# Air Pollution: ENGI-9624

**Spring Semester 2024**

## "Emissions from Refineries and Cost-Efficient Measures for the Reduction of $CO_2$ Emissions in the Refinery Sector"

**(PROJECT TYPE-3)**

## Group Project Report

**July 4th, 2024**


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**Member's Contribution**

**Introduction and Methodology - Arif Hassan**

**Emissions from Refineries (Different Techniques, Energy Efficiency, Global Costs) - Nahidul Kabir Siddiki & Md Tareq Rahman**

**Cost Efficient Measures for the Reduction - Avinash Chaurasiya**

**Results and Conclusion - Rukhshar Patel**

# Table of Contents



# Executive Summary:

A significant source of air pollutants, such as toxic metals, particulates, and various gases, are factories like this oil refinery (nitrogen oxides, Sulphur oxides, methane, carbon monoxide, benzenes, and others). Numerous gases produce ozone pollution and are warming the planet because of the greenhouse effect. Several different petrochemical products are produced through petroleum-related products, which are produced as byproducts of crude oil and have extensive and intricate supply chains. The oil refinery industries have significant infrastructure investment structures and build extensive supply chains. This review paper aims to comprehensively analyze emissions from refineries and evaluate cost-efficient measures for reducing $CO_2$ emissions.

# Objective:

We will review some papers, specifically focusing on five key studies in the field. The review will highlight the primary sources and quantities of $CO_2$ emissions within refineries by synthesizing findings from these selected papers. It will also explore various emission reduction strategies' effectiveness and economic feasibility, including technological innovations and process optimizations. Special attention will be given to advancements in carbon capture and storage (CCS), energy efficiency improvements, and the transition to renewable energy sources. This project seeks to identify best practices and propose actionable recommendations for stakeholders to achieve significant emission reductions while maintaining economic viability. This review aims to contribute to the ongoing discourse on sustainable practices in the refinery sector.

This study is also a review of relevant papers and different energy system models discussed to analyze the co-impacts of $CO_2$ emission reduction and the $SO_x$ and $NO_x$ emission constraints on oil refinery sectors.

# 1.Introduction

One of the major worldwide concerns on the global agenda today is climate change (UN, 2021). Introducing substances into the air, water, or soil/ground that pose a risk and negatively impact both human health and the ecosystem is one of the numerous elements that determine the state of the natural environment (Manisalidis et al 2020). The large-scale buildup of any substance—solid, liquid, gaseous, or energy—on the surface of the earth may have a negative impact on climate, soil, water, animate life, human health, and other environmental factors. Since different pollutants are discharged into the atmosphere from a variety of sources and the amount of environmental pollution is not uniform throughout, these pollutants spread throughout the atmosphere.

Furthermore, can be changed into new compounds, and rules are being created to slow down this process. As per stated by Ahmad et al in 2021, a range of petrochemical items is continuously generated from petroleum-related compounds, which are produced as byproducts of crude oil and have extensive and complex supply networks. The industries that build oil refineries have very large supplier chains. During the building of refineries and as well as while they are in the process of refining, they emit gases. Emissions from Refineries & Cost-Efficient Measures are undoubtfully the process of getting into the task of reducing $CO_2$ Emissions in the Refinery Sector.

# 2.Methodology

The present study was accomplished by collecting the relevant published literature, and information from different government and non-government organizations related to Reduction of $CO_2$ Emissions in the Refinery Sector as well as for the assessment of the efficiency and economical perspectives of the applied reduction measures. They cover assessment of energy conservation measures and $CO_2$ transportation and disposal methods, as well as the application of non-conventional fuels. This also covers the cost implication of emissions control to the global economies and an analysis of the cost effectiveness of the various measures discussed in the review. The aim is to define the strategies that will allow for the reduction of emissions and to indicate the further development of strategies for all interested parties, thus promoting the principles of sustainable practices in the refinery business.

