

Liquefied Petroleum Gas: A Comprehensive Review of Its Manufacturing and Refining Routes

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Abstract

Liquefied Petroleum Gas (LPG) is a clean-burning, high-energy fuel that plays a vital role in energy systems across residential, commercial, and industrial sectors globally. This paper offers an extensive review of the diverse manufacturing and refining methods involved in LPG production, emphasizing both traditional and innovative technologies. LPG is mainly produced as a by-product of natural gas processing and petroleum refining. The review delves into essential processes such as crude oil distillation, catalytic cracking, and hydro processing, which are crucial for the separation and enhancement of propane and butane, the primary constituents of LPG. Furthermore, the paper examines the incorporation of gas recovery systems in upstream natural gas operations and the significance of fractionation units in maintaining the purity and safety of the final LPG product. It also addresses strategies for process optimization aimed at improving yield and energy efficiency, alongside environmental considerations linked to LPG production. Given the rising demand for low-emission fuels, the potential for producing bio-LPG from renewable resources is briefly discussed as a promising alternative. Data analysis was conducted using advanced Python programming, with predictive results generated accordingly. The study also sheds light on global production trends, regional differences in refining technologies, and the challenges related to storage, transportation, and regulatory compliance. Ultimately, this review aspires to be a valuable resource for engineers, researchers, and policymakers who wish to comprehend the technological framework of LPG manufacturing while pinpointing opportunities for innovation and enhancement considering changing energy needs and sustainability objectives.

Keywords: LPG production; Natural gas processing; Petroleum refining; Hydrocarbon separation; Process optimization; Bio-LPG

Abbreviations: BPCL: Bharat Petroleum Corporation Limited; C_2H_4 : Ethylene; C_3H_6 : Propylene; C_3H_8 : Propane; C_4H_{10} : Butane; CAGR: Compound Annual Growth Rate; C_nH_m : General formula for Hydrocarbons (where n and m are integers); CO: Carbon Monoxide; CO_2 : Carbon Dioxide; FCC: Fluid Catalytic Cracking; GAIL: Gas Authority of India Limited; HPCL: Hindustan Petroleum Corporation Limited; HYSYS: Hyprotech Systems (Process Simulation Software by AspenTech); IOCL: Indian Oil Corporation Limited; LPG: Liquefied Petroleum Gas; MT: Metric Tons; NaOH: Sodium Hydroxide; R-SH: Generic formula for Mercaptans (Thiols); RIL: Reliance Industries Limited; rLPG: Renewable Liquefied Petroleum Gas; RSH: Mercaptan (another form of R-SH); RSSR: Disulfides (Result from Oxidation of Mercaptans); TPA: Tonnes Per Annum; UOP: Universal Oil Products (now Honeywell UOP); USA: United States of America; USD: United States Dollar

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Introduction

Liquefied Petroleum Gas (LPG) is a versatile energy source derived from natural gas processing and crude oil refining. It is primarily composed of propane and butane and is used widely as a fuel and petrochemical feedstock [1]. This review explores the manufacturing and refining routes of LPG, highlighting key processes, economic considerations, and environmental impacts. Figure 1 provides an overview of world LPG demand by market sector [2].

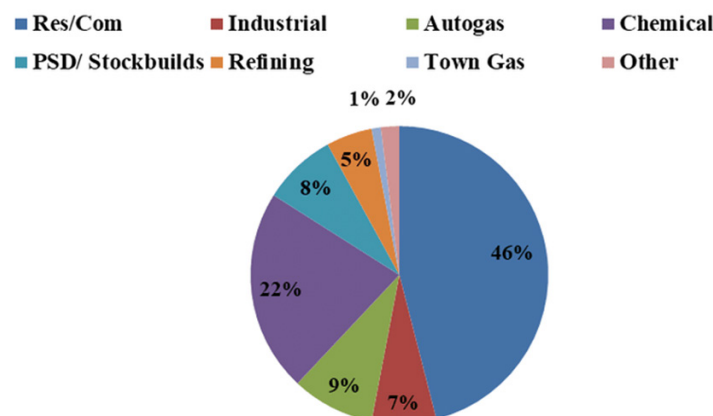


Figure 1: World LPG demand by market sector.

