A Flare gas recovery unit for refineries in Libya: Innovative technologies are a step towards a sustainable environment (zero flare in 2030)

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الملخص

تعاني صناعة النفط في ليبيا من حرق الغازات المشتعلة التي تهدر موارد هامة وتزيد من انبعاث الغازات المسببة للاحتباس الحراري وتزيد من الأضرار البيئية. ينبعث من الحرق كميات كبيرة من غاز ثاني أكسيد الكربون وأكاسيد الكبريت وأكاسيد النيتروجين والهيدروكربونات، بالإضافة إلى آثار ضارة أخرى على كل من الانسان والنظام البيئي. يبحث هذا البحث في أهمية استرجاع غاز الشعلة في المصافي الليبية والمزايا البيئية لاسترجاع غاز الشعلة في تعزيز الاستدامة البيئية من خلال الحد من حرق الغازات واعتماد ممارسات بيئية مستدامة. تركز الدراسة على الاستراتيجيات والتقنيات المستخدمة للقضاء على حرق الغاز على مستوى العالم بحلول عام 2030. وتبحث في التقديرات السنوية لحرق الغاز وكفاءة حرق الغاز على الصعيدين العالمي والوطني في ليبيا في الفترة من 2019 إلى 2023. ويسلط الضوء على أهمية استعادة الغاز المشتعل والفوائد المحتملة من خلال الدراسات البحثية الوطنية والمقارنة. كما يسلط الضوء على المشكلات البيئية الناجمة عن هذه الغازات، ويعرض التقنيات الرائدة ويناقش أساسياتها وفوائدها وعيوبها. ومن النتائج البحث اهمية وحدة استرداد غاز الشعلة (FGRU) فهي حل متقدم يحول غاز الشعلة إلى منتجات مثل غاز البترول المسال والغاز الطبيعي المضغوط (CNG). ومن خلال الأنظمة المبتكرة تلعب أنظمة التكثيف المتقدمة، وأنظمة الفصل بالتبريد، وأنظمة الترشيح بالأغشية، وأنظمة ترقية الغاز الحيوي، والأنظمة الهجينة دورًا حاسمًا في استعادة غاز الشعلة من خلال تعزيز النقاء، وزيادة معدلات الاسترداد، وتوفير الطاقة، وتوفير المرونة، والفعالية من حيث التكلفة، والاستدامة البيئية. ومن الضروري النظر بعناية في التحديات المرتبطة بهذه التكنولوجيا أثناء تصميم هذه الأنظمة وتشغيلها.

Abstract
Libya's oil industry suffers from flaring, which wastes important resources, increases the emission of greenhouse gases and increases environmental damage. Flaring emits large amounts of carbon dioxide, Sulphur oxides, nitrogen oxides and hydrocarbons, in addition to other harmful effects on both people and the ecosystem. This research investigates the importance of flare gas recovery in Libyan refineries and the environmental advantages of flare gas recovery in promoting environmental sustainability by reducing flaring and adopting sustainable environmental practices. The study focuses on the strategies and technologies used to eliminate gas flaring globally by 2030. It examines annual estimates of gas flaring and gas flaring efficiency globally and nationally in Libya from 2019 to 2023. It highlights the importance of flared gas recovery and potential benefits through national and comparative research studies. It also highlights the environmental issues caused by these gases, showcases leading technologies and discusses their fundamentals, benefits and drawbacks. The Flare Gas Recovery Unit (FGRU) is an advanced solution that converts flare gas into products such as LPG and compressed natural gas (CNG). Innovative Systems Advanced condensing systems, cryogenic separation systems, membrane filtration systems, biogas upgrading systems and hybrid systems play a critical role in torch gas recovery by enhancing purity, increasing recovery rates, saving energy, providing flexibility, cost effectiveness and environmental sustainability. Careful consideration of the challenges associated with this technology is essential during the design and operation of these systems.

Key word: Flare Gas Recovery (FGR), a sustainable environment, Innovative technologies

Introduction
Global climate change has been a worry for numerous nations ever since the UNCHE Summit in Stockholm, Sweden in 1972. The Summit focused on sustainable development for future generations and was endorsed by the Paris Agreement in lowering greenhouse gas emissions from 2.0°C to 1.5°C Celsius, along with numerous initiatives to combat global warming. Developing and industrialized countries both widely conduct gas emissions. Financial assistance is one strategy employed by developed nations to decrease greenhouse gas emissions. The rise in carbon dioxide levels (from 408.84 ppm to 410.79 ppm) from June 2017 to June 2018 has led to escalating global temperatures, melting ice caps, higher sea levels, and climate change, all stemming from greenhouse gas emissions.[1]

According to the World Bank, 150 to 170 billion m3 of gases are burned off or released into the atmosphere every year, with a total value of approximately $30.6 billion, which is equivalent to one-fourth of the gas consumed by the United States or 30% of the gas consumed by the European Union each year. Therefore, it is essential to decrease or eliminate gas flaring. Hence, it is crucial to determine the composition, distribution, and volume of flared gas, as well as select the appropriate system for flare gas recovery or disposal .[2].

Figure (1) depicts the spectrum of burning efficiency, categorized into four quadrants ranging from "red for high absolute burning and high burning intensity" to "green for low absolute burning and low burning intensity." Libya is a top concern, along with "orange" nations (those with intense burning but less than 1.5 billion cubic meters of total burning, like Egypt and Australia), and "yellow" nations (those with over 1.5 billion cubic meters of burning but at lower rates, such as Saudi Arabia, the United States and China. Several environmentally conscious countries (like the UK, Qatar, and Brazil) still have ample potential for enhancement.

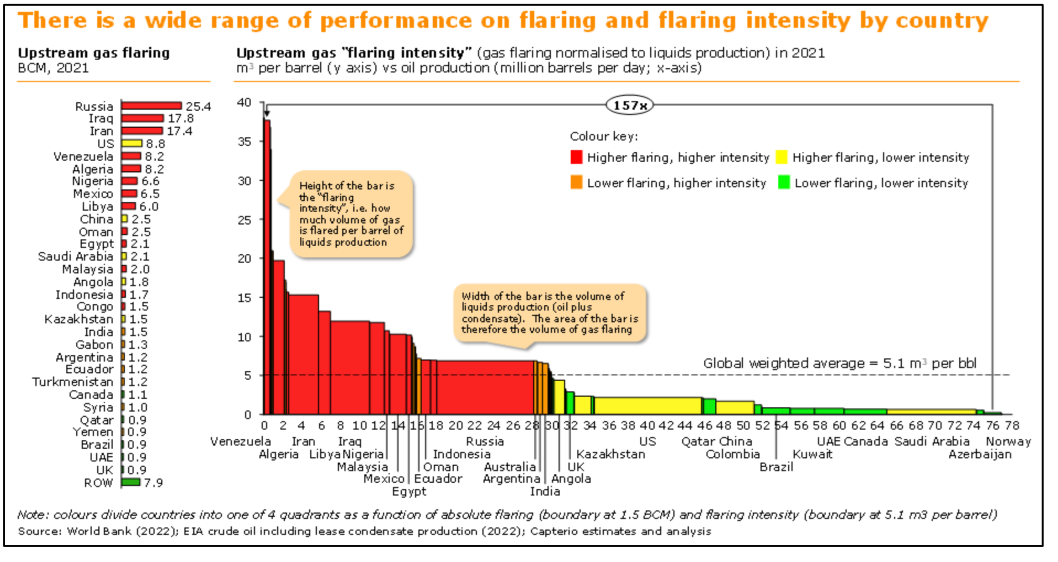

Figure 1 there is wide range of performance on flaring and intensity by country. [3].

