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هيئة تحرير مجلة ستاردوم العلمية للعلوم "الطبيعية والهندسية"

Associated Petroleum Gas Flaring in Yemen: Current Status and Potential Utilization

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الملخص:

تهدف هذه الدراسة إلى تسليط الضوء على مشكلة حرق غاز البترول المصاحب (APG) في اليمن، والتي تمثل تحديًا كبيرًا في الحد من فقدان موارد الطاقة القيّمة في البلاد. تمتلك اليمن احتياطيات غنية من النفط والغاز، إلا أن البنية التحتية الحالية لا تزال غير كافية للاستفادة الفعّالة من هذه الموارد. يُورَّد الغاز الناتج من حقول النفط عادةً إلى شركات الغاز أو مصانع المعالجة أو محطات توليد الطاقة الحرارية. وعند عدم توفر منافذ أو أنظمة مناسبة لاستخدام هذا الغاز الغني بالطاقة، يتم حرقه في المشاعل. يُعد غاز البترول المصاحب مادة خامًا أساسية لتوليد الكهرباء والتدفئة وإنتاج مختلف المنتجات البتروكيماوية، ومع ذلك فقد ظلت اليمن تحرق هذا المورد الثمين لعقود، سواء عبر مشاعل متقطعة أو لهبٍ مستمر في مواقع الإنتاج. ونظرًا لأن ما يقارب 40٪ من هذا الغاز يُهدر سنويًا، أصبح تقليل حرق الغاز المصاحب أمرًا بالغ الأهمية للتخفيف من التدهور الاقتصادي المزمن في البلاد وحل مشكلة نقص الطاقة المستمرة. ومع استمرار اليمن في مواجهة نقص في إمدادات الكهرباء وانقطاعات واسعة النطاق، تبرز الحاجة الماسّة إلى الاستثمار في مشاريع الاستفادة من موارد الطاقة المتاحة. وتقدم هذه الورقة البحثية نظرة شاملة على الوضع الحالي لحرق الغاز المصاحب في اليمن، كما تستعرض طرق الاستفادة الممكنة منه، مع التركيز على الجدوى التقنية والفوائد الاقتصادية وتقليل الأثر البيئي.

كلمات مفتاحية: الغاز المصاحب للبترول في اليمن، الإستفادة من الغاز المصاحب للبترول، مكونات الغاز المصاحب، التاثير البيئ للغاز

Abstract:

This study aims to shed light on the issue of associated petroleum gas (APG) flaring in Yemen, which poses a major challenge in preventing the loss of the country's valuable energy resources. Yemen is rich in oil and gas reserves; however, the existing infrastructure remains inadequate for the efficient utilization of these resources. Gas produced from oil fields is typically supplied to gas companies, processing plants, or thermal power stations. When no feasible outlet or utilization system is available, this energy-rich gas is subjected to flaring. APG is a vital feedstock for electricity generation, heating, and various petrochemical products, yet Yemen has been burning this valuable resource for decades—either through intermittent flare torches or continuous flames at production sites. Considering that approximately 40% of this gas is wasted annually, reducing APG flaring has become crucial to mitigating the country's economic decline and chronic energy shortages. As Yemen continues to experience insufficient power supply and widespread blackouts, greater investment in energy resource utilization is urgently needed. This paper provides an overview of the current status of APG flaring in Yemen and explores potential utilization methods, emphasizing their technical feasibility, economic benefits, and environmental impact reduction.

Keywords: Associated petroleum gas in Yemen. Associated petroleum gas utilization. Constituents of Associated Gas, Environmental Impact of Gas.

1. Introduction

Yemen is one of the oil-producing countries that has been burning a significant portion of its natural wealth. The first oil discovery in Yemen occurred in 1984, and since then, associated gas has been flared either continuously or intermittently [1].

Associated Petroleum Gas (APG) is a form of raw natural gas that occurs in association with crude oil, either dissolved in the oil or as a free gas cap. It is considered a by-product of crude oil extraction and must be separated from the oil during upstream processing. Because APG is often regarded as waste, a large portion of it is released directly into the atmosphere, routed to flare stacks for combustion, or, in more advanced cases, re-injected into reservoirs to maintain pressure and enhance oil recovery [2].

