Natsurv 15

Water and Wastewater Management in the Oil Refining and Re-refining Industry

(Edition 2)

J.E. Burgess, T. Mocumi, D-R. Southgate

WATER RESEARCH COMMISSION

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Water and Wastewater Management in the Oil Refining and Re-refining Industry

(Edition 2)

Report to the
Water Research Commission

by

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The publication of this report emanates from a directed project titled *Revision of NATSURV 15: Water and Wastewater Management in the Oil Refining and Re-refining Industry* (WRC Project No. C2022/2023-00760).

This is an updated and revised version of NATSURV 15 that was published in the NATSURV series in 2005 as WRC Report number TT 180/05.

Executive Summary

BACKGROUND

This project involved updating and expanding the first edition of NATional SURVey (NATSURV) 15, which recorded the norms and standards for water management in oil refining in South Africa in 2005. The objectives included providing an industry overview, evaluating production processes, assessing water consumption and wastewater generation, and recommending future targets or best practices to lower water consumption and better manage wastewater. However, one refinery has announced closure, another has ceased processing oil, a gas to liquid plant placed on care and maintenance and the future of the remaining two oil refineries are uncertain, some objectives have been replaced. These new objectives focus on understanding the future business plans of remaining refineries, exploring the situation in the Southern African Development Community (SADC) countries, studying overseas refiners transitioning to non-fossil oils, and providing recommendations for the next NATSURV 15 edition.

METHODOLOGY

The methodology began with a comprehensive review of the status of the oil refining and re-refining industry, with a specific focus on water and wastewater management. It aimed to provide an initial assessment of the industry's present state, considering drivers influencing water use and management. The original intent was to assess local electricity, water, and effluent tariffs and by-laws to identify opportunities for savings and lower environmental impact. However, the primary driver affecting water management in South African refineries was the industry's precarious position.

The production processes at the refineries were reviewed, focusing on water-intensive methods. Generic refining techniques were identified, and water consumption ranges were quantified, noting that water consumption is highly dependent on local ambient conditions. Data on water usage and wastewater generation were compiled.

The desktop research was followed by stakeholder engagement through questionnaires, workshops, and interviews. Questionnaires were sent to all existing refineries, and interviews were conducted to address gaps in information identified. Corporate water management and disclosure standards were also examined, and the findings were used to formulate insights into the current state of the oil refining and re-refining industry, its water management practices, and the challenges it faces, especially in the context of a changing industry landscape.

INDUSTRY OVERVIEW

The oil refining and re-refining industry encompasses the transformation of crude oil and used oil into various products, including fuels, lubricants, chemicals, and plastics. While traditional refineries use virgin crude oil as feedstock, re-refineries recycle used oil. The industry's scope covers traditional crude oil refineries, Gas-to-Liquid (GTL) refineries using natural gas, and Coal-to-Liquid (CTL) refineries using coal. These refineries contribute to diverse petroleum product production, addressing energy demands and environmental concerns.

In South Africa, the industry faces challenges as several refineries have closed or are non-operational (Table 1). Refinery closures, especially smaller refineries, have been a global trend, accelerated by the move towards renewable energy. South Africa's refining capacity has declined, leading to increased fuel imports to meet local demand. Since 2019, the country's real refining capacity has declined to 438,000 barrels per day, or ~61% of its 2023 theoretical capacity, shown in Table 2.

Table 1: Refinery overview, 2023

Name	Operational status 2021	Operational status 2023
Astron	Running at reduced capacity	Running
Enref	Closing	Closed
Natref	Running	Running; future uncertain
PetroSA GTL	Running	Closed
Sapref	Paused	Closed
Secunda CTL	Running	Running; future uncertain

Table 2: Theoretical installed capacity reported in NATSURV edition 1 (2005) and this report

Refinery name	Location	Ownership 2005*	Ownership 2023	Capacity 2005 (barrels/day)[1]	Capacity 2023 (barrels/day)
Astron (formerly Caltex)	Cape Town	Chevron (Caltex)	Astron Energy (Glencore)	110,000	100,000
Enref	Durban	Engen (subsidiary of Petronas)	Engen	105,000	135,000
Natref	Sasolburg	Sasol and Total	Sasol 64% and Total 36%	85,000[2]	108,000
PetroSA (formerly Mossgas)	Mossel Bay	Central Energy Fund	PetroSA (synfuels)	35,000 equivalent	45,000 equivalent
Sapref	Durban	Shell and BP	BP 50% and Shell 50%	165,000	180,000
Sasol	Secunda	Sasol	Sasol (synfuels)	160,000 equivalent	150,000 equivalent

Astron refinery was in the process of reopening after a long shutdown following an explosion in 2020. The refinery underwent repair and refurbishment and resumed production. In February 2023 it was in the final steps of a safe full restart of the refinery and fully recommenced the production of refined products by the end of 2023.

Enref ceased operations in 2020. Engen decided to convert the refinery into an import terminal, aligning with economic considerations and a strategic shift toward facilitating the importation of refined fuels. Engen was exploring the construction of a biorefinery on the same site, with a feasibility study underway when this report was written.

Sasol's Natref refinery was considering upgrades to produce higher-quality fuel. The refinery shut down in July 2022 due to supply challenges but resumed production once the issues were resolved. The future of the Natref refinery was being evaluated by Sasol Ltd. and TotalEnergies.

Sapref suspended operations in 2022 in search of a buyer. However, severe floods hindered the refinery's prospects, and repairing it would require extensive capital investment and several years. The future of Sapref remains uncertain as efforts continue to find a buyer.

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[1] Figures provided in NATSURV 15, first edition.

[2] Information gathered during this study indicates that this figure was incorrect, and should have been 108,000.

Secunda refinery faces feedstock quality issues impacting production output. The refinery is actively pursuing two projects to supply 850 GWh of green electricity, subject to regulatory approvals.

PetroSA's Mossel Bay closed due to feedstock supply issues. Offshore gas and condensate feedstocks ran out in 2020. Efforts were underway to develop a long-term feedstock solution that would enable the refinery to resume operation by 2027/2028.

South Africa has relied on imported oil since 2006, when it switched to net deficit production. Imports in 2019 amounted to about 7bl and around 15bl are expected to be imported during 2023 to meet its liquid fuel needs, meaning that 90% of domestically consumed crude oil was being imported by 2024. South Africa's imports of ready-refined petroleum product are expected to triple from pre-pandemic levels as more domestic refineries close down.

WATER USE

Refinery water consumption is influenced by factors like the environment in which it operates (altitude, ambient conditions, etc.) size, refinery configuration, feedstock and product range. Understanding the water balance is crucial for optimizing usage and treatment. Most water in refineries can be recycled, but some is lost through processes like evaporation. To assess their effectiveness and efficiency in water utilisation, data was collected from refineries, including details of source water, production volumes, water quality, and average water consumption for different products. This information was then compared with industry benchmarks and the initial edition of NATSURV 15.

South African refineries predominantly rely on municipal water sources for all their needs (Figure 1). Additionally, some refineries utilise surface water and treated wastewater, sourced from on-site dams and rivers

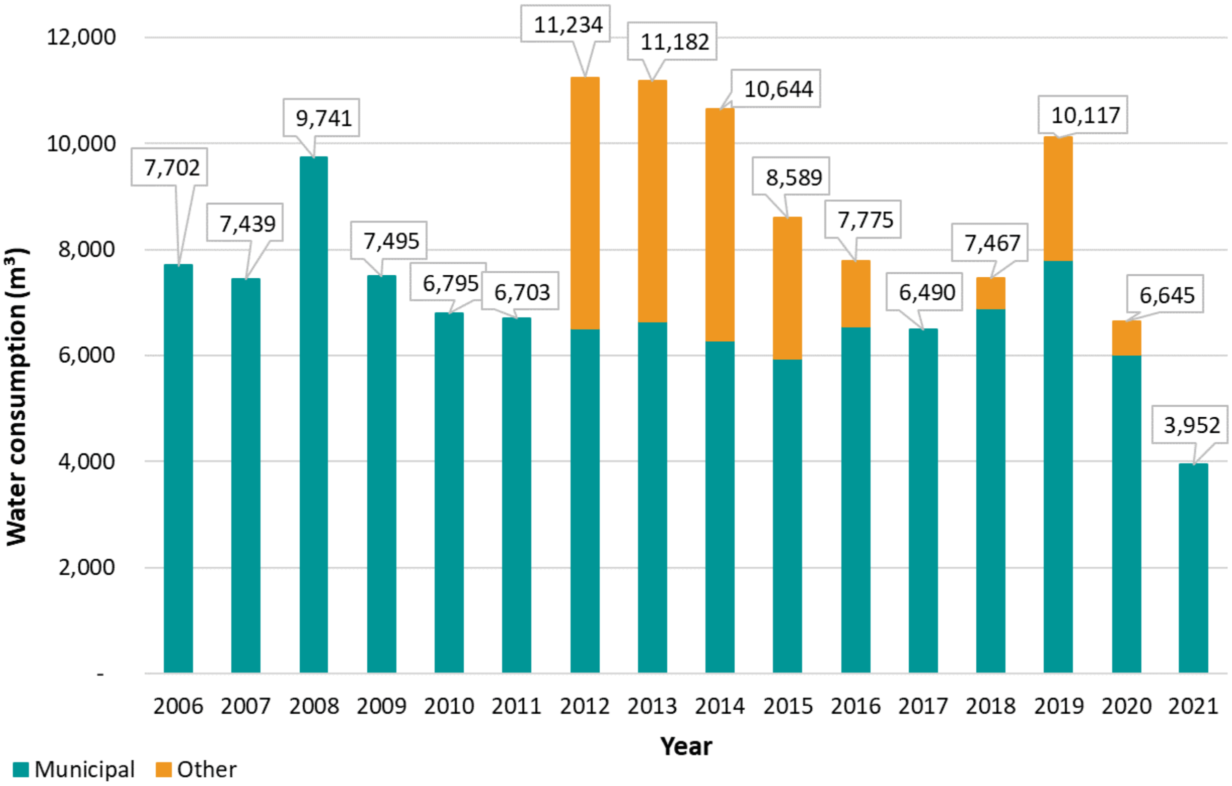

Figure 1: Crude oil refineries' combined water consumption from 2006 to 2021 in m³, showing total consumption (data callouts) and the volume obtained from municipal supplies vs. other sources

The quality of source water plays a pivotal role in the efficiency and effectiveness of various processes. Treatments such as demineralization, membrane filtration, coagulation, settling and filtration, softening, and disinfection are employed to ensure compliance with process water, cooling and steam quality requirements, as well as stringent product standards and to maintain water quality.