Gas flaring at upstream oil and gas facilities saw a 7 percent rise in 2023, with an increase of 9 billion cubic meters from 139 bcm in 2022 to 148 bcm in 2023. Simultaneously, there was a mere 1 percent increase in oil production, resulting in a 5 percent growth in the worldwide average flaring intensity, which measures the quantity of gas flared per barrel of oil extracted. Given the current gas price, the total value of flared gas in 2023 could have ranged from $9 billion to $48 billion.

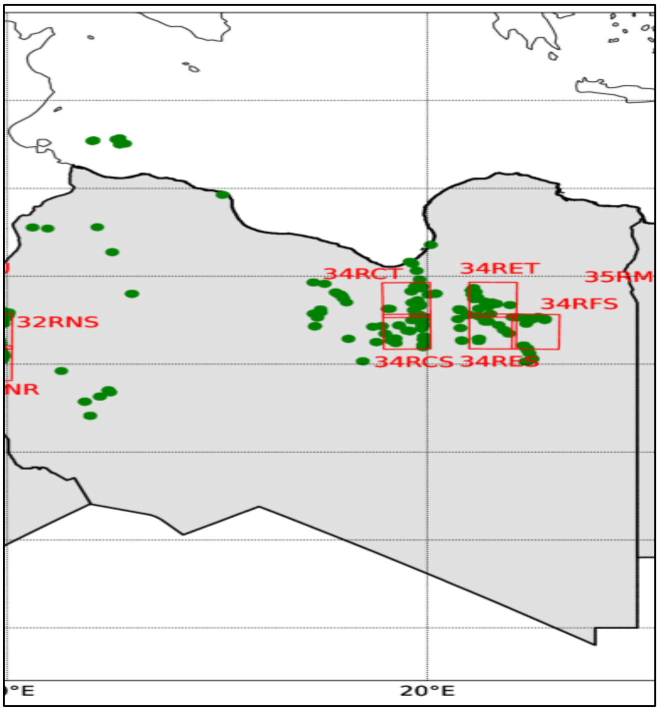

Figure 2: Gas flaring emissions monitoring map for North Africa (Libya) 2022.[4]

Getting rid of gas flaring could prevent a minimum of 381 million tons of carbon dioxide equivalent emissions from being discharged into the atmosphere annually. This rise shows a turnaround from the decline in gas flaring from 2021 to 2022, leading to the highest amount in the past five years and a growth in flaring intensity. This indicates that the world's current attempts to decrease gas flaring are not lasting, and immediate measures are necessary to reach Zero Routine Flaring by 2030.

Effective partnerships and solutions for monetizing associated gas can lead to substantial decreases in gas flaring and intensity. Nations like the US, Angola, Algeria, and Venezuela made significant progress from 2020 to 2023. Nevertheless, some countries saw significant increases in gas flaring in 2023 that surpassed the positive changes mentioned, as shown in Figure (3).

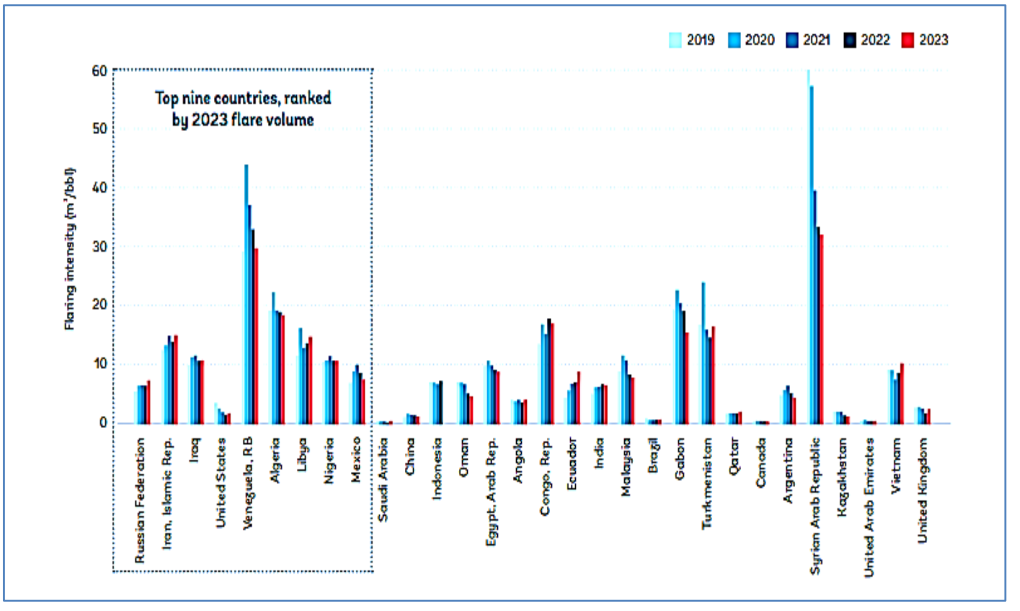

Figure 3. Flaring intensity in the top 30 flaring countries from 2019 to 2023 in order of 2023-flare volume, with the top 9 flaring countries indicated. [3]

However, even after making some progress, the Russian Federation, the Islamic Republic of Iran, Iraq, the United States, the Bolivarian Republic of Venezuela, Algeria, Libya, Nigeria, and Mexico continue to be the leading nine countries in gas flaring in 2023. Combined, these nine nations account for 75 percent of worldwide gas flaring. Gas is combusted, yet just 46 percent of oil produced worldwide is consumed. The shared factor among these nine nations, responsible for 75% of worldwide gas consumption, is their rising oil and gas production with no clear resolutions for the environmental impact of burning gases as shown in figure (4).

