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ANALYSIS SWOT ON BLUE AMMONIA PRODUCTION AS AN ALTERNATIVE TO REDUCE CO_2 EMISSIONS IN ECUADOR

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Abstract: The global energy trend aims to replace traditional hydrocarbons with unconventional fuels such as hydrogen. The latter has been the subject of research in developed countries in recent decades, due to its enormous energy content and little or no environmental pollution. However, its production cost is still not competitive enough in relation to fossil fuels. The production of ammonium can be carried out on the basis of hydrogen. The aforementioned is obtained by methods such as: catalytic decomposition of hydrocarbons, pyrolysis, gasification from biomass, ethanol processing, the anhydrous transformation of methanol, and photoelectrochemical and photocatalytic reactions of water. Liquefied petroleum gas and associated petroleum gas are raw materials for ammonia generation. Several member countries of OPEC are working to facilitate the gradual transition from oil to fuels little or nothing known. In this article we summarize several strategies to carry out this transition, putting for your consideration the pros and cons of implementing a system for the use of liquefied petroleum gas and associated petroleum gas that is currently burned in oil field burners. The authors affirm that there is great potential for the production of ammonium in the area of Bajo Alto province of El Oro, as an alternative energy resource in Ecuador. The global energy trend aims to replace traditional hydrocarbons with non-conventional fuels such as hydrogen. However, its production cost is still not competitive enough in relation to fossil.

Keywords: Alternative energies, natural gas, blue hydrogen production, ecology, fossil fuel residues in the environment.

1. INTRODUCTION

The actual environmental status in the world before the global warm up due to the increment of green-house gases (GHG) effect has given place to monitoring and quantification on the local and global impact, technical and political debates, research on technological approaches and new solutions to cope with the problem, re-utilization/storage of pollution compounds for energy generation or minimization of their effect in the atmosphere, etc. Several countries have signed an agreement called the Paris Agreement, as a compromise to contribute mitigating and minimizing the production and release of GHG into the atmosphere. This agreement was first signed in 2016. The goal of the Paris agreement is to limit the mean global temperature rise produced by the emissions of GHG into the atmosphere, to below 2 °C.

Among the top two countries in 2021, regarding air pollution with CO_2 emissions are China and U.S.A. (Global Energy Review, 2021; Oxford U., 2022). As well-known the GHG

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are CO_2, CH_4 and N_2O. The climate watch data reported that the global greatest share (73.2%) of GHG emissions are produced as a result of the energy generation process, where 24.2% is for industries, 17.5% in buildings and 16.2% for transport. Thanks to the exothermic reaction of a combustion process of organic matter, these gases are released in the form of CO_2. The fuel to energy generation correspond to a fossil source as coal in the first place, followed by crude oil and natural gas (Global Energy Review, 2022). Basing on data published by Poore and Nemecek, 2018, a data base project called the Our World in Data organized by the Oxford University reported that around 26% of GHG refer to methane which is released from the food industry (Oxford U., 2022).

During production and depletion of oil reservoirs, methane and other light oil fractions (APG) are released on the surface of oil fields. However, as usual practice this gas is avoided to be released into the atmosphere and therefore, is burned in a process called gas flaring on the top of oil wells. The School of mines and the association for Global Gas Flaring Reduction (GGFR) together with the National Oceanic and Atmospheric Administration (NOAA) of the United States since 2012 count with a system for estimation of the quantity of Associated Petroleum Gas (APG) in the world. This is based on quantification of infrared satellite images (Figure 1) (UN &The Paris agreement, 2015). The World Bank claims that in 2020, the world's gas flaring volume was about 142 billion m3, coming from APG and Liquefied Natural Gas (LPG). In 2020 Ecuador took the 25th position among the biggest COx emitters in the world with a total of 1.04 billion m3 of gas (GGFR, 2022).

The goal of this paper is to analyse the potential alternatives to leverage wasted hydrocarbon resources for conversion into a utilized end-fuel instead of flaring it and subsequently, the no meaningless reduction of CO2 emissions into the atmosphere.

