2]. H_2 can be produced through diverse pathways depending on the choice of the feedstock and conversion technology. Carbon-containing feedstocks, including methane, biomass, and plastic waste, are commonly converted into H_2 via thermochemical routes such as pyrolysis, gasification, plasma gasification, and partial oxidation. Alternatively, H_2 may be generated from water through electrochemical and photochemical processes, including water electrolysis, photoelectrochemical splitting, and photocatalysis. However, these water-based routes are typically energy-intensive and may entail significant economic and environmental constraints due to associated greenhouse gas emissions and high electricity demand [2]. Plastic waste, characterized by its high content of hydrocarbons, has recently gained attention as a promising feedstock for H_2 production, particularly in light of the continuous growth in global plastic production, which is projected to nearly triple by 2050 if current trends persist [3]. Integrating pyrolysis with downstream steam reforming represents an innovative strategy for H_2 generation, offering a synergistic approach that enhances energy recovery while simultaneously addressing plastic waste management challenges in a cost-effective manner [4].

Prior investigations have established that plastic waste exhibits distinct behaviors in H_2 production processes, attributable to differences in its chemical structure and elemental composition. Plastics with simpler hydrocarbon backbones and higher hydrogen-to-carbon (H/C) ratios generally yield higher H_2 production, whereas polymers containing heteroatoms such as oxygen or chlorine tend to generate undesirable by-products, including corrosive gases, which adversely affect process performance.

Thermochemical conversion is the most widely used method for upcycling plastic to H_2 [5]. The influence of the plastic type on H_2 production was simulated by the Aspen plus software through the thermochemical gasification of plastic waste in a fluidized bed reactor, where the effects of the composition, temperature, and pressure of the feedstock were analyzed. The H_2 yields ranged from 15.33 to 284.40 Nm^3 H_2 per ton of the feed, with polyethylene (PE) and polypropylene (PP) achieving the highest H_2 production under optimized operating conditions [6]. Synergistic effects in co-gasification systems have also been reported. In an experimental study, which involved the partial oxidation and steam gasification of low-density polyethylene (LDPE) blended with coal residues at 800–1000 °C, the concentrations of up to 59 vol% of H_2 were achieved, with H_2/CO ratios ranging from 2.3 to 4.7. The enhanced H_2 yield was attributed to the high reactivity of LDPE and the catalytic influence of potassium and calcium present in coal ash, which resulted in the superior gasification efficiency compared to single-feed systems [7]. Plasma gasification has been explored as an alternative pathway for H_2 production from medical plastic waste, with analyses focusing on the composition of the syngas, equivalent power generation capacity, and CO_2 emission rates in comparison with diesel fuel-based systems [8]. In addition to thermochemical routes, H_2 production from plastic waste via photoelectrochemical methods has been investigated. In a laboratory-scale study, polyethylene terephthalate (PET) waste was converted into H_2 using a photoelectrochemical system; however, the achieved photocurrent densities were lower than those observed in conventional water-splitting processes, which indicated limited efficiency [9]. The conversion of high-density polyethylene (HDPE) into H_2 has also been examined in a bench scale unit using integrated pyrolysis and steam reforming. To mitigate the high energy demand associated with these processes, limited oxygen injection was performed into the reforming reactor to establish autothermal conditions. Under optimal operating parameters, an H_2 yield of 250 kg per ton of the feedstock was obtained, which represented a 28% reduction in energy consumption compared with fully energy-intensive routes [10]. Thermodynamic equilibrium simulations have further assessed H_2 production from HDPE, PP, and polystyrene (PS), both individually and in combination with biomass, via pyrolysis coupled with in-line oxidative steam reforming. These studies identified the optimal temperature, steam-to-plastic ratio, and oxygen equivalence ratio (ER) for maximizing hydrogen yield. The results confirmed that polyolefin plastics with high H/C ratios, particularly HDPE, exhibit the greatest potential for H_2 production, while the inclusion of oxygen-rich materials, such as biomass or PET, decreases the concentration of H_2 and increases the formation of CO and CO_2 [11].