The Chairman of the Board of Directors of the National Oil Corporation predicted that Libya will produce over 1.5 million barrels per day of oil by 2025 and hit 2 million barrels per day by 2027. During the budget review for 2022-2023, it was highlighted that continuous funding is necessary for ongoing projects to achieve the growth in production. Nevertheless, there was no reference to the need for businesses to continue investing money to back environmental projects in order to eliminate gas flaring in Libya by 2030

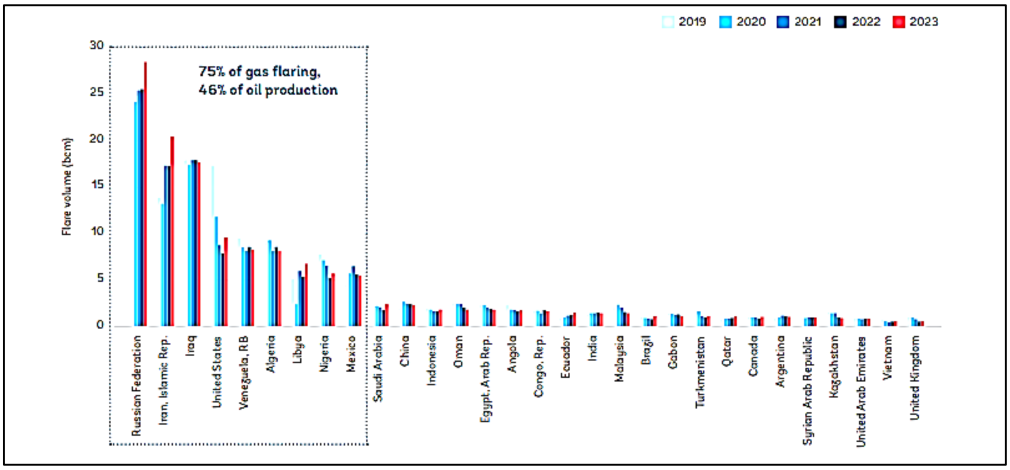

Figure 4. Flare volumes in the top 30 flaring countries, in order of 2023 flare volume with the top 9 flaring countries indicated, 2019–23. [3]

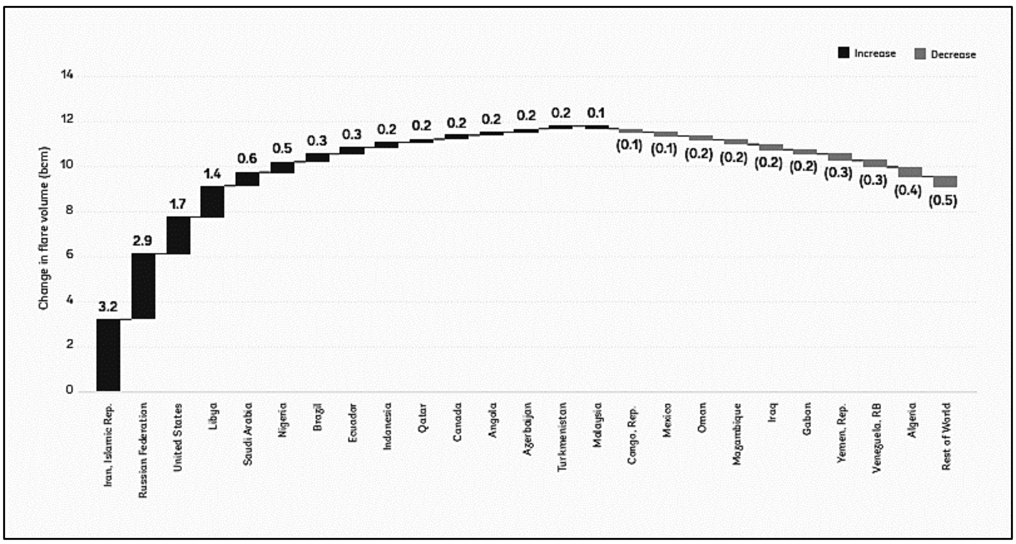

Figure 5. Change in flare volume across countries where it was significant, and rest of world, 2022–2023.[3]

During 2019, Libya saw a significant rise in gas flaring of 1.4 billion cubic meters. This decreased in 2020 due to oil field closures. However, the flaring rate spiked in 2021, followed by a slight decrease and then another increase in 2023, as depicted in the figure 6(a, b).

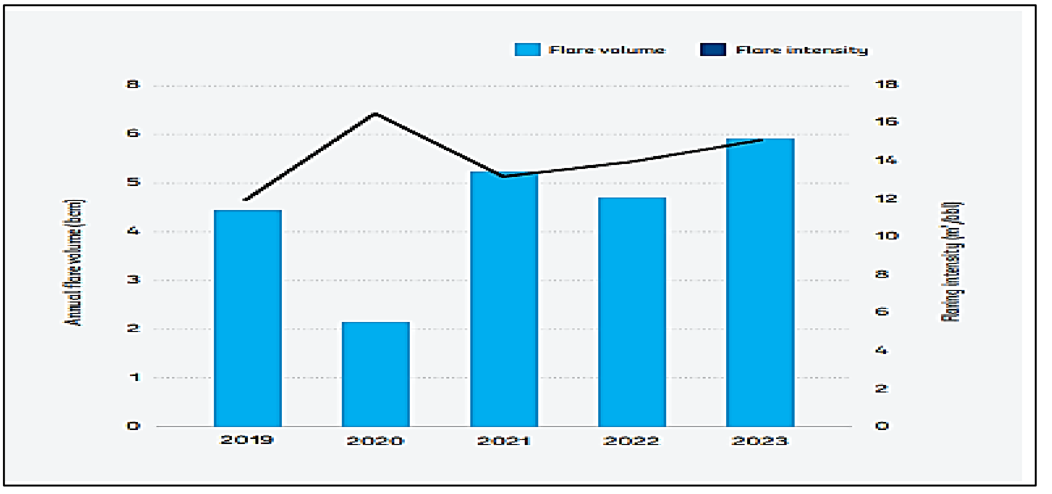

Figure 6(a). Flare volume and flaring intensity in Libya, 2019–23.[3]

