ISSN 2664-4150 (Print) & ISSN 2664-794X (Online)
South Asian Research Journal of Engineering and Technology
Abbreviated Key Title: South Asian Res J Eng Tech

| Volume-8 | Issue-1 | Jan-Feb- 2026 | **DOI: https://doi.org/10.36346/sarjet.2026.v08i01.005**

Review Article

Gasification of Plastic Waste as a Sustainable Route for Energy Recovery and Circular Economy Integration

Mukhalad Hamza Hussein[1]*, Qassim Ammar Ahmood AL-Janabi[1], Roaa Basim Shnain[1]
[1]Environmental Pollution Department, Collage of Environment Science, Al-Qasim Green University, Babylon51013, Iraq

***Corresponding Author:** Mukhalad Hamza Hussein
Environmental Pollution Department, Collage of Environment Science, Al-Qasim Green University, Babylon51013, Iraq

Article History
Received: 03.12.2025
Accepted: 26.01.2026
Published: 02.02.2026

Abstract: The accumulating piles of plastics have emerged to be among the greatest environmental issues across the world because of their inability to degrade, the low recycling rates, and non-biodegradability. Gasification has potential as a sustainable and technologically encouraging pathway towards converting plastic waste into useful energy carriers, and, in particular, synthesis gas, a mixture of hydrogen and carbon monoxide. As opposed to incineration, gasification is controlled with the oxygen conditions, which transforms the plastics into clean syngas with less emission and more energy efficiency. By facilitating the recovery of energy, reuse of resources, and the possibility of downstream generation of fuels and chemicals, this process promotes waste reduction as well as the objectives of the circular economy. The current paper is a review of the gasification of plastic waste, focusing on the mechanism of the process, reactor configuration, operating parameters, the composition of the syngas, and its environmental performance. It also addresses the concept of techno-economic viability and the results of life-cycle assessment and integration in the context of the circular economy. Even though there are still some challenges, such as tar formation, feedstock heterogeneity, and scalability, the improvement of catalytic reforming, co-gasification, and integration of renewable energy is improving the possibility of large-scale implementations. Gasification, therefore, is an important way forward in ensuring sustainable waste management and a low-carbon system of energy, which helps to not only protect the environment but also enhance economic strength.

Keywords: Plastic Waste, Gasification, Syngas, Circular Economy, Life-Cycle Assessment, Tar Reduction, Hydrogen Production.

1. INTRODUCTION

The manufacturing of plastics across the world has grown in the past few decades to more than 400 million metric tonnes each year, and it is anticipated that by 2050, this number is set to rise again to twice the current demand. Plastics have proved to be irreplaceable in all industries, including the packaging, building, and electronics sectors, due to their durability, light weight, and low prices. Nevertheless, they are also the properties that make them resistant to the environment to cause severe ecological and health risks related to mismanagement and inappropriate disposal (Davidson *et al.,* 2021). The accumulation of plastic waste in landfills and oceans has become one of the classic environmental crises of the 21st century, with microplastics penetrating food chains and threatening the health of the human population. The current linear take-make-dispose system of producing and disposing of plastics has not turned out to be sustainable and requires the implementation of transformative strategies that will reclaim value and reduce environmental effects (Thiounn and Smith, 2020).

Recycling of plastics through mechanical recycling, as the most common recycling approach implies, involves collecting, sorting, grinding, and remolding plastics. Even though it is simple, it is limited to polymer degradation, contamination, and the inability of plastics to mix, which results in downcycled materials of low quality (Kijo-Kleczkowska and Gnatowski, 2022). On the same note, landfill disposal and incineration, although they are effective in reducing the volume of waste, do not help in minimizing greenhouse gas emissions and toxic residues. The traditional ways of operation

CITATION: Mukhalad Hamza Hussein, Qassim Ammar Ahmood AL-Janabi, Roaa Basim Shnain (2026). Gasification of Plastic Waste as a Sustainable Route for Energy Recovery and Circular Economy Integration. *South Asian Res J Eng Tech, 8*(1): 28-34.

do not create a material loop, leading to resource inefficiencies and climate change (Faraca & Astrup, 2019). Therefore, other recycling routes that are able to deal with mixed, contaminated, or composite plastic streams have gained importance.