Aspen Plus and Aspen HYSYS simulators, which apply mass and energy balances and phase equilibrium data, have been widely utilized in many studies to model the gasification process with a thermodynamic approach in order to evaluate the effect of key parameters and estimate the performance of a gasifier [6]. A novel multi-stage pyrolysis-reforming framework was applied to maximize H_2 yield, produced from mixed plastic waste, including HDPE, PP, and PS. Aspen Plus was utilized to design and simulate the pyrolysis and in-line reforming process due to its extensive database, which is crucial for accurately modeling and simulating complex chemical processes like plastic waste pyrolysis. The influence of reforming temperature and pressure was evaluated on H_2 and CO yields [12]. Process-level simulation using Aspen HYSYS has also been applied to mixed plastic waste streams containing PE, PP, PVC, and PS. The proposed process involved fast pyrolysis at 500 °C with sodium carbonate (Na_2CO_3) for the neutralization of HCl, followed by steam reforming and water–gas shift reactions at 700 °C, and the purification of the final H_2 using pressure swing adsorption (PSA). The simulation results indicated an annual H_2 production capacity of approximately 34×10^3 tons, which demonstrated both technical feasibility and favorable energy efficiency [4]. The aforementioned technical studies primarily focused on identifying optimal operating conditions through detailed process modeling, advanced engineering simulations, and the application of emerging optimization tools such as machine learning. In recent years, numerous chemical processes have also been subjected to comprehensive techno-economic evaluation using Aspen HYSYS. In particular, the Aspen Process Economic Analyzer (APEA) module has been employed to assess the economic feasibility of H_2 production via the gasification of biomass feedstocks, including coconut coir [13] and rice husk [14]. These analyses demonstrated that such processes could be highly profitable and represent economically attractive investment opportunities.

Sorting different plastics accurately is one of the major challenges due to the complexity of polymer types. In this study, the conversion of 12 distinct plastic waste streams was simulated having used an integrated pyrolysis and steam reforming process. The influence of the composition of the feedstock on H_2 production, solid carbon (char) formation, heavy oil yield, and the composition of the exhaust gas was systematically evaluated. This technical assessment enables the identification of optimal feedstocks that maximize H_2 yield while minimizing CO_2 emissions, thereby elucidating the strengths and limitations of each plastic stream. From an economic standpoint, capital and operating costs were estimated for each scenario using the Aspen Economic Analyzer, and key performance indicators were derived to assess the efficiency and profitability of the process. The combined technical and economic evaluation provides a robust framework for process optimization and supports the development of scalable and economically viable pathways for H_2 production from heterogeneous plastic waste streams.

2. Process description

The three stages, including pyrolysis, catalytic steam reforming and water gas shift processing, were considered to produce H_2 from plastic waste [15]. Grounded plastic waste (millimeter-scale) from different sources is used after removal of metals, glass, and mineral. After pre-heating, the feedstock is introduced into the first conversion reactor (CRV-100), where the pyrolysis reactions occur at 500 °C and 1 atm in a fluidized bed design (Figure 1).

During catalytic pyrolysis, the polymeric C–C and C–H bonds undergo homolytic cleavage to generate free-radical intermediates, a process facilitated by solid acid catalysts such as alumina and zeolites. Although the catalyst can increase the reaction rate, its effect is ignored in this simulation due to the use of a conversion reactor. The generated radicals are converted into secondary products including light gases, light to medium hydrocarbons, such as CH_4, C_2H_6, C_2H_4, and solid carbon. The reactions carried out in the pyrolysis reactor are as follows [4]:

- PP pyrolysis:

$$29C_3H_6 \rightarrow 19H_2 + CH_4 + C_2H_6 + C_2H_4 + C_3H_8 + C_4H_{10} + C_8H_{16} + C_{16}H_{32} + C_{28}H_{56} + 23C \quad (1)$$

- PE pyrolysis:

$$36C_2H_4 \rightarrow 3H_2 + CH_4 + C_2H_6 + C_2H_4 + C_3H_8 + C_4H_{10} + C_8H_{16} + C_{16}H_{32} + C_{28}H_{56} + 7C \quad (2)$$

- PVC pyrolysis:

$$C_2H_3Cl \rightarrow C_2H_2 + HCl \quad (3)$$

- PS pyrolysis:

$$19C_8H_8 \rightarrow 5H_2 + CH_4 + C_2H_6 + C_2H_4 + C_3H_8 + C_4H_{10} + C_8H_{16} + C_{16}H_{32} + C_{28}H_{56} + 85C \quad (4)$$

- PET pyrolysis:

$$29C_{10}H_8O_4 \rightarrow C_9H_8O_2 + C_6H_6 + C_2H_2 + CO + CO_2 + C_6H_5COOH \quad (5)$$

The separation of solid carbon from the bottom of the reactor and gaseous products from the top of CRV-100 prevents excessive coke accumulation and enables the improved control of carbon conversion. These two streams are subsequently recombined in the first mixer (MIX-100) to ensure uniform composition, enhance reaction efficiency, and maintain stable feed conditions prior to entering the second conversion reactor (CRV-101).