Gas flaring, the controlled burning of excess natural gas during oil and gas extraction, has long been a significant environmental and economic challenge in the global energy sector. Initially adopted as a necessary practice due to limited infrastructure, market demand, and economic feasibility, flaring has become a controversial issue as the world shifts toward sustainable energy solutions [3]. During oil extraction, this gas is frequently burned off into the atmosphere due to the lack of infrastructure required to capture, process, and utilize it [4], as illustrated in Figure 1

Figure 1: Associated Petroleum Gas (APG) horizontal flared in Shabwa field -Yemen

(Source: Author)

Associated Petroleum Gas (APG) typically exists as a mixture of light hydrocarbons such as methane (CH_4), ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), and pentane (C_5H_{12}). In addition, it contains non-hydrocarbon components including water vapor (H_2O), hydrogen sulfide (H_2S), carbon dioxide (CO_2), nitrogen (N_2), and trace gases [5]. At the early stages of oil production, the quantity of APG generated at individual facilities is relatively small, making the installation of gas gathering and transportation pipelines economically unfeasible. However, as production volumes increase over time, the associated gas output rises significantly [6]

2. Overview of APG in Yemen:

The volume and composition of APG vary depending on the production area and the specific geological characteristics of each oil field. During the extraction and separation of one ton of crude oil, between 25 and 800 cubic meters of associated gas can be produced [6]. While some of this gas is captured and utilized—thanks to significant investments by governments and oil companies—many operators continue to flare APG because of technical limitations, regulatory gaps, or economic constraints [7, 8].

Globally, thousands of flare stacks across more than 17,000 oil production facilities burn approximately 144 billion cubic meters of natural gas annually, releasing over 350 million tons of CO_2 and various other pollutants into the atmosphere [9, 10]. Figure 2 illustrates the trend of gas flaring from 2012 to 2024, clearly highlighting the vast quantities of gas wasted—resources that could otherwise be harnessed for productive uses, particularly in electricity generation and petrochemical production. Table 1 presents the composition of associated petroleum gas (APG) from Block #5 oil fields in Yemen. The Halwaeh field is particularly significant, with flared gas volumes reaching up to 90 million standard cubic feet per day (MMSCFD). The APG composition in these fields is dominated by methane, propane, and butane, making it highly suitable for various

utilization pathways that could yield substantial economic benefits for the country [11]