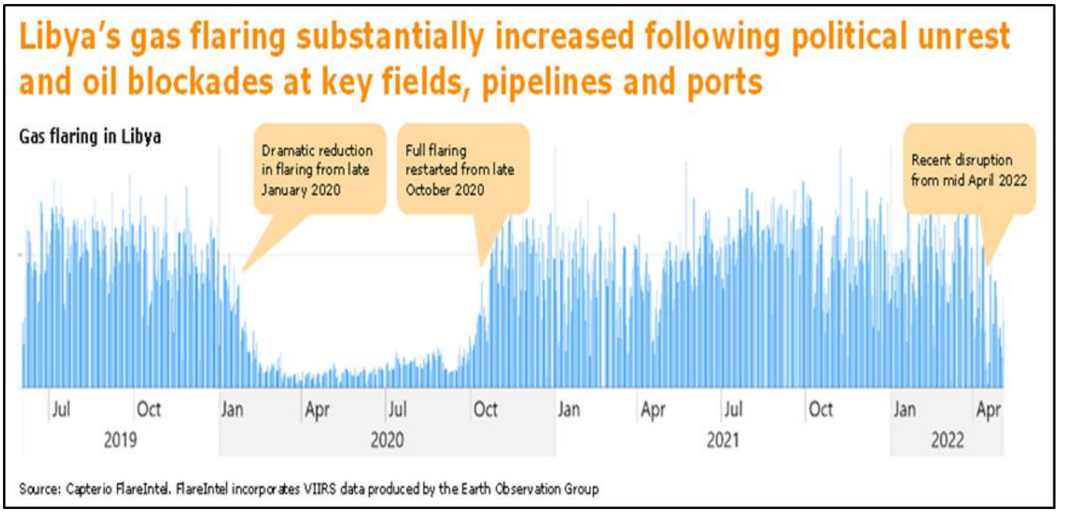

Figure 6(b). Flare volume and flaring intensity in Libya, 2019–22 .[3]

Gas flaring in Libya rose by 1.4 bcm (25 percent) in 2023, with a 16 percent increase in oil production, causing flaring intensity to rise by 8 percent from 14.0 m 3/bbl in 2022 to 15.2 m 3/bbl. Routine gas flaring occurs when there is a lack of infrastructure or investment to recover and use associated gas that is being flared, leading to an increase in flaring with increased oil production. The higher intensity of flaring indicates a lack of investment in gas infrastructure and utilization. [3]

These emissions possess a significant global warming impact and play a role in climate change. The measurement of flared gas and its emissions is of great importance and has proven to be quite difficult. Various flow meters are utilized to measure flared gas, but ultrasonic flow meters are the preferred choice in the industry, with over 3000 installations across various process plants globally. Reducing and recovering flare gas is highly important as it serves environmental and economic efficiency goals.[2]

The importance of flare gas recovery

Flare gas extraction is a vital procedure in the oil and gas sector due to its environmental and economic benefits. Capturing this gas, particularly methane, helps reduce greenhouse gas emissions, leading to a cleaner environment and potential economic benefits. It carries valuable energy that can be captured and commercialized. Unburned or unregulated flares have the potential to cause fires, explosions and danger to neighboring communities. The flare gas recovery procedure minimizes these risks by ensuring that the flare is well managed and burns efficiently. Efficiency in the production process can be enhanced through flare gas recovery, helping to minimize energy loss during combustion. This can lead to lower costs and improved financial performance. Compliance with gas flaring regulations can be achieved through flare gas recovery, helping companies avoid fines and reputational damage. Improved resource recovery the use of flare gas recovery can also enhance the recovery of oil and gas from the reservoir by reducing pressure build-up and increasing the amount of fluids generated. Reducing waste, and in the context of Libya, recovering 1.4 billion cubic meters of flare gas is essential not only to reduce emissions, but also to generate revenue and demonstrate the company's dedication to environmental accountability. This work contributes to the drive to achieve zero flaring in Libya for 2030 by highlighting the magnitude of the issue and the importance of developing urgent solutions to accompany the expenditure to increase production.

Literature Review

Sustainability is seen as more important for companies, but in Libya, oil companies are not moving quickly to address operational problems that could help with environmental issues. This study seeks to evaluate the environmental consequences of oil and gas activities. The study used a literature review, an environmental impact assessment (EIA) study, qualitative analyzes from fieldwork experiences, and 56 semi-structured interviews. The study results reveal that primary environmental impacts consist of aquatic, terrestrial, or atmospheric impacts, with the most prominent pollutants associated with the latter group, derived primarily from engine exhausts, turbine emissions, gas flaring, and ventilation. Significant environmental degradation has been identified in Libyan upstream activities with several proposals put forward to reduce their impact. Great emphasis is placed on establishing stringent sustainability policies and regulations, as well as implementing an environmental management system.[5]

Estimates of gas flared volume are determined using calibrations created with a mix of gas flaring volumes reported nationally and data from individual flaring activities. The calculation of burning efficiency was determined by the amount of gas burned per barrel of crude oil produced. Gas flaring on a global scale has been relatively consistent for the past 15 years, fluctuating between 140 and 170 billion cubic meters. Between 1994 and 2005, the worldwide gas flaring efficiency was between seven and eight cubic meters per barrel, but it decreased to 5.6 cubic meters per barrel by 2012. In the USA, gas flaring in 2012 accounted for 139 billion cubic meters, which equals to 21% of natural gas use. The emission from the fire in 2008 contributed over 278 million metric tons of carbon dioxide equivalent to the air. Global gas flaring has decreased by 19% since 2005 according to estimates of gas flaring volumes.

Ifeboomwan et al. concentrated on creating and simulating a flare gas recovery unit for a standard conversion refinery, specifically for a typical refinery situation in Nigeria. Using just one liquid loop compressor, the design achieved a production efficiency of 97.95% and could handle flow increases of up to 40% of the standard gas rate. This saved $35,924.00 in equipment costs compared to traditional reciprocating compressors. The product gas, post amine treatment, meets pipeline gas quality standards with 4 ppm H_2S and 3 mol% CO_2, and is deemed sufficient for producing 8 MW of electricity with gas turbines. The project cost a total of $26,767,050.89 to set up and had operating expenses of $2,139,483.54. It made $9,419,920.00 in revenue from selling electricity at an industrial tariff rate of JPY 48.39 per kilowatt hour. The study showed practicality with a payback or breakeven time of 4 years and 4 months, an NPV of $35,555,817.46 over a 20-year project lifespan, and an IRR of 17.10%. Nevertheless, it is advisable to make investment choices only if interest rates are less than 34.6% and inflation rates exceed -6%.[6]

According to Shehata et al, the research examines how utilizing gas compressors to recover flare gases impacts the economic and environmental aspects of a current oilfield facility. The software aspen HYSYS Version 11, a commercial simulation program, was utilized. The plant under study is the Kalabsha Central Processing

Facility (KCPF) located in the Western Desert of Egypt. The plant processes 30 million standard cubic feet per day (MMSCFD) of fluids from the free water knock out drum and 1.6 MMSCFD of gases from heaters. 20 MMSCFD of gas is directed into the gas pipeline, while 10 MMSCFD is diverted to the flare along with 1.6 MMSCFD. There is a suggestion to put in gas compressors to collect gases from the free water knock out drum and heaters before they are sent to the flare. This technology can serve as a tool to enhance both current and upcoming oil and gas facilities in order to minimize gas flaring. Moreover, protecting the environment can result in additional financial benefits by utilizing the recovered gas for burning, in addition to extending the lifespan of flare equipment.[7]