The off-gas from CRV-100 may contain chlorinated species, such as HCl, originated from PVC-containing feedstocks. To mitigate corrosion and downstream operational issues, this gas stream is directed to a fixed-bed dechlorination reactor (CVR-101). Sodium carbonate (Na_2CO_3) is introduced into the reactor via a second mixer (MIX-101) and acts as a reactive sorbent, neutralizing HCl to form NaCl, H_2O, and CO_2. This reactor operates at 500 °C and 1 atm and is modeled as a conversion reactor. The outlet stream from

CVR-101 is then combined with the preheated steam (500 °C) supplied from the heat exchanger (E-100) in a third mixer (MIX-102). The resulting mixture enters the third conversion reactor (CRV-102), a fluidized-bed design, operating at 700 °C and 1 atm, where steam reforming and water–gas shift reactions occur, promoting H_2 production and the conversion of CO to CO_2. Solid carbon, as a by-product, is simultaneously removed from the bottom of CRV-102 [4].

- Steam reforming of hydrocarbons:

$$C_nH_{2n}+nH_2O \leftrightarrow nCO+2nH_2 \qquad (6)$$

$$C_nH_n+nH_2O \leftrightarrow nCO+\frac{3}{2}nH_2 \qquad (7)$$

$$C_nH_{2n+2}+nH_2O \leftrightarrow nCO+(2n+1)H_2 \qquad (8)$$

- Steam reforming of oxygenated compounds:

$$C_6H_5COOH+7H_2O \leftrightarrow 7CO+10H_2 \qquad (9)$$

$$C_{10}H_8O_4+10H_2O \leftrightarrow 10CO+14H_2 \qquad (10)$$

$$C_9H_8O_2+9H_2O \leftrightarrow 9CO+13H_2 \qquad (11)$$

- Water gas shift reaction:

$$CO+H_2O \leftrightarrow CO_2+H_2 \qquad (12)$$

The gas stream exiting CRV-102 consists of H_2 along with CO_2, CO, H_2O, and carboxylic acids (CAs). This stream is first cooled in the heat exchanger (E-101) to 40 °C and subsequently fed into the liquid–gas two-phase separator (V-100). The liquid by-product (heavy oil) collected from V-100 contains CO_2, CAs, and H_2O. High boiling aliphatic oil or waxy products with only small amounts of gas and aromatics can be obtained by pyrolysis at ~550 °C [16]. The gas phase leaving V-100 is directed to a gas separation unit (X-100) for the purification of the final H_2, achieving up to 99.9% H_2 purity using conventional methods such as pressure swing adsorption (PSA) or membrane separation. The residual off-gas from X-100, primarily CO_2, CO, and trace water vapor, is vented or treated as waste (Figure 1).

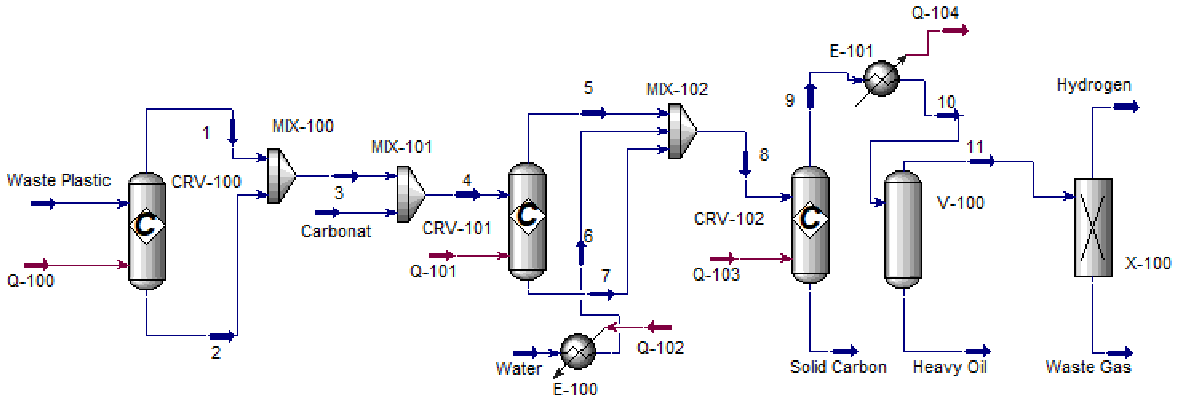

Figure 1. Aspen HYSYS process flow diagram for H_2 production from plastic waste (adapted from [4]).

2.1. Raw materials

Plastics are widely used across different industries due to their lightweight, durability, and cost-effective processing. PE is mainly used in the packaging sector for making films, bags, and containers. PP is applied in automotive components and textile fibers because of its good mechanical strength and low density. PVC is widely used in making medical equipment such as tubes and intravenous bags, as well as in producing construction materials like pipes and flooring. PS is commonly used in food packaging and medical disposables due to its clarity and ease of molding, and PET is extensively used in making beverage bottles and in the textile industry for producing synthetic fibers (Table 1).

