

## Greenhouse Gas Emissions from a Petroleum Naphtha Storage Tank

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### Abstract

Greenhouse gas (GHG) emissions from a petroleum naphtha storage tank are a significant environmental concern. During crude oil refining, naphtha accounts for approximately 20–30% of total products as a key feedstock for petrochemical industries worldwide. However, naphtha storage is one of the most pressing issues in Thailand due to the use of Fixed Roof Tank (FRT) lacking effective vapor control mechanisms, which leads to fugitive GHG emissions. This study estimated GHG emissions at the petroleum refinery in Chonburi Province from four types of petroleum naphtha storage tanks, including FRT without emission control, FRT with a Vapor Recovery System (FRT–VRS), Internal Floating Roof Tank (IFRT), and External Floating Roof Tank (EFRT), using the TANKS 5.1 model, GHG emissions calculation equations, and Root Cause Analysis (RCA). The results indicate that FRT without emission control emits the highest at 7,476.83 kg/year, while EFRT releases a total of 2,093.51 kg/year. FRT–VRS reduces emissions by 90% to 747.68 kg/year. IFRT has the lowest emissions at 267.49 kg/year. This study highlights the importance of implementing effective control technologies and operational improvements to minimize environmental impacts and promote long-term sustainable industrial management.

**Keywords:** Naphtha, Greenhouse gas Emission, TANKS MODEL, Root Cause Analysis, Storage Tank

### Introduction

Climate change and global warming are significant global issues that profoundly affect the environment and social and economic development today (Khalid & Muhammad, 2013). These impacts are likely to intensify in the future. The global community has established the UNFCCC to address these issues. Under the Paris Agreement, measures are being implemented to control Greenhouse gas (GHG) emissions to limit the global temperature rise to no more than 1.5 °C (Mothe et al., 2023; Matthew et al., 2025). According to the biannual report (Thailand BTR1) (Department of Climate Change and Environment, 2024), GHG emissions from the petroleum industry (energy sector) account for the highest proportion of emissions, which is considered one of the main factors contributing to global warming (Intergovernmental Panel on Climate Change (IPCC), 2023). These emissions originate from processes involved in petroleum refining, which pose risks of releasing greenhouse gases (GHGs) such as methane (CH<sub>4</sub>) and volatile organic compounds (VOCs). These emissions adversely affect air quality and increase the concentration of GHGs in the atmosphere (Minh-Hoang et al., 2023; Barbhaya et al., 2023).

Emissions from petroleum storage tanks account for 20–30% of the total emissions in petroleum refineries. These tanks can release significant amounts of VOCs and other pollutants, primarily due to temperature and pressure changes during filling and transfer operations resulting in evaporative losses. Effective monitoring and management strategies are therefore essential (Maimaiti et al., 2021).

Storage tanks are key facilities in petroleum industries, playing an important role in storing large volumes of petroleum products. However, they pose significant environmental and safety risks due to the inherent properties of the stored products, such as flammability, volatility, and toxicity (Guo et al., 2020). Accidents or leakages in oil storage facilities can lead to severe ecological damage, air pollution, and fire hazards, resulting in long-term impacts on human health and surrounding ecosystems (Kang et al., 2014). Due to the global dependency on petroleum products as a primary energy source, storage tanks remain indispensable assets despite the risks associated with their operation (Karbassi et al., 2009). According to the International Energy Agency (IEA, 2021), oil continues to hold the largest share of the global energy supply, accounting for 30.9% in 2019 and remaining the dominant energy source worldwide. Consequently, understanding the operation, emission behavior, and environmental implications of petroleum storage tanks is necessary. It is essential for promoting safety, sustainability, and compliance with international energy and environmental standards.

In 2021, Capelli et al. reported that VOC emissions varied significantly and exert notable health and environmental impacts depending on their characteristics and production process (Capelli et al., 2021). This is consistent with previous research in Thailand that investigated and identified volatile organic compounds associated with oil storage tanks (Jindamanee et al., 2024; Saikomol et al., 2019). These compounds can affect the respiratory system and nervous system, and increase the risk of cancer. For this reason, the Ministry of Public Health (Thailand) emphasizes the importance of controlling air pollution and VOCs, as air pollution remains a cause of premature death.