Thermochemical conversion, which also includes processes such as pyrolysis and gasification, has become an alternative of promise in terms of plastic waste valorization. Gasification, specifically, entails the transformation of carbon-based plastic substances to a synthesis gas (syngas) which is mainly composed of carbon monoxide (CO) and hydrogen (H2) by partial oxidation in high temperatures, usually 600-1,000 °C (Lopez *et al*., 2018). This process is different than incineration, as it is conducted under sub-stoichiometric oxygen conditions and, as such, a vast amount of pollutant emissions are reduced with a resultant output of syngas that can be used as a feedstock source of fuels, chemicals, and power generation. Gasification, therefore, offers two opportunities: to recover energy and to dispose of plastics in landfills, which will serve both the goals of the circular economy and environmental sustainability (Davidson *et al*., 2021).

Most recent gasification technology innovations have proven their possibility to co-process the plastics with the biomass and municipal solid waste to maximize the carbon conversion efficiency and enhance the calorific value of its product, syngas (Saebea *et al*., 2020). Researchers note that gasification is very efficient in energy recovery, and it generates fewer pollutants than incineration, particularly when it is accompanied by efficient gas-cleaning systems and catalysts (Costa *et al*., 2022). In addition, the combination of gasification with renewable energy feeds or carbon capture, utilization, and storage (CCUS) technologies further increases its performance with respect to the environment. Regardless of these benefits, they have their issues, such as changing feedstock composition, tar formation, and high operational costs (Hossain *et al*., 2022). Overcoming these technological and economic challenges is important to increasing gasification to be an industrially viable option in managing plastic waste.

The overall objective of the research is to give a detailed overview of plastic waste gasification as a developed thermochemical recycling route. The article discusses the mechanism of the process, reactor design, operating conditions, and life-cycle operation based on environmental and economic measures. It also discusses how gasification can be incorporated into the framework of the circular economy with a focus on its contribution to the conversion of plastic waste into valuable resources and energy carriers. Lastly, it points out the major obstacles, such as technical, economic, and policy-related hindrances to large-scale uptake and describes the course of action to make the processes more efficient, lower the emissions, and increase the sustainability of the world.

2. Gasification Process for Plastic Waste

2.1 Feedstock Characteristics and Preprocessing

Physical and chemical properties of the feedstock have a tremendous impact on the efficiency and stability of plastic waste gasification. Common gasification feeds are post-consumer polymers, including polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET), and polyvinyl chloride (PVC), either singular or in mixed plastic waste streams (Lopez *et al*., 2018). The different types of polymers vary in composition, calorific value, elemental ratios, and degradation pathways, which influence the syngas yield and composition. Due to the high hydrogen-to-carbon (H/C) ratio and absence of halogen, such polyolefins as PE and PP tend to generate a higher-quality syngas of higher hydrogen content and fewer toxic by-products than chlorine-containing PVC or oxygenated polymers such as PET (Saebea *et al*., 2020). Contamination of feedstock- through additives, dyes, fillers, or embedded metals- is a major challenge that causes instability in the operation and facilitates tar formation through reaction. Therefore, proper pre-processing measures like sorting, shredding, and drying are crucial to obtaining homogenous feedstock quality and effective conversion. Shredding enhances the surface heat transfer, whereas drying decreases the amount of moisture that otherwise would decrease the temperature of the reactor and change the composition of gases (Kijo-Kleczkowska and Gnatowski, 2022).

Preprocessing helps in an important environmental and operational purpose as well by eliminating inert substances, halogens, and metals that may render catalysts inactive or corrode reactor elements. Density-based separation and near-infrared (NIR) spectroscopy, which are classified as advanced sorting technologies, are currently being employed to sort polymers and remove contaminants before the gasification process (Qureshi *et al*., 2020). Plastic and biomass or coal co-gasification has been found to address the problems of high volatile content and low reactivity of some plastics by enhancing the overall gasification kinetics and calorific value of the resulting syngas (Hossain *et al*., 2022). Furthermore, the size of particles and bulk density of the feedstock should be optimized to be able to feed it continuously into gasifiers, particularly fluidized or downdraft reactors, where homogeneous heat transfer is necessary to reduce tar formation and maximize the gas output (Costa *et al*., 2022). Hence, the efficiency of the process, as well as the quality of the product, is based on proper feedstock preparation, which is an essential step to the large-scale viability of plastic waste gasification and its environmental sustainability.