Manufacturing and refining routes

Natural gas processing: LPG is often produced as a by-product during the processing of natural gas. This involves the extraction of natural gas liquids, including LPG, from the natural gas stream [3]. The process typically includes purification steps such as amine and caustic treatments to remove sulfur, as well as dehydration and fractionation to separate the desired components [4].

Crude oil refining: LPG can also be produced during the refining of crude oil. This process involves the separation of LPG from other petroleum products through distillation and other refining techniques [5]. The composition of LPG can vary widely depending on the specific refining process and the desired end products.

Economic and environmental considerations

Cost and efficiency: The production of LPG from natural gas and crude oil involves significant capital and operating expenses [6]. Innovative processes, such as the nitrogen self-recuperation expansion-based process, have been developed to reduce energy consumption and costs. This process can produce LPG with 80% less energy than traditional methods, offering a more economically viable option for offshore production [7].

Environmental impact: LPG is considered a cleaner energy source compared to coal and oil, with lower carbon emissions [8]. However, the production and processing of LPG still have environmental impacts, including CO₂ emissions. Efforts to optimize processes, such as hydrodesulfurization, aim to reduce these emissions by producing ultra-clean LPG with minimal sulfur content [9].

Challenges and future directions

Meeting demand: In regions like Ecuador, domestic LPG production is insufficient to meet demand, leading to significant imports [10]. By optimizing natural gas processing, such as utilizing associated gas from oil fields, domestic production can be increased, reducing reliance on imports and associated costs. Figure 2 represents the LPG cylinder manufacturing process flowchart.

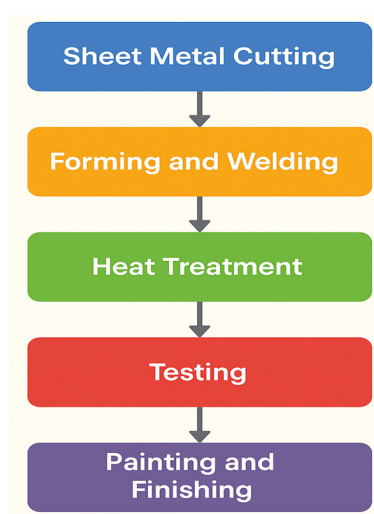


Figure 2: LPG cylinder manufacturing process flowchart.

Technological advancements: Advancements in process simulation and optimization, such as those using Aspen HYSYS, have shown potential to improve the efficiency and cost-effectiveness of LPG production [11]. These technologies allow for better design and operation of LPG plants, leading to increased production and reduced energy consumption [12]. Thus, the manufacturing and refining of LPG involve complex processes with significant economic and environmental considerations. Continued innovation and optimization in these processes are crucial for meeting global energy demands while minimizing environmental impacts [13].

Materials and Methods

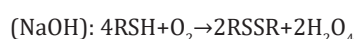
Liquefied Petroleum Gas (LPG) undergoes several chemical processing steps to ensure it meets quality and safety standards for various applications [14]. These processes focus on the removal of impurities and the conversion of specific components to enhance the fuel's performance. The primary chemical processing techniques include:

Removal of acidic impurities

- Amine Gas Treating:** This process removes hydrogen sulfide (H₂S) and carbon dioxide (CO₂) from LPG by using aqueous

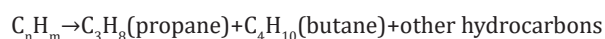
solutions of alkylamines (amines). The LPG is contacted with the amine solution, which absorbs the acidic gases, resulting in a purified product [15].