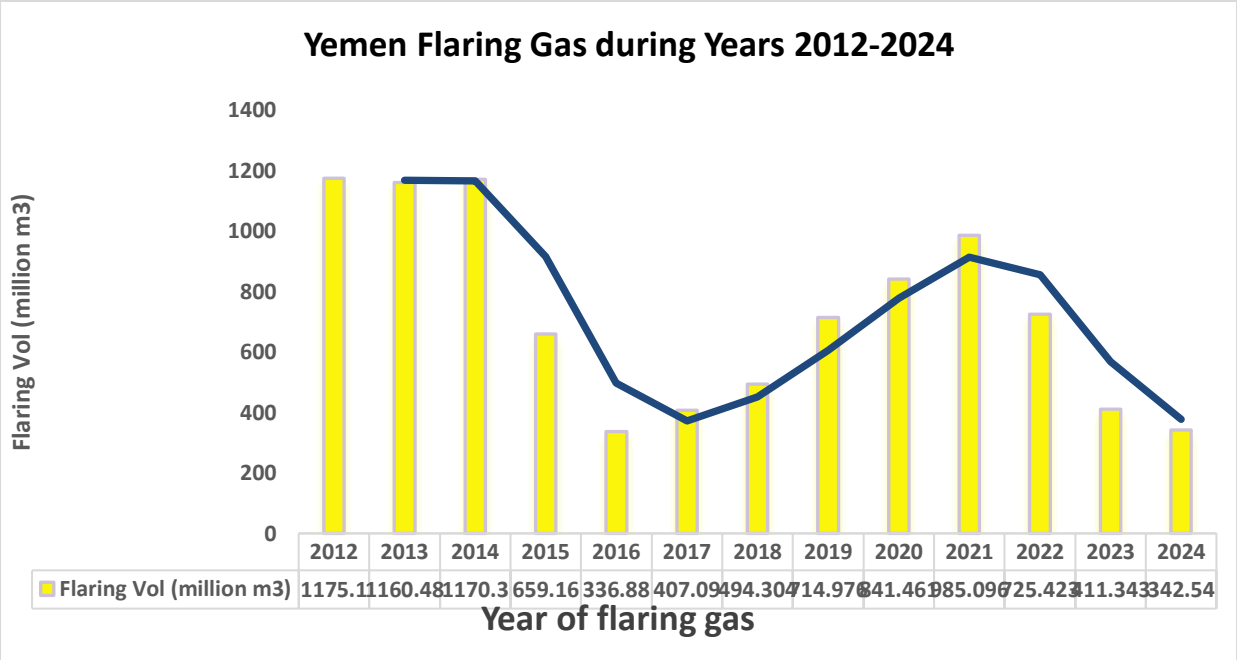


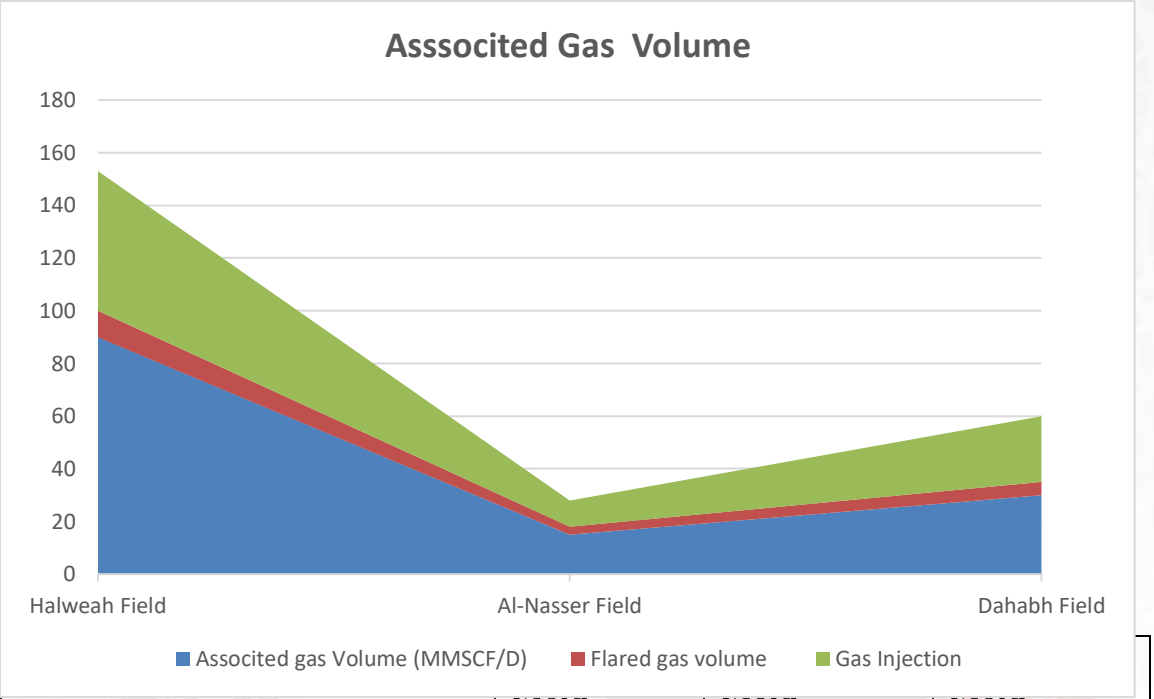
Figure 2 Yemen Flaring Gas During Years 2012-2024

Yemen possesses considerable natural oil and gas resources, most of which have been discovered and developed through joint ventures between national and international petroleum exploration and production companies.

Table 1: Volume and Composition of APG for different fields in Yemen

(MMSCF/D is million standard cubic Feet/day and one MMSCF=1180 m^3/hours) Despite its potential,

Yemen is among the countries with the highest flaring intensity, placing among the top 30 globally in terms of gas wasted per barrel of oil produced [12].



	Field	Field	Field
Volume (MMSCF/D)	90	15	30
Volume of Flare (MMSCF/D)	3	3	3
Temperature (°C)	35	35	35
Pressure (Psig)	2160	1450	1400
Associated Gas Composition (% mol)			
Methane	89.32	56.09	79.64
Ethane	4.93	16.62	8.82
Propane	2.98	15.08	6.78
Iso-Butane	0.5	2.82	0.99
Normal-Butane	1.04	6.23	2.13
Iso-Pentane	0.26	1.2	0.44
Normal-Pentane	0.29	1.22	0.5
Hexane	0.16	0.4	0.28
Heptane	0.14	0.18	0.23
Nitrogen	0.08	0.04	0.11
Carbon Dioxide	0.3	0.12	0.08
Carbon Monoxide	<0.01	<0.01	<0.01
Oxygen	<0.01	<0.01	<0.01

Figure 2 percentage of associated gas to flared gas

To combat excessive APG flaring, Yemen must adopt regulatory frameworks requiring modern flare control technologies and detection systems akin to those used in North America and Europe. The practice is particularly prevalent in oil-rich countries such as Russia, Nigeria, Iran, Iraq, Venezuela, and the United States, where large volumes of associated gas, natural gas found alongside crude oil are flared due to inadequate processing and transportation infrastructure [13]. However, the country currently lacks sufficient monitoring capacity and technical infrastructure. Only limited efforts by national and international bodies exist to address the problem.