2.2 Mechanism and Reaction Pathways

Plastic waste gasification is a multistage, complex thermochemical process that consists of numerous simultaneous reactions and sequential reactions that ultimately convert solid polymers to synthesis gas (syngas) that is high in hydrogen (H2) and carbon monoxide (CO). Thermal depolymerisation is used to initiate the process and the long polymer chains are subjected to high temperatures (usually 600-1000 degC) to split into a variety of smaller hydrocarbon fragments, radicals, and oligomers (Lopez *et al*., 2018). These unstable intermediates then volatilize and are further cracked into light gases, including methane, ethylene, and other light molecule compounds (Saebea *et al*., 2020). The second step is reaction reforming, where the volatiles are reacted with oxidising or gasifying reagents such as steam, carbon dioxide, or oxygen, to form syngas by endothermic reaction reforming. Meanwhile, the formation of tar and char is a process that takes place when heavy hydrocarbons condense or polymerise to leave behind residues that have high boiling points and may interfere with the operation of the reactor or reduce the purity of the syngas (Qureshi *et al*., 2020). The tars may be subsequently thermally or catalytically cracked to produce light gases, which improves hydrogen and carbon monoxide. The temperature, the ratio of the gasifying agent, the type of catalyst, and overall process efficiency determine the composition of the resulting syngas and its overall efficiency (Bashir *et al.,* 2025).

The **core reactions** that govern plastic gasification include both heterogeneous and homogeneous reactions. Typical reactions include *steam reforming* ($C_nH_m + H_2O \rightarrow CO + H_2 + H_2O$), *dry reforming* ($C_nH_m + CO_2 \rightarrow 2CO + H_2$), and *char gasification* with steam or carbon dioxide ($C + H_2O \rightarrow CO + H_2$; $C + CO_2 \rightarrow 2CO$). These reactions are highly endothermic and therefore require significant heat input, often maintained through partial oxidation reactions that generate exothermic heat (Costa *et al*., 2022). The ratio of these reactions depends on the equivalence ratio (ER), the ratio of real supply of oxygen to stoichiometric supply, which directly determines the composition and calorific value of the produced syngas. The higher ER values are associated with a better quality of syngas (large content of CO and H_2), whereas the higher the values of ERs, the higher the content of CO_2 and H_2O, but the lower the heating value (Hossain *et al*., 2022). Nickel-based catalysts or olivine-based catalysts are commonly used to enhance tar reactions and reforming reactions in order to optimize the production of syngas and to minimize tar-related issues (Kijo-Kleczkowska and Gnatowski, 2022). The type of reactor also affects the kinetics of the reaction and the gas composition: fluidized-bed and plasma gasifiers offer greater mixing and temperature homogeneity, but fixed-bed simple systems are also possible, whereas they tend to accumulate tar. Therefore, managing the interactions of thermal cracking, reforming, and oxidation reactions has continued to be a key in streamlining the plastic waste gasification process towards energy savings and environmental competence.

2.3 Reactor Types and Operational Parameters

Various reactor designs have been investigated based on gasification of plastic waste, and the designs affect the conversion efficiency, composition of the syngas, and tar formation. The most used reactor types are fixed-bed, fluidized-bed, dual-stage, and plasma reactors, with each having different strengths depending on the type of feedstock and the purpose of the process. Under a fixed-bed gasifier, plastic garbage undergoes the process of drying, pyrolysis, oxidation, and reduction in various reaction zones where gases move co-currently or counter-currently. They are easy and economical but have defects in the distribution of temperature and an increase in tar generation (Lopez *et al*., 2018). The fluidized-bed gasifier, on the other hand, is able to guarantee enhanced mixing, temperature stability, and scalability, and thus is applicable in the continuous processing of heterogeneous feedstocks like mixed plastics (Saebea *et al*., 2020). It has been demonstrated through experiments that the bubbling fluidised-bed reactors produced a high-quality syngas, with heating values of about 6-8 MJ/m3, when plastic waste is air gasified at around 750 °C with equivalent ratios of 0.25-0.35 (Qureshi *et al*., 2020). Dual-stage gasifiers are pyrolysis systems that improve tar cracking and purification of the synthesized syngas by separating oxidation and volatile generation stages (Kijo-Kleczkowska and Gnatowski, 2022). More sophisticated systems are using plasma gasification, which utilizes very high temperatures (>1300 °C) and plasma arcs so that virtually all polymers are broken down, with the resulting production of cleaner syngas and a minimum of tar and solid residues (Bashir *et al*., 2025).