# 3.0 Emissions from Refineries and Cost-Efficient Measures

## 3.1. GHG mitigation options

The oil refining industry remains the third-largest stationary emitter of greenhouse gases in the world. The Paris Agreement's targets of keeping global warming below 1.5°C by 2100 will not be met because of the continually growing fossil fuel-based energy infrastructure. Upgrading heavy oil processing technology and increasing refinery efficiency will help the oil refining industry cut CO2 emissions by up to 10% between 2020 and 2030 (Lei et al., 2021). Depending on the characteristics of their refineries, different regions require various low-carbon adaptive strategies.

Oil refineries, producing a large variety of products, are considered one of the main sources of air contaminants such as sulfur oxides ($SO_x$), hydrocarbons, nitrogen oxides ($NO_x$), and carbon dioxide ($CO_2$), which are primarily caused by fuel combustion. The International Maritime Organization (IMO) developed plans for CO2 emission reductions under the Paris Agreement.

When we are considering changes in the amounts of several kinds of petroleum products, such as naphtha, gasoline, light oil, kerosene, heavy oil, and so forth, are co-products and, therefore, each product cannot be produced independently, and the configuration of products depends on the type of crude oil and the structure of the oil refinery.

The selected mitigation options are energy efficiency measures (EEM), CO2 capture and storage with enhanced oil recovery (EOR), biooil co-processing at the refinery, miscellaneous technological measures (MTM) involving blue and green hydrogen, and electrification alternatives as well as green electricity (low carbon) from the national grid.

## 3.2 Using Different Desulphurization Techniques

In refineries, desulfurization is a vital procedure used to eliminate sulfur compounds from petroleum products and thus lower emissions of sulfur dioxide ($SO_2$), which is a major cause of acid rain and air pollution. Over time, a variety of desulfurization methods have emerged, each with distinctive advantages and effectiveness. Hydrodesulfurization (HDS), which entails the catalytic removal of sulfur by reacting it with hydrogen at high temperatures and pressures, is one of the main techniques. Because it can effectively reduce sulfur content to ultra-low levels and meet strict environmental laws, this technology is widely used (Song & Ma et al., 2020).

In addition, oxidative desulfurization (ODS) is another innovative method, which oxidizes sulfur compounds into sulfones by using oxidizing agents such as hydrogen peroxide or organic peroxides. These sulfones are then removed by extraction or adsorption. The lower operating temperatures and pressures of ODS make it a more energy-efficient alternative to HDS (Babich & Moulijn et al., 2021).

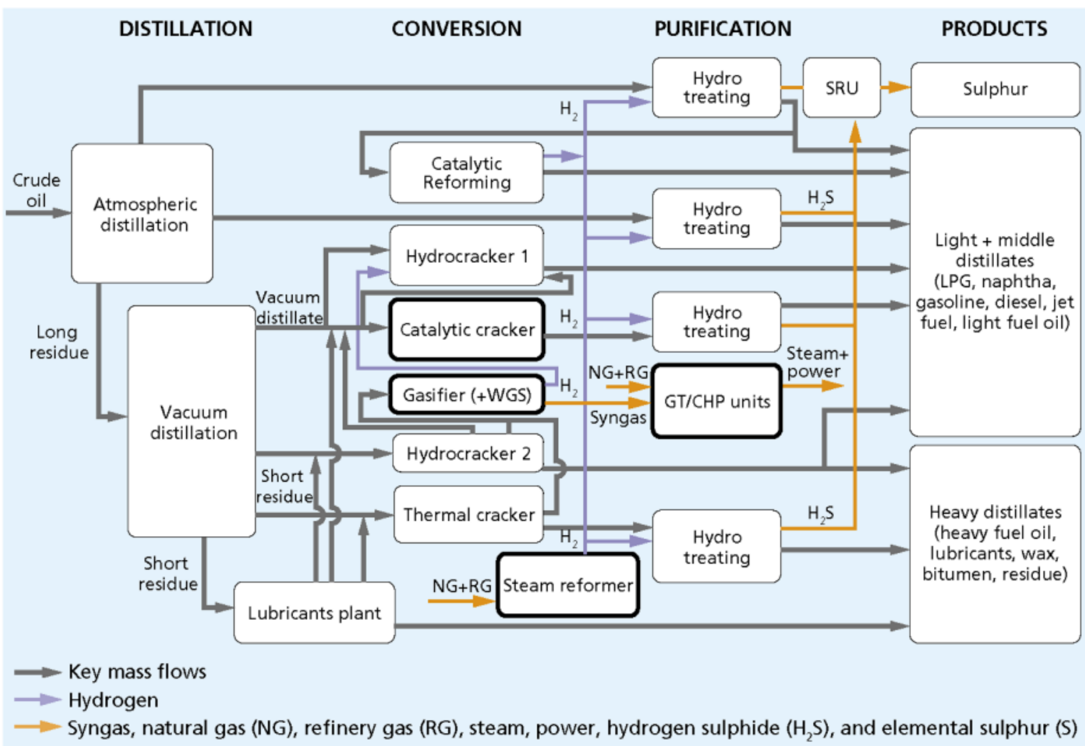
The process of bio-desulfurization (BDS) is an emerging technology that utilizes sulfur-oxidizing bacteria to convert sulfur compounds into harmless sulfates. This method is environmentally friendly and operates under mild conditions, but it currently faces challenges in terms of processing speed and scalability (Monticello et al., 2019).