Water Consumption and Specific Water Intake (SWI)

Water consumption varies across different refining processes, with cooling water and boiler feed water being primary consumers. The choice of cooling system significantly impacts water consumption, with once-through cooling systems typically having larger withdrawals but lower consumption compared to recirculating cooling tower systems.

In the oil refining industry, Specific Water Intake (SWI) measures the amount of water required per unit of product produced or feedstock processed. SWI varies according to the type of feedstock, refining complexity, and water management practices. The participating refineries could not provide submetering data for the water consumption of individual production process steps, however the 2005 data can be compared with estimates of more recent SWI. The updated estimated values have been calculated from the most recent publicly available data from the refineries' operational periods.

The estimates (Table 3) appear to indicate that SWI values have improved in the CTL and GTL refineries, however, edition 1 (2005) noted that the range of monthly SWI data was 2.3-4.61 m³ water / ton oil equivalent processes in the synfuels refineries, a range with which the estimated updated data are consistent.

The 2005 data for the crude oil refineries fell into the range 0.42 to 0.78 m³ water / ton feedstock. Our estimates for Astron, Enref and Natref are consistent with that range, but our calculations for Sapref are considerably higher and should be treated with caution owing to the lack of real data available for the actual feedstock amounts refined for the specific periods, and the water consumption data sources being secondary in nature.

Table 3: Average SWI from the first edition of NATSURV 15, compared to estimated recent SWI values calculated from public data

Feedstock	Refinery	Average SWI 2005 (m³/t)	Recent SWI estimates
Crude oil	Astron	0.51 - 0.67	0.8
	Enref		0.7
	Natref		0.7
	Sapref		2.5
Gas	PetroSA	2.9 (synfuels average)	1.2
Coal	Secunda		2.2

WASTEWATER CHARACTERISTICS, TREATMENT AND DISCHARGE

The specific effluent volume (SEV) is a metric for assessing industrial wastewater management, representing the amount of wastewater discharged per unit of feedstock processed. In South African refineries, SEV data are often undisclosed or unavailable. Estimates suggest that Astron and Natref refineries may have SEVs around 2.97 m³/t and 2.38 m³/t, respectively, based on similar data and assumptions.

Comparisons with 2005 data and international data reveal significant variations in SEVs. Wastewater characteristics include pollutants like pH, COD, TSS, oil content, and phenols, with different refineries displaying varying concentration ranges. Some improvements have been observed since 2005, likely due to enhanced operational practices and stricter regulations.

Wastewater treatment methods predominantly involve primary treatments like desalter oil/water separation, American Petroleum Institute (API) separation, and dissolved air flotation. Secondary treatments, such as aerated lagoons and biological processes, are also employed in some refineries. These practices align with international standards.

The insufficient data underscores the need for actual SEVs and effluent characteristics for accurate environmental impact assessment and regulatory compliance.

IMPLEMENTATION OF WATER, WASTEWATER, AND ENERGY BEST PRACTICE

Refineries favour efficient cooling methods over once-through cooling. A growing emphasis on effluent recycling suggests increased recognition of water security and sustainability risks requiring mitigation. Refineries are motivated by rising water and energy costs, as well as water scarcity concerns. Significant water consumption reductions have been made through water treatment and reuse, equipment upgrades and process modifications.

THE FUTURE OF THE INDUSTRY

The prevailing trend in oil refining in South Africa is it’s disappearance. Most refinery owners were unable to provide comprehensive details about the future of their sites, as such information is strategically and economically sensitive. The following summaries are based on limited information obtained through personal communications and/or public sources:

Astron was shut down in 2020 following a fatal incident. Repairs and refurbishment to equipment followed and operations resumed in 2023. Astron Energy said that it would continue to supply its customers with refined products from its storage facilities until the refinery resumes full capacity operation.

Enref was shut down in 2020 following a fire. In January 2021, Engen announced that it would repurpose Enref into a fuel importation terminal by 2023. The site is not expected to refine oil again.

Natref was operating and produces gasoline, diesel, jet fuel, and liquefied petroleum gas. However, in September 2020, TotalEnergies announced it would be selling its stake in Natref as part of its asset divestment plan. The refinery temporarily shut down in July 2022 but had resumed production in 2023.

PetroSA's GTL plant no longer operated as a refinery from 2020 to the time of writing due to feedstock unavailability.

Sapref: Jointly owned by Shell and BP, Sapref paused operations in April 2022 following severe flood damage, and was searching for a buyer at the time of this study. The future of Sapref remains uncertain, given the extensive capital investment required for reopening.

Secunda CTL has been operational since 1980. Sasol aims to reduce emissions by at least 10% by 2030 through a R2 billion investment. The refinery is exploring alternative feedstocks and green electricity projects.

The international oil companies operating in South Africa have announced plans to reduce global crude oil refining activities. Their strategies align with the global energy transition and the demand for low-carbon fuels. The proposed merger of PetroSA and other Central Energy Fund subsidiaries to form the South African National Petroleum Company (SANPC) was approved to stabilize petroleum supply and boost state participation in oil and gas developments. This report underscores a transformative shift in the global oil industry towards sustainability and low-carbon alternatives.

INDUSTRY STATUS IN THE SADC

The industry in the Southern African Development Community (SADC) countries is facing significant challenges and changes, leading to a shift in the sector's dynamics. Several key factors are influencing this shift, including the impact of the COVID-19 pandemic, cleaner fuel policies, competition from cheaper imported products, security and safety issues, and the global energy transition towards renewable energy sources. These factors have contributed to the closure of oil refineries across Africa.

Angola is alone among the SADC member states in increasing its domestic refining capacity, potentially surpassing South Africa as the region's largest refiner. Tanzania's experience with converting a refinery to an import facility, Tanzania International Petroleum Reserves Limited, is similar to the conversion of Enref to an import terminal.

Overall, the future of the oil refining industry in southern Africa is expected to move away from refining and towards import, storage, and distribution of pre-refined products. This transformation reflects the evolving global and regional energy landscape and the challenges faced by traditional oil refining facilities worldwide.

THE BRAZILIAN ENERGY INDUSTRY’S TRANSITION FROM FOSSIL FUELS TO RENEWABES

The Brazilian energy industry serves as an insightful case study for South Africa's potential transition from fossil fuels to renewables. Brazil, similar to South Africa in many aspects, has successfully shifted from fossil-fuel-derived liquid fuels to renewables, primarily biofuels, particularly ethanol from sugarcane. Several key strategies have driven Brazil's transition, including developing new technologies for various biofuels, investing in research and innovation, expanding domestic and international biofuel markets, diversifying its energy portfolio, and enhancing regulatory support. These strategies have helped Brazil achieve its energy security, environmental, and economic objectives while maintaining its global leadership in biofuels.

Notable drivers for Brazil's transition include economic viability, energy security, environmental sustainability, the National Biofuel Program (RenovaBio), growing market demand, technological advancements, and geopolitical considerations. These factors converged to create an attractive environment for transitioning to renewable liquid fuels. Central to this transition was Petrobras, a state-owned oil company responsible for a significant portion of Brazil's oil and gas production, demonstrating a parallel with South Africa's oil industry and the proposed creation of the South African National Petroleum Company (still the subject of a draft bill). Various Acts exist which can permit the development of a national oil company via the Central Energy Fund.

A critical component of Brazil's biofuel transition is the RenovaBio program. Launched in 2017, it aims to expand the use of renewable fuels, reduce carbon intensity, and foster sustainability. This market-driven program issues decarbonization credits (CBIOs) to incentivize biofuel production and consumption. The RenovaBio program is projected to prevent more than 600 million tons of carbon emissions over the next decade, making a significant environmental impact.

Brazil's oil companies have actively embraced the transition to renewables by diversifying their product portfolios, blending ethanol into gasoline, forming biofuel partnerships, investing in refining infrastructure, expanding the biofuel market, and ensuring compliance with RenovaBio certification requirements. This industry-wide shift has been underpinned by a combination of economic, environmental, and policy drivers.

The Brazilian experience offers valuable insights for South Africa. Both countries share similarities in economic status, development aspirations, and social inequalities. While the economic circumstances leading to Brazil's biofuels transition differ, South Africa's surplus of cane sugar and a reduced market for human consumption, coupled with government policy adjustments and seed investment, might present opportunities to partially decouple transport costs from oil prices and embrace the circular economy for its transportation needs.

CONCLUSIONS AND RECOMMENDATIONS

South Africa's oil refining industry is facing a probable irreversible decline, with only three operational refineries. The SWI and SEV figures have been estimated based on available data, but due to limited primary data, firm values could not be provided. The operational refineries have implemented some water and energy conservation measures, reflecting international trends.

Recommendations for future work in the next edition of NATSURV 15 include:

- Listing South Africa's operational crude oil refineries, CTL, and GTL refineries.
- Providing a summary of the sources of South Africa's liquid fuels, including the relative proportions of supply from domestic refining, imports, recycling, and re-refining, and the stability of supply.
- Focusing attention on oil recycling, such as technological innovation, and policy support.