The issue of operational parameters is determinant of gasification performance. The temperature is normally between 600-900 °C, and the higher the temperature, the more char is converted and the less tar generated but the higher the energy requirement (Costa *et al*., 2022). One of the control variables is the equivalence ratio (ER), the ratio of supplied oxygen to stoichiometric oxygen: a balance of energy supply and the quality of the syngas can be achieved with 0.2-0.4 (Lopez *et al*., 2018). The composition of the product depends on the type of gasifying agent (air, steam, CO_2, or pure oxygen); steam gasification is more likely to provide hydrogen-rich syngas, whereas CO_2 gasification increases the production of carbon monoxide (Saebea *et al*., 2020). It has been reported that steam-to-carbon ratios above 1 favour the hydrogen production via the steam-reforming reactions to the advantage of the H2/CO ratio essential to the downstream synthesis applications (Hossain *et al*., 2022). The stability of the reactor and its conversion efficiency are influenced by other operational factors which include the size of feed particles, the rate of feeding as well as the presence of catalysts or inert materials. Nickel-based materials and olivine are common catalysts applied in tar cracking and minimizing the formation of heavy hydrocarbons, as well as enhancing the generation of gases (Qureshi *et al*., 2020). Optimization of reactor like the improvement of the heat transfer and control of the residence time is still necessary in increasing the product quality and guaranteeing the commercial feasibility of plastic waste gasification.

2.4 Syngas Yield and Quality

The quality of the gas that is obtained after the process of plastic waste gasification is an important parameter that defines the prospect of energy recovery of the process and its efficiency. It is usually measured in options like lower heating value (LHV), ratio of hydrogen to carbon monoxide (H2/CO), cold gas efficiency (CGE) and tar content. LHV gives an indication of how much high-energy content the syngas has, whereas the H2/CO ratio will give an indication of how suitable the syngas can be in the downstream process like Fischer-Tropsch synthesis or hydrogen fuel (Lopez *et al*., 2018). As a result of experimental studies, it has been demonstrated that plasma-assisted gasification, which is done at an extremely high temperature (>1300 °C) under controlled atmospheric conditions, produces a high quality of syngas than conventional methods. As an example, when medical plastic waste (e.g. FFP2 masks) was plasma-gasified in the presence of carbon dioxide as a gasifying medium, a syngas made of about comprised of a mixture of carbon dioxide and water vapor approximately of 80 vol% combined H_2 + CO (H_2: 24.6 vol%; CO: 55.8 vol%), with an LHV of around 13.88 MJ/Nm³, a syngas yield of 3.13 Nm³/kg feedstock, carbon conversion efficiency of 70.6%, and a CGE of 47.8% (Srinivasan *et al*., 2023). These findings demonstrate that high-temperature plasma conditions facilitate near-complete molecular breakdown, enhancing hydrogen production and reducing tar formation.

For conventional air or steam gasification processes, the syngas characteristics tend to vary based on parameters such as equivalence ratio, gasifying agent, and feedstock composition. Typical LHV values for mixed plastic waste range from 3 to 12 MJ/Nm³, it is dependent on the degree of oxidation and type of polymer (Saebea *et al*., 2020). PE and PP give rise to hydrogen-rich syngas, whereas oxygenated polymers (PET or PVC) should produce higher CO2 and CH4 fractions, respectively, because of the elements of oxygen and chlorine (Kijo-Kleczkowska and Gnatowski, 2022). Plastic-biomass or plastic-coal co-gasification has also become a promising attempt to enhance the quality of gases and the level of energy production. Biomass presence not only increases the reactivity and stabilizes the distribution of the temperature, but also causes synergistic effects, which contribute to the increase in the total carbon conversion and the decrease in tar yields (Bashir *et al*., 2025). Moreover, it is possible to optimize the steam-carbon ratio (>1.0) to increase the yield of hydrogen via endothermic reactions during the reforming of feeds via endothermic reactions, and applying nickel-based or olivine catalysts further improves the quality of the syngas by cracking heavier hydrocarbons and purifying them (Qureshi *et al*., 2020). Therefore, by means of attentive management of the processing variables and synthesis techniques, plastic waste can be gasified to produce high-grade syngas that can be used in energy production as well as in the synthesis of chemicals, which is a feasible waste-to-fuel conversion approach in the sustainable energy model.