Naphtha was defined as a complex mixture of volatile hydrocarbons that mainly consists of C5–C12 alkanes, cycloalkanes, and aromatic compounds derived from petroleum refining processes (Pagliaro et al., 2023; Speight, 2016). Due to its high volatility, naphtha has been considered one of the petroleum products with the largest potential for emissions during storage and handling processes (American Petroleum Institute, 2021). Naphtha has been a key feedstock used widely across various industries, particularly in the petrochemical sector (James & Nour, 2018). Its high volatility, largely resulting from the presence of light hydrocarbons such as pentanes, hexanes, and benzene, leads to considerable evaporative losses during storage operations. Emission rates from naphtha storage have been reported to be approximately 3–5 times higher than those associated with heavier petroleum products, including diesel and fuel oil (IEA, 2023; U.S. Environmental Protection Agency (U.S.EPA), 2023). These emissions raise significant environmental concerns, as they contribute to the formation of ground-level ozone via photochemical processes and, more globally, to climate change through the release of VOCs with global warming potential. As a result, effective emission control measures are essential for petroleum storage and handling facilities (Carter, 2010; Derwent et al., 2010).

This study aims to assess the amount of GHG emissions from a petroleum naphtha storage tank under different operating scenarios using the U.S.EPA TANKS 5.1 model coupled with mathematical equations and to identify GHG emission reduction measures using Root Cause Analysis (RCA).

## **Materials and Methods**

### **Study area and Data Collection**

The study was carried out at a modern, highly complex refinery located within a petroleum industrial estate in Chonburi, Thailand (Fig.1), where petroleum naphtha is stored. All data used in the analysis were obtained

as secondary information from the refinery's validated operational database. These data included storage tank dimensions (m), properties of the stored liquid, vapor pressure (kPa), operating temperature (°C), and pressure conditions (kPa). Meteorological parameters including wind speed (m/s) and ambient temperature (°C) were obtained from the Thai Meteorological Department. The datasets represent averaged values derived from multiple operational cycles under normal conditions. Variations in operational and environmental parameters were accounted for by applying time-averaged data, which were cross-checked for consistency against the default parameter ranges recommended by the U.S.EPA TANKS 5.1 model and the Intergovernmental Panel on Climate Change (2006) guidelines. This approach ensured that the input data were both reliable and representative before emission estimation.



**Figure 1** Study area located at Chonburi, Thailand

#### **Emission Estimation Using U.S.EPA TANKS 5.1**

The TANKS 5.1 model estimates total losses, working losses, and standing losses (breathing losses) based on the tank's configuration and environmental conditions. Standing losses represent evaporation from the liquid surface within the vapor space during storage. Working losses occur during the filling and emptying processes when vapor is displaced by the movement of liquid (U.S.EPA, 2023). This model required specific tank parameters (including tank type, dimensions, liquid properties, environmental conditions, and operational data) to ensure accurate calculations. Both fixed-roof and floating-roof tank equations were applied in this study. The total emissions ( $L_T$ ) were calculated as:

$$L_T = L_S + L_W \quad (1)$$

Where  $L_T$  = Total loss emissions (lbs./year or kg/year),  $L_S$  = Standing Losses (evaporation from liquid surface) (lbs./year or kg/year), and  $L_W$  = Working Losses (emissions due to filling and emptying operations) (lbs./year or kg/year)

#### **Evaluation of Greenhouse Gas Emission**

In this study, the evaluation of GHG emissions from the petroleum naphtha storage tank involves calculating the total CO<sub>2</sub>-equivalent (CO<sub>2</sub>eq) emissions from the VOC emissions (estimated by TANKS 5.1). VOC

emissions are representative of petroleum naphtha vapor losses released from the storage tank. The total GHG emissions were obtained by the calculation methodology outlined in Equation 4.2.1 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). Emission factors related to pollutant emissions and the activity that generates them serve as conversion coefficients for estimating GHGs. The emission factors were obtained from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and the Thailand Greenhouse Gas Management Organization (TGO) database (TGO, 2023). Given the current absence of Thailand-specific emission factors for fugitive emissions from naphtha storage, the study utilized the TGO carbon footprint (CFP) emission factor as a surrogate indicator (TGO, 2023). Consequently, this approach utilizes the TGO factor as a Thailand-specific proxy, and the results should be interpreted as the CFP impact associated with emission loss rather than direct GHG emissions resulting from vapor release. The total GHG emissions were calculated as:

$$\text{GHG Emission (CO}_2\text{eq)} = \text{AD} \times \text{EF.} \quad (2)$$

where GHG Emission = greenhouse gas emissions (kg CO<sub>2</sub>eq), AD = Activity Data (VOC Emission in this study) (kg/year), and EF = Emission Factor for each gas (kg CO<sub>2</sub>eq/kg VOC)