Also, Ionic Liquids (ILs) are used for desulfurization. Sulfur compounds in gasoline can be selectively dissolved by ILs, making their removal possible. A benefit of this technique is that it uses ILs to target specific sulfur compounds, making it a customizable and efficient desulfurization method. (Zhao et al., 2022).

These desulfurization techniques contribute significantly to reducing emissions from refineries. For instance, HDS catalyst developments have led to more efficient and robust desulfurization processes, which reduce SO2 emissions and improve air quality (Ma & Gao et al., 2021). Moreover, the use of multiple desulfurization techniques within a refinery can optimize sulfur removal while simultaneously balancing energy consumption and operational costs (Feng et al., 2020).

## 3.3 Energy Efficiency Measures

A study was done by Berghout et al. (2019), for greenhouse gas emissions reductions in an industrial plant. They considered different energy efficiency measures for both short and




medium-term energy potential reduction.

Figure: Simplified process layout of the case refinery. (Berghout et al., 2019)

In the figure the main CO2 emission sources in the refinery are depicted in bold. The other two

$CO_2$ emission sources (furnaces and flares) are not displayed. GT, CHP, LPG, SRU, WGS stand for gas turbine, combined heat power, liquid petroleum gas, sulfur recovery unit, and water gas shift, respectively.

| | | Energy Efficiency Measures | Energy Reduction % |
|---|---|---|---|
| Short Term | 1 | Energy management and control | 3 |
| | 2 | Heat integration distillation units | 3 |
| | 3 | Motors & pumps | 2.4 |
| | 4 | Steam distribution system | 2 |
| | 5 | Heat integration & waste heat recovery | 2 |
| | 6 | Fouling mitigation | 1 |
| | 7 | Improved furnace performance | 1 |
| | 8 | Hydrogen management & recovery | 0.7 |
| Medium Term | 9 | Advanced desulphurization | 10 |
| | 10 | Advanced separation systems | 6.8 |
| | | Total | 40 |

Table: Energy reduction potential for the refinery

The largest primary energy reductions can be achieved via heat integration between the distillation units (~3%) and improvements in energy management & control (~3%). The joint primary energy reduction of short term EEMs amounts up to 15%. For the medium term, with advanced desulphurization systems showing the largest primary energy reductions (~10%). In total, an estimated reduction in energy use of 40% was computed for both short and medium term.

## 3.4 CO2 Capture and Storage

Three first-generation CO2 capture technologies are assessed: post-, pre- and oxyfuel combustion capture. Post-combustion capture is applied to the main CO2 sources on the refinery site: furnaces, catalytic cracker, in situ CHP unit, and the in-situ hydrogen plant. Oxyfuel and pre-combustion technology are applied to all these sources, except to the in-situ hydrogen plant (no oxyfuel combustion) and catalytic cracker (no pre-combustion), respectively, due to technological constraints. CO2 capture from the in-situ refinery gasifier, which processes catalytic cracker residue, does not require a specific technology as the separation of the CO2 is already an inherent part of the gasification process.