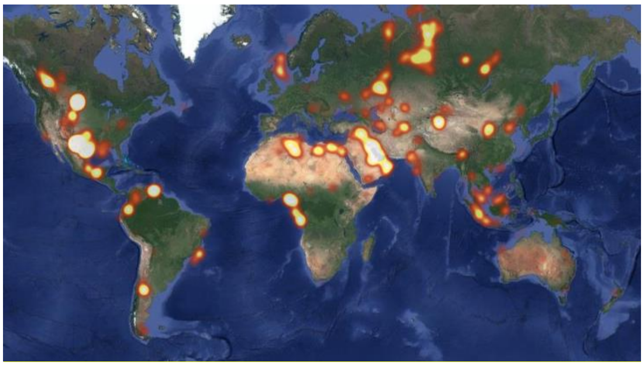

Figure 1. APG flaring activity sites worldwide (The Paris Agreement UN, 2015)

2. MATERIALS AND METHODOLOGY

The SWOT analysis is a strategic planification technique used for the evaluation of the position of a certain process. In this article, the authors will emphasize the recycling and APG utilization for the ammonia production. The analysis consists of four key elements: strengths, weaknesses, opportunities and threads (Li et al., 2022). This is a general analysis, so that, it should be used as part of a broader strategy along with traceable parameters and measures of the results to allow for and improvement of the system.

2.1. Strengths

Among the current Ecuador's and world's challenges are the transition from fossil fuels to renewable or environmentally safe fuels and the mitigation of world's temperature increment due to GHG effects. The energy transition process is not fast nor easy, instead itis slow and technically complex and expensive. The energy transition debates, as well-known started because of the decline in the world's oil production rates as a consequence of the steady depletion of conventional oil reserves. This has traced concern in the way we obtain energy and on what will be the energy source in the near future when fossil fuels will be exhausted. For these reasons it is not meaningless to provide analysis that foster proposals for further actions on minimizing energy waste and maximizing efficient energy consumption.

The term "carbon neutral" used in available literature, refers to the energy source that do not generate GHG emissions to the atmosphere (European Parliament, 2019). Among the most popular fuels available in the market nowadays are presented in Figure 2. From the shown fuels in Figure 2, two of them while combusting, do not generate COx emissions. These are hydrogen (H_2) and ammonia (NH_3). The energy density difference between them is remarkable, being H_2 the most energy releasing fuel. However, NH_3 is a competitive fuel since its energy density is quite close to that of methanol.

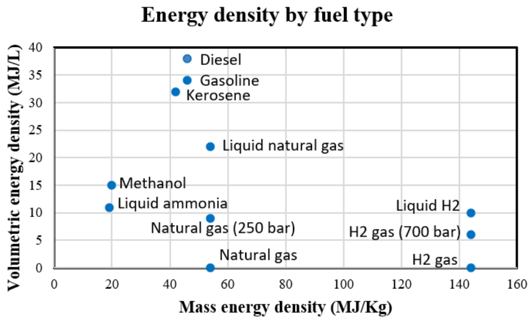

Figure 2. Energy density of most popular fuels (Duynslaegher et al., 2017)

The use of H_2 for the energy generation poses a challenge of its high production cost and complexity during its treatment storage and transport. While processing H_2, the phase change from gas to liquid (liquefaction) requires substantially low operational temperatures. It is liquefied at the temperature of -253°C. Nowadays there is a steadily increasing interest for the use of NH_3 as an alternative energy source in comparison to H_2. The advantage of the NH_3 processing before H_2 is that its processing is less complex and cheaper. Another fact that makes NH_3 attractive is its higher liquefaction temperature which means less energy is necessary to drop down the fuel temperature to a certain point. The NH_3 liquefaction temperature is at -33°C.