3. Environmental and Energy Perspectives – Life Cycle, Techno-Economics and Circular Economy

Environmental and energy studies indicate that in combination with an effective system of energy systems and renewable sources, the gasification of plastic waste can be used to provide quantifiable environmental benefits over such disposal methods as incineration or landfill. In the case of life-cycle assessment (LCA) studies, it was established that the process significantly lowers the emission of greenhouse gases and the potential of fossil depletion as a result of the valorisation of the plastic waste into syngas, instead of its release as CO2 and other pollutants. According to Davidson, Furlong and McManus (2021) LCA offers a system in which the sustainability of chemical recycling processes such as gasification can be determined by taking into consideration matters relating to the use of energy and the consumption of resources and the emission of gases. According to Costa, Vaz de Miranda, and Souza (2022), the purity of the feedstock, the efficiency of the reactor, and selection of the source of energy have a strong impact on the life-cycle performance. Gasification has a smaller carbon footprint when using renewable electricity compared to pyrolysis and incineration as evidenced by Gandhi, Farfaras, and Wang (2021). Nevertheless, such studies also point to the possible existence of trade-offs, in particular, the human toxicity and marine ecotoxicity that is likely to rise during the extraction and production of renewable energy materials. Therefore, clean electricity integration, efficient gas cleaning, and heat recovery should be the main priorities of the future gasification systems to maximize the environmental performance.

Techno economic assessment (TEA) is an addition to the environmental assessment as it evaluates the financial viability and financial pay off of gasification plants. According to research like that of Jeswani *et al*., (2021), the economic appeal of gasification is positive in a scenario where plants are large scale, with feedstocks that are mixed or low cost, and supported by policy incentives favoring the use of waste-to-energy facilities. An illustration of this is that mid-scale gasification facilities integrated with renewable energy sources are projected to have short payback periods of as low as two to three years and internal rates of returns of more than 35 percent. Arena, Mastellone, and Perugino (2003) also argue that the cost of life-cycle could be lowered in case by-products, e.g., hydrogen or methanol, are monetized. The co-location of the process with waste management infrastructure also improves the techno-economic perspective, which minimizes the logistics costs and allows for maintaining the uninterrupted feedstock.

Gasification is a strategic approach in terms of the circular economy in terms of being a last-resort measure in mechanical recycling of plastics that cannot be recycled by mechanical methods because of contamination or degradation. According to Bashir *et al*., (2025), plastic gasification has the potential to generate syngas as a universal energy source to power production, chemical production, or hydrogen production-enabling resource-saving and bridging the gap between the production of waste and energy recovery. Plastics co-gasified with biomass or municipal solid waste have synergistic advantages, including creating a better energy balance, greater use of carbon, and lesser tar (Saebea *et al*., 2020). Through it, gasification helps to lessen the reliance on landfills and achieve a low-carbon and circular economy. However, the shift to industrial sizes requires combined policies, a price on carbon, and cooperation of the stakeholders to make sure that the gains of the environmental aspects are accompanied by economic feasibility.

4. Challenges and Future Perspectives

Although plastic-waste gasification is a sustainable waste-to-energy solution, there are still a number of technical and operational challenges that make it difficult to conduct on a large scale. The problem of the feedstock heterogeneity is one of the most acute because a mixed plastic stream with different compositions, contamination with halogen, metals, and additives, and irregular particle size can frequently result in process instability and uneven gas yields. These contaminants may lead to the formation of deleterious by-products, reactor corrosion, and unstable quality of syngas, rendering it hard to maintain steady-state operation (Lopez *et al.*, 2018). The second issue that remains is the formation of tar and char because heavy hydrocarbons formed during thermal decomposition are likely to condense against colder surfaces in the reactor and downstream equipment. This not only decreases the yield and efficiency of the gas but also hinders the pipeline and filters, resulting in operational downtimes and increased maintenance expenses (Qureshi *et al*., 2020). In addition, there is also a problem with the design and durability of catalysts that are used in the process of tar cracking and reforming. Nickel-based and olivine compounds are good catalysts but can be deactivated by impurities and sintered during long-term exposure to high-temperature processes (Kijo-Kleczkowska and Gnatowski, 2022). On the same note, reactor design should be further optimized to guarantee even heat transfer, residence time, and good mixing to convert it completely. The downstream integration of gasification with hydrogen extraction, methanol production, and electricity production is also quite a technical challenge because it requires a sophisticated system of gas cleaning and extracting contaminants (Saebea *et al*., 2020). Last, gasification system scale-up is a significant obstacle; despite a large number of studies having proven the technical feasibility in the laboratory and pilot phases, commercial-scale implementation is not a success yet, particularly relative to better-established biomass or coal gasification systems (Davidson *et al*., 2021).