#### **Root Cause Analysis and Mitigation Strategies**

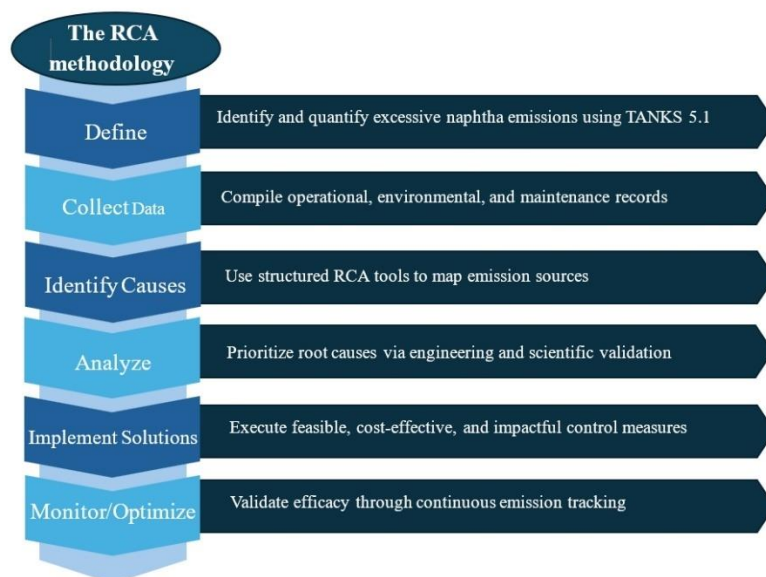
Root Cause Analysis is a systematic process used to identify the underlying causes of problems or events. Rather than addressing the symptoms. RCA helps researchers to pinpoint the fundamental causes and develop effective strategies (Andersen & Fagerhaug, 2006). In this study, RCA was integrated with the emission estimation results obtained from the USEPA TANKS 5.1 model to investigate the factors responsible for GHG emissions from petroleum naphtha storage tanks.

The TANKS 5.1 model was first used to quantify emissions under different storage tank configurations and operating conditions. The model outputs provided detailed information on the contribution of individual emission sources, including standing losses, working losses, rim seal losses, withdrawal losses, and deck fitting losses. These results were subsequently used as the basis for the RCA process by identifying the dominant emission mechanisms and prioritizing the emission sources that contributed most significantly to total losses.

To systematically identify and categorize emission sources, RCA was performed using two structured methodologies: 1. Fishbone (Ishikawa) Diagram – This technique categorizes causes into six key factors: Materials, Methods, Machines, Measurement, Personnel, and Environment. This allows for a comprehensive analysis of contributing variables (Borkowski, 1995). And 2. 5-Why Analysis – A systematic questioning method used to trace back the root cause of emissions by asking “Why?” iteratively until the fundamental issue is identified (Serrat, 2017). For example, high working losses predicted by the model were further examined to determine whether they were associated with tank design limitations, inadequate vapor recovery systems, operational practices, maintenance deficiencies, or environmental conditions.

The RCA methodology was used to systematically identify and address the underlying causes of emissions from naphtha storage tanks. The method began by defining the problem using the quantified emission estimates generated by TANKS 5.1. Next, relevant operation data, environmental parameters, and maintenance records were collected to assess emission patterns and performance deviation. Then, Potential causes were identified and categorized using structured RCA tools such as the Fishbone Diagram and 5-Why Analysis, enabling the classification of emission sources and influencing factors. The root cause was analyzed and prioritized based on

engineering assessment and scientific evidence. Afterward, emission control solutions were developed and implemented based on technological feasibility, cost-effectiveness, and environmental sustainability. Finally, the effective measures were evaluated through continuous monitoring and optimization to ensure long-term emission reductions and operational improvements, as shown in Fig. 2. This structured approach ensures that sustainable mitigation strategies are developed, ultimately leading to optimized emission reduction efforts.