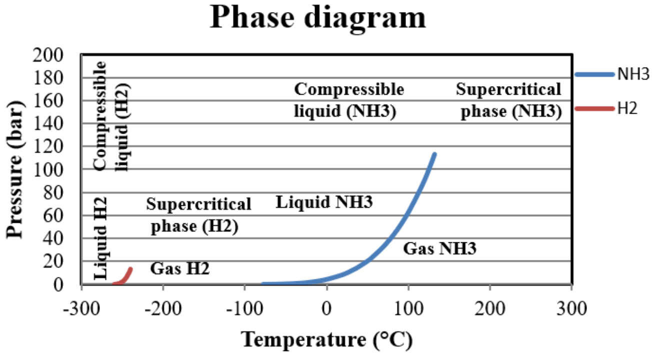

Figure 3. Phase diagram of NH_3 and H_2 (Ammonia, 2018)

The molecular composition of NH_3 lacks chemical elements as carbon or sulphur. For this reason, after that NH_3 is in contact with an O_2 molecule and reaches the activation energy for the combustion reaction (1) it produces zero COx or SOx emissions, alike the hydrocarbon combustion that does generate COx emissions (Rojas et al., 2021; Lyon, 1976) since they contain carbon molecules. Kinetic studies on NH_3 oxidation have reported that the nitrogen oxides (NOx) as the nitrogen monoxide (NO), nitrogen dioxide (NO_2), nitrous oxide (N_2O) and other products that can be generated (2 – 13) during the oxidation reactions of NH3. Due to the high reaction temperatures, two types of NOx can be formed: thermal or also know in the literature as the Zeldovich mechanism (2 – 4) and combusting (5 – 13) (Klippenstein et al., 2011, Kobayashi et al., 2019).

From the environmental point of view, NO and NO_2 are producers of acid rain, meanwhile the N_2O is a GHG. The NO thermal reactions are favoured at temperatures higher than 1500 °C. However, (2) is limited by the reaction rate. For this reason, by regulating the operational temperature, the NO thermal production can be controlled (Glaborg et al., 2018; Li et al, 2021). Consequently, the oxidation of NO (2 – 9) takes to the NO_2 formation. The reaction types as (10) and (11), have been reported as important, due to the fact that are the governing reactions under all NO reduction reaction conditions. Additionally, Lyon R., 1976 mentioned that under certain temperature and O_2 saturation in air conditions, the NH_3 reduction could improve by using a process called DeNOx. Finally, N_2O produced via (12) is consumed via (13).

$$4NH_3 + 3O_2 \Rightarrow 2N_2 + 6H_2O \tag{1}$$
$$N_2 + O \leftrightarrow NO + N \tag{2}$$
$$N + O_2 \leftrightarrow NO + O \tag{3}$$
$$N + OH \leftrightarrow NO + H \tag{4}$$
$$NH_3 + O \leftrightarrow NH_2 + OH \tag{5}$$
$$NH_2 + O_2 \leftrightarrow H_2NO + O \tag{6}$$
$$NH_2 + O_2 \leftrightarrow HNO + OH \tag{7}$$
$$NH + O_2 \leftrightarrow HNO + O \tag{8}$$
$$NH + O_2 \leftrightarrow NO + OH \tag{9}$$
$$NH_2 + NO \leftrightarrow NNH + OH \tag{10}$$
$$NH_2 + NO \leftrightarrow N_2 + H_2O \tag{11}$$
$$NH_2 + NO_2 \leftrightarrow N_2O + H_2O \tag{12}$$
$$N_2O + H \rightarrow N_2 + OH \tag{13}$$

The amount of energy produced from the NH3 full combustion reaction is slightly lower than that of natural gas, gasoline or diesel (Figure 2). It has the potential to be used as a powerful energy source. Also, in order to increase even more the NH_3 power supply during combustion reactions, attempts have been done by mixing other gases and create a hybrid combustion with H_2 and CH_4.