To address these issues, specific research and innovation should be done to enhance the design of processes or system integration. The higher quality of the feedstock and sorting can be enhanced by the high degree of contamination reduction through the use of advanced technologies in pretreatment, which will result in standardizing the quality of input and improved stability of processes. Another research field of deep importance is the creation of new, affordable catalysts that can remain active even in the most adverse conditions. These catalysts might enhance the efficiency of tar reforming and also increase the ratio of H2/CO and reduce deactivation. Simultaneously, the new reactor types, including dual-stage, plasma-assisted, or fluidized-bed gasifiers, can be refined to enhance the conversion rates and the energy efficiency (Bashir *et al*., 2025). In the future, hybrid co-gasification methods also need to be highlighted, in which the plastics are managed with biomass or coal to capitalize on the complementary reaction kinetics and thermal characteristics. The integration of these systems with carbon capture, utilization, and storage (CCUS) can result in a further decrease in net emissions and a better environmental impact of the gasification plants (Costa *et al*., 2022). In addition to technical improvements, system-level life-cycle analysis (LCA) and techno-economic analysis (TEA) through the whole value chain, from waste collection process to the use of energy, should be conducted to determine the best process configuration that suits various regional environments, especially in developing nations where waste is high. Finally, the technology will need the support of policies and innovative business models to scale up. Industrial investment can be triggered by incentives like feedstock subsidies, carbon credits, and regulatory frameworks that give incentives to transition of waste to value. Big-scale pilot and demonstration projects and especially in countries such as India, where the problem of plastic waste has been acute, will be very crucial in the validation of economic feasibility, optimization of the operational parameters, and the creation of confidence in the full-scale commercial implementation.

5. CONCLUSION

One of the best and most sustainable technological avenues in solving the increasing plastic waste crisis in the world is plastic waste gasification. Gasification, in contrast to conventional mechanical recycling, is not restricted by polymer degradation and contamination because the thermochemical process can accept heterogeneous, multi-layered, and contaminated plastic waste streams that otherwise would suffer in landfills or an open dump. These materials are transformed into a high-energy synthesis gas (syngas) that is mostly made up of hydrogen and carbon monoxide gases that can be utilized as clean fuels or as feedstock by the chemical industries and power generation. This way, gasification will not only leave massive amounts of non-recyclable plastic in the environment, but it will also ensure energy recovery and resource circularity. It plays a very important role in the management of waste and the renewable energy system in facilitating the general goals of sustainable development and environmental protection.

Research has indicated that gasification is capable of drastically cutting down on greenhouse gas emissions as well as fossil fuel reliance when combined with renewable energy sources or carbon-capturing technologies. It is also cost-effective, energy-efficient, and has a high ROI in case of appropriate scaling. Gasification helps bring about a more circular economy where waste can be used as a resource and not as a burden through the conversion of waste into valuable products, including hydrogen, methanol, and synthetic fuels. Nevertheless, in spite of its obvious benefits, the technology is subject to numerous obstacles to its implementation on a large scale. Issues like variability of feedstock, tar and char formation, reactor fouling, and catalyst degradation remain a constraint to operational stability and commercial viability. These technical challenges will be overcome by continued development of superior reactor approaches, better catalysts, and effective techniques of pretreating feedstock.

The development of this direction in the future will rely on combining gasification with other technologies and balancing the chain of the process, i.e., the collection and sorting of wastes, recovery of energy, and regulation of emissions. The potential to increase carbon efficiency and balance of generation can be achieved by a hybrid system with plastic gasification and biomass or municipal solid waste treatment. The creation of full-life-cycle assessment and techno-economic assessments to guarantee environmental and financial sustainability will also be important. The application of gasification technologies will also accelerate with policy initiatives that can encourage the implementation of the circular economy like carbon credits, renewable energy incentives, and public-private associations.