Key proposed solutions include deploying low-cost flare detection systems, creating an independent environmental oversight body, fostering international collaboration, and building local capacity for flare monitoring [14]. These measures would compel producers to adopt best-available flare reduction technologies and prevent flare use as a way to avoid higher-cost emission controls

In recent years, attention to gas flaring throughout all phases of oil and gas operations has grown significantly [15]. The central concerns include the loss of valuable hydrocarbons, degradation of local air quality, health risks to communities, ecological damage, and economic losses to companies and host countries. Rising oil prices and energy demand further increase the incentive to produce more oil — and with it, more associated gas — amplifying the risks of unchecked flaring [16]

Figure 3 benchmarks Yemen’s flare volumes relative to other Arab nations.

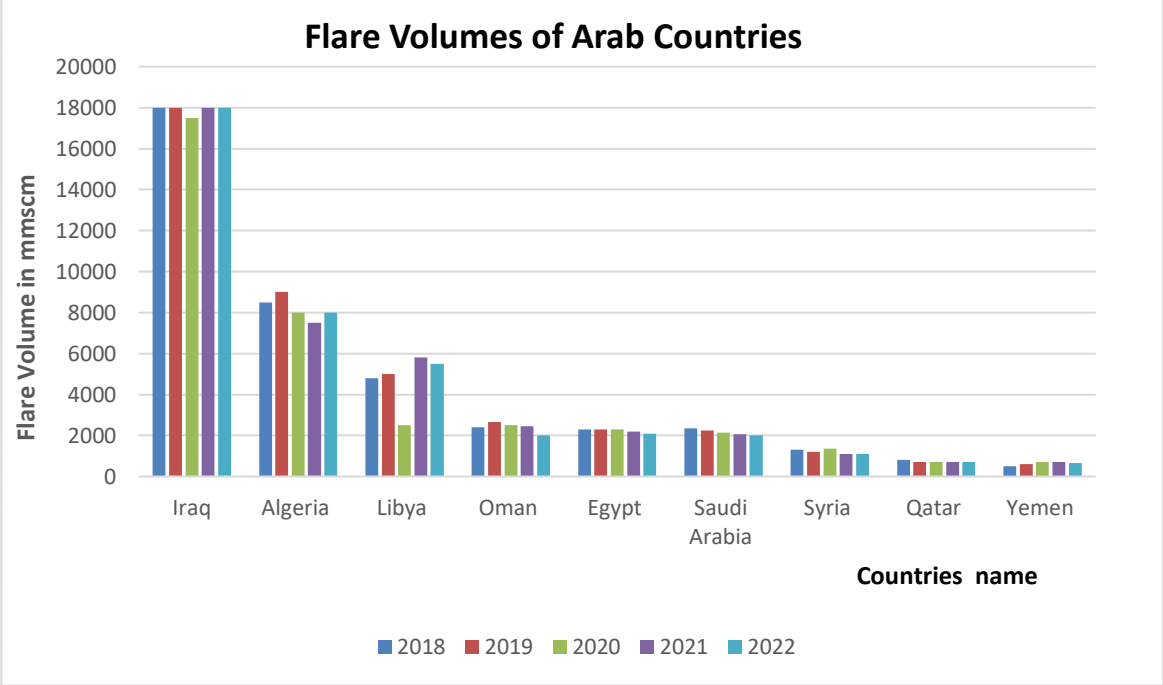


Figure 3: Flare Volumes of Arab Countries

Due to rising oil prices and advances in energy-efficiency technologies, the use of more capital-intensive equipment for oil production has become profitable. As a consequence, oil output has increased—and along with it, the total volume of associated petroleum gas (APG) generated [17]

For many oil-exporting countries, the management of APG has taken on heightened importance. Further increases in oil production risk imposing substantial losses if CO_2 emissions quotas continue to tighten. These regulations can lead to increased costs for refinery upgrades and may complicate oil exports, especially under schemes requiring emission-related taxes or restrictions [18]

Some oil-exporting nations have already begun utilizing APG as a feedstock for onsite electricity generation, thereby reducing both flaring and diesel consumption. In Yemen, the PetroMasila project has implemented this approach by using mobile GE TM2500 gas turbine units that convert flare gas into electricity. These systems have successfully supplied power to oil field operations and local communities, replacing high-cost diesel generators and reducing greenhouse gas emissions [19,20]. This initiative serves as a model for cost-effective flare gas utilization in other developing oil-producing countries.

In Yemen, historical data show that in past periods the country flared about **1.5 BCM/year** when oil production was ~320,000 barrels/day [2]. While there are reports of larger APG generation and utilization potentials, those figures require verification from more recent data. Much of the gas associated with oil extraction

still gets flared close to wellheads, complicating oil stabilization and transport, increasing emissions, and resulting in adverse ecological and health impacts. As production increases, these environmental burdens become more pronounced, generating public concern and environmental risks [21]

3-Methods and Approaches

For many decades, oil companies have burned associated petroleum gas (APG) as an unwanted by-product of crude oil production. Flaring is part of safety and operational control systems, allowing the combustion of excess gases to prevent overpressure or accidents. The term gas flaring refers to the open-air burning of hydrocarbon gases without energy recovery, typically at the top of vertical flare stacks installed in oil and gas production facilities [22].