In a study conducted by Mousavi, it was found that utilizing environmental flow charts, HYSYS software, Thermoflow, and Aspen can help reduce energy consumption and manage environmental pollution. An examination was conducted on three primary FGR scenarios in a gas field in southern Iran, focusing on both the technical and economic aspects related to energy consumption and a total flare gas flow of 4.5 million standard cubic feet per day. The initial option involves compressing and injecting surplus flared gas into oil wells, the second option involves generating power and injecting excess flared gas into oil wells, and the third option involves generating energy through a combined heat, power, and internal combustion engine system. One of the most effective methods to decrease gas flaring is by compressing flared gas and injecting it into oil wells, with an internal investment rate of 171% and a payback period of 1.02 years. Also, all levels of pollution in soil, air, and water are assessed collectively. Once environmental indicators are determined and data is gathered, a visual representation called an environmental flow diagram (EFD) is created to show the origins and locations of pollution and how they relate to environmental concerns. In this area, the levels of CO_2, carbon dioxide and nitrogen oxide in the ovens, dehumidifier, and burner were reduced by 100%, 100%, and around 57% with EFD, as per the related gas collection data. [8]

Real data from the field was used in conducting this study. All instances were modeled using Aspen HYSYS software. The mini-GTL unit is designed using an autothermal reforming technique. Both methods will lead to a decrease of 107.68 tonnes of CO_2 emissions per day. The economic evaluations showed that the NGL and sales gas product is valued at 77.03 MMUSD in net present value (NPV), with the mini-GTL product having an NPV of 73.7 MMUSD. The research indicated that it is possible to obtain natural gas Liquids (NGLs) such as propane, LPG, and sales gas from raw gas or transform it into liquid products like gasoline and diesel. The anticipated internal rate of return (IRR) and payout time (POT) for NGL and sales gas approach are 150.73% and 0.27 years, respectively. Using the mini-GTL method is suggested because of Egypt's lack of petroleum fuel and is the optimal solution when a connection to the national gas grid is not available at the facility. Yet, the mini-GTL method shows an IRR of 30.09% and a POT of 1.19 years.[9]

The study by Zollfaghari et al. compares three methods - gas-to-liquid (GTL), gas turbine generation (GTG), and gas to ethylene (GTE) - and determines the best method from an economic perspective. A sample of natural gas is obtained from the Asaluya refinery for this purpose, and the simulation is performed using Aspen HYSYS. Meanwhile, the Aspen Capital Cost Estimator tool was used to assess capital and operational costs and review the processes involved. Based on the results, electricity generation from combustion gases is among the most cost-effective approaches. The FGD approach, which generates approximately US$480 million in revenue annually, has a higher ROI. [10]

The study puts forward three techniques for gas extraction in the Salwa gas refinery as an alternative to the customary burning method. These approaches seek to minimize the negative impacts on the environment and economy caused by burning torch gas. The suggested techniques include: 1) converting gas into liquid fuel (GTL) production, 2) producing electricity with gas turbines, and 3) compressing and injecting gas into refinery pipelines. To determine the best approach, we simulated the necessary equipment for the three mentioned methods. These simulations calculate the quantity of flare gas, the quantity of GTL drums, the power produced by the gas turbine and the necessary pressure force. Results from the simulation indicate that the initial method generates 48,056 barrels per day of valuable GTL products. The second technique produces 2130 megawatts of electricity, while the third technique supplies compressed natural gas at 129 bar for injection into the refinery pipelines. Furthermore, the economic aspects of various methods for extracting torch gas were analyzed and contrasted. The findings indicate that out of the 356.5 million standard cubic feet of flared gas from the Asalawi gas refinery, GTL production offers the highest rate of profit. Nevertheless, GTL necessitates a higher amount of capital to be invested. Compression of gas provides the second highest return on investment and is the most cost-effective choice for the Assalwi gas refinery due to its minimal capital needs.[11]

The significance of gas pipeline infrastructure in reducing flaring of Associated Natural Gas in oilfields has been addressed. The close proximity to a current gas pipeline, the amount of gas available, and the extra capacity of the pipeline were key factors in the development of this strategy for using flare gas. The IFPEX-1 process was chosen as a cost-effective method to produce pipeline sales gas and household LPG for cooking according to local regulatory standards. This guarantees the most efficient utilization of flare gas by converting the gas and its byproducts into profit, eliminating gas flaring, and decreasing gaseous pollutants in the environment. The IFPEX-1 process offers cost savings in both CAPEX and OPEX through improved heat integration of the refrigeration and fractionation system, resulting in a 36.2% reduction in utility consumption according to simulation results. Despite the relatively low OPEX, methanol losses in the Pipeline Sales gas stream are frequent, thus requiring adequate on-site methanol storage for efficient operation. The small amount of methanol left in the pipeline gas is insignificant and does not impact the product requirements. In general, the procedure can be expanded easily for small and large oil fields, offering a distinctive solution with multiple advantages.[12]

Various FGRS options in industry include collecting and compressing gas, converting gas to liquid, and producing electricity. FGRS have faced various technical obstacles, including fluctuating flow rates and composition, as well as waste gases with low heating value and pressure. The method of gathering and compressing gas into pipelines for processing and selling is a widely-accepted and effective way to reduce flaring and venting. Due to environmental and economic factors, the use of FGRS has risen to lower noise and thermal radiation levels, as well as decrease operating and maintenance expenses, air pollution, and gas emissions, while also cutting down on fuel gas and steam utilization.[2]

Edeh and Olawa conducted a simulation to produce 430,600 kg/hour of fluid catalytic cracking (FCC) gases at a southern Nigeria refinery by recovering flare gases from the flare system header and redirecting them for recycling within the refinery, petrochemical plants, and other industries. The Unisim Design 471 simulation tool is utilized for this task, utilizing flare data from the refinery's fluid catalytic cracking unit. The simulation runs at steady state, employing a Bunge-Robinson fluid package to extract methane, ethane, propane, butane, isobutene, and initial products recovered from the flare stream. The average recovery rate for the product in the simulated plant is 94 per cent. Installing a CO2 recovery system into the flare could potentially decrease CO2 emissions to the environment by about ten million tons annually .[13]

Continuous burning of natural gas results in the wastage of significant energy resources and the escalation of greenhouse gas emissions, which add to the issue of global warming. Our research gives a summary of a method to recover clean fuel and lower CO2 emissions to a minimal extent. Two ways to recover rich gas are: the retrieval of natural gas liquids and sales gas production using an existing LPG unit, and the creation of liquid fuels with a mini-GTL unit (gas to liquid).[9]