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Acronyms and abbreviations

BMP	Best management practices
BOD	Biochemical oxygen demand
CDP	CDP is not an abbreviation. For clarity, CDP is a charity that runs the global disclosure system for companies to manage their environmental impacts; formerly Carbon Disclosure Project until 2012.
COD	Chemical oxygen demand
COP	Crude oil pipeline
CTL	Coal-to-liquid
DAF	Dissolved air flotation
DEA	Department of Environmental Affairs
DMRE	Department of Mineral Resources and Energy
DWS	Department of Water and Sanitation
EU	European Union
FCC	Fluid Catalytic Cracking
F-T	Fischer-Tropsch
GDP	Gross domestic product
GHG	Greenhouse gases
GTL	Gas-to-liquid
HGO	Heavy gas oil
IAF	Induced air flotation
ISO	International Organisation for Standardisation
IWRM	Integrated Water Resource Management
KPI	Key performance indicator
LNG	Liquified natural gas
LPG	Liquified petroleum gas
NATSURV	National Survey
NRCS	National Regulator for Compulsory Specifications
NWA	National Water Act
PPP	Public-private partnership
RO	Reverse osmosis
SADC	Southern African Development Community
SANPC	South African National Petroleum Company
SAPIA	South African Petroleum Industry Association
SBM	Single buoy mooring
SEV	Specific effluent volume
SMME	Small, Medium and Micro Enterprises
SWI	Specific water intake
TDS	Total dissolved solids
TIPER	Tanzania International Petroleum Reserves Limited
TNPA	Transnet National Ports Authority

TPH	Total petroleum hydrocarbons
TSS	Total suspended solids
UN	United Nations
UV	Ultraviolet
VLCC	Very large crude carrier
WRC	Water Research Commission
WSA	Water Services Authority
WWTW	Wastewater treatment works

CHAPTER 1: INTRODUCTION

The Water Research Commission national surveys (NATSURVs) TO document norms and standards for water intake, wastewater disposal, and management in various industrial sectors, including the oil refining and re-refining industry. The first edition of NATSURV 15 was published in 2005 (Pearce and Whyte, 2005).

The NATSURVs have been well used since they were developed by the sector. However, South Africa and its industrial sectors have either grown or – as in this case – shrunk considerably since Edition 1 was published. Thus, the landscape has changed. New technologies and systems have been adopted by some of the industries, and therefore, certain information contained in the first edition can be regarded as obsolete. Further, initiatives like the UN CEO mandate, water stewardship, water allocation and equity dialogues, amongst others suggests growing awareness related to water use, water security, and waste production.

The oil industry is divided into upstream and downstream activities. Upstream refers to the exploration and production of crude oil, and is not included in the project scope. Downstream refining refers to the refining, transportation and provision of end-user products.

1.1 OBJECTIVES

The aim of this project was to update and expand the first edition of NATSURV 15. The specific objectives were as follows:

1. Provide a detailed overview of the industry in South Africa, and its changes since edition 1 was published.

2. Critically evaluate and document the “generic” industrial production processes in terms of current practice, best practice and cleaner production.

3. Determine the water consumption and specific water consumption (local and global indicators, targets; benchmarks, diurnal trends) and recommend targets for use, reuse, recycling and technology adoption.

4. Determine wastewater generation and typical pollutant loads, and best practice technology adoption.

5. Determine electricity, water, and effluent prices and by-laws within which these industries function and critically evaluate if the trends and indicators are in line with water conservation demand management and environmental imperatives.

6. Critically evaluate the water (including wastewater) management processes adopted and provide appropriate recommendations.

7. Evaluate the industry adoption of cleaner production, water pinch, energy pinch, life cycle assessments, water footprints, wastewater treatment and reuse, best available technology and ISO 14000, etc.

8. Provide recommendations on the best practice for this industry.

During the project it became clear that only three refineries remained partly or fully operational, with even their futures uncertain. Objectives 1 to 4 could still be met, but after discussion with the Reference group it was concluded that objectives 5 to 8 no longer hold value in the context of a disappearing industry and were therefore replaced with the following:

5. Ascertain what the refineries that have not yet closed expect to be their business plan going forward.
6. Explore the situation in the industry in the SADC countries search for any illustrative examples of potential future routes the South African industry might take.
7. Investigate how overseas refiners are transitioning to non-fossil oils in countries where there is a strong regulatory or political drive towards renewables or biofuels.
8. Provide recommendations for what the next NATSURV 15 might include.

1.2 METHODOLOGY

To begin with, a comprehensive review was undertaken to establish the current size, nature and status of the oil refining and re-refining industry, both locally and internationally. The emphasis was on water and, especially, wastewater management in the industry, and how systems and technologies have developed since 2005. The objective was to provide an initial assessment of the current state of the industry.

As part of the initial desktop work, we undertook research to gather and collate information in three distinct areas. Firstly, we evaluated the drivers influencing industrial water use and wastewater treatment at three levels: local (e.g. municipal tariffs and by-laws), national (e.g. the National Environmental Management Act and its regulations), and international (e.g. international water law, UN Watercourses Convention). The original aim was to inspect the local electricity, water, and effluent tariffs and by-laws within which these producers function to determine whether they are operating within the required parameters, and what opportunities exist to benefit from savings and lower environmental impact through water conservation and water demand management, effluent treatment and energy savings initiatives. However, the project revealed that the primary drivers influencing water management in South Africa’s refineries are not the tariffs and by-laws we expected, but the precarious position of the industry as a whole.

Secondly, we reviewed the production processes used at the refineries and assessed which ones are the most water intensive. The generic refining methods were identified and documented. Typical water consumption has been be expressed as cubic metre per tonne of feedstock processed. The refineries have been be mapped and quantified, including all available data on water usage, the specific water consumption and the volumes of wastewater that are generated.

Finally, we sought to identify ongoing or future industrial water stewardship activities and investigate existing investments. In this project we also explored market development strategies, new initiatives as well as ongoing ones aimed at facilitating industrial wastewater management. The projected future scenarios for the industry domestically and overseas have also been considered.

The desktop study was followed by engagement with the industries via questionnaires (Appendix A), workshops and interviews. To maximise response rates and willingness to engage, sessions were held with the industry associations SAPIA, the South African Petroleum Industry Association – as well as with the individual refineries. The stakeholders were first briefed to explain the nature and purpose of the project. They were assured that their sites and companies would not be identifiable from the research report and they were shown a recent example of another NATSURV (e.g. Welz et al., 2017). To incentivise their participation, they were offered (i) confidential access to the results of data analytics performed on their own information, (ii) the opportunity to preview and request amendments to the draft NATSURV, and (iii) resources for their internal stakeholder engagement on water stewardship and benchmarking within their own businesses.

Questionnaires were sent to all six existing refineries. The team monitored the response rate and validated the data to identify gaps and reach out as required to provide clarity by using interviews to support the questionnaire responses. Prior to all interviews (online or via phone call) conducted for this project, a list of the types of questions and information to be obtained was defined and shared with the interviewees to provide comfort that the interview would be sympathetically conducted and to ensure that the correct information would be captured. The questions were piloted to ensure they were well constructed questions, clear, and avoided ambiguity.

Examples of questions are:
- Are industries self-supplied or do they use water from public suppliers?
- What are the main water resources?
- What is the typical post-treatment implemented in the industrial sites?
- What are typical water quality standards for wastewater discharge?
- What are the national regulations regarding industrial wastewater discharge? When were they put into action? What are the penalties in case of not complying?
- What is the responsible water governance body for this site?
- Is the organisation a member of any water stewardship framework? Which one(s)? Do they use the framework(s) as provided or have they tailored their internal stewardship goals at a corporate or site level?

Interviews were requested to address potential gaps faced in information accessible via the desktop study research. The type of information sought was tailored to each stakeholder. The interviews were intended to determine the global indicators of water consumption and specific water consumption, targets, benchmarks, and diurnal trends.

Case studies were sought with the intention to document water treatment technologies that are in place in the refineries, as well as on other technologies being considered as appropriate technologies. This information was intended to be used to provide recommendations for wider uptake of best practice and to inform some recommended technology adoption targets. However, chapter 3 shows that no cases studies were available.

To provide a useful NATSURV 15 in the absence of a large national dataset, international companies including Shell, BP, and TotalEnergies (formerly Total) were added to the interview schedule to enable the NATSURV to address questions such as:
- What is the situation in the industry in the SADC / region and globally?
- How are overseas refiners transitioning to non-fossil oils in countries where there is a strong regulatory or political drive towards renewables or bio-fuels? Brazil was selected owing to its climatic and socio-political similarities with South Africa.

Corporate water management and disclosure standards have been added to this edition of NATSURV 15 by carrying out desktop research on company and cross-sector levels (e.g, CDP reports), reviewing representative publicly available corporate documents and presenting a qualitative and, wherever possible, quantitative summary of the findings. The recommendations and measures consider the following aspects:
- Availability and provision of water and wastewater treatment infrastructure;
- Level of technical capacity and water and wastewater management knowledge;
- Robustness and relevance of the water quality data;
- Market shifts and key drivers;
- Climate change and strategy development.

CHAPTER 2: INDUSTRY OVERVIEW

2.1 OIL REFINING AND RE-REFINING

2.1.1 Definitions

Oil refining and re-refining industry transforms crude oil and used oil into various products, such as fuels, lubricants, chemicals, and plastics. The refining and re-refining processes involve several steps, such as distillation, cracking, reforming, alkylation, hydrotreating, and blending. The main difference between refining and re-refining is that refining uses virgin crude oil as the feedstock, while re-refining uses used lubricating oils as the feedstock. Used oil is any oil that has been contaminated or degraded by use, such as engine oil, transmission fluid, hydraulic oil, or industrial oil.

The NATSURV 15 report includes Gas-to-Liquid (GTL) and Coal-to-Liquid (CTL) processes as well as oil refining. It encompasses the processing, transformation, and reuse of crude oil, natural gas, and coal resources. This industry is responsible for converting raw materials into refined petroleum products and alternative fuels for various applications.