- b. Merox Process:** Developed by UOP, the Merox (mercaptan oxidation) process converts mercaptans (RSH) in LPG into disulfides (RSSR) using a catalyst in an alkaline environment [16]. This sweetening process enhances the odor and stability of LPG. Post-production, LPG may contain sulfur compounds like mercaptans, which need to be removed to meet product specifications [17]. Here, RSH represents the mercaptan, and RSSR is the resulting disulfide. This reaction enhances the odor and stability of LPG. The Merox process is employed for this purpose, involving the oxidation of mercaptans to disulfides in the presence of a catalyst and caustic soda



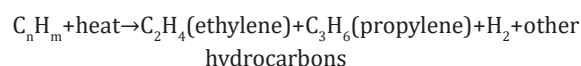
Conversion processes

a. Fluid Catalytic Cracking (FCC): FCC is a pivotal process in refineries for breaking down heavier hydrocarbons into lighter fractions, including LPG components. In the FCC unit, high-molecular-weight hydrocarbons undergo catalytic cracking in the presence of a zeolite-based catalyst at elevated temperatures (approximately 535 °C) and moderate pressures. This process not only yields LPG but also produces gasoline and olefins. The catalyst becomes deactivated due to coke deposition and is regenerated by burning off the coke in a regenerator unit. The general reaction can be represented as:



- b. Steam Cracking:** In this high-temperature process, LPG

components like propane and butane are thermally cracked in the presence of steam to produce lighter alkenes such as ethylene and propylene. These olefins are valuable feedstocks for petrochemical industries [18]. In this process, hydrocarbons are mixed with steam and subjected to high temperatures (around 850 °C) in the absence of oxygen, leading to the thermal decomposition of saturated hydrocarbons into smaller, often unsaturated, hydrocarbons [19]. While the primary aim is to produce ethylene and propylene, propane and butane are also generated and can be recovered as LPG components [20]. The reaction is highly endothermic and occurs rapidly:



Fractionation

a. Fractional distillation: This technique separates LPG into its constituent components, mainly propane and butane based on their boiling points. The process involves heating the LPG mixture and condensing the vapors at specific temperatures to isolate each fraction [21].

Each of these processes plays a crucial role in refining LPG to meet stringent specifications, ensuring its efficiency and safety in end-use applications [22]. Figure 3 illustrates the LPG Merox Process, a widely employed sweetening method used in petroleum refining to remove mercaptans (R-SH) from Liquefied Petroleum Gas (LPG), enhancing its odor quality and making it suitable for commercial use [23]. This process relies on a catalytic oxidation reaction in an alkaline medium and operates in a closed-loop caustic system to minimize waste and operating costs (<https://thepetrosolutions.com/>, 2025).