The flared gas was decreased from 190 to 31 million MMSCMD in total. Additionally, the CO2 emission level went from 380,000 to 63,000 tons while overall greenhouse gas emissions saw a reduction of over 700%.[14]

Researchers conducted a study on gas flaring locations in Omuyopolo IH LGA and Agbada 2 in Obio /Akpor LGA, Rivers State. The identification of heavy metals (cadmium, arsenic, lead, and chromium) in samples has been achieved through the use of atomic absorption measurement. Levels of cadmium in tubers exceed the acceptable threshold established by the Food and Agriculture Organization and the World Health Organization for both groups. The research revealed that the crops collected from the study location are polluted and may present a significant health risk to humans and animals if eaten. This research suggested that authorities and regulatory agencies enforce the implementation of a flare gas recovery system (FGRS) to lessen the discharge of flammable gases into the atmosphere.[15]

Ndunagu et al. are concentrating on a methanol-based gas treatment and recovery technique for liquefied petroleum gas (LPG) using a marginal Nigerian oil field with high flaring density located close to a gas pipeline. The flare gas's qualities can present different obstacles, but the project's viability is influenced by external factors like distance to the gas pipeline and market access. The flaring profile of the oil field indicated a capacity of 60 million cubic feet per day, leading to the selection of a propane cooling system for the cooling process. The HYSYS V9 Cubic Plus Association (CPA) equation of state was utilized to accurately forecast the separation of methanol (employed as a hydrate inhibitor) within the methanol-hydrocarbon mixture. The operation yielded natural gas at a rate of 57.15 MMscfd, LPG at 163.7 tonnes/day, and stabilised condensate at 33.19 tonnes/day, in accordance with the Nigerian Gas Transmission Code (NGTC) standards.[12]

His study semmari et al primarily aims to demonstrate the capabilities and thermodynamic efficiency of using ORC technology to generate electricity and provide cooling by coupling an absorption chiller with heat recovery from gas combustion, proposing to consider an ORC system for toluene for use in an Algerian petrochemical facility. Producing electricity using ORC technology is a simple energy efficiency solution that can effectively meet the growing need for natural resources. Originally intended for a gas power plant, ORC gas is now mainly fueling Algeria's electricity production.[16]

The two researchers studied the technical and economic aspects of gas flaring technology by comparing two methods for combining compressed natural gas (CNG) and gas-to-wire (GTW) with compressed natural gas (CNG) and their use in this sector. Both approaches are presented and compared to the financially optimal one. Based on the results, using flare gas to produce CNG is the most cost-effective approach; it offers a higher return on investment, generates annual profits of about $3.65 million, and has a payback period of 2.09 years.[17]

Both Elvidge et al centered on techniques for worldwide assessment of natural gas flaring using data obtained from the National Aeronautics and Space Administration (NASA) visible infrared imaging radiometer array. A series of methods for global assessment of natural gas flaring utilizing NASA data is discussed. The VIIRS array by NASA/NOAA for capturing visible and infrared images. The precision of predictions for the amount of combustible gas is 9.5%. The researchers determined that VIIRS is well-suited for identifying and quantifying radioactive emissions from gas flares by gathering shortwave and near-infrared data at night, and capturing peak radioactive emissions produced by the flares. The findings validate that most natural gas combustion takes place in production regions. Main. VIIRS information can be used to track natural gas flaring at specific locations to assess progress in reducing and stopping routine gas flaring.[18]

The following study presented an innovative technical and economic analysis for choosing an integrated ejector system in the flare gas extraction process in a refinery plant, as the compression process in the flare gas extraction process, which is usually carried out by compressors, is considered the most expensive. It was then proposed to use an integrated gas-gas ejector system instead of, the compressor and its technical and economic study, implementing the modeling of the flare gas recovery process, including the gas sweetening unit, for both the compressor and ejector systems. Various arrangements of the integrated ejector system were also studied in the form of multi-stage (series) ejectors in parallel branches. To find the ejector geometry to simulate the integrated ejector system at Aspen HYSYS, as well as predict ejector performance under different pressures and mass flow rates of the inlet gas, a computer code was developed in MATLAB. The results of the economic analysis showed that the compression method with a three-branch parallel arrangement (containing a three-stage ejector in each branch) was the most suitable solution in flare gas recovery in a typical oil refinery, with an investment cost of

US$4.84 million, an acceptable payback period of 2 years and a recovery of Approximately 90% of the burner gas volume during normal operation.[19]

A study by Nassar et al revealed that actual data was tracked while energy was transferred from oil fields to the refinery and ultimately to the power plant. Generating 1 megawatt hour of electricity requires burning 291 kg of diesel fuel, which in turn needs to refine 1,141 kg of crude oil. A flow chart was created to depict the CO2 output of the process, revealing that approximately 983 kgCO2/MWh is emitted in total. The oil industry sector contributes 0.97% from extraction and 5.43% from refining, with the remaining emissions originating from electricity. The results revealed significant variations in the CO2 emission factors listed in inventories approved by multiple environmental agencies across all categories. Additionally, the methodology employed in this study resulted in a 6.7% rise in carbon dioxide emission factors as opposed to the conventional method, opening up avenues for equitable competition with alternative electricity generation options like renewable energy sources. This method offers a fresh outlook on handling environmental concerns by integrating engineering and economic aspects, allowing for the enhancement of engineering design with an environmental focus .[20]

Innovative Technologies for Flare Gas Recovery

Selecting the most feasible technology for implementation in the refinery plant is a crucial aspect of designing a gas flare recovery system. Ejector and liquid ring compressor are the top technologies used in petrochemical industries.[21]

The ejector, also known as a jet pump operates based on Bernoulli's principle where an increase in velocity results in a decrease in pressure, and vice versa. This allows capturing flare gas before compressing it to intermediate pressure between LP and HP using HP driving fluid, which can be liquid or gas providing energy for final compression. The ejector offers great cost efficiency and is utilized in numerous refinery operations. A one-stage ejector comprises of driving nozzle, suction nozzle, mixing chamber, throat, and diffuser. The HP fluid passes through the nozzle, causing its kinetic energy to increase while the pressure energy decreases. This results in a significant pressure drop and the creation of a low-pressure area downstream the nozzle, where the LP fluid is drawn back into the ejector.[22].