## 3.5 Global Costs for CO2, SOx, and NOx Emission Reduction

Kanaboshi et al. (2021) introduced a linear programming model for assessing global energy systems and global warming mitigation, in which the worldwide costs are shown to be minimized. In their study, the results show that using high sulfur fuel oil with installing scrubbers (exhaust gas cleaning device), using low sulfur fuel oil, switching from petroleum fuel to LNG, and so forth can be selected as the countermeasures against the SOx and NOx regulations by the IMO. The global countermeasure costs against the IMO's SOx and NOx regulations are estimated to be around 7-9 billion US$ 2000/year in 2030 and 13-14 billion US$ 2000/year in 2050.

Nevertheless, under the scenario of achieving the 2°C target with a 66% probability for a particularly severe emission reduction, it is necessary to greatly reduce the use of oil itself in the first place in 2050, which implies that the countermeasure costs against SOx and NOx regulations will also drop to around 2 billion US$ 2000/year.

| | 2030 (US$ 2000/yr) | 2050 (US$ 2000/yr) |
|---|---|---|
| Countermeasure costs against the IMO's SOx and NOx regulations | 7-9 Billion | 13-14 billion |
| After reducing the use of oil, countermeasure costs | | 2 billion |

**Table: Global Cost for countermeasures (Source: Kanaboshi et al., 2021)**

## 3.6 Using Low Carbon Alternative Fuel

Chu-Van et al. (2019) showed a study that liquefied natural gas (LNG) and biofuel may be suitable fuels to meet the above targets. Alternative fuel is considered the most likely option to comply with IMO regulations and reduce air pollution and climate change. Some of the alternative fuels are-

**Methanol**

Researchers have addressed methanol as a low carbon alternative fuel (Chu-Van et al., 2019). The total life-cycle emissions of methanol use were compared to conventional marine gas oil (MGO) and heavy fuel oil (HFO) in order to identify the environmental benefits of using methanol. Generally, emissions of SOx, NOx, PM and GHGs (CO2, CH4 and N2O) were used in the total life-cycle model. Methanol use is expected to reduce emissions of SOx, NOx, CO2, and PM by up to 99%, 60%, 25%, and 95%, respectively. However, a major barrier in using Methanol is, it's high production cost.

**Liquefied Natural Gas**

Natural gas in the form of LNG is considered the most preferable alternative fuel option to reduce air pollution. LNG as a fuel would be preferable from an environmental perspective due to a significant reduction of particles, NOx, SO2, and CO2 when used LNG. However, uncertainties related to future price and global availability of LNG is questionable.

**Biofuel**

Biofuels are of increasing interest and a promising alternative transport sector. Potential biofuels should be required to a reduction in greenhouse gas emissions. Microalgae-based biofuels have recently received great attention from researchers because of their potential for large-scale fuel production (Nurdiawati,et al., 2022). A variety of methods, such as mechanical disruption, ultrasonic-assisted extraction, solvent extraction, hydrothermal liquefaction (HTL), and supercritical fluid extraction, can be used to extract oil from microalgae.

# 4.Cost-Efficient Ways to reduce CO2 Emissions

Here are some cost-effective methods to reduce $CO_2$ emissions in the petrochemical and oil refinery industries:

**Technological Advances**

- **Carbon Capture and Utilization (CCU):** CCU captures $CO_2$ emissions and uses them to make chemicals like methanol. This not only cuts $CO_2$ emissions but also creates useful byproducts. Hydrogen Steam Methane Reforming (SMR) and utility systems can also help capture carbon.
- **Using Hydrogen:** Hydrogen can be used in refinery processes like desulfurization. Refineries can produce hydrogen or get it from outside sources. Projects like Germany's GreenHydroChem aim to make renewable hydrogen, reducing greenhouse gas emissions.
- **Modern Heat Exchangers:** Installing modern heat exchangers can make refineries more energy-efficient and lower $CO_2$ emissions. For example, the Preemraff Lysekil refinery saw a big drop in emissions after upgrading their heat exchangers.