Table 1.
Industrial applications of common polymers [17-20].

Feedstock	PE	PP	PVC	PS	PET
PKG	plastic bags	food packaging	beverage bottles	disposable containers	beverage bottles
MED	sterile covers	syringes	blood bags	petri dishes	bottles
AUT	fuel tanks	dashboard	door panels	sound panels	interior panels
CON	water pipes	sewage pipes	windows	thermal insulation	asphalt additive
TEX	Carpets	nonwoven fabrics	synthetic leather	foam padding	carpets

The waste generated in the packaging (PKG), construction (CON), textile (TEX), automotive (AUT) and medical (MED) industries and municipal solid waste (MSW) account for the largest share of plastic production worldwide [17-20]. These types of waste are generally found in the form of mixtures of PE, PP, PVC, PS, PET. To evaluate the performance of the plastic waste streams, the selected feeds in this study were chosen from these industries. Therefore, eleven different feedstocks containing specific blends of the mentioned five polymers were investigated (Table 2).

Table 2.
Components of the studied polymeric feedstocks.

Feedstock	PE	PP	PVC	PS	PET	H/C ratio		Price*
	%	%	%	%	%	-		USD/ton
single polymer								
PE	100	-	-	-		2.00	↓	350
PP	-	100	-	-		2.00		400
PVC	-	-	-100	-		1.50		290
PS	-	-	-	100		1.00		410
PET	-	-	-	-	100	0.80		420
mixed polymer								
PKG	56	29	3	5	7	1.85	↓	375
MED	30	40	15	10	5	1.77		365
AUT	25	45	13	5	12	1.74		370
MSW	44	22	9	13	12	1.68		373
CON	35	3	52	8	2	1.64		327
TEX	12	15	3	5	65	1.16		387

*2025 [21]

2.2. Process simulation

The process was designed and simulated for a feed capacity of 200×10^3 t/y using Aspen HYSYS (version 14). The Peng–Robinson thermodynamic package was selected due to its high accuracy in predicting the phase behavior, vapor–liquid equilibrium, and non-ideal gas properties in complex hydrocarbon mixtures. This equation of state is particularly suitable for light gases such as H_2, as well as heavier hydrocarbons formed through the cracking of polymer chains. Conversion reactors, where the reaction rate is determined by the overall conversion of the polymer feed to H_2, light hydrocarbons, and by-products, are made of stainless steel to withstand high temperatures and corrosive environments.

2.3. Process economics

An economic evaluation of the H_2 production process with a 20% rate of return (ROR) and a 20-year service life was performed using APEA. The feed price was defined separately for each plastic feedstock and was assumed to be 23% of the cost of virgin (unused) plastics [19,20]. Due to the fast pyrolysis and steam reforming reactions, a short residence time of 5 s was considered in the reactors. To obtain maximum olefins from recycling polyolefins, it is necessary to have a short residence time of the product gases in the fluidized bed zone, so that secondary reactions won't happen. Long residence times can intensify the secondary reactions and cause the production of more aromatics and coke [22]. The price of H_2 in 2025 was assumed to be 6000 USD/t, while the prices of heavy oil and Na_2CO_3 were 500 and 300 USD/t respectively [21]. The key design parameters of conversion reactors for each feedstock were extracted from the process simulation. Meanwhile, the total capital investment, including equipment and installation costs, as well as the operating cost was determined by simulator. Considering total product sales, three indicators, i.e., payback period, net profit and gross margin were calculated and evaluated for each plastic feedstock.

3. Results and discussion

Sorting, cleaning, and processing plastic waste require significant investment in technology, infrastructure, and labor which are the economic, technical and environmental challenges. From the technical point of view, the H/C ratio plays a crucial role in determining the H_2 production rate during pyrolysis. Polymers such as PE and PP have simple linear or slightly branched structures and high H/C ratios, which enhance thermal decomposition and promote higher H_2 generation efficiency. In contrast, polymers like PET and PVC have lower H/C ratios and more complex structures with aromatic rings, oxygenated, or chlorine functional groups that hinder decomposition, lead to the formation of coke and acidic by-products, and ultimately reduce the H_2 production yield.