In the case of Iraq, where the processes of plastic waste generation have been growing exponentially with the growth and industrialization of cities, gasification can be particularly seen as a promising route to sustainable waste management and energy diversification. Waste-to-energy strategies are not only timely but also very necessary in the country due to the increasing energy requirements as well as environmental issues. Gasification can assist Iraq in decreasing its reliance on landfills as well as generate green jobs and enhance its renewable energy base by transforming non-recyclable plastic wastes into valuable fuels and raw materials. By establishing properly planned pilot projects and facilities that are capable of processing mass-produced wastes on an industrial scale, Iraq can be one of the region's leaders in sustainable waste valorization. In the long run, gasification of plastic waste is capable of becoming part of the foundation of Iraq's approach to cleaner production, reduced carbon emissions, and increased conformity to the global sustainability agenda.

REFERENCES

- Arena, U., Mastellone, M. L., & Perugini, F. (2003). Life cycle assessment of a plastic packaging recycling system. *International Journal of Life Cycle Assessment, 8*(2), 92–98. https://doi.org/10.1007/BF02978432
- Bashir, M. A., Ji, T., Weidman, J., Soong, Y., Gray, M., & Shi, F. (2025). Plastic waste gasification for low-carbon hydrogen production: A comprehensive review. *Energy Advances, 4*(3). https://doi.org/10.1039/D4YA00292J
- Costa, L. P., Vaz de Miranda, D. M., & Souza, D. A. (2022). Critical evaluation of life cycle assessment analyses of plastic waste pyrolysis. *ACS Sustainable Chemistry & Engineering, 10*(3), 1245–1259. https://doi.org/10.1021/acssuschemeng.1c06991
- Davidson, M. G., Furlong, R. A., & McManus, M. C. (2021). Developments in the life cycle assessment of chemical recycling of plastic waste–A review. *Journal of Cleaner Production, 293*, 125996. https://doi.org/10.1016/j.jclepro.2021.125996
- Faraca, G., & Astrup, T. F. (2019). Plastic waste from recycling centres: Characterisation and evaluation of plastic recyclability. *Waste Management, 95*, 388–398. https://doi.org/10.1016/j.wasman.2019.06.038
- Gandhi, N., Farfaras, N., & Wang, N. H. L. (2021). Life cycle assessment of recycling high-density polyethylene plastic waste. *Journal of Renewable Materials, 9*(5), 1124–1139. https://doi.org/10.32604/jrm.2021.014961
- Hossain, R., Islam, M. T., Shanker, R., Khan, D., & Locock, K. E. S. (2022). Plastic waste management in India: Challenges, opportunities, and roadmap for circular economy. *Sustainability, 14*(5), 3021. https://doi.org/10.3390/su14053021
- Jeswani, H., Krüger, C., Russ, M., Horlacher, M., & Azapagic, A. (2021). Life cycle environmental impacts of chemical recycling via pyrolysis of mixed plastic waste in comparison with mechanical recycling and energy recovery. *Science of the Total Environment, 769*, 144483. https://doi.org/10.1016/j.scitotenv.2020.144483
- Kijo-Kleczkowska, A., & Gnatowski, A. (2022). Recycling of plastic waste, with particular emphasis on thermal methods. *Energies, 15*(8), 2829. https://doi.org/10.3390/en15082829
- Lopez, G., Artetxe, M., Amutio, M., Bilbao, J., & Olazar, M. (2018). Thermochemical routes for the valorisation of waste polyolefinic plastics to produce fuels and chemicals. *AIMS Energy, 6*(5), 735–757. https://doi.org/10.3934/energy.2018.5.735
- Qureshi, M. S., Oasmaa, A., Pihkola, H., Deviatkin, I., Tenhunen, A., Mannila, J., & Laine-Ylijoki, J. (2020). Pyrolysis of plastic waste: Opportunities and challenges. *Journal of Analytical and Applied Pyrolysis, 152*, 104804. https://doi.org/10.1016/j.jaap.2020.104804

- Saebea, D., Ruengrit, P., Arpornwichanop, A., & Patcharavorachot, Y. (2020). Co-gasification of plastic waste and biomass in a downdraft gasifier: Effects of operating parameters and product gas quality. *Renewable Energy, 146*, 1441–1452. https://doi.org/10.1016/j.renene.2019.07.044
- Srinivasan, A., Albalawi, F., Ramasamy, D. L., & Subramanian, P. (2023). Plasma gasification of medical plastic waste to syngas in a CO_2 environment. *Sustainability, 17*(5), 2040. https://doi.org/10.3390/su17052040
- Thiounn, T., & Smith, R. C. (2020). Advances and approaches for chemical recycling of plastic waste. *Nature Reviews Materials, 5*(9), 706–724. https://doi.org/10.1038/s41578-020-0190-4.