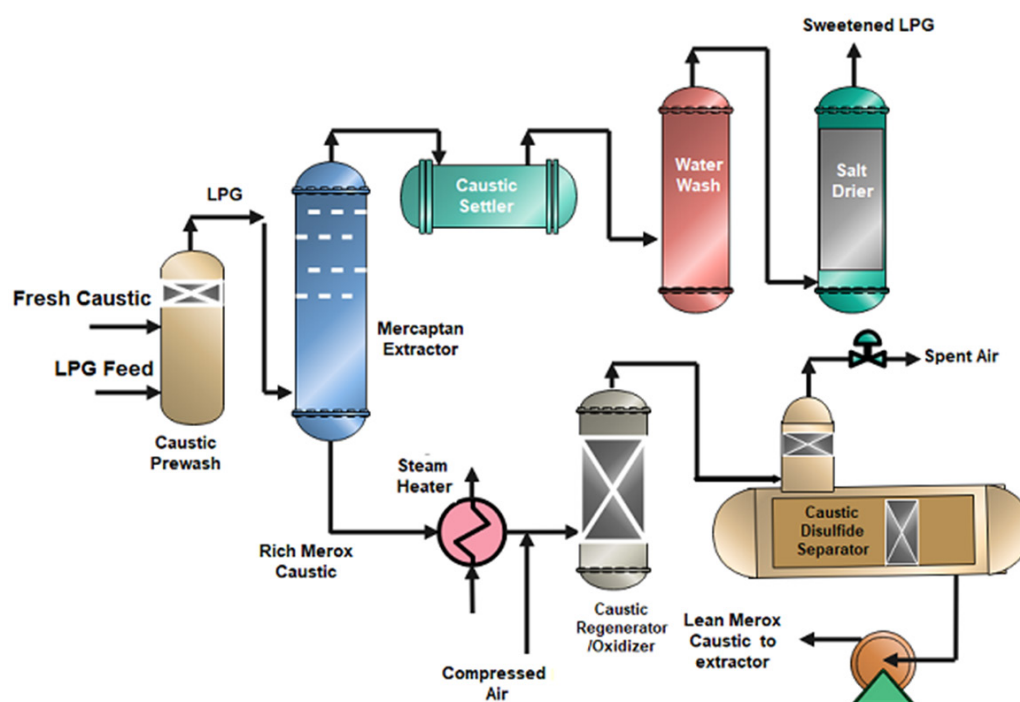


Figure 3: LPG merox process flow diagram.

The process begins with the Caustic Prewash unit, where fresh caustic soda solution is introduced to the LPG feed to neutralize acidic components and prepare the stream for efficient mercaptan extraction [24]. The partially treated LPG then enters the Mercaptan Extractor, where it contacts the lean Merox caustic solution. In this vessel, mercaptans are extracted from the LPG into the aqueous caustic phase, forming "rich Merox caustic." This rich caustic is sent through a Steam Heater, where it is preheated before entering the Caustic Regenerator/Oxidizer [25]. Here, compressed air is introduced, and mercaptans are catalytically oxidized to disulfides, which are less odorous and insoluble in caustic. The disulfides separate from the caustic and are removed in the Caustic Disulfide Separator, allowing the regenerated lean caustic to be recycled back to the extractor [26]. Meanwhile, the treated LPG flows through a Caustic Settler and then undergoes a Water Wash to remove any caustic carryover. The final polishing step is done in the Salt Drier, which removes residual moisture to yield sweetened LPG. This process is efficient, environmentally friendly, and cost-effective, and is widely used in gas processing and refineries [27].

Result and Discussion

Figure 4 represents a typical gas chromatogram used for analyzing the composition of Liquefied Petroleum Gas (LPG). The graph illustrates distinct peaks that correspond to various hydrocarbons commonly found in LPG, including propane (C_3H_8), n-butane, iso-butane, and minor components such as ethane and butylene. Each peak's position along the x-axis indicates the retention time, which is unique to each compound based on its molecular structure and interaction with the chromatographic column [16]. The y-axis denotes the detector response, which reflects the concentration of each component [28]. The area under each peak is directly proportional to the quantity of hydrocarbon present in the sample, allowing precise quantitative analysis. This technique is essential in ensuring LPG meets commercial specifications and safety standards. Gas chromatography thus serves as a powerful tool for quality control, ensuring consistent fuel performance and regulatory compliance [29]. While specific production capacities for Liquefied Petroleum Gas (LPG) are often proprietary and not publicly disclosed in detail, several major companies are recognized as leading producers in the global LPG market. Below is (Table 1) of notable LPG-producing companies along with available information on their production capacities:

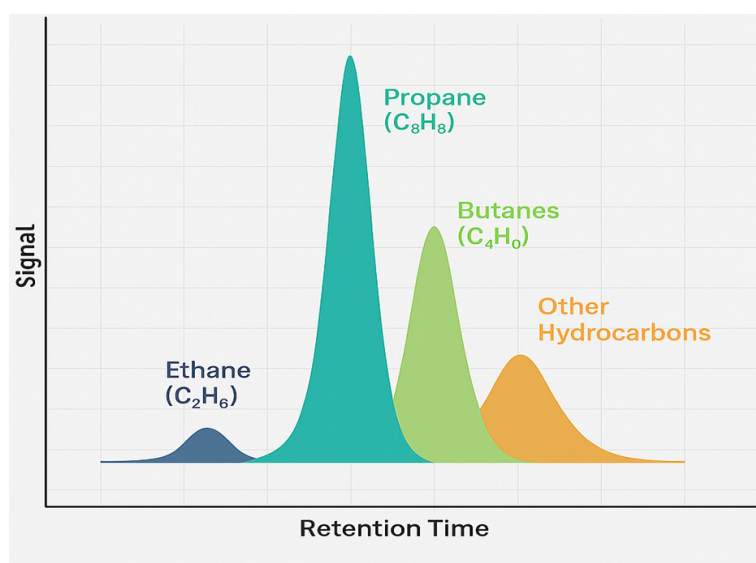


Figure 4: LPG composition analysis using gas chromatography.