**Figure 2** Flowchart of the RCA methodology

## Results

### Emission rates of petroleum naphtha storage tank

The total annual emission rate from the petroleum naphtha storage tank for the Fixed Roof Tank (FRT) without emission control was estimated at 7,476.83 kg/year. This total comprised 0.27 kg/year from standing losses and 7,476.56 kg/year from working losses. The results indicate that working losses overwhelmingly dominate total VOC emissions from the FRT, accounting for approximately 99.63%. This finding highlights the critical influence of operational activities, particularly filling and emptying cycles, on vapor displacement within the tank. Temperature-driven expansion and contraction of the vapor space further intensify these losses, reinforcing the sensitivity of uncontrolled FRT systems to routine operational and environmental fluctuations. The annual vapor space displacement was estimated to be 428,688.63 cubic feet, highlighting the significant contribution of vapor displacement in VOC emissions. The negligible contribution of stand losses, in contrast, suggests that diurnal breathing alone plays a minor role in overall emissions under the studied conditions. Instead, the large vapor space displacement volume reflects the absence of mitigation mechanisms capable of retaining or recovering hydrocarbon vapors during throughput operations. Consequently, FRT without emission control measures represented a significant source of VOC emissions in naphtha storage systems. The results underline the importance of implementing vapor control technologies and alternative tank configurations. These measures effectively reduce emissions associated with working losses, as presented in Table 1.

**Table 1** Fixed Roof Tank without emission control

| Parameter          | Units               | Fixed Roof Tank (FRT) |
|--------------------|---------------------|-----------------------|
| Total Losses       | kg/yr.              | 7,476.83              |
| Standing Losses    | kg/yr.              | 0.27                  |
| Working Losses     | kg/yr.              | 7,476.56              |
| Vapor Space Volume | ft <sup>3</sup>     | 428,688.63            |
| Throughput         | m <sup>3</sup> /yr. | 1,161,119.65          |

## Evaluation of Greenhouse Gas Emission

To assess GHG emissions, the estimated emissions were calculated using emission factors provided by both the IPCC 2006 Guidelines and Thailand's national database from Thailand Greenhouse Gas Management Organization (TGO). The IPCC default emission factor is 0.3100 kg CO<sub>2</sub>eq/kg; the total GHG emissions from the FRT were found to be 2,317.82 kgCO<sub>2</sub>eq/year. On the other hand, applying the TGO Thailand-specific CFP emission factor of 0.2972 kgCO<sub>2</sub>eq/kg, the total yield was slightly lower at 2,222.11 kgCO<sub>2</sub>eq/year. The higher emissions associated with the IPCC emission factor reflect its generalized global applicability, whereas the TGO emission factor derived from region-specific studies provides a more accurate estimate for local operational conditions. These results indicate that using local emission factors enhances the precision of GHG assessments, which can be seen in Table 2.

**Table 2** Greenhouse Gas Emission of Scenario 01 Fixed Roof Tank without emission control

| Parameter                 | Units                    | IPCC 2006 | TGO      |
|---------------------------|--------------------------|-----------|----------|
| Total Losses Emissions    | kgCO <sub>2</sub> eq/yr. | 2,317.82  | 2,222.11 |
| Standing Losses Emissions | kgCO <sub>2</sub> eq/yr. | 0.08      | 0.08     |
| Working Losses Emissions  | kgCO <sub>2</sub> eq/yr. | 2,317.73  | 2,222.03 |

## Mitigating Greenhouse Gas Emissions with Root Cause Analysis

To identify fundamental causes of GHG emissions from the petroleum naphtha storage tank, focusing on factors influencing emission rates. This structured approach ensures the mitigation strategies address core issues more than symptoms, enabling targeted solutions to reduce emissions effectively. Two tools used in this analysis were the Fish Bone Diagram (Ishikawa Diagram) and the 5-Why Question.

The Fish Bone Diagram (Ishikawa diagram) was shown in the results section to illustrate the key factors contributing to high emissions from the naphtha storage tank. The contributing factors were identified through systematic analysis of the collected operational and environmental data, including temperature measurements, operational logs, maintenance records, and equipment specifications. These data were examined and organized into four primary cause categories: environment, equipment, operation, and material.