3.1 Causes of Gas Flaring

Gas flaring generally occurs for three main reasons

Emergency flaring – Performed during plant upsets, maintenance, or shutdowns to ensure operational safety.

Isolated well flaring – Happens when newly drilled wells produce oil and gas before being connected to a gas gathering or processing network.

Capacity limitation flaring – Occurs when gas collection or processing systems are unable to handle the full volume of associated gas produced.

In Yemen, the latter two causes are dominant due to limited infrastructure for gas capture, compression, and transport.

3.2 Methodological Framework

This study follows a hybrid analytical approach combining data analysis, comparative evaluation, and techno-economic modeling to identify feasible APG utilization options in Yemen's oil-producing regions.

Data Collection:
Field-level production and flaring data were obtained from the World Bank Global Gas Flaring Reduction Partnership (GGFR) Annual Report 2024 [22], IEA Methane Tracker 2024 [23], and the Ministry of Oil and Minerals (MOMR) Yemen Annual Review 2023 [24].

Gas Characterization:
Gas composition data from the Halwaeh, Al-Nasser, and Dahab fields were analyzed to determine APG utilization potential for re-injection, power generation, or liquefied gas recovery [25].

Technology Evaluation:
Utilization technologies such as gas re-injection, onsite gas-to-power (GTP) systems, small-scale gas-to-liquids (GTL), and fractional distillation were evaluated based on technical feasibility, capital cost, and scalability [5,8,26].

Economic and Environmental Assessment:
Potential reductions in flaring and greenhouse gas (GHG) emissions were estimated using emission factors from the IPCC Sixth Assessment Report (2023) [27] and cost models published by the IEA (2024) [23].
The assessment used a weighted multi-criteria model with economic (40%), technical (35%), and environmental (25%) performance indicators.

3.3 APG Utilization Options

Several technological pathways are available for APG recovery and use, reducing the need for routine flaring. Table 2 summarizes key utilization methods and their associated economic and environmental impacts under Yemeni conditions.

Table 2: APG Possible Utilization in Yemen

APG utilization methods	Description	Economic aspect	Environmental aspect
Re-injection into oil reservoir	This process involves the injection of APG into the gas cap. The goal is to increase oil recovery by increasing the intra-reservoir pressure.	No large capital investments are required. The economic effect depends on the growth of oil recovery in the field.	Environmental impact is considered to be zero.
Injection the gas to injection wells	Sending part of the APG to the main gas pipeline for sale to consumers. The implementation of such a process is associated with technological limitations (for instance, the distance from the gas pipeline; a certain ratio of APG and natural gas).	Monetizing APG as a conventional fuel gas.	Environmental impact is considered to be zero.
Power generation	As a result of fractional processing, the following commercial products are obtained at the output: stable condensate, gas gasoline, propane-butane fraction, etc. Osylan power plant 8MW consumed per day .850 mmscfd	Sale of electricity or its use for the field's own needs	Gas turbine emissions: NO_2, NO, CO, etc.
Chemical processing (for example, Cyclar and APG in BTK processes)	The Cyclar process is the production of a mixture of aromatic hydrocarbons from the propane-pentane fraction of APG. APG in BTK process: APG is processed into a mixture of aromatic hydrocarbons (for instance, it can be mixed with the main oil stream).	Aromatic hydrocarbon concentrate is a valuable raw material for the petrochemical industry; its independent implementation is possible.	Greenhouse gas emissions CH_4, CO_2 from gas processing plants.
GTL technology	Technology is based on the Fischer-Tropsch synthesis and the conversion of hydrocarbons into synthesis gas. Syngas is a mixture of carbon dioxide and hydrogen.	Converting gas to liquid to produce liquid hydrocarbons such as naphtha, kerosene, diesel, jet fuel, gasoline, etc.	Greenhouse gas emissions CH_4, CO_2 from gas processing and petrochemical plants.
Fractional (non-chemical) method	As a result of fractional processing, the following commercial products are obtained at the output: stable condensate, gas gasoline, propane-butane fraction, etc.	Sales of the received commercial products.	

3.4 Comparative Evaluation

Each utilization pathway was benchmarked against international case studies. Results indicate that on-site gas-to-power and small-scale LPG recovery systems represent the most practical near-term solutions due to their low capital requirements and rapid deployment potential [5,26]. Medium- to long-term solutions such as GTL and chemical processing offer

higher economic returns but demand substantial investment and advanced infrastructure.