Table 1: Notable LPG-producing companies along with available information on their production capacities.

Company Name	Headquarters Location	Production Capacity (Approximate)	Notes
Saudi Aramco	Saudi Arabia	Data not publicly available	Recognized as one of the largest LPG producers globally, leveraging extensive oil and gas operations.
Sinopec (China Petroleum & Chemical Corporation)	Beijing, China	Data not publicly available	As the world's largest oil refining, gas, and petrochemical conglomerate, Sinopec significantly contributes to global LPG production.
ExxonMobil Corporation	Texas, USA	Data not publicly available	A leading international energy company involved in extensive LPG production and distribution.
Chevron Corporation	California, USA	Data not publicly available	Engages in LPG production with operations spanning over 180 countries.

TotalEnergies	Paris, France	Data not publicly available	Operates in various regions with significant LPG production capabilities.
Gazprom	Moscow, Russia	Data not publicly available	A major producer and supplier of LPG, operating extensive gas fields and production facilities in Russia.
GAIL (India) Limited	New Delhi, India	Over 1million TPA	GAIL operates seven LPG plants across India, producing over 1million Tonnes Per Annum (TPA) of LPG and other liquid hydrocarbons.
Hindustan Petroleum Corporation Limited (HPCL)	Mumbai, India	Data not publicly available	Operates multiple refineries and LPG bottling plants, contributing significantly to India's LPG production and distribution.
PTT Global Chemical Public Company Limited	Bangkok, Thailand	Data not publicly available	Engages in LPG production as part of its petrochemical operations, with refineries equipped to produce LPG among other products.
Badak LNG	Bontang, Indonesia	1.2 million TPA	One of the largest LNG plants globally, Badak LNG also produces approximately 1.2million tonnes per annum of LPG as a by-product.
Reliance Industries Limited (RIL)	Mumbai, India	1.9 million TPA	The Jamnagar Refinery, operated by RIL, produced approximately 1.9 million tonnes of LPG in the fiscal year 2021-2022.
Indian Oil Corporation Limited (IOCL)	New Delhi, India	3.07 million TPA	IOCL's refineries collectively produced about 3.07million tonnes of LPG in the fiscal year 2021-2022, making it one of the largest producers in India.

Python computer language programming

Advanced computer programming using Python language was done as mentioned below for the historical and projected price trends of Liquefied Petroleum Gas (LPG) from 2023 to 2033, based on data and forecasts from reputable sources such as IMARC Group, Procurement Resource, and ChemAnalyst [30]. Complete Python computer language code is mentioned in Appendix-1 for reference. Figure 5 illustrates the historical and projected price trends of Liquefied Petroleum Gas (LPG) from 2023 to 2033. The plotted values using Python computer programming language, reflect quarterly averages for the years 2023 and 2024, followed by annual forecast values through 2033. In 2023, LPG prices showed

significant volatility, peaking at approximately USD 1,170/MT due to winter demand and increased imports in regions like China. A downward trend followed in early 2024, influenced by logistical challenges and easing crude oil prices. From 2025 onwards, the graph depicts a gradual upward trend, forecasting consistent price growth driven by rising global energy demand, expansion in LPG applications, and inflation-adjusted energy market adjustments. This trend underscores the importance of strategic planning and risk assessment in LPG procurement and production. The clear demarcation between historical data and future projections helps stakeholders visualize expected market dynamics, making this figure a valuable tool for technical and economic analyses in energy-related research and industrial decision-making.