Environmental factors, particularly temperature fluctuations and ambient weather conditions, were found to significantly influence vapor pressure, thereby increasing evaporative emissions. Equipment-related issues, including inadequate maintenance practices, were found to result in suboptimal system performance and potential leakages. Operational factors, such as inefficient filling and emptying processes, were identified as contributing to exacerbated emission losses. Material-related issues, particularly degraded seals and ineffective vapor recovery systems, were determined to contribute substantially to uncontrolled vapor releases. The relationships among these factors are shown in Fig. 3.

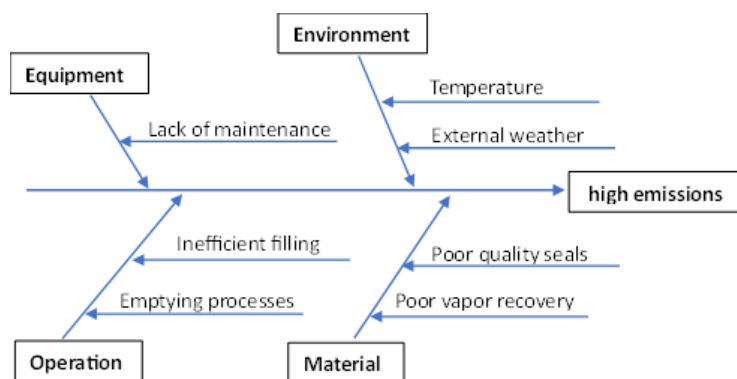


Figure 3 Fish Bone Diagram of storage tank

The root cause of emission from FRT was investigated by using the 5-Why analysis, as shown in Fig. 4. The analysis revealed that 2 cause is 1. A large vapor space created during product transfer, coupled with the fixed roof's inability to respond to changes in liquid levels, led to frequent vapor expansion and excessive evaporation. and 2. strong temperatures due to direct sunlight and a lack of insulation, most stemming from the fundamental design limitations of FRT. To solve these issues, 5 targeted solutions were proposed: 1. installing vapor recovery systems (VRS) (American Petroleum Institute, 2015; Lee & Chen, 2021), 2. improving tank insulation to reduce temperature changes (Mzad & Abdallah, 2020), 3. implementing cooling or temperature control systems (Choi et al., 2024), 4. applying reflective coatings or external shading (Chen et al., 2023), and 5. ultimately converting Fixed Roof Tanks to Floating Roof Tanks (EFRT or IFRT) to eliminate vapor space and minimize emissions (Zinke et al., 2020; Yang et al., 2024), as shown in Fig. 5. These recommendations are directly based on the root causes identified and are expected to provide both immediate and long-term reductions in GHG emissions from storage.