4. Discussion

Globally, billions of cubic meters (BCM) of natural gas are flared annually at oil production sites, representing a massive economic and environmental loss. Gas flaring remains one of the most persistent challenges in the petroleum industry, wasting valuable hydrocarbons that could otherwise be used for power generation, petrochemicals, or domestic energy production [22,23]. According to the World Bank Global Gas Flaring Reduction Partnership (GGFR), global flaring volumes rose to approximately 148 BCM in 2023, compared to 144 BCM in 2021 and 141 BCM in 2013 [22]. This increase underscores the urgent need for countries with high flaring levels—such as Yemen—to implement gas capture and utilization technologies.

In Yemen, Associated Petroleum Gas (APG) is primarily produced from the gas caps of the Marib and Shabwa oil-producing fields, as well as from non-associated gas fields in Seiyun, Behalf, and Habban. According to the Ministry of Oil and Minerals (MOMR, 2023), Yemen holds 17 trillion cubic feet (TCF) of proven gas reserves, ranking 31st globally, with reserves equivalent to approximately 980 times its annual consumption [24]. Despite this potential, inadequate gas processing infrastructure severely limits the country's capacity to utilize these resources effectively [8,24]

It is estimated that Yemen produces between 4 and 6 BCM of APG annually. However, in recent years, total APG output has reached 5–7 BCM per year, while the national gas processing capacity remains below 0.5 BCM [24,25]. Consequently, more than 90% of associated gas is flared or vented into the atmosphere, contributing to greenhouse gas emissions and local air pollution [8,23]. If current trends continue without intervention, these losses will persist and likely increase in the coming years due to rising oil output and limited reinjection or recovery facilities [5,26]

Yemen has a huge resource of flared APG and has many prospects to utilize this source economically. Research on the occurrences of gas flares, design of burning flame pattern for smokeless combustion and design of a gas re-injection plant for possible utilization of flared gas is described. Three different approaches for sitting of waste gas utilization plants on the basis of flare distribution pattern are described as Flare-gas to power. Small-scale LNG / CNG &LPG plant, Reinjection for reservoir pressure support, investigation is based on crude oil flaring [28].

Out of Yemen's six oil-producing regions under the Ministry of Oil and Minerals, four currently report significant flaring activity. Preliminary field assessments confirm that flaring intensity is highest in Block 5 (Halwaeh field) and Block 10 (Kharir field), with combined flaring volumes exceeding 90 million standard cubic feet per day (MMSCFD) [24,25].

Without proper mitigation measures, such volumes will continue to produce substantial economic losses and exacerbate local environmental degradation, including increased CO_2, methane (CH_4), and volatile organic compound (VOC) emissions [30].

This study faced several limitations that should be acknowledged. The analysis was primarily based on secondary data collected from international databases and government reports, which may not fully reflect recent on-ground developments in Yemen's oil fields. Due to security challenges and limited field access, there were constraints in obtaining real-time measurements of flaring rates and gas compositions. Furthermore, the lack of direct measurements from major oil fields, such as Marib and Shabwa, prevents a detailed evaluation of seasonal variations in flaring intensity. Another limitation lies in the unavailability of comprehensive economic modeling to estimate the capital and operational costs of proposed APG utilization projects. Consequently, the findings should be interpreted as indicative rather than definitive, emphasizing the need for improved data transparency and empirical validation through field-based studies.

To advance the sustainable utilization of APG in Yemen, several actions and research directions are recommended. The government and oil operators should prioritize the establishment of a centralized flare monitoring and reporting system using satellite-based and on-site sensing technologies, in line with the Global Flaring and Methane Reduction (GFMR) initiative. Future studies should focus on conducting techno-economic feasibility assessments of small-scale gas-to-power (GTP), gas-to-liquids (GTL), and flare-gas recovery systems adapted to Yemen's operating conditions. In addition, pilot projects integrating APG utilization into local power grids could provide practical models for replication across multiple oil fields