The scope of the industry can be defined as follows:

- **Traditional Crude Oil Refineries:** Traditional refineries primarily focus on the processing of crude oil to produce a petrol, diesel, jet fuel, heating oil, base oils, and other petrochemicals. Traditional refineries utilise processes such as distillation, catalytic cracking, hydrocracking, and reforming to separate, convert, and enhance the properties of crude oil components.

- **Gas-to-Liquid Refineries:** GTL refineries utilise natural gas as a feedstock to produce synthetic fuels and other high-value liquid hydrocarbons. The GTL process involves the conversion of natural gas into liquid hydrocarbons through processes such Fischer-Tropsch synthesis, subsequent upgrading and refining into transportation fuels and specialty chemicals.

- **Coal-to-Liquid Refineries:** CTL refineries employ coal as a feedstock to produce liquid hydrocarbon fuels. The CTL process involves coal gasification to produce synthetic gas (syngas), which is then converted into liquid hydrocarbons through Fischer-Tropsch synthesis and subsequent refining. CTL refineries offer an alternative source of liquid fuels, particularly in regions abundant in coal resources.

The refining processes within the oil refining and re-refining industry involve complex operations and technologies to optimise the conversion of raw materials into valuable products. These refineries contribute to meeting energy demands, diversifying fuel sources, and reducing environmental impacts through advanced processing and emission control technologies. It's important to note that the specific types and extent of GTL and CTL refineries may vary depending on the region and availability of resources.

2.1.2 Global Refining Capacity

The global industry (Figure 1) comprises over 600 refineries worldwide, with a combined refining capacity of approximately 102 million barrels per day (Statista, 2023). The five dominant refining countries are the United States, China, Russia, India, and Japan, accounting for approximately 50% of the world's refining capacity (IEA, 2023).

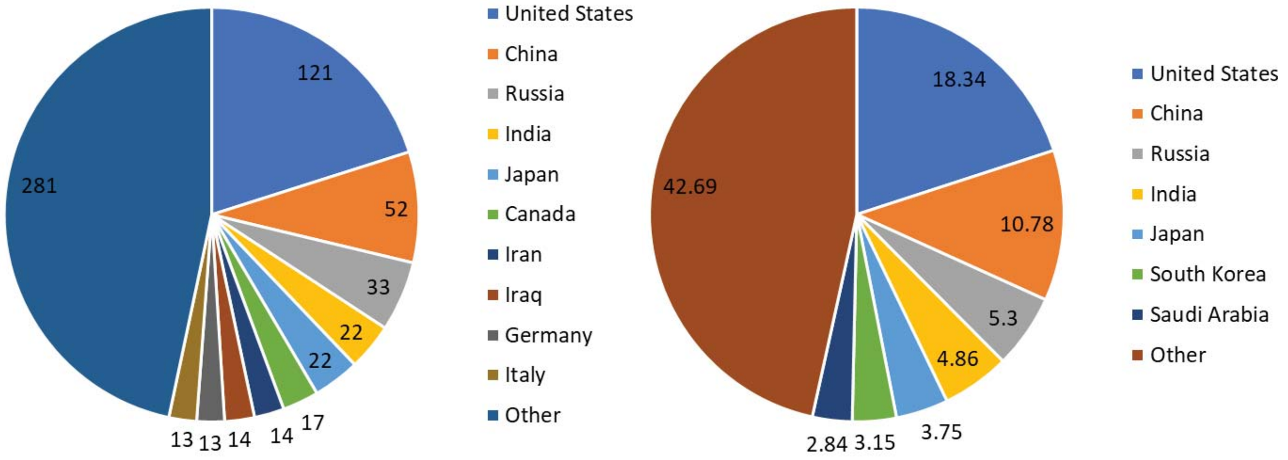

Figure 1: Global refining capacity in number of refineries (left) and million bbl/d (right) (IEA, 2023; Statista, 2023)

Since 2005, global refining capacity has demonstrated consistent growth (Figure 2). In 2022, the worldwide demand for crude oil, including biofuels, reached 99.57 million barrels per day, and demand is expected to rise to 101.89 million barrels per day in 2023, and then decline. The decline in demand in 2020 is attributable to the economic and mobility disruptions caused by the COVID-19 pandemic, leading to widespread temporary shutdowns. In some cases these shutdowns were converted to permanent closures. However, when compared to the daily oil demand in 2005, the overall upward trajectory of demand over the past decade remains evident (Statista, 2023).

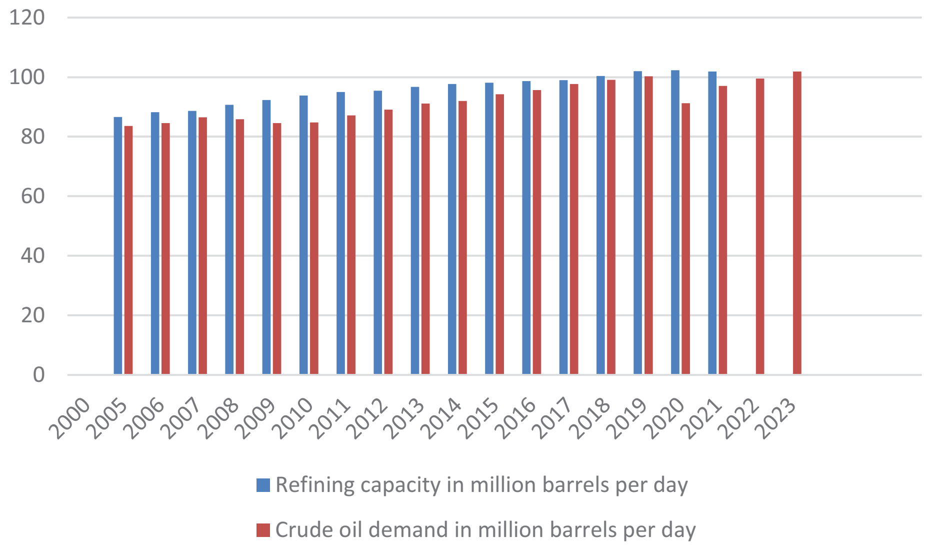

Figure 2: Global refining capacity trending with demand for crude oil from 2005 to 2023 (Statista, 2023)

*Crude oil demand data for year 2000 and refining capacity data for years 2022-2023 was unavailable

China has notably expanded its refinery capacities in recent years, with the China Petroleum and Chemical Corporation (Sinopec) currently possessing one of the largest atmospheric distillation capacities in the world. Nevertheless, the United States remains the largest oil refining country, with a throughput of 14.2 million barrels per day, slightly higher than the figure recorded in 1990. ExxonMobil, the largest U.S. oil company, had a refinery throughput of approximately 3.8 million barrels per day in 2020, reflecting a decline of over one million barrels since 2012 (Statista, 2023).

The US refinery fleet ranges from about 20,000 bpd to the biggest of about 600,000 bpd (Figure 3). The smaller refineries are specialists, making bitumen or base oils, whereas the largest are more complex. The average (from a count of refineries and 10 points around the mid-point) ranges from 125,000 to 155,000 bpd. See graph below (2021 figures)

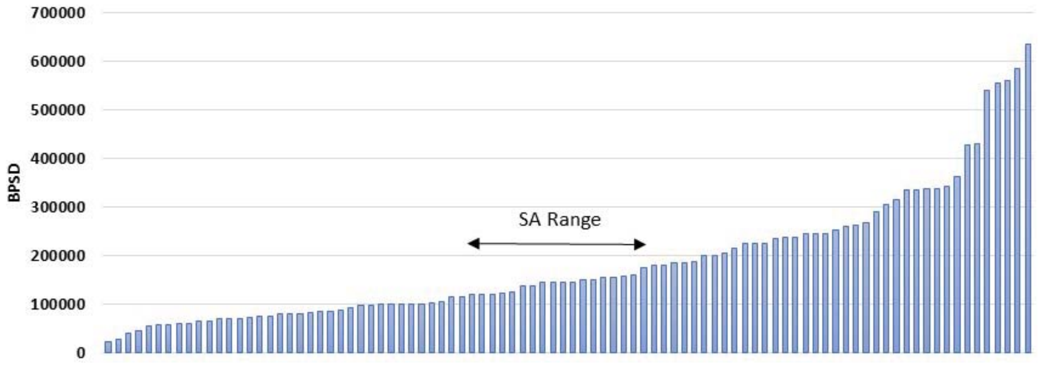

Figure 3: US refinery nameplate capacity range with comparison to South Africa's range, 2021 data (SAPIA, 2023, pers. comm.)

As more countries shift towards renewable energy, the demand for petroleum products is expected to peak in 2023 and then decline (IEA, 2023), necessitating a realignment of the refining industry's focus. Furthermore, the refining industry is under growing pressure to reduce greenhouse gas emissions, although refinery GHG emissions are very small compared to the overall emissions from the products' life cycles. In South Africa, they comprise less than 0.5% of energy emissions (SAPIA, 2023, pers. comm.). The mitigation of GHG emissions is primarily achieved in the use of the products from refining and not in the refineries themselves. With countries adopting more ambitious climate targets, the industry is facing increased scrutiny to mitigate its overall environmental impact. This may require significant investments in new technologies, such as carbon capture and storage, to effectively offset emissions.

2.1.3 National Refining Capacity

The oil refining and re-refining industry in South Africa is small compared to global markets (Figure 4). South Africa had six refineries at the time of writing which appears at first glance to be similar to the situation in 2005. However by 2023, three of the six had not been operational for two years or more. This trend of refinery closures is not uniquely South African; small refineries are being closed all over the world in favour of a lower number of larger refineries as the international industry transitions toward mega-refineries – 28 smaller refineries closed in 2020 alone (GWI, 2023). One of the primary causes that the companies interviewed for this report cited for this trend is the increasing pace of transition away from fossil fuels to renewable energy sources, accelerated in response to the Russia-Ukraine conflict and the resulting energy crisis.