The APG conversion for the NH_3 production demands the use of energy during its treatment. In most of the cases, this energy comes from fossil sources. However, nowadays with the rising of systems that allow to obtain renewable energy (i.e. solar, hydraulic, wind, etc) this can be counter backed. By applying this approach, the NH_3 could finish its cycle by being a neutral carbon fuel from is processing to consumption. The NH_3 production is an exploited industry in several countries of the world. In the Figure 3 is shown the NH_3 production by country, where it is observed that China, Russia, India and U.S.A., are the top worldwide producers.

2.2. Weaknesses

The NH_3 production as a fuel for its integration into the country's energy matrix requires the use of hydrocarbons as a feed. Regardless the carbon neutrality of NH_3, it still is dependent on its source before processing which requires the exploitation of oil fields. Another fact is that despite NH_3 does not produce GHG, at the end of all it is a non-renewable energy source, and its availability might be linked to available hydrocarbon resources and conversion rates. Moreover, one of the main problems to leverage energies and their effective incorporation into the energy matrix of each country is related to political and financial discussions. Usually, energy projects demand great investment on infrastructure of diverse types related to the commodity's transport, treatment and storage before it is handed out to the end customer. Also, other factors such as: land ownership and socio-environmental agreements, current hydrocarbon prices, demand and consumption, availability of hydrocarbon resources, availability of import terminals in the case of absence of resources, etc. Finally, changes in legislation are necessary to foster and support research and development (R&D) in the country.

2.3. Opportunities

APG is a mixture of light hydrocarbon gases and in most of the cases it surpasses the 80% content of methane, and 20% of ethane to pentane and other non-hydrocarbon gases. Under the assumption that APG is made of 100% methane, then, the mass balance equation for full combustion of APG is presented in (14). By simple balance of the molecularity of each component, it indicates that each kgCH_4 produces 2.75 kgCO_2 and that 1 m3CH_4 produces 1m3CO_2 (densityCH_4, SC 0,648 kg/m3 and density CO_2, SC 1,784 kg/m3) after combustion.

$CH_4 + 2O_2 \Rightarrow CO_2 + 2H_2O$

Within the strategies to counter back the carbon emissions into the atmosphere we bring up the idea of instead of flaring gas on top of oil fields in the Ecuadorian Amazon, using APG for conversion into a carbon-neutral fuel as ammonia to optimize the use of available energy resources from fossil fuels in the country and in this way, reaffirm the Paris Agreement (The Paris Agreement, 2015). The estimated volumes of flared APG in 2020 in the Ecuadorian amazon are presented in Figure 4. It is shown that approximately 1 trillion m3 of APG were flared at the top of oil wells in oil fields. This indicates that by not flaring APG and instead implementing a method of leveraging these hydrocarbon resources, approximately 1 trillion m3 CO_2 would not be released into the atmosphere every year.

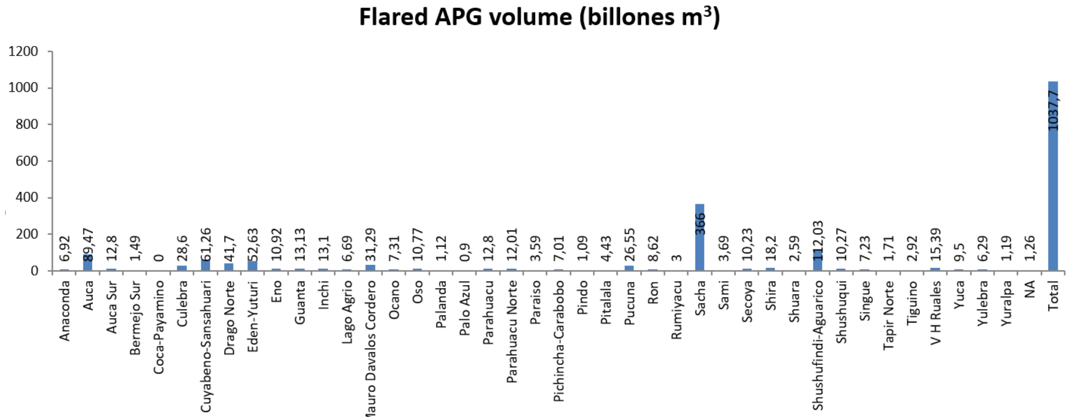

Figure. 4 Annual flared APG volume in Ecuadorian oil fields in 2020 (Global Gas Flaring Data, 2020; Global Gas Flaring Data, 2021)