Table 1 the some Technologies for Flare Gas Recovery

N.O	Technology	systems use	Product	Ref
1	Flare Gas Recovery Systems	a combination of heat exchangers compressors, and other equipment	Electricity, fuel, or CO2.	[23-25]
2	Cryogenic Flare Gas Recovery	cryogenic separation	natural gas liquids (NGLs) and natural gas liquids (NGLs)	[25]
3	Flare Gas Compressor Technology	compressor	making it possible to transport it through a pipeline	[24, 25]
4	Flare Gas Power Generation	Power generation units (internal combustion engines, gas turbines, or micro turbines.)	generate electricity	[25]
5	Carbon Capture and Utilization (CCU)	captures CO2	Chemicals, fuels, or building materials.	[24, 25]
6	Flare Gas Processing		Separate the components of the gas stream (methane, ethane, propane, butane, and NGLs.)	[25]
7	Advanced Analytics and Sensor Technology	advanced sensors and analytics to monitor flare gas emissions in real-time	Enabling operators to detect anomalies and optimize flare gas recovery.	[25]
8	Flare Gas Recovery from Associated Gas	involves recovering flare gas from associated gas streams	Rich in hydrocarbons and can be processed for sale or further processing.	[25]
9	LNG Flare Gas Recovery	recover liquefied natural gas from flare gases	Liquefy it for storage or transportation.	[25]
10	Flare Gas Utilization through Enhanced Oil Recovery (EOR)	injects flare gas into oil reservoirs	Improve oil recovery and reduce the amount of flare gas emitted.	[25]
11	Biogas Flare Gas Recovery	biogas produced by flaring gases	Generate electricity or heat.	[25]
12	flare Gas Fuel Cells	uses torch gas as a fuel source for fuel cells	Generate electricity with low emissions.	[24, 25]

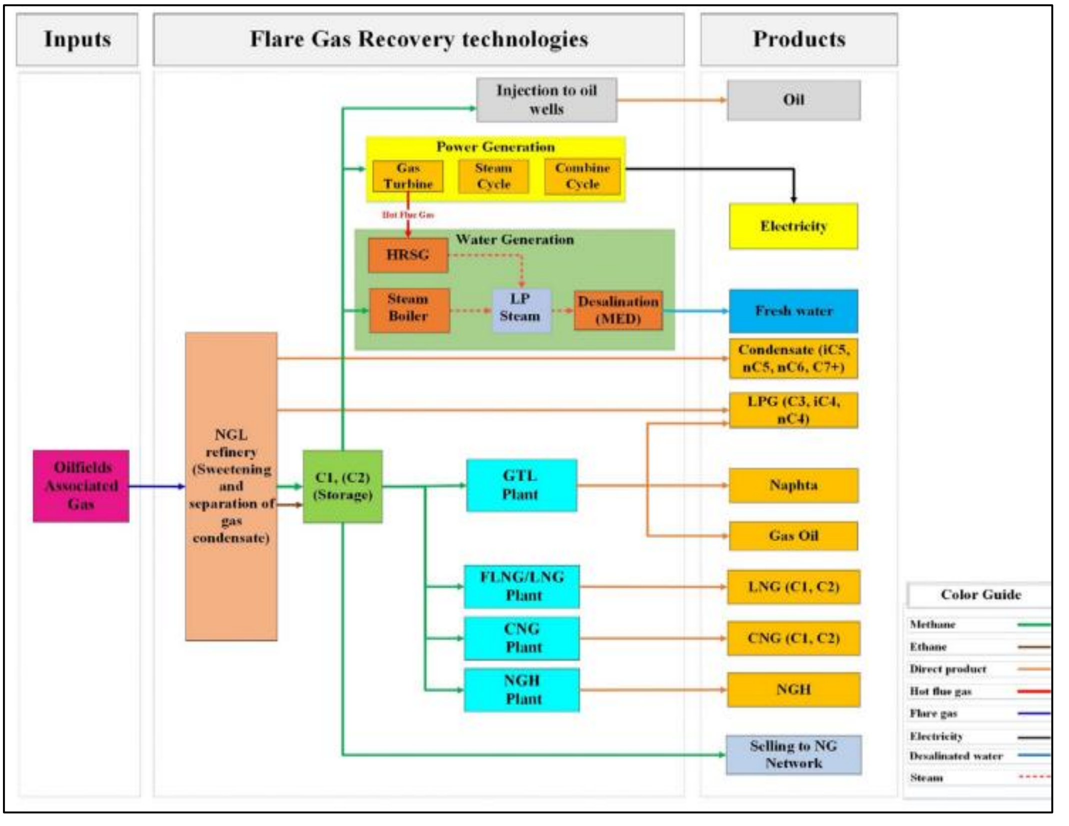

Figure 7 Conceptual module of the references energy system (RES) of flare recovery scenarios [25]

Innovative technologies

Advanced condensation systems

Sophisticated condensation systems are essential technology for recovering flare gas, as they allow the efficient condensation of flare gas components, leading to the creation of high-quality gas streams. Below is an in-depth explanation of the process: Sophisticated condensation systems employ advanced designs, materials, and operating parameters to enhance the condensation process, resulting in high purity and recovery percentages being achieved. Types of technology utilized: Finned tube condensers employ a setup of tubes with fins to enhance the surface area for heat transfer, leading to improved condensation efficiency. Micro-channel condensers utilize narrow channels to enhance heat transfer surface area, resulting in quicker and more effective condensation. Advanced cooling systems, such as air-cooled or water-cooled systems, offer optimal temperature regulation for condensation. Gas pretreatment: Getting rid of contaminants and moisture from the flare gas stream to enhance condensation efficiency. The usual process of the advanced condensation system involves gas pretreatment, where impurities and moisture are removed from the flare gas stream by cleaning and drying it. The pretreated gas stream is cooled with a sophisticated cooling system to a temperature below the gas components' dew point. The chilled gas is next routed through a finned tube or micro-channel condenser, where the gas elements are converted into a liquid form. Separation involves using gravity or centrifugal separation methods to separate the condensed liquid from the rest of the gas stream. The concentrated liquid might go through further purification processes like filtration or distillation in order to attain a high level of purity.

Cryogenic separation systems

Cryogenic separation systems play a crucial role in torch gas recovery by efficiently and cost-effectively extracting valuable gases from torch gas streams. It involves using very cold temperatures to isolate and retrieve various elements of a gas mixture. Separation is utilized in the gas recovery process using a torch. Cooling system to separate useful gases like methane, ethane, and propane from the gas released by the torch. During the head start process, the torch gas stream is cooled to an extremely low temperature, typically about -150°C, by a refrigerant like liquid nitrogen or carbon dioxide. As the gas stream cools down, the components with higher volatility, like methane and ethane, turn into liquid, while the less volatile components, such as carbon dioxide and nitrogen, stay in their gaseous form.[26]

Afterwards, the liquid and gaseous streams are separated using a dehumidifier or collector to eliminate any remaining liquid droplets from the gas stream. The condensed liquids are subsequently fractionated to isolate various hydrocarbon components (such as methane, ethane, and propane) according to their boiling points. Extra purification steps like pressure swing adsorption (PSA) or membrane separation can be used on the separated components to eliminate impurities and enhance their quality.