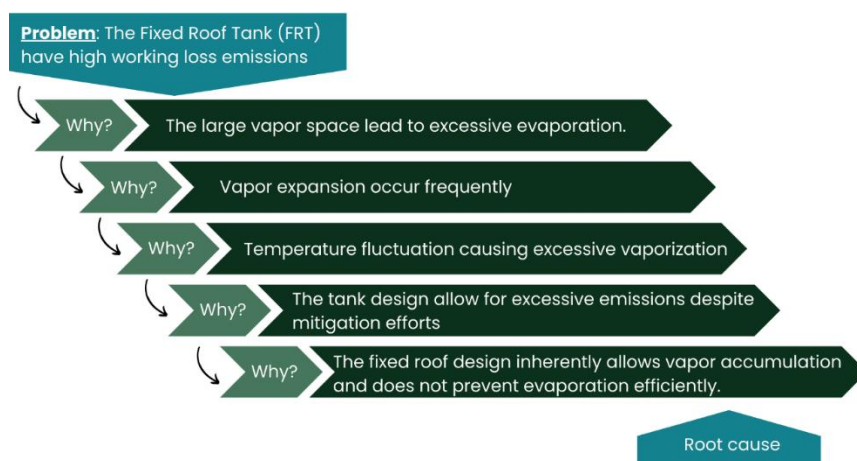


Figure 4 Flowchart 5 Why Question in Scenario 01

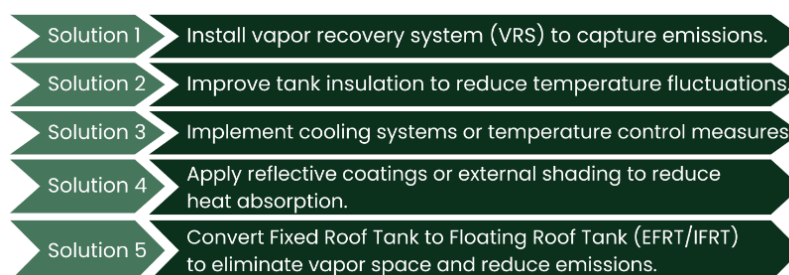


Figure 5 Solution of 5 Why Question in Scenario 01

## Comparison of emissions under different scenarios

A comparison of four tank configurations was conducted to assess the effectiveness of different emission control strategies. The scenarios included 1. Fixed Roof Tank without emission control (FRT, Sc01), 2. Fixed Roof Tank equipped with a 90% efficient Vapor Recovery System (VRS) (Sc02), 3. Internal Floating Roof Tank (IFRT, Sc03), and 4. External Floating Roof Tank (EFRT, Sc04). The results showed that the uncontrolled Fixed Roof Tank (Sc01) produced the highest total emissions at 7,476.83 kg/year, equivalent to 2,222.11 kgCO<sub>2</sub>eq/year. Among these losses, working losses were the highest, accounting for 99.99% of the total, while standing losses contributed about 0.01% of the total. This clearly indicates that most emissions occur during the filling and emptying cycles. These operational activities are the primary source of emissions in uncontrolled systems, as shown in Fig. 6.

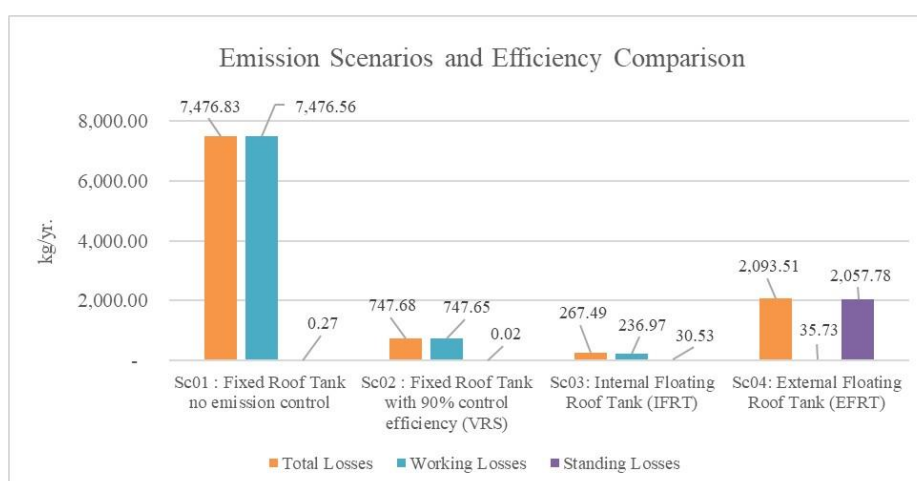


Figure 6 Emission Scenarios and Efficiency Comparison Histogram

Comparison of the total losses with all scenarios. It was found that emission control systems significantly reduced vapor releases. The Fixed Roof Tank with a 90% efficient Vapor Recovery System (Sc02) reduced total losses to 747.68 kg/year, representing a 90% reduction from Sc01's emissions. The Internal Floating Roof Tank (IFRT, Sc03) achieved the greatest reduction, with total losses of only 267.49 kg/year and corresponding to a 96.4% decrease relative to the uncontrolled scenario. The External Floating Roof Tank (EFRT, Sc04) emitted 2,093.51 kg/year, equivalent to a 72% reduction in total losses compared to Sc01's emission. These results confirm that floating roof tank design, particularly the IFRT, is the most effective configuration for minimizing emissions because they greatly reduce the vapor space between the liquid and the atmosphere.

As presented in Table 3, the total GHG emissions calculated using the Thailand-specific TGO carbon footprint (CFP) emission factor (0.2972 kgCO<sub>2</sub>eq/kg) are consistently lower than those derived from the default IPCC (2006) emission factor (0.3100 kgCO<sub>2</sub>eq/kg), demonstrating a uniform reduction of approximately 4.13% across all four operational scenarios. Because both emission factors maintain a linear proportionality with the VOC activity data, this constant percentage difference preserves the relative ranking of emission control performance across the evaluated configurations (Sc03 IFRT, Sc02 FRT-VRS, Sc04 EFRT, and Sc01 FRT in ascending order), confirming that the choice of emission factor does not alter the comparative mitigation efficacy of the tank designs.