PE and PP achieve the highest H_2 production rates of 62×10^3 t/y, while PVC and PET show the lowest rates of 32×10^3 and 27×10^3 t/y respectively. This is due to the bond dissociation energy of the C–CH_3 bond being lower, as compared to C–H bonds. The aromatic structured PS produced a lower H_2 yield and PET with an aromatic and oxygenated structure produced a low yield of H_2 and a high yield of CO_2 [23]. The presence of ester groups and aromatic rings in PET stabilizes the polymer structure; however, these groups require high energy to break and thus slow down the release of H_2. The presence of chlorine atoms in PVC causes the formation of stable C-Cl bonds and increases the thermal and chemical resistance of the polymer chain while limiting thermal decomposition and the release of H_2. Among plastic waste feedstocks, PKG and MED demonstrate the highest H_2 production rates of 59×10^3 and 57×10^3 t/y respectively, mainly due to their high content of PE and PP. Moreover, AUT and MSW perform well at around 56×10^3 t/y, whereas TEX and CON exhibit lowest H_2 production rate because of their more complex polymer compositions and lower content of H_2 (Table 3). At high temperatures, the degradation of polymers is caused by the side chain elimination followed by the alpha scission mechanism producing heavy hydrocarbon fractions in the pyrolytic oil which can be confirmed by the presence of wax components at higher temperatures. Tar formation during plastic gasification is characterized by the production of a complex mixture of condensable hydrocarbons. This mixture comprises predominantly single to 5-ring aromatic compounds, alongside other organic molecules containing oxygen, sulfur, and nitrogen. The mechanism of tar formation and evolution depends on the plastic composition. For example, primary tars of alkanes and alkenes are mainly derived from the degradation of polyolefins, while primary tars of an aromatic nature are mainly produced from the degradation of polymers with aromatic rings in their structure, i.e., PS and PET. Char is the solid residue after gases and tar having been generated from a carbonaceous material during devolatilization or pyrolysis [24].

Table 3.
H_2 production and by-products for each feedstock (capacity: 200×10^3 t/y).

Feedstock	Main product, H_2		By-products (10^3 t/y)				
	Flow rate (10^3 t/y)	Yield (t H_2/t feed)	C (solid)	Heavy oil	Waste gas	CO_2	CO
single polymer							
PE	62	0.31	42	0	347	173	98
PP	62	0.31	68	0	392	271	121
PVC	32	0.16	10	266	352	299	0
PS	43	0.22	126	17	337	300	0
PET	27	0.14	23	106	350	281	0
mixed polymer							
PKG	59	0.30	45	10	407	255	153
MED	57	0.29	33	22	353	321	32
AUT	56	0.28	31	30	405	332	73
MSW	56	0.28	39	22	404	313	91
CON	51	0.25	17	99	442	369	22
TEX	42	0.21	32	46	402	370	0

The H_2 production yield (t H_2/t feed) from the pyrolysis of various plastic feedstocks, based on a capacity of 200×10^3 t/y, ranges between 0.14 t of H_2/t of the feed (PET) and 0.31 t of H_2/t of the feed (PP and PE). Other feedstocks including PKG, MED, AUT, MWS, CON, PS, TEX, and PVC exhibit yields within this range too. Oxygen- or chlorine-containing polymers such as PET and PVC show lower H_2 production yields, primarily because of side reactions and the formation of undesired by-products during the pyrolysis. Aromatic rich polymers tend to produce higher amounts of solid residues, such as coke, whereas polymers with simpler or less aromatic structures favor the formation of liquid and gaseous products. PS exhibits the most increase formation of coke, with approximately 126×10^3 t/y of solid carbon. The aromatic rings in PS provide high thermal stability, leading to carbon deposition and the accumulation of heavy oil fractions [25], and reducing the yield of gaseous products such as H_2. PP follows with around 68×10^3 t/y of solid carbon, indicating extensive chain cracking but the partial retention of carbon in solids and heavy liquids.

PVC demonstrates negligible coke formation under the studied conditions, reflecting a decomposition pathway that promotes conversion into light gases and liquid products. The absence of aromatic structures enables the efficient formation of H_2, light hydrocarbons, and oils. CON shows the least formation of solid carbon, around 17×10^3 t/y, due to minimal aromatic content and limited side groups, resulting in the enhanced conversion of polymer into gaseous and liquid products and minimal solid residues. Beyond solid residues, gas and oil streams are pivotal for process optimization. Off gases, mainly comprising H_2, CO, CO_2 and C_2H_6, can be valorized or recycled within the plant to improve energy efficiency and reduce emissions. Heavy oils with higher boiling points require the careful control of pyrolysis parameters, such as the feed temperature, residence time, and heat and pressure integration, to minimize coke precursors and maximize the yield of lighter liquid products.