Here we are summarizing three existing methods for the obtention of NH3 (Glarborg et al, 2018; Varfolomeev et al, 2021):

- The grey NH_3 is produced from natural gas. It requires the addition of CO_2 to the feed. To produce 1 Ton of grey NH_3 it is required the addition of 2 tons of CO_2.
- Blue NH_3, in its production all the gases must be recycled.
- Green NH_3, the key difference is that the energy used in its production must be generated from renewable energy sources such as solar, wind, tidal, geothermal, and other non-traditional power plants with little performance.

In most techniques, the capture of COx is considered since production is related to both combustion and burning and polluting emissions to the environment. In Ecuador, CO_2 is not captured or stored.

Through COx capture technology, it is possible to predict the amount of CO_2 captured and therefore apply it to economic benefits at an international level.

In the case of NH_3 production, there are no residual emissions, 100% goes as blue NH_3 after the process (Table 1).

Companies like MAN are committed to using ammonia as a future fuel.

VLSFO and Ammonium energy cost2030 (US Geological survey, 2020):

- 12.5 to 15 dollars/GJ (Gigajoule) for VLSFO (2020);
- $13.5/GJ for conventional ammonium today (stable as of 2018);
- US$13.5 to US$15/GJ, the projected cost of green ammonium from solar and wind power between 2040 and 2050;
- 16 to 21.5 dollars/GJ for carbon ammonium as fuel in 2025.

To keep it in the liquid phase (Ammonia, 2018; Amin et al., 2013; European Parliament, 2019) as the ambient temperature increases, they normally design NH_3 tanks without hypothermia for 18 bar pressure.

For the future energy source, without CO_2 residues, to be attractive, the price of fuel, including all costs, should be competitive with the price of traditional fuel. If this is achieved by CO2/GL regulation, the period for conversion of the engine to the future fuel can be as short as the regulations come into force.

Liquid NH_3 can be stored at a pressure greater than 8.6 bar at a temperature of 20ºC.

2.4. Threats

Following threats are identified:

- New technology in Ecuador, there are no feasibility studies therefore its effectiveness is not guaranteed;
- Radical environmentalists (social groups) are opposed to the use of fossil fuels.

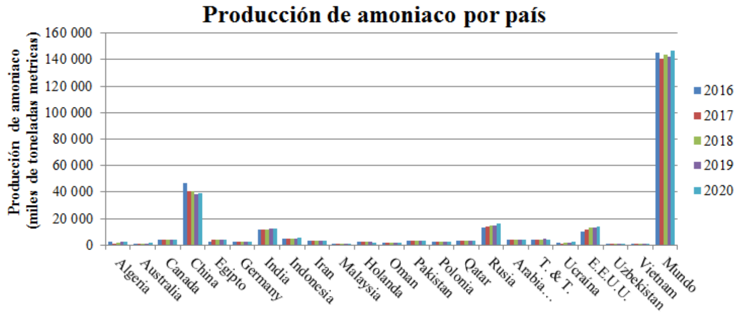

Figure 5. Annual flared APG volume in Ecuadorian oil fields in 2020 (Bautista et al., 2023).

3. RESULTS AND DISCUSSION

This study analyses the ammonia industry, in order to know the state of the art of this compound and its characteristics, describing the main methods of production, importing and exporting countries, the technologies used for its transport and storage, as well as the security measures for its handling and the regulations and standards applicable to the different elements of its value chain. In addition, it analyses the opportunities and considerations to take into account for the use of ammonia as a carrier of green hydrogen or as fuel, either through internal combustion engines, turbines, boilers or fuel cells (Table 1).