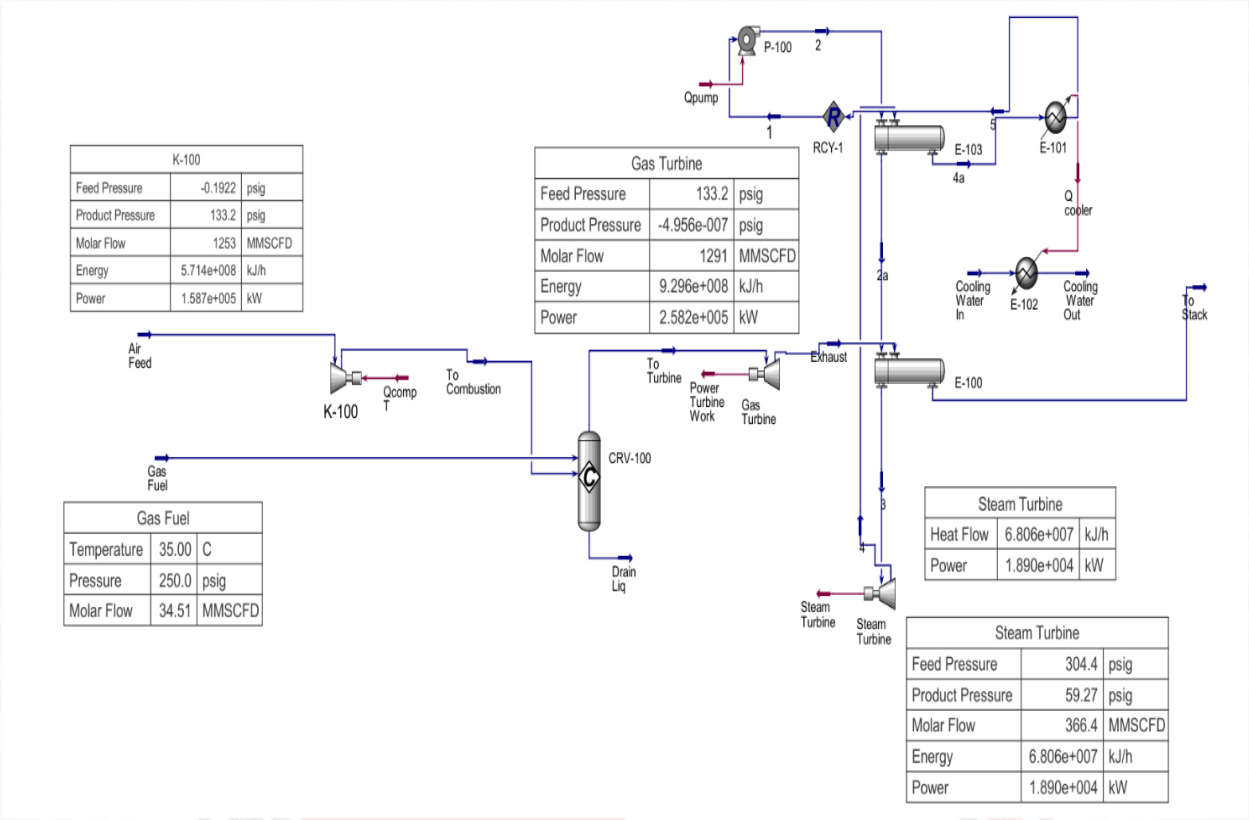


Figure 4 Simulation associated gas utilization gas to power

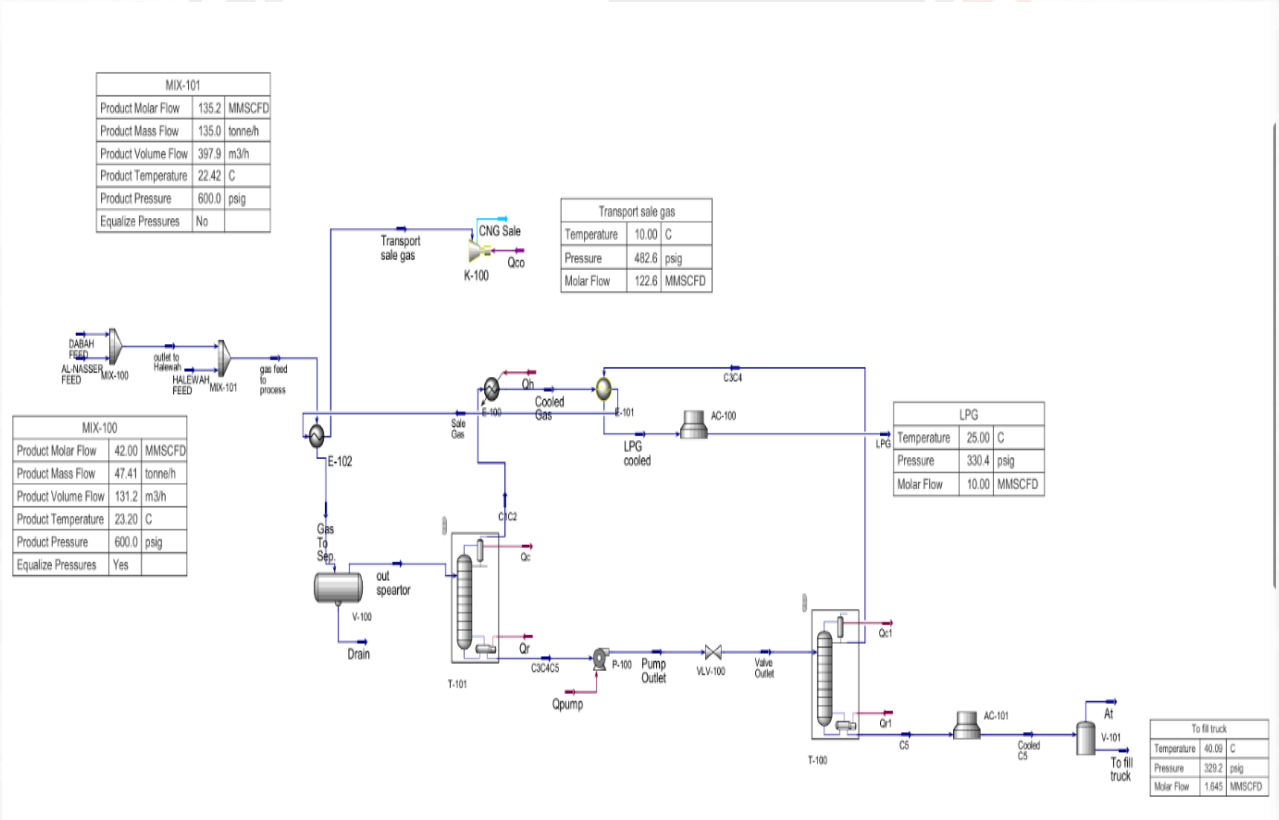


Figure 5 Simulation associated gas utilization for used as gas plan

5. Conclusions

This study examined the status of associated petroleum gas (APG) flaring in Yemen and highlighted the urgent need to reduce the waste of this valuable national energy resource. Despite possessing significant oil and gas reserves, Yemen continues to flare large volumes of APG due to insufficient infrastructure, weak regulations, and limited technological capabilities. According to the Global Gas Flaring Tracker Report (2023), Yemen ranks among the top 30 flaring countries worldwide, with gas flaring having increased nearly 200-fold since 1999.

Currently, Yemen burns approximately 891.2 million cubic meters of gas annually, equivalent to an estimated US$ 378 million in lost value. The continuous flaring and venting of APG not only cause substantial economic losses but also contributes to environmental degradation and increased greenhouse gas emissions.

To address these challenges, three practical utilization pathways for APG are recommended:

Flare Gas-to-Power (Onsite Generation): Using gas engines or turbines to generate electricity for oilfield operations, nearby communities, or local power grids. Modular gas-to-power systems are particularly advantageous for small to medium gas volumes and can be rapidly deployed.

Small-Scale LNG/CNG and Bottled LPG Production: Converting APG into liquefied or compressed natural gas for domestic energy use—such as cooking and transportation—can support local energy security while creating new economic opportunities.