Generally, the chemical structure of polymers dictates by-product formation, influencing both the quantity and composition of solids, gases, and oils. Knowing the production rate and the type of by-products is important for environmental, economic and technical perspectives. The amount of the CO_2 produced during pyrolysis varies between 173×10^3 t/y for PE and 370×10^3 t/y for TEX, mainly depending on the polymer structure and the presence of heteroatoms affecting thermal decomposition. The high molecular weight and stable C–C bonds in PE require greater energy for full decomposition, limiting gas-phase conversion. PS and PVC show the average CO_2 emissions of around 300×10^3 t/y. The high carbon content and aromatic structure of PS facilitate the formation of solid and liquid residues during pyrolysis, which reduces the fraction of carbon released as CO_2. In PVC, chlorine atoms generate reactive intermediates that alter decomposition pathways and influence carbon distribution. These results highlight how polymer chemistry governs the pathways of carbon released during pyrolysis. The review of the existing literature indicates that a systematic cost analysis of plastic pyrolysis processes using Aspen HYSYS is still lacking. The economic evaluation reveals that the capital costs associated with H_2 production from plastic waste are consistent and show minimal variations (Table 4). In fact, changes in the type of the plastic feedstock have only a minor effect on the costs associated with the design, size, or specifications of the major process equipment involved in the process. The total operating cost (TOC) includes all ongoing expenses of the plant, such as labor, energy, maintenance, and consumable chemicals. Total raw materials cost refer to the cost of purchasing all feedstocks and consumables required for product production, such as incoming plastics and additives. Total product sales (TPS) refer to the aggregate monetary value associated with the production of the final product. This metric typically includes operating expenses and raw material costs and may also encompass additional expenditures related to packaging, processing, or preparation for market distribution. The total capital investment (TCI) ranges between 12×10^6 and 15×10^6 USD. This small variation indicates that the type of the plastic feedstock has only a limited impact on the estimated initial investment, as the overall design of the plastic waste pyrolysis process is largely standardized in terms of infrastructure. In the equipment cost (EC) category, all feedstocks show a similar value of around 2-3×10^6 USD. This suggests that a significant portion of costs is allocated to major equipment, such as reactors and heat exchangers, which are similar across production pathways. Moreover, the installation cost (IC) is in the range of 4 to 5×10^6 USD and is directly related to the equipment cost. This ratio reflects good efficiency in project execution and the control of facility costs. Comparatively PVC has the highest capital costs of 15×10^6 USD. This higher investment requirement can be attributed to the specific chemical characteristics of this polymer. For instance, PVC contains chlorine, which necessitates corrosion-resistant equipment and the strict control of reaction conditions, while PP and CON may have complex functional groups that demand precise temperature and pressure management. These factors increase the complexity and costs associated with the production system. In contrast, PE and PET, with capital costs of 14×10^6 and 12×10^6 USD respectively, involve simpler chemical processes, allowing for less specialized equipment and lower overall investment. This cost reduction stems from the simpler structure of PE and the higher thermal stability of PET.

Based on the sales and investment indicators (Table 4), TPS ranges from 287 to 472×10^6 USD/y. Among single-polymer feedstocks, PP and PE achieve the highest revenues, each reaching approximately 472×10^6 USD/y. These streams also exhibit relatively high operating expenditures (227–240×10^6 USD/y), reflecting large processing capacities and favorable economies of scale. The resulting sales-to-operating-cost ratios indicate superior profitability and shorter payback periods compared with other polymers. In contrast, PET and PS generate lower revenues (287 and 331×10^6 USD/y respectively), while their operating costs (242–245×10^6 USD/y) remain comparable to those of other feedstocks. This reduced margin between revenue and cost suggests diminished economic attractiveness for H_2 production from these polymers. Mixed plastic streams (PKG, AUT, MED, TEX, and MWS) show heterogeneous economic performance, with PKG and MED yielding the highest revenues among mixed feedstocks. Sales-to-operating-cost ratios across most cases fall within the range of 1.1–2.1, highlighting the strong economic viability of the thermochemical plastic waste conversion for H_2 production. Variations in economic performance are primarily attributed to differences in hydrogen yield, by-product distribution, and feedstock preprocessing requirements. Collectively, these results indicate that PP- and PE-rich feedstocks offer clear economic and energetic advantages over aromatic or chlorinated polymers, such as PS and PVC.

Table 4.

Sale and costs of H_2 production from various feed stocks.