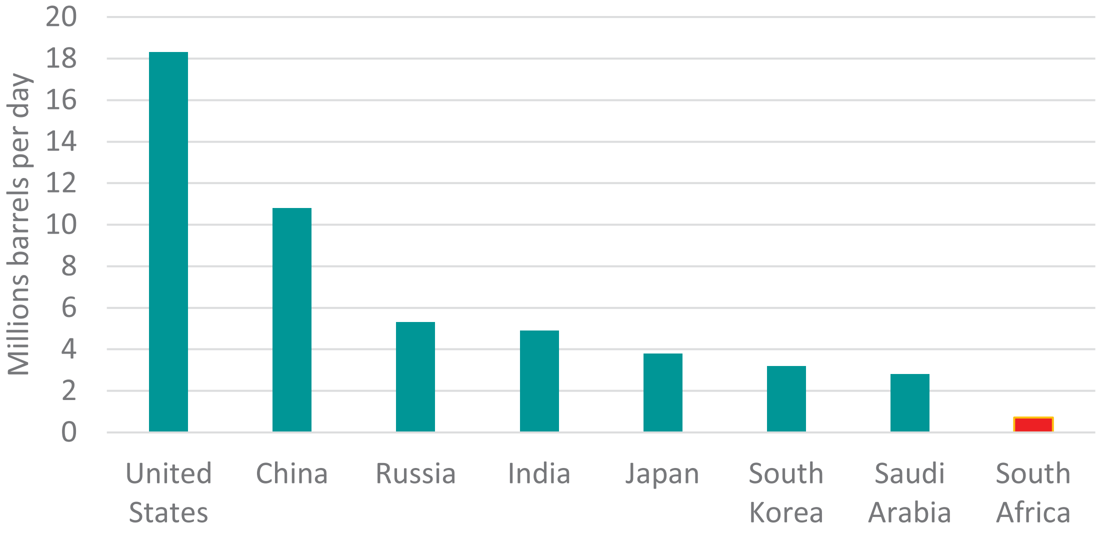

Figure 4: Refining capacity for the seven top refining countries and South Africa (Oil and Gas Journal, 2020)

The refineries are the same six as existed in 2005, when the first edition of NATSURV 15 was published. There is a theoretical total installed refining capacity of 520,000 barrels per day. The four crude oil refineries were constructed in the 1950s to early 1970s. In addition to the crude oil refineries, there is one CTL refinery with a capacity of 160,000 barrels per day, and one GTL refinery capable of producing 45,000 barrels per day, both of which were built in the 1980s. Secunda CTL was built and commissioned in two phases. The Sasol II unit was constructed in 1980 and the Sasol III unit in 1984 (Bergh *et al*., 2022).

Figure 5 and Table 1 show that four refineries are in coastal regions, with two located in KwaZulu Natal and two in the Western Cape. Two refineries are inland, in the Free State and Mpumalanga. The industry contributes around 8% to South Africa's Gross domestic product (GDP) and provides 30,000 direct and indirect jobs. It also plays a role in ensuring energy security by meeting the demand for petroleum products across various sectors (Timm, 2021).

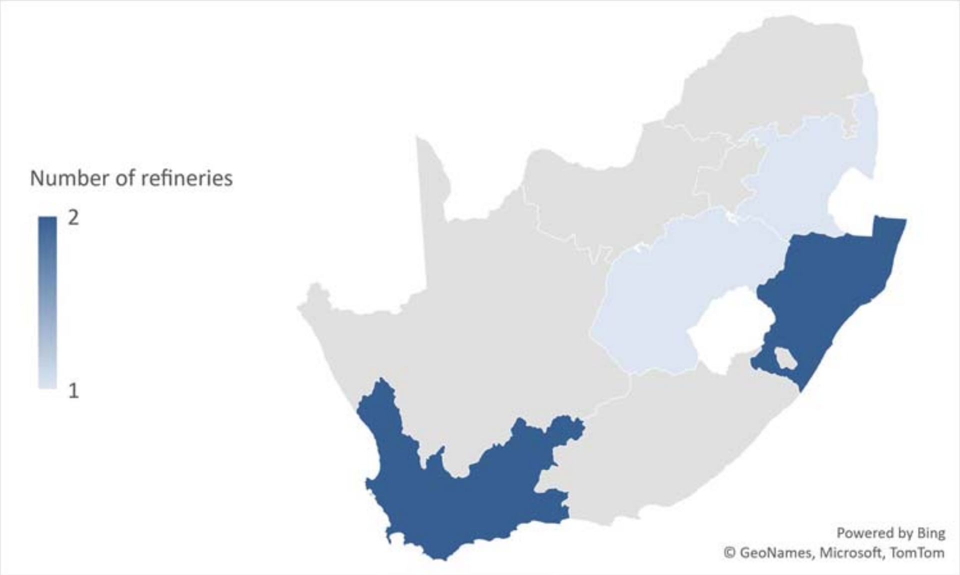

Figure 5: Number of refineries per province

The refineries are owned by seven companies: Astron Energy, BP, Engen, PetroSA, Sasol, Shell, and TotalEnergies, which are represented by the South African Petroleum Industry Association (SAPIA), an organisation that aims to address issues related to the refining, distribution, and marketing of petroleum products and promote socio-economic and environmental progress in the industry.

Table 1: Comparison between theoretical installed capacity in 2005 and 2023

Refinery name	Location	Ownership 2005*	Ownership 2023	Capacity 2005 (barrels/day)*	Capacity 2023 (barrels/day)
Astron (formerly Caltex)	Cape Town	Chevron (Caltex)	Glencore[3]	110,000	100,000
Enref	Durban	Engen (a subsidiary of Petronas, the national oil company of Malaysia)	Engen	105,000	135,000
Natref	Sasolburg	Sasol and Total	Sasol 64% and Total 36%	85,000[4]	108,000
PetroSA (formerly Mossgas)	Mossel Bay	Central Energy Fund	PetroSA (synfuels)	35,000 equivalent	45,000 equivalent
Sapref	Durban	Shell and BP	BP 50% and Shell 50%	165,000	180,000
Sasol	Secunda	Sasol	Sasol (synfuels)	160,000 equivalent	150,000 equivalent

* Pearce and Whyte (2005)

Table 2 shows the product volumes produced per refinery size categories; Small-Medium or Medium-Large. Petrol and diesel account for the largest production proportions for both size categories, with petrol production making up 30-40% and 50-60% respectively, and diesel at 30-40% and 20-30% respectively. There is also a focus on Jet fuel in the medium-large sized refineries, providing 10-20% of their total production.

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[3] built in 1966 by Caltex, a joint venture between Standard Oil of California (later Chevron) and Texaco, two American oil companies. In 1996, Chevron acquired Texaco's stake in Caltex and became the sole owner of the refinery. Chevron continued to operate the refinery under the Caltex brand until 2018, when Glencore, a global commodity trading and mining company based in Switzerland, acquired Chevron's assets in South Africa, including the refinery. Glencore renamed the refinery as Astron Energy and operated it under a licence agreement with Chevron to use the Caltex brand.

[4] Information provided to the team during this study claimed that this figure was incorrect and should have been 108,000 in 2005.

Table 2: Oil refinery production volumes and spread

Product	Refinery size	Product volumes (MMbbl/yr)	Proportion of total production (%)
Petrol	Medium - large	9 - 11	30 - 40
	Small - medium	1.5 - 2.5	50 - 60
Diesel	Medium - large	9 - 12	30 - 40
	Small - medium	0.9 - 1.2	20 - 30
Jet fuel	Medium - large	4 - 8	10 - 20
	Small - medium	0.3 - 0.6	0 - 10
Fuel oil	Medium - large	1.2 - 2.5	0 - 10
	Small - medium	0.05 - 0.15	0 - 10
Liquified petroleum gas (LPG)	Medium - large	0.04 - 0.11	0 - 10
	Small - medium	0.15 - 0.3	0 - 10

*The data presented is an aggregate or generalized representation and that the specific volumes for individual refineries are not disclosed to ensure confidentiality

At first glance, there appears to be little change between the industry status in 2005 and 2023. However, by 2021 only half of the six refineries were fully or partly operational (Table 3).

Since 2019, the country's refining capacity has declined to 438,001 barrels per day, or 61% of its theoretical capacity. The COVID-19 pandemic lockdown regulations exacerbated the existing strain on refineries, leading to capacity shortages. The industry also grapples with the challenges of transitioning to cleaner fuels, with the government still uncertain about how the costs associated with upgrading refineries to meet cleaner fuel specifications will be recovered; SAPIA has emphasized the need for substantial investment support to ensure the success of these upgrades and to reduce the country's reliance on fuel imports (Timm, 2021).

Table 3: Oil refining industry member overview

Name	Operational status 2021 (PMG, 2021)	Operational status 2023
Astron	Running at reduced capacity	Running at reduced capacity
Enref	Closing	Closed
Natref	Running	Running; future uncertain
PetroSA GTL	Running	Closed
Sapref	Paused	Closed
Secunda CTL	Running	Running; future uncertain

Astron refinery was in the process of reopening after a long shutdown following an explosion in 2020. The refinery underwent repair and refurbishment. Recent news articles reported that the Astron refinery had resumed production (Reuters, 2023). Astron Energy stated in February 2023 that it was in the final steps of a safe full restart of the refinery and planned to fully recommence the production of refined products by the end of 2023. Astron Energy also said that it had completed a R400 million upgrade to produce very low sulphur fuel to meet Euro V and South African Cleaner Fuels 2 standards.

Enref, owned by Engen, had also ceased operations in 2020 (due to a fire). Instead of resuming operations, Engen decided to convert the refinery into an import terminal, aligning with economic considerations and a strategic shift toward facilitating the importation of refined fuels. Engen was exploring the construction of a biorefinery on the same site, with a feasibility study underway when this report was written. The conversion of Enref into an import terminal permanently ended oil refining at this site (Reuters, 2021).

Sasol's Natref refinery was considering upgrades to produce higher-quality fuel. The refinery shut down in July 2022 due to supply challenges but resumed production once the issues were resolved. The future of the Natref refinery was being evaluated by Sasol Ltd. and Total SE, considering necessary upgrades to meet market demands and regulatory requirements.