Gas Reinjection for Reservoir Pressure Maintenance: Reinjecting APG into producing reservoirs remains the most technically and environmentally sustainable option. It enhances oil recovery, minimizes flaring, and contributes to long-term gas storage.

In conclusion, reducing APG flaring in Yemen requires coordinated action from government authorities, oil companies, and international partners. Investments in gas capture, processing, and utilization technologies—supported by robust environmental policies—are essential to transform flared gas from a wasted by-product into a source of economic growth and energy security. The successful implementation of these measures will not only conserve Yemen’s energy resources but also contribute significantly to sustainable development and environmental protection..

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6. Nomenclatures

6. Symbols and Abbreviations

Symbol / Abbreviation	**Description**
APG	Associated Petroleum Gas
BCM	Billion Cubic Meters
MMSCFD	Million Standard Cubic Feet per Day
CO_2	Carbon Dioxide
CH_4	Methane
C_2H_6	Ethane
C_3H_8	Propane
C_4H_{10}	Butane
C_5H_{12}	Pentane
H_2O	Water Vapor
H_2S	Hydrogen Sulfide
N_2	Nitrogen
O_2	Oxygen
LPG	Liquefied Petroleum Gas
CNG	Compressed Natural Gas
LNG	Liquefied Natural Gas
GTL	Gas-to-Liquids
BTX	Benzene, Toluene, and Xylene

Symbol / Abbreviation	Description
GTP	Gas-to-Power
GHG	Greenhouse Gases
VOC	Volatile Organic Compounds
TCF	Trillion Cubic Feet
IEA	International Energy Agency
GFMR	Global Flaring and Methane Reduction Partnership
MOMR	Ministry of Oil and Minerals (Yemen)
PEPA	Petroleum Exploration and Production Authority (Yemen)

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جامعة ستاردوم

مجلة ستاردوم العلمية للدراسات الطبيعية والهندسية

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