Feedstock	**TPS**[1] (**10^6 USD**)	**capital costs (10^6 USD)**			**operating costs (10^6 USD/y)**		
		TCI[2]	**EC**[3]	**IC**[4]	**TOC**[5]	**UC**[6]	**RMC**[7]
Single waste plastics							
PE	472	14	3	5	227	1.0	208
PP	472	14	3	5	240	1.0	219
PVC	407	15	3	5	212	2.0	193
PS	331	12	2	4	242	0.9	222
PET	287	12	2	4	245	1.0	224
Mixed waste plastics							
PKG	460	13	3	5	233	1.1	213
MED	445	14	3	5	231	1.1	211
AUT	433	14	2	4	232	1.2	212
MWS	433	13	3	5	232	1.1	212
CON	441	14	3	5	221	1.4	202
TEX	342	12	2	4	236	1.0	216

[1]Total product sale; [2]Total capital investment; [3]Equipment cost; [4]Installion cost; [5]Total operating cost [6]Utility cost, [7]Raw materials cost

Utility costs fall within a narrow range (0.9–2.0×10^6 USD/y), indicating that the overall energy demand and auxiliary services are largely insensitive to polymer type. PVC exhibits the highest utility cost, followed by the CON stream, due to the increased process complexity and the need for stringent control of operating conditions. The presence of chlorine in PVC further elevates energy requirements and necessitates corrosion-resistant materials and additional gas-cleaning steps. In contrast, PS, PE, PP, and PET show the lowest utility costs, reflecting more favorable thermal behavior and reduced auxiliary energy demand. Mixed plastic streams, such as PKG and MWS, exhibit average utility costs (1.1–1.2×10^6 USD/y), consistent with the relatively uniform energy consumption across hydrocarbon-based feedstocks. The average utility cost is approximately 1.0×10^6 USD/y, which is the representative of industrial-scale operations and could be further reduced through heat integration and process optimization.

Gross margin, defined as the percentage of revenue remaining after deducting direct production costs (including the feedstock, by-product handling, and operating costs of the processing units) serves as a key indicator of operational efficiency and cost control. In this study, gross margins range from 22 to 67% across the evaluated feedstocks. The highest margins are observed for PE and MED, at 62 and 67% respectively, reflecting high process efficiency and relatively low production costs. In contrast, PET and PS exhibit the lowest margins (22 and 29% respectively), indicating higher cost intensity. Other feedstocks, including PP, MSW, AUT, and CON, fall within an average range, suggesting the stable and economically viable operation. The cost analysis results obtained in this study using the Aspen Economic Analyzer within Aspen HYSYS (2025) are comparable to those previously reported for five single polymers and their equiponderant mixture (2022), which were estimated using the factorial cost estimation method.

Net profit, defined as the revenue remaining after accounting for all operating and capital-related expenses, represents the overall profitability of the process. Net profits span from approximately 42 to 232×10^6 USD/y. The highest values are achieved for PE, PKG, and MED (232, 227, and 223×10^6 USD/y respectively), whereas TEX and PET yield the lowest profits (42 and 87×10^6 USD/y). The average net profit of approximately 170×10^6 USD/y highlights the strong economic potential of H_2 production from plastic waste, particularly when supported by the appropriate feedstock selection and process optimization.

The payback period across the evaluated feedstocks ranges from 0.8 to 2.3 y. The shortest payback period is observed for MED (0.8 y), reflecting rapid capital recovery driven by its high net profit. In contrast, TEX exhibits the longest payback period (2.3 y), requiring a longer time to recover the initial investment due to comparatively high operating and utility costs. Among simple hydrocarbon polymers, PE and PP display the payback periods of 1.2 and 1.3 y respectively, indicating a well-balanced relationship between capital investment, operating expenditures, and product revenues. PS, PVC, and PKG show similar the payback periods of approximately 1.3 y, suggesting relatively fast capital recovery. Mixed and industrial streams such as CON and AUT exhibit the moderate payback periods of around 1.4 y, reflecting stable and reliable economic performance. The payback period analysis confirms that H_2 production from plastic waste offers rapid and attractive economic returns, with an average payback period of approximately 1.4 years, underscoring the strong investment potential of the proposed process (Figure 2).