The country's largest refinery, Sapref, has suspended operations since April 2022 in search of a buyer. However, severe floods further hindered the refinery's prospects, and repairing it would require extensive capital investment and several years. The future of Sapref remains uncertain as efforts continue to find a suitable buyer (News24, 2023a).

Sasol Secunda refinery faces feedstock quality issues impacting production output. The refinery is actively pursuing two projects to supply 850 GWh of green electricity, subject to regulatory approvals. These projects aim to contribute to the refinery's sustainability efforts, but their implementation depends on regulatory clearance (News24, 2023b).

PetroSA's Mossel Bay refinery was closed due to feedstock supply issues. Offshore gas and condensate feedstocks ran out in 2020, resulting in the suspension of petrol, diesel, and other value-added product production. Efforts were underway to develop a long-term feedstock solution that would enable the refinery to resume operation by 2027/2028.

Importation becomes necessary to balance supply when the demand for petrol, diesel, or jet fuel exceeds the volume produced by South Africa's local refining sector. With three refineries out of operation, import volumes of refined products have significantly increased, with a corresponding reduction in crude oil imports (Figure 6).

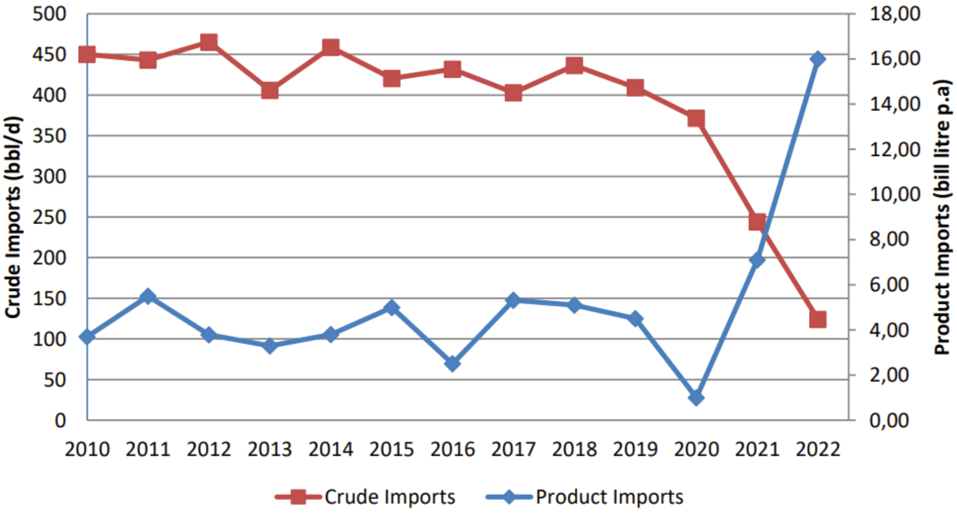

Figure 6: South African crude and product imports from 2010 to 2022 (Wright, 2022)

South Africa now relies on imported oil and refined fuels to meet its liquid fuel needs, with nearly 90% of domestically consumed crude oil being imported. The majority (86%) of crude oil imports come from three countries: Saudi Arabia (36%), Nigeria (31%), and Angola (19%). Even when fully operational, all four crude oil refineries in South Africa imported their feedstock

PetroSA operates the offshore mooring near the Port of Mossel Bay, the FA Platform[5], where the feedstock is imported for the PetroSA GTL refinery. Another key facility for oil imports is the single buoy mooring (SBM) system offshore from Durban, which is operated and managed by Sapref and owned by BP, Shell, Engen, Sasol Oil, and Total. Crude oil is also landed at the port of Saldanha Bay in the Western Cape to supply Astron Energy's Cape Town refinery.

Upon delivery, crude oil is pumped into storage and stored until it is processed through the refineries. Astron stores its crude in the Saldanha Bay crude storage facility, while Engen and Sapref pump crude off the ships via the SBM to their tank farm located south of Sapref before feeding it to the refineries. For the Natref refinery, crude oil is pumped off the ships via the SBM to the NATCOS5 tank farm owned by Sasol Oil and Total. It is then transported to Sasolburg using the crude oil pipeline (COP) operated by Transnet Pipelines (Timm, 2021).

South Africa's monthly petroleum product imports are expected to triple from pre-pandemic levels as domestic refineries close down. This increase in imports highlights the need for improvements to storage facilities, ports, and pipelines. Furthermore, the implementation of a clean-fuels policy, expected to be implemented in 2027, may result in additional refinery closures if they fail to meet the new standards.

2.1.4 Re-refining

Re-refining involves the recycling of used oils and the creation of new products from the recycled oils. The main players in the oil re-refining industry are the members of the ROSE (Recycling Oil Saves the Environment) Foundation, which is a national non-profit organization established to promote and encourage the environmentally responsible management of used oils and related waste in South Africa (ROSE Foundation, 2023). The ROSE Foundation is funded by the major oil refiners including TotalEnergies, Astron, Shell, Sasol and Engen to enable them to meet their environmental and extended producer responsibilities.

There are four private companies that undertake oil re-refining in South Africa: FFS Refiners (Pty) Ltd, Oil Separations (Pty) Ltd, The Old Oil Man, and BME. FFS Refiners has two re-refineries, one in Durban and one in Germiston. The Durban plant has a capacity of 80 Mℓ/y and the Germiston plant has a capacity of 70 Mℓ/y. FFS Refiners has been certified in terms of the ISO 9001 Quality Management System and the ISO 14001 Environmental Management System.

Oil Separations has two re-refineries in South Africa, one in Durban and one in Johannesburg. The Durban plant has a capacity of 30 Mℓ/y and the Johannesburg plant has a capacity of 20 Mℓ/y. Oil Separations has also been certified in terms of the International Organization for Standardization standard ISO 9001 Quality Management System and the ISO 14001 Environmental Management System.

BME is primarily a mining explosives and blasting services company but it offers used oil services as part of its technical services division. It has one re-refinery, in Delmas. The plant has a capacity of 10 Mℓ/y.

The used oil collected is sold to licensed waste managers who process and convert it to industrial heating fuel for use in cement, brick, and lime kilns, boilers, furnaces, and smelters. The used oil can also be re-refined into new lubricating oils or other products (base oils, industrial fuels, solvents, waxes, and bitumen emulsions). There are a very few private companies that specialize in re-refining used oils and solvents, such as FFS Refiners (Pty) Ltd and Oil Separations (Pty) Ltd.

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[5] The "FA" stands for "F-Area", which is the name of the offshore gas field that the platform is located on. The F-Area gas field was discovered in 1980 and was the first gas field to be developed by PetroSA (then known as Mossgas) in the Bredasdorp Basin, off the south coast. The FA Platform was installed in 1989 and started production in 1992.

The re-refining industry is driven by the need to reduce the dependence on imported petroleum products, create value addition and employment opportunities, and enhance environmental sustainability. The oil recycling industry also contributes to the circular economy and the energy transition by recovering valuable resources from waste streams and reducing greenhouse gas emissions. Of all the oil that is sold in South Africa, approximately 150 million litres becomes used oil, of which 120 million litres is collectable for recycling. Retrieving and recycling this product has proved to be a lucrative enterprise that creates a circular economy and protects the environment.

Oil recycling is one of the six identified clusters of waste research, development and innovation (RDI) activity in the Waste RDI Roadmap for South Africa, which is a government initiative aimed at supporting South Africa's transition to a circular economy, through the generation of scientific evidence for the waste sector (CSIR and DSI, 2021.

2.1.5 Broad regulatory framework

While South Africa’s official policy is premised on building domestic refining capacity, regulatory changes including these tightening cleaner fuels standards have made it increasingly difficult for local refineries to compete with imports. South Africa expects all refineries to produce petrol and diesel to the Cleaner Fuels 2 standard by 2027 (Government Gazette no. 45068 of 31 August 2021; 46589 24 June 2022).

The Petroleum Products Act, No 120 of 1997 (Petroleum Products Act) and its regulations provide a licensing and regulating framework for the manufacture, wholesale and retail of petroleum products. The types of licences issued in terms of the Petroleum Products Act include manufacturing, wholesale, retail and corresponding site licences. In addition, the Petroleum Products Act also aims to provide measures in the saving of petroleum products, economy in the cost of their distribution, and the maintenance and control of their pricing. The Controller of Petroleum Products, acting on behalf of the Department of Mineral Resources and Energy (DMRE), is responsible for issuing manufacture, wholesale, retail and site licences. The controller is also responsible for gathering information and investigating offences relating to the Petroleum Products Act.

The import of petroleum products to South Africa requires authorisation from the DMRE accompanied by an import permit issued by the International Trade Administration Commission of South Africa and an import/export licence issued by the South African Revenue Services. However, it was stated to the project team during this project that the DMRE policy is impossible to implement properly.

Oil recycling and re-refining is regulated by the National Environmental Management: Waste Act (2008), which requires the producers of used oils to take responsibility for their waste and ensure its environmentally sound management. The Waste Act also provides for the establishment of industry waste management plans (IWMPs), which set out the measures and targets for waste prevention, minimization, reuse, recycling, recovery, treatment, and disposal (DFFE, 2020).

CHAPTER 3: GENERIC REFINING PROCESSES

The practice of refining varies depending on the type, quality, and availability of the feedstock, the product specifications and demand, the technology and equipment used, the environmental regulations and standards, and the economic factors and market conditions.

Most refineries use a combination of distillation and conversion processes to separate and transform crude oil into various products. Distillation is the process of heating crude oil to separate it into fractions based on their boiling points. Conversion is the process of breaking down or rearranging the hydrocarbon molecules in the fractions to produce more desirable or intermediate products. Some of the common conversion processes are thermal and catalytic cracking (breaking larger molecules into smaller ones thermally or over a catalyst reforming (changing the structure of molecules to increase octane or produce hydrogen), alkylation (combining smaller molecules into larger ones), and hydrotreating (removing sulphur and other impurities). The products from distillation and conversion are then blended to meet the desired specifications for different markets.