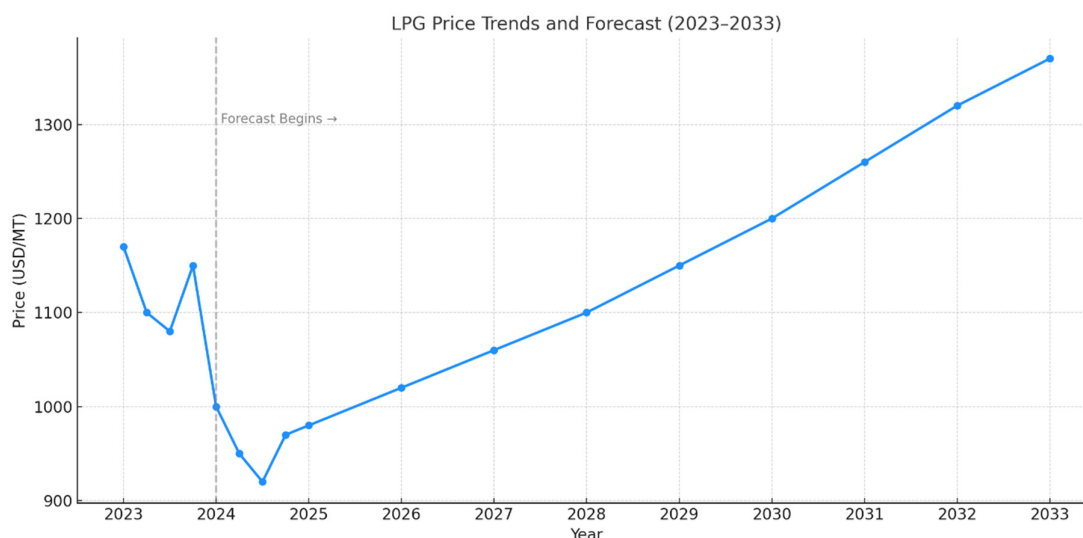


Figure 5: LPG price trends and forecast graph (2023-2033).

The production of Liquefied Petroleum Gas (LPG) is integral to the global energy landscape, yet it faces several significant challenges that impact its efficiency, safety, and sustainability. Key challenges include:

- a. **Supply chain and price volatility:** LPG prices are highly susceptible to fluctuations due to geopolitical tensions, supply-demand imbalances, and currency variations. These factors complicate cost forecasting and margin management for both producers and consumers [29]. Additionally, infrastructure constraints, such as inadequate storage facilities and transportation networks, particularly in remote areas, hinder the efficient distribution and accessibility of LPG.
- b. **Environmental and regulatory pressures:** Despite being a cleaner fuel compared to other hydrocarbons, LPG production and usage still contribute to greenhouse gas emissions [31]. The extraction and processing stages can lead to environmental degradation, including habitat disruption and pollution. Stricter carbon emission policies are prompting industries to explore alternative energy solutions, positioning LPG at a competitive disadvantage.
- c. **Safety concerns:** The handling and storage of LPG pose significant safety risks. Incidents such as the 1984 San Juanico disaster in Mexico, where a series of explosions at an LPG storage facility resulted in numerous fatalities and injuries, underscore the potential hazards [32]. Ensuring the integrity of storage tanks and distribution systems is paramount to prevent leaks and catastrophic failures.
- d. **Technological and infrastructure limitations:** In certain regions, particularly rural areas, LPG dissemination is hampered by poor road conditions and limited delivery infrastructure [33]. These logistical challenges impede timely and efficient distribution, affecting accessibility for consumers.

Addressing these challenges requires a multifaceted approach, including investments in infrastructure, adherence to stringent safety protocols, exploration of environmentally friendly alternatives, and implementation of policies to stabilize market dynamics [34].

Conclusion

Liquefied Petroleum Gas (LPG) is poised to play a significant role in the global energy landscape, especially during the ongoing transition toward cleaner and more sustainable energy sources. Its versatility, relatively lower carbon emissions compared to other fossil fuels, and adaptability to various applications position LPG as a valuable energy carrier in the foreseeable future (<https://www.imarcgroup.com/>, 2025).

Market growth and demand

The global LPG market is experiencing steady growth. Valued at approximately USD 115.3 billion in 2024, it is projected to reach USD 153.6 billion by 2030, reflecting a Compound Annual Growth Rate (CAGR) of 4.9% during this period. This expansion

is driven by increasing demand across residential, industrial, and transportation sectors, particularly in developing regions where LPG serves as a cleaner alternative to traditional biomass fuels [35].