Table 1. Analysis SWOT on Blue ammonia production as an alternative to reduce CO_2 Emissions in Ecuador

STRENGTHS	OPPORTUNITIES
-Fuel with high energy content -Its complete combustion does not generate polluting waste to the environment -Reduce carbon footprint -Strengthens the commitment of the Paris agreement -Contributes to the global energy transition (transition from fossil resources to hydrogen)	-Tax benefits -Unconventional source of energy -Extraction of methane gas in unconventional deposits -Exploitation of unused energy resources -Development and application of CCUS in Ecuador (Carbon capture and storage) -Carbon Bonds -Reduces gas flaring in oil fields
WEAKNESSES	**THREADS**
-Non-renewable energy source -Lack of infrastructure for transportation and storage -Environmental impact by extracting the methane and capturing carbon -Lack of incentives and legislative policies by the government for innovation and optimization of unused natural resources	-New technology in Ecuador, there are no feasibility studies therefore its effectiveness is not guaranteed -Radical environmentalists (social groups) are opposed to the use of fossil fuels.

4. CONCLUSION

In Ecuador, are no previous economic studies of the impact generated by burning associated gas from the point of view of energy/unused mass (opportunity cost).The green hydrogen that could be produced in Ecuador, being the flared APG one of the main sources. If the data shown in the tables of this publication is taken as a reference, 7.8 [Mton] of ammonia could be produced annually. Which is equivalent to 42.3% of the ammonium marketed worldwide in the year 2020.

It is necessary to implement some type of Ecuadorian regulation of CO_2 emissions. According to our analysis, it is possible to monetize the lighter gases. In this way we will be able to limit and reduce COx emissions into the atmosphere, parallel to this, the study and implementation of technologies that use greenhouse gases in Ecuador will be favored. Companies that emit enormous amounts of gases into the air will have to submit reports on this.

The physical and chemical properties of blue ammonium are important and involve field studies to define the system design, including storage.

Finally, we can affirm that there is a real opportunity to lower the carbon footprint and generate energy using the lighter gases that pollute the atmosphere both in Bajo Alto and in the rest of Ecuador.

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REFERENCES

Duynslaegher, C., Jeanmart, H., & Vandooren, J. (2009). Flame structure studies of premixed ammonia/hydrogen/oxygen/argon flames: Experimental and numerical investigation. Proceedings of the Combustion Institute, 32(1), 1277–1284.

Engineering ToolBox, (2018). Ammonia - Properties at Gas-Liquid Equilibrium Conditions. (online). Retrieved from: https://www.engineeringtoolbox.com/ammonia-gas-liquid-equilibrium-condition-properties-temperature-pressure-boiling-curve-d_2013.html (Accessed on April 24, 2023).

European Parliament News. (2019). What Is Carbon Neutrality and How Can It Be Achieved by 2050?. *Society*. Retrieved from: https://www.europarl.europa.eu/news/en/headlines/society/20190926STO62270/what-is-carbon-neutrality-and-how-can-it-be-achieved-by-2050 (Accessed on April 24, 2023).

Glarborg, P., Miller, J. H., Ruscic, B., & Klippenstein, S. J. (2018). Modeling nitrogen chemistry in combustion. Progress in Energy and Combustion Science, 67, 31–68. Retrieved from: https://doi.org/10.1016/j.pecs.2018.01.002 (Accessed on March 23, 2022).

IEA. (2021). Global Energy Review: CO2 Emissions in 2020–Analysis. https://www.iea.org/reports/global-energy-review-co2-emissions-in-2021-2

Klippenstein, S. J., Harding, L. B., Glarborg, P., & Miller, J. H. (2011). The role of NNH in NO formation and control. Combustion and Flame, 158(4), 774–789.

Kobayashi, H., Hayakawa, A., Somarathne, K. K. A., & Okafor, E. C. (2019). Science and technology of ammonia combustion. Proceedings of the Combustion Institute, 37(1), 109–133.