**Table 3** Comparison of Greenhouse Gas Emissions Using IPCC 2006 and TGO CFP Emission Factors across Naphtha Storage Tank Scenarios

| Scenario               | Total VOC Emission<br>(kg/yr) | IPCC 2006<br>(kgCO <sub>2</sub> eq/yr) | TGO CFP<br>(kgCO <sub>2</sub> eq/yr) | Difference<br>(kgCO <sub>2</sub> eq/yr) |
|------------------------|-------------------------------|----------------------------------------|--------------------------------------|-----------------------------------------|
| Sc01: FRT (no control) | 7,476.83                      | 2,317.82                               | 2,222.11                             | 95.70                                   |
| Sc02: FRT-VRS (90%)    | 747.68                        | 231.78                                 | 222.21                               | 9.57                                    |
| Sc03: IFRT             | 267.49                        | 82.92                                  | 79.50                                | 3.42                                    |
| Sc04: EFRT             | 2,093.51                      | 648.99                                 | 622.19                               | 26.80                                   |

Overall, the comparison highlights that a combination of mechanical design improvements and vapor recovery technologies provides good emission reduction results. The quantitative outcomes such as 90% reduction with VRS (Sc02), 96.4% reduction with IFRT (Sc03), and 72% reduction with EFRT (Sc04), compared with FRT (Sc01), demonstrate that both technological upgrades and structural optimization can significantly mitigate GHG emissions.

### Discussion

The results from this study clearly demonstrate that FRT without emission control contributes the highest levels of VOC and GHG emissions among all the scenarios considered. This consequence is consistent with the characteristics of FRT, which create a large vapor space that facilitates significant evaporation during temperature fluctuations and liquid transfers (working losses). As a result, FRT is not suitable for storing high-vapor-pressure products such as petroleum naphtha, unless equipped with advanced emission control technologies.

Previous research in Thailand supports these findings (Jindamanee et al., 2024). Demonstrated that storage tanks account for up to 88% of total VOC emissions in petroleum refinery settings, and other studies in the Map Ta Phut industrial estate have highlighted storage tanks as the primary source of VOC releases, contributing directly to local air quality issues and health risks in surrounding communities. These domestic studies support the necessity for Thailand's refineries to prioritize emission mitigation strategies for storage tanks. Such measures are essential for national regulations and protect public health (Singkaew et al., 2013).

A comparison of the scenarios highlights the significance of emission mitigation strategies. Specifically, the installation of a VRS in Scenario 02 resulted in a 90% reduction in emissions compared to the uncontrolled baseline. It shows that VRS is highly effective in capturing vapors and reducing their release into the atmosphere. However, while VRS provides substantial benefits, it requires additional operational and maintenance costs. In

contrast, IFRT demonstrated superior performance by minimizing vapor space and achieving the lowest emissions among all scenarios. This structural design provides a passive and long-term solution for emission control. These make it highly effective and sustainable. On the other hand, EFRT showed mixed results. While working losses were significantly reduced, standing losses increased. Because of vapor leakage at deck fittings and seals, that makes EFRT is less effective than IFRT in reducing overall emissions.

The application of Root Cause Analysis further enhances these findings by identifying the excessive emissions' fundamental reasons. The Fishbone diagram and 5-Why analysis revealed the primary cause. These are related to the lack of design standards for high-vapor-pressure liquids, poor temperature management, and insufficient vapor containment. The proposed solutions included installation of VRS, improving insulation, applying reflective coatings, and converting FRT to IFRT or EFRT to effectively address the vapor space problem.

Converting from a fixed-roof tank to a floating-roof tank provides substantial environmental, regulatory, and economic benefits. From the results, floating-roof tanks reduce evaporative emissions by eliminating most of the vapor space above the liquid surface, achieving a substantial and observable decrease in emissions compared to a fixed-roof tank. This reduction is critical for compliance with air quality regulations, such as the U.S. Environmental Protection Agency's New Source Performance Standards (U.S.EPA, 2024) and national standards enforced by agencies such as the Pollution Control Department (PCD) in Thailand. These regulations often set emission limits or require the use of best available control technology (BACT) for storage tanks. The floating-roof designs are widely recognized as an effective compliance measure.