Most re-refiners use a combination of distillation and other processes to remove contaminants and restore used oil to its original quality. Some common purification processes are solvent extraction (using a solvent to dissolve unwanted components) and hydrotreating, the same process as used in virgin oil refining.

3.1 CRUDE OIL REFINING

The refining of crude oil into refined products encompasses various refinery configurations, broadly categorised into four types: simple, compound, complex, and petrochemical. The simple configuration involves crude distillation, catalytic reforming, and refining processes. Compound refineries incorporate these processes along with vacuum distillation and catalytic cracking. Complex refineries have a broader range of products, including the manufacture of base oils and deep conversion. The petrochemical type includes petrochemical plants and those focused on producing aromatic hydrocarbons.

South African oil refineries convert crude oil into petrol, diesel, jet fuel, illuminating paraffin, fuel oil, and liquefied petroleum gas (LPG). These refining processes align with those employed globally. The process flow diagram and products produced from a typical complex refinery are shown in Figure 7.

Refining processes can be grouped into four primary categories: separation processes, conversion processes, treatment processes, and blending processes. South African refineries also utilise secondary processes, such as isomerisation and alkylation, to improve specific fractions' properties.

During the refining process, crude oil feedstock is distilled into fractions. The lighter fractions, namely naphtha, kerosene, and light gas oil cuts (diesel), are considered refinery gas liquids and require minimal to moderate upgrading to be used as fuels (LPG, petrol, jet fuel, diesel). The remaining fractions, heavier than premium refined products, constitute a significant portion of the crude barrel. These heavier fractions undergo cracking processes to maximise the production of premium transportation fuels. Petroleum refineries typically employ between 10-20 different processes to refine crude into various products. Refineries differ from other energy-related industries due to factors such as plant complexity, uniqueness of individual refineries, variation in crude oils, capital-intensive nature, energy intensity, environmental impact, and dependence on market prices (Marano, 2007; Gary et al., 2007).

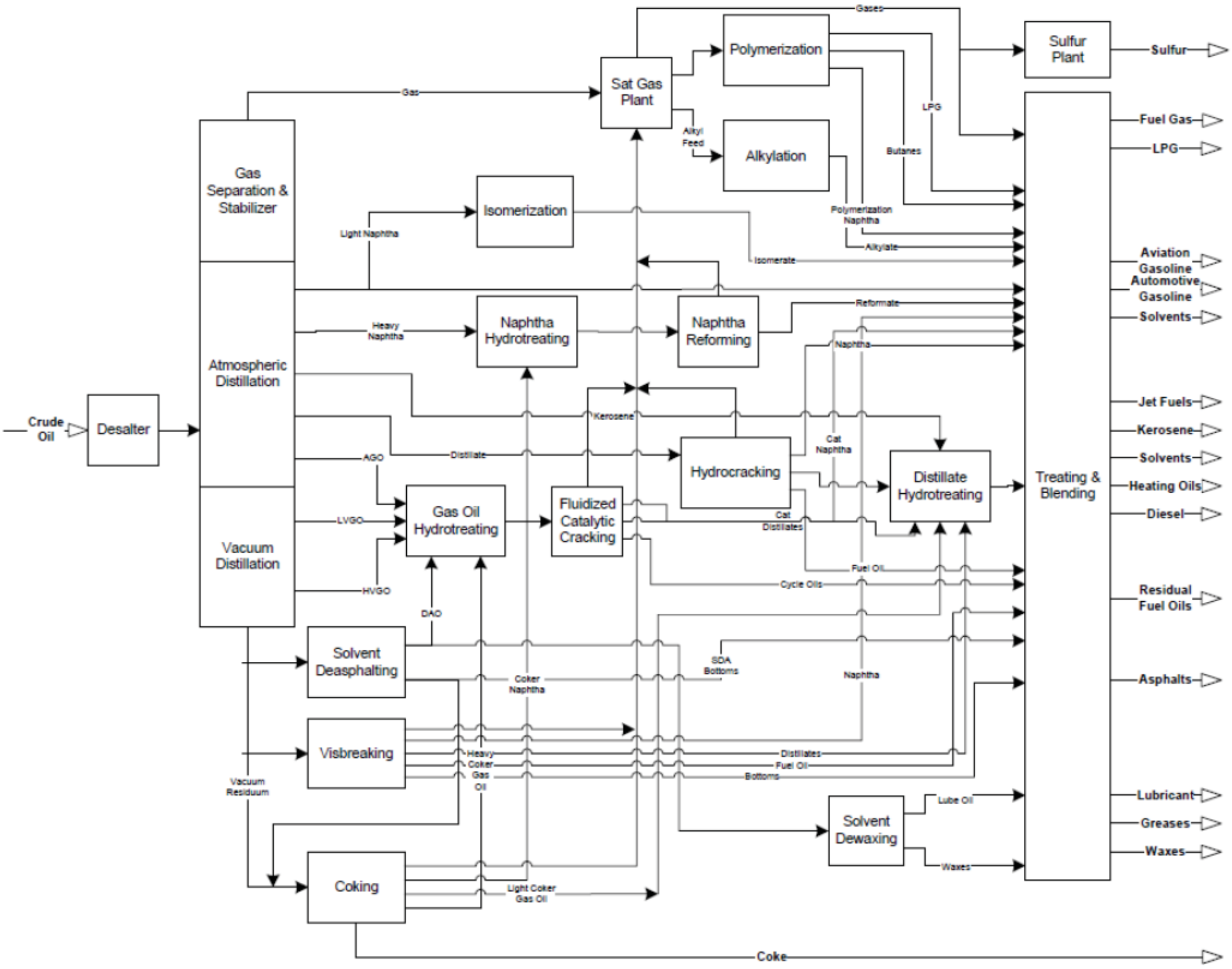

Figure 7: Petroleum refining process aggregated into a block flow diagram to indicate options (Gasser, 2017)

The most common separation process used in South African refineries is fractional distillation, where crude oil is heated and vaporised, and then the vapor is condensed to produce different fractions. The fractions produced include LPG, naphtha, kerosene, diesel, and residual fuel oil.

The wastewater from desalting contains oil, water, salt, and other impurities. The exact amount of wastewater generated depends on the quality of the crude oil and the desalting method used but according to Suez (2022), the typical wastewater generation rate from desalting is about 0.5% of the crude oil throughput.

The liquid waste products from distillation consist of condensate from steam stripping operations, which contains oil, water, dissolved gases, and organic compounds. The amount of wastewater generated depends on the type and amount of crude oil processed and the distillation method used. The typical wastewater generation rate from distillation is about 0.1% of the crude oil throughput (Sengupta, 2023).

The wastewater from cracking includes water from quenching and cooling, which contains oil, dissolved gases, organic acids, phenols, cyanides, ammonia, and sulphides. The amount of wastewater generated depends on the type and amount of feedstock processed and the cracking method used, and the typical wastewater generation rate from cracking is about 0.2% of the feedstock throughput (Sengupta, 2023).

Hydrotreating wastewater consists of water from cooling and washing, which contains oil, dissolved gases, sulphides, ammonia, and nitrates. The amount of wastewater generated depends on the type and amount of product treated and the hydrotreating method used. The typical wastewater generation rate from hydrotreating is about 0.3% of the product throughput (Suez, 2022).

Blending involves mixing different components or fractions of crude oil and/or other products to produce a final blend that meets specific product specifications. The blending process is typically the final stage in the refining process and is essential to ensure that the end-product has the desired properties, such as the correct octane rating for petrol, or the correct flash point for diesel fuel (Purohit and Suryawanshi, 2013).

3.2 GAS- AND COAL-TO-LIQUID REFINING

The Fischer-Tropsch (F-T) process is a versatile refinery technology that enables the conversion of various feedstocks, including natural gas, coal, and biomass, into liquid hydrocarbons through a series of chemical reactions. In the PetroSA GTL variant of the F-T process (Figure 8), natural gas or gaseous hydrocarbons from liquid natural gas (LNG) or sourced from the PetroSA FA Platform are directly converted into longer-chain hydrocarbons such as petrol or diesel fuel. The process involves the use of syngas, which is a mixture of hydrogen and carbon monoxide, as an intermediate. In the CTL variant, coal is gasified to produce syngas, which is then subjected to the F-T process for the production of liquid hydrocarbons (de Klerk et al., 2013).

Regardless of the feedstock used, the F-T process relies on the same fundamental principles. The syngas, composed primarily of carbon monoxide (CO) and hydrogen (H_2), is introduced into the F-T reactor. Inside the reactor, a catalyst, typically based on transition metals like cobalt, iron, or ruthenium, facilitates the conversion of the syngas into liquid hydrocarbons through a series of complex reactions. The catalyst promotes the bonding of CO and H_2 molecules, leading to the formation of longer-chain hydrocarbons.