Li, J., Lai, S., Chen, D., Wu, R., Kobayashi, N., Deng, L., & Huang, H. (2021). A review on combustion characteristics of ammonia as a carbon-free fuel. Frontiers in Energy Research, 9, 760356.

Lyon, R. K. (1976). The nh3-no-o2 reaction. International Journal of Chemical Kinetics, 8(2), 315-318.

Mashruk, S., Kovaleva, M., Tung Chong, C., Hayakawa, A., Okafor, E. C., & Valera-Medina, A. (2021). Nitrogen Oxides as a by-product of Ammonia/Hydrogen combustion regimes. Chemical Engineering Transactions 89, 613-618.

Miller, J. A., & Bowman, C. T. (1989). Mechanism and modeling of nitrogen chemistry in combustion. Progress in energy and combustion science, 15(4), 287-338.

Miller, J. A., & Melius, C. F. (1992, January). The reactions of imidogen with nitric oxide and molecular oxygen. In Symposium (International) on Combustion (Vol. 24, No. 1, pp. 719-726). Elsevier.

Oxford University. (2020). Our world in Data. Emissions by sector - Our World in Data. Retrieved from: https://ourworldindata.org/emissions-by-sector (Accessed on April 20, 2023).

Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. Science, 360(6392), 987-992.

Rojas, A.A., Yuan, C., Emelianov, D.A., Saifullin, E.R., Mehrabi-Kalajahi, S., Varfolomeev, M.A., Sudakov, V.A., Lotfullin, B.R., Shevchenko, D. V., Ganiev, B.G., Lutfullin, A.A., & Zaripov, A.T. (2021). A 3-Step Reaction Model for Numerical Simulation of In-Situ Combustion. SPE Russian Petroleum Technology Conference, October 2021. Retrieved from: doi: https://doi.org/10.2118/206430-MS (Accessed on March 23, 2022).

Song, S., Hanson, R. K., Bowman, C. T., & Golden, D. M. (2001). Shock tube determination of the overall rate of NH2+ NO→ products in the thermal De-NOx temperature window. International Journal of Chemical Kinetics, 33(11), 715-721.

Sutherland, J. W., Patterson, P. M., & Klemm, R. B. (1990). Flash photolysis-shock tube kinetic investigation of the reaction of oxygen (3P) atoms with ammonia. Journal of Physical Chemistry, 94(6), 2471-2475. Global Gas Flaring Data. (2020). World Bank. https://www.ggfrdata.org/

Global Gas Flaring Data. (2021). World Bank. Retrieved from: https://www.worldbank.org/en/topic/extractiveindustries/publication/global-gas-flaring-tracker-report(Accessed on March 23, 2022).

United Nations, The Paris Agreement (2015), Retrieved from: https://unfccc.int/sites/default/files/english_paris_agreement.pdf (Accessed on March 23, 2022).

Nitrogen Statistics and Information | U.S. Geological Survey. (2020). Retrieved from: https://www.usgs.gov/centers/national-minerals-information-center/nitrogen-statistics-and-information (Accessed on March 23, 2022).

Varfolomeev, M. A., Bolotov, A., Minkhanov, I. F., Mehrabi-Kalajahi, S., Saifullin, E. R., Marvanov, M. M., Baygildin, E. R., Sabiryanov, R. M., Rojas, A. A., Emelianov, D. A., Al-Muntaser, A. A., Ganiev, B., Zaripov, A. T., Beregovoi, A. N., & Shaihutdinov, D. K. (2021). Effect of copper stearate as catalysts on the performance of in-situ combustion process for heavy oil recovery and upgrading. Journal of Petroleum Science and Engineering, 207, 109125.

Amin, M. G., Sharear, S., Siddique, N., & Islam, S. (2013). Simulation of Ammonia Synthesis. American Journal of Chemical Engineering, 1(3), 59.