- **Methanol to Olefins (MTO):** The MTO process turns methanol into olefins (like ethylene and propylene), making the most of resources and cutting $CO_2$ emissions.

**Switching Fuels and Improving Efficiency**

- **Liquefied Natural Gas (LNG):** Switching from oil to LNG as a fuel can significantly cut $CO_2$ emissions. LNG burns cleaner than traditional fuels, which helps meet $NO_x$ regulations.
- **Replacing Natural Gas:** Using natural gas instead of traditional fuels like butane in hydrogen production can also lower $CO_2$ emissions. The Preemraff Lysekil refinery saw a significant drop in emissions after making this switch.
- **Boosting Energy Efficiency:** Improving energy efficiency through equipment upgrades, waste heat recovery systems, and better process management can greatly reduce $CO_2$ emissions. Energy management systems (EMS) and regular energy audits can help find more opportunities for efficiency.
- **Optimizing Processes:** Making existing processes more efficient, like better monitoring and control of heaters and boilers and maintaining steam systems, can lead to lower emissions.

**Policies and Regulations**

- **IMO Regulations:** Following the International Maritime Organization's (IMO) rules for $SO_x$ and $NO_x$ emissions encourages the use of cleaner fuels and technologies, which helps cut $CO_2$ emissions.
- **Carbon Pricing:** Putting a price on carbon gives industries financial incentives to reduce their carbon footprint, leading to significant energy savings and emission reductions.

- **Subsidies and Incentives:** Government subsidies and incentives can make it easier and more affordable for industries to adopt green technologies and practices, helping them move towards low-carbon operations.

## Results

The report "Cost-efficient Measures in the Oil Refinery and Petrochemical Sectors" shows that significant $CO_2$ emission reductions can be achieved by 2030 and 2050 through energy efficiency, low-carbon electricity, and carbon capture and storage (CCS). By 2050, the UK oil refining industry could cut emissions to 36% of 2012 levels using these technologies. In contrast, without changes, China's oil refining industry could see emissions triple by 2030, though targeted goals could help reduce this increase. Decarbonization efforts also bring benefits like less environmental risk, better public health, and more efficient resource use.

The "$CO_2$ Emission Reduction and Regulatory Impacts" report highlights that major $CO_2$ cuts are needed to meet the 2°C targets, especially in the oil refinery sector. Cost-effective strategies include using high sulfur fuel oil with scrubbers and switching to low sulfur fuel oil to comply with IMO regulations. Additionally, a significant drop in oil supply is expected after 2050 due to strict emission reduction measures, especially in transportation sectors like international aviation and marine bunkers.

## Conclusion

The "Cost-efficient Measures in the Oil Refinery and Petrochemical Sectors" report highlights that the oil refining industry will stay crucial as it shifts to low-carbon energy sources. Significant cuts in emissions can be achieved by improving energy efficiency, using more low-carbon electricity, and implementing carbon capture and storage (CCS) technologies. However, these reductions will need significant investments and supportive policies. More research is necessary to explore the economic feasibility, integrate renewable energy sources, and create policies that incentivize emission reductions. Collaboration among the government, industry stakeholders, and researchers is essential to drive innovation and implement low-carbon technologies.

The "CO2 Emission Reduction and Regulatory Impacts" report stresses that meeting strict CO2 reduction targets under the Paris Agreement requires big changes in the oil refinery sector. These include adopting new technologies, enhancing energy efficiency, and switching to alternative fuels. At first, it costs a lot to follow SOx and NOx rules, but these costs will go down over time as we use less oil and get better at production. Following these rules also makes the air cleaner and people healthier, which can help cover some of the costs. Switching to cleaner fuels like LNG, hydrogen, and biofuels is needed to meet the 2°C goal, even though it's hard and can be expensive. Government, businesses, and researchers need to work together to smoothly move to a low-carbon future and cut emissions. To do this, we need good laws, financial help, and more research.

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