High recovery rates are one of the benefits it offers. Cryogenic separation is capable of achieving high rates of recovery for valuable gases, frequently surpassing 90%.

Membrane separation systems

Membrane separation systems are a common technology used for flare gas recovery, offering a cost-effective and energy-efficient method to separate and reclaim important gases from flare gas streams. [27] The process of membrane separation involves the use of semi-permeable membranes to separate molecules depending on their size, shape, and chemical characteristics. Membranes are utilized in flare gas recovery to isolate various components of the flare gas stream, including methane, ethane, propane, and heavier hydrocarbons. The process of membrane separation usually includes gas pretreatment, where the flare gas stream is cleaned and dried to eliminate impurities and moisture. Separation of components in the gas stream occurs as it passes through a membrane unit, where molecular size and properties are utilized for differentiation. The membrane permits the passage of smaller molecules like methane but blocks larger molecules like heavier hydrocarbons. Collecting the permeate gas stream, which contains separated components, is done for utilization or commercialization. The permeate gas stream, with rejected components, can be reused in the flare gas stream or processed again to extract valuable components. Carbon-based materials with controlled pore sizes are utilized in polymeric membranes, inorganic membranes, and carbon molecular sieve membranes for separation purposes.

Biogas upgrading systems

Biogas upgrading systems play a vital role in flare gas recovery by purifying and enriching biogas to create a high-quality fuel gas for replacing fossil fuels. A thorough explanation of the technique is provided. Biogas purification systems involve a mix of technologies to filter out impurities from the biogas, yielding a refined gas suitable for use as a fuel. Gas purification the biogas is initially purified to eliminate impurities like water, solids, and other contaminants. Adsorption under pressure (PSA) Next, the purified biogas is brought through a PSA unit that utilizes activated carbon or zeolite adsorbents to eliminate carbon dioxide and other impurities.[28]

After going through PSA treatment, the biogas is directed to a methanation reactor to create methane-rich gas through the reaction of methane with steam. The refined biogas is compressed to the required pressure for storage or transportation. Additional processing i.e. filtering and drying, may be necessary for the compressed biogas to meet quality standards at the final stage of treatment. Adsorption involves the selective attachment of molecules onto the surface of specific materials like activated carbon or zeolite. Pressure swing adsorption (PSA) is a unique adsorption method that manipulates pressure variations to govern the adsorption and desorption of gases. Methanation is a process where carbon dioxide is transformed into methane with the help of steam.

Hybrid systems combining multiple technologies

Hybrid systems that combine different technologies are gaining popularity in flare gas recovery due to their enhanced efficiency, effectiveness, and cost benefits. A thorough explanation of the Hybrid systems method involves the integration of various technologies to separate and extract flare gas components, utilizing the advantages of each technology to create a more thorough and effective process. [11] Technologies utilized Membrane separation employs semi-permeable membranes to sort molecules according to their size, shape, and chemical characteristics. Adsorption involves the use of activated carbon or zeolite substances to selectively trap impurities and contaminants. Cryogenic separation involves the use of low temperatures to separate substances according to their boiling points. Compression is utilized to raise the gas stream pressure for future processing or storage.

Table 2 Advantages and disadvantages of FGRU techniques

		Advantages	disadvantages
1	Advanced condensation systems	High-purity gas Increased recovery rate Energy efficiency Flexibility	System complexity Maintenance(Scalability
2	Cryogenic separation systems	High recovery rates Low capital costs Low operating costs Environmental benefits	High operating temperatures Refrigerant usage Component purification
3	Membrane separation systems	Energy efficiency Cost-effective Flexibility Scalability	Membrane fouling Selectivity Gas compression
4	Biogas upgrading systems	High-purity gas (produce high-purity gas with methane content above 95 %.) Flexibility Cost-effective Environmentally friendly	Scalability Energy consumption System reliability
5	Hybrid systems combining multiple technologies	Improved purity Increased efficiency Cost savings Flexibility	Complexity Maintenance Scalability

Discussion

Sophisticated condensing systems play a crucial role in torch gas recovery by enhancing purity, boosting recovery rates, saving energy, and offering flexibility. The benefits and difficulties have been recognized as indicated in the table (2) provided. Cryogenic separation systems are typically advantageous in recovering flare gas due to their high recovery rates, cost-effectiveness, and environmental advantages. Nevertheless, careful consideration of the challenges linked to this technology is essential during the design and operation of these systems.

In addition to the pros and cons of this approach, contemporary methods of flame gas retrieval. Membrane filtration systems offer energy efficiency, cost savings, versatility, and scalability. Nevertheless, it is essential to take into account the negative effects of membrane fouling and selectivity in the design and operation of these systems.
Biogas upgrading systems are an essential technology in the recovery of flare gas, allowing for the creation of top-quality fuel gas from biogas streams. Despite the challenges they pose, these systems provide many advantages in terms of purity, flexibility, cost-effectiveness, and environmental sustainability.
By integrating various technologies, hybrid systems offer a complete solution for recovering flare gas, allowing for the creation of pure gas streams with enhanced efficiency, cost benefits, and versatility. Despite the drawbacks and challenges, investing in these systems can be beneficial for companies wanting to optimize the value of their flare gas resources that have been experiencing excessive flaring for many years.

Conclusion:

In conclusion, the oil sector in Libya is encountering major obstacles as a result of the negative impact of gas flaring, which not only wastes important resources but also adds to the release of greenhouse gases and harm to the environment. The results of this study highlight the pressing necessity of adopting flare gas recovery tactics to address these negative effects. Utilizing cutting-edge technologies like Flare Gas Recovery Units (FGRUs) and other inventive systems can help Libya smoothly shift towards a more sustainable energy framework. This shift has the possibility of numerous advantages, like decreasing emissions, saving energy, and converting waste gas into useful products like LPG and CNG.

Furthermore, analyzing data on gas flaring at both global and national levels between 2019 and 2023 offers important insights into the magnitude of the problem and potential areas for enhancement. The inclusion of flare gas recovery supports sustainability and is in line with worldwide goals to end gas flaring by 2030. Nevertheless, it is crucial to recognize the difficulties involved in creating and implementing recovery technologies that are specifically suited to the specific conditions in Libya's industrial sector.

In the end, this study highlights the important impact of flare gas recovery on promoting a more sustainable and responsible oil sector in Libya. By focusing on creative ideas, enacting successful measures, and tackling current obstacles, Libya can greatly improve its environmental care and tap into the economic opportunities linked to unused resources. Achieving sustainability in Libya's oil sector is attainable, leading towards a future that is both more resilient and environmentally aware

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