Applying floating-roof technology in refineries can avoid regulatory penalties, reduce the cost to add-on vapor recovery or thermal oxidation systems, and demonstrate adherence to international environmental frameworks such as ISO 14001. From a safety perspective, floating roofs also reduce the accumulation of flammable vapors and reduce the risk of fire or explosion. In the operations section, they help minimize corrosion and maintenance costs, while economically they recover valuable product lost from evaporation. Beyond regulatory and financial aspects, reduced emissions and odors improve local air quality and enhance community relations. This action makes the refinery a leader in environmental stewardship and sustainable operations.

This study focuses primarily on quantifying GHG emissions from petroleum storage tanks. The results from the 5-Why Analysis revealed that the primary causes of excessive emissions were related to inefficient vapor recovery systems, deteriorated sealing mechanisms, and improper tank operation. These root cause findings directly support the proposed mitigation strategies by identifying specific failure mechanisms that can be addressed through targeted interventions. The direct link between these RCA findings and the resulting mitigation strategies is essential for ensuring that the proposed interventions are comprehensive and sustainable rather than superficial (Hibbert et al., 2018).

Furthermore, these actionable insights simultaneously align with the principles of the Bio-Circular-Green (BCG) Economy Model applied in sustainable industrial practices and policy development. These findings are in accordance with the principles of the Bio-Circular-Green Economy Model (BCG Model). These are applied in policy development and sustainable industrial practices. Within this study, the VRS implementation represents the practical application of the Circular Economy concept. That means efficient resource utilization and emission reduction. Furthermore, the recommendations derived from this research suggest potential future applications. Bio Economy is the use of bio-based additives to minimize evaporation. Green economy is the use of solar-powered systems to provide energy for vapor recovery units (VRUs). These enhance energy sustainability.

Finally, mitigation measures were proposed and evaluated according to their technical feasibility, environmental benefits, and economic practicality. This integrated approach not only supports Thailand's BCG policy framework and mitigation strategies but also provides a foundation for extending the research toward sustainable and low-carbon industrial development in future studies.

### **Conclusion and Suggestions**

This study focuses on greenhouse gas emissions from a petroleum naphtha storage tank. The U.S.EPA TANKS 5.1 model, along with IPCC and TGO CFP emission factors, was utilized to calculate emissions across four distinct operating scenarios. The results showed that FRT without any emission control had the most total losses. Working losses made up over 99% of those emissions. Installing 90% efficient VRS can reduce total emissions by about 90%. Then the IFRT achieved the greatest reduction of about 96.4%. This confirms that both structural modifications and vapor recovery technologies serve as effective mitigation strategies. In comparison, the EFRT achieved a reduction of approximately 72%, though it exhibited higher standing losses due to vapor leakage. The Root Cause Analysis identified that excessive emissions stemmed mainly from the fixed roof design, insufficient vapor containment, and exposure to heat. These losses can be effectively mitigated through improved insulation, vapor recovery, and the use of a floating-roof tank. Although this study focuses on quantifying GHG emissions from petroleum storage tanks, its results align with the principles of Thailand's BCG Economy Model. By improving resource efficiency and implementing vapor recovery systems, industries can reduce emissions while contributing to the green economy pillar of the BCG framework and advancing toward sustainable, low-carbon refinery operations.

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### **Author Contributions**

**Pavaris Charuchitsopon:** Conceptualization, methodology, software, validation, and writing—original draft. **Peemapat Jookjantra:** Investigation. **Pornpavit Mapraditkul:** Investigation. **Korn Premrunghet:** Data curation. **Sirapong Sooktaewee:** Supervision. **Sarawut Thepanondh:** Writing – review & editing, and Supervision.

### **Conflict of Interests**

All authors declare that they have no conflicts of interest.

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### Declaration of Generative AI and AI-assisted Technologies

During the preparation of this manuscript, the authors used ChatGPT to check and improve the language and used NotebookLM to create a graphical abstract. Following its use, the authors thoroughly reviewed and edited the content and accept full responsibility for the final version of the publication.

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