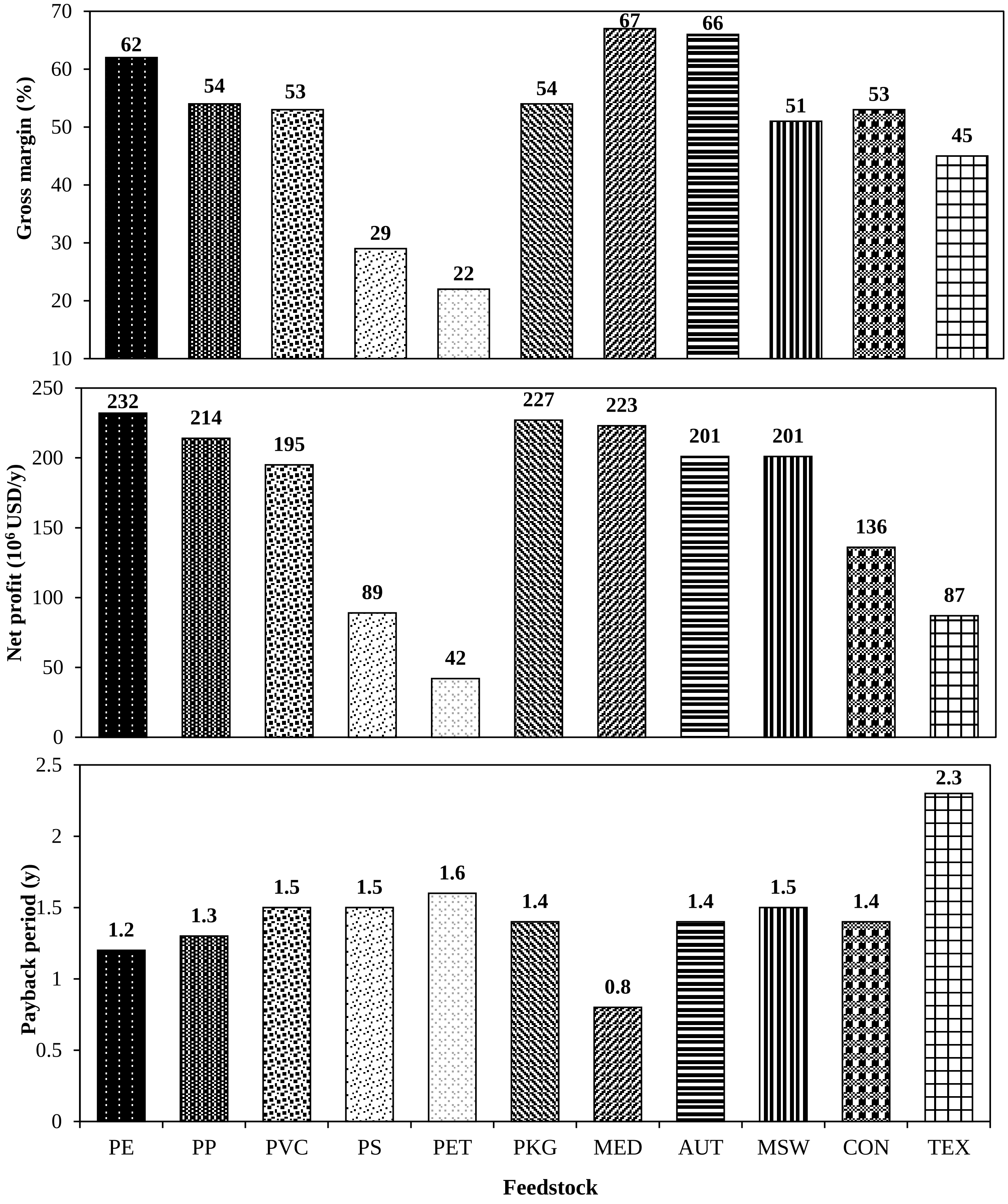

Figure 2. Economic evaluation of H_2 production from different feedstocks.

4. Conclusions

The techno-economic assessment of H_2 production from plastic waste reveals clear trade-offs among feedstocks in terms of the H_2 yield, by-product formation, operating costs, and payback period. Linear polymers with high H/C ratios favor efficient thermochemical conversion, resulting in higher H_2 yields and the reduced formation of solid carbon and greenhouse gas by-products. Industrial mixed plastic streams such as MED and PKG emerge as attractive feedstocks due to their high content of effective polymers, achieving the H_2 yields of 0.29 and 0.30 t of H_2 per t of feed respectively, with operating costs of approximately 231×10^6 and 233×10^6 USD/y. From an economic perspective, PE and MED demonstrate the strongest performance, with the net profits of 232×10^6 and 223×10^6 USD/y and gross margins of 62 and 67% respectively, accompanied by the short payback periods of 1.2 and 0.8 y. In contrast, PET and TEX exhibit lower economic attractiveness due to reduced H_2 yields and comparatively higher operating costs. Total capital investment and utility costs remain relatively stable across all cases, within the ranges of 12–15×10^6 USD and 0.9–2.0×10^6 USD/y respectively, indicating robust process scalability and industrial reliability. When technical and economic metrics are jointly considered, the most promising feedstocks for industrial-scale H_2 production from plastic waste are MED, due to its superior profitability and shortest payback period; PE, owing to its consistently high H_2 yield and strong economic performance; and PP, which offers a balanced combination of technical efficiency, moderate costs, and solid profitability.

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