Role in energy transition

As the world shifts toward sustainable energy solutions, LPG offers a transitional pathway due to its cleaner combustion profile. Initiatives are underway to produce renewable LPG (rLPG) from sustainable sources, which could potentially meet up to 50% of the global non-chemical LPG demand by 2050. This development underscores LPG's potential to contribute significantly to decarbonization efforts.

Technological innovations

Advancements in LPG technology are enhancing its safety, efficiency, and environmental footprint. Innovations such as smart cylinder technology and predictive analytics are being explored to optimize supply chain operations and improve user safety. These technological strides are crucial for maintaining LPG's competitiveness in the evolving energy market [36].

Infrastructure developments

Significant investments are being made to bolster LPG infrastructure globally. For instance, the Panama Canal Authority has initiated plans for constructing an LPG pipeline to facilitate more efficient transshipment and meet growing demands, particularly from Asian markets. Such projects aim to alleviate logistical bottlenecks and enhance the global LPG supply chain.

Challenges and considerations

Despite its advantages, LPG faces challenges, including competition from other clean energy sources and the need for policy support to optimize its role in the energy transition. Government policies will be crucial in determining the pace and nature of LPG utilization, ensuring it contributes effectively to minimizing the environmental impact of energy use [37].

In conclusion, LPG is set to remain a vital component of the global energy mix. Its growth is underpinned by increasing demand, technological innovations, and infrastructure developments. However, its future prominence will depend on strategic policy frameworks and its integration with renewable energy initiatives to ensure a sustainable and environmentally friendly energy transition [38]. This extensive review examines the changing dynamics of Liquefied Petroleum Gas (LPG) production and refining, merging traditional techniques with new innovations. Despite significant progress in areas such as catalytic cracking, gas processing, and environmental management, notable research gaps remain. Critical topics that require further investigation include the incorporation of renewable feedstocks in LPG production, enhancing energy efficiency in small-scale refineries, and developing real-time emissions monitoring systems. Emerging trends like bio-based LPG, artificial intelligence-driven process optimization, and carbon capture-enhanced LPG refining are transforming the industry and necessitate focused research and development efforts. From both

policy and industrial perspectives, regulatory frameworks should promote cleaner production technologies, offer incentives for circular economy initiatives, and facilitate the commercialization of green LPG alternatives. Industry participants are encouraged to invest in automation, digital twin technologies, and lifecycle analysis tools to improve operational efficiency and ensure environmental compliance. The alignment of technological advancements with supportive policies will be essential for guiding LPG production towards sustainability and resilience during the energy transition [39-43].

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Appendix-1. Python Computer Language Code

```
import matplotlib.pyplot as plt

# Historical and forecast LPG prices (hypothetical values based
on referenced sources)

years = [
    2023.0, 2023.25, 2023.5, 2023.75,
    2024.0, 2024.25, 2024.5, 2024.75,
    2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033
]

prices = [
    1170, 1100, 1080, 1150, # 2023 quarters
    1000, 950, 920, 970, # 2024 quarters
    980, 1020, 1060, 1100, 1150, 1200, 1260, 1320, 1370 #
Forecast
]

# Create plot

plt.figure(figsize=(12, 6))

plt.plot(years, prices, marker='o', linestyle='-',
color='dodgerblue', linewidth=2)

# Annotate key years

plt.axvline(x=2024, color='gray', linestyle='--', alpha=0.5)

plt.text(2024.05, max(prices) * 0.95, 'Forecast Begins →',
color='gray')

plt.title("LPG Price Trends and Forecast (2023-2033)",
fontsize=14)
```

```
plt.xlabel("Year", fontsize=12)

plt.ylabel("Price (USD/MT)", fontsize=12)

plt.grid(True, linestyle='--', alpha=0.6)

plt.xticks(range(2023, 2034))

plt.tight_layout()

# Save and show the figure

plt.savefig("/mnt/data/LPG_Price_Trends_and_Forecast_
Graph.png")

plt.show()
```

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