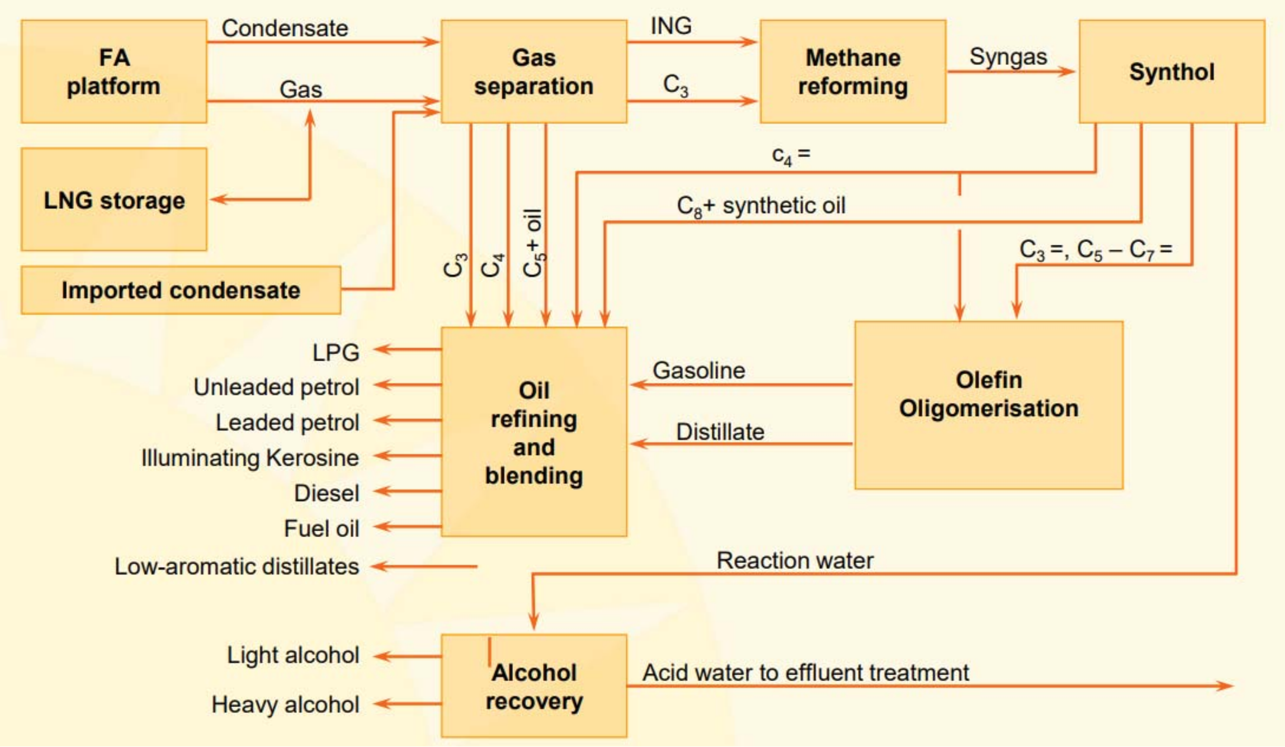

Figure 8: Mossel Bay GTL Process flowsheet (PetroSA, 2023)

The choice of catalyst depends on the specific characteristics of the feedstock. Cobalt catalysts are preferred for F-T processes utilising natural gas or methane-rich gases as the feedstock. Iron catalysts, on the other hand, are commonly used for F-T processes involving lower-quality feedstocks like coal or biomass. Cobalt catalysts generally exhibit longer lifetimes compared to iron catalysts, making them suitable for gasification processes using cleaner feedstocks (de Klerk et al., 2013).

The F-T process offers several advantages. It enables the production of synthetic fuels and chemicals from diverse feedstocks, reducing dependence on crude oil imports and providing energy security. Furthermore, the process can unlock the potential of abundant coal reserves through CTL, offering an alternative pathway for producing liquid hydrocarbons.

3.2.1 Best practice in the literature

Some of the best practices of refining are optimizing the crude selection and processing configuration to maximize margins and flexibility; integrating refining with petrochemicals or trading hubs to capture synergies and value; implementing advanced process control and digital technologies to improve operational performance and reduce costs; adopting low-carbon solutions such as biofuels, hydrogen, carbon capture, utilization, and storage (CCUS), or renewable power to reduce emissions and comply with regulations; enhancing maintenance and turnaround practices to increase availability and reliability; improving safety culture and management systems to prevent accidents and incidents.

Some of the best practices of re-refining are securing a stable supply of used oil with consistent quality and quantity; using state-of-the-art technologies such as vacuum distillation with thin-film evaporation or solvent extraction with ionic liquids to produce high-quality base oil; producing value-added products such as naphtha or diesel from light oil or asphalt from heavy oil; implementing quality control and assurance systems to ensure product specifications and customer satisfaction; adopting environmental management systems to minimize waste generation and disposal; promoting public awareness and education on the benefits of re-refining.

3.2.2 Cleaner production in the literature

Some of the cleaner production practices of refining are using alternative feedstocks such as bio-oil or gas-to-liquids (GTL) to reduce dependence on fossil fuels; applying energy-efficient technologies such as cogeneration or waste heat recovery to reduce energy consumption; installing emission-control technologies such as flue gas desulfurization or selective catalytic reduction to reduce air pollution; implementing water-conservation technologies such as membrane filtration or zero liquid discharge to reduce water consumption; applying waste-minimization technologies such as catalytic cracking or hydrocracking to reduce solid waste generation (Kulkarni, 2017).

Cleaner production practices in re-refining include using renewable energy sources such as solar or wind power to reduce greenhouse gas emissions; applying solvent-free technologies such as hydrotreating or clay filtration to reduce solvent consumption and waste; installing closed-loop systems such as vapor recovery or solvent recovery to reduce fugitive emissions and losses; implementing waste-management technologies such as incineration or pyrolysis to treat and dispose of waste; applying life-cycle assessment tools such as ISO 14040 or Eco-Indicator 99 to evaluate and improve the environmental performance of re-refining (GEIR, 2016).

3.2.3 Water balance

The size, complexity, crude feedstock, and product range of refineries influence their water consumption (Leite et al., 2017). The water network within a refinery is as unique as its operational processes. While water is utilised in many refinery processes, not every process requires raw or treated water, and water can be cascaded or recycled at multiple points (Ali, Saman, and Jaafar, 2017). A considerable portion of water used in a refinery can be continuously recycled within the facility, but there are also losses to the atmosphere, such as steam losses and evaporation and drift in cooling towers. Additionally, a small amount of water may exit the refinery with the products. Certain processes within the refinery necessitate a continuous supply of makeup water, such as steam generation and cooling systems (Leite et al., 2017). Understanding water balance for a refinery is a key step towards optimising water usage, recycle and reuse as well as optimising performance of water and wastewater treatment systems. Figure 10 shows a typical example of the water balance in a refinery.

3.3 LIQUID WASTE STREAMS

This section provides an overview of typical wastewater sources and side streams in a refinery (see Figure 9) and discusses the importance of managing and treating these effluents. Each has unique characteristics and requires specific treatment to ensure compliance with environmental regulations.

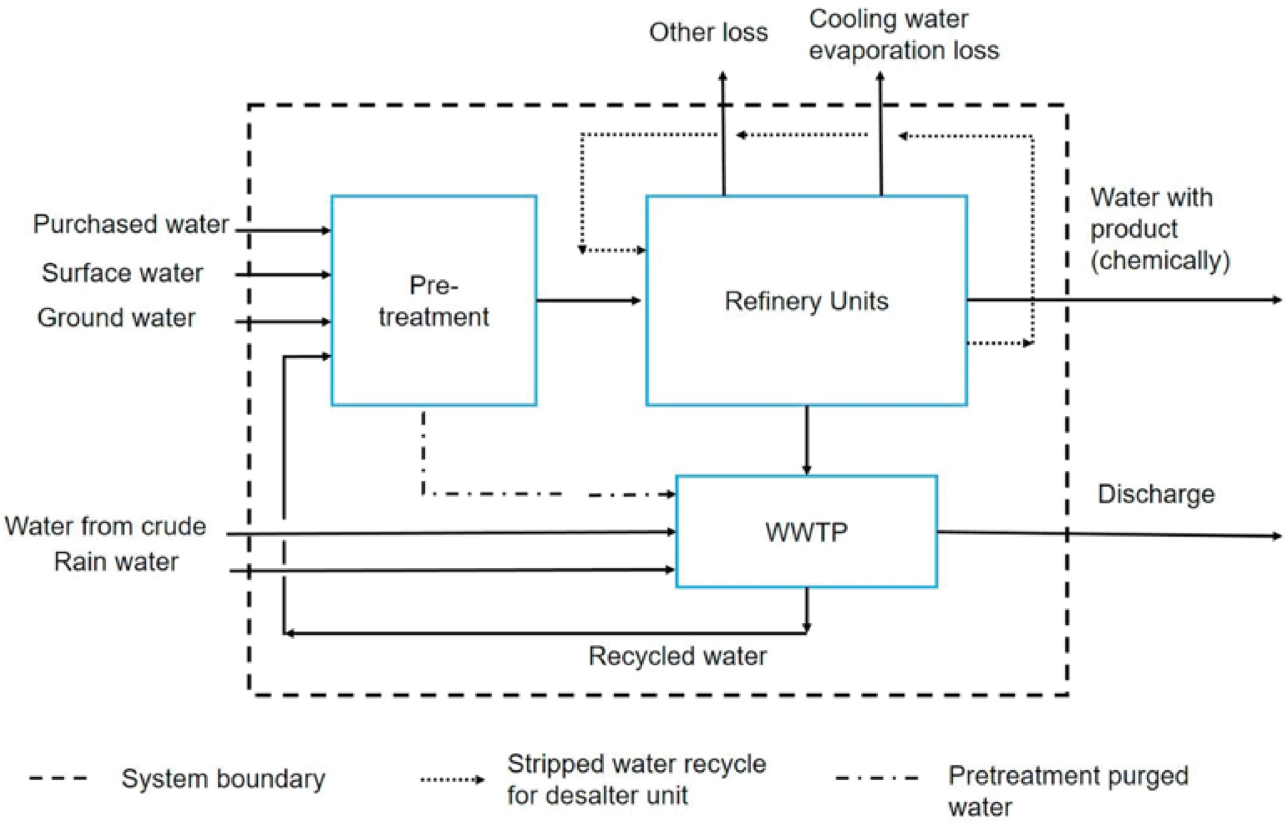

Figure 9: Water balance in a typical crude oil refinery (Sun et al., 2018)

3.3.1 Desalter effluent

Crude oil contains inorganic salts, primarily sodium chloride, in the form of an emulsified solution. These salts originate from the brine present in the oil field where the crude is extracted. The amount of water accompanying the crude oil to the refinery varies but typically ranges from 0.1-2.0% in volume (Speight, 2014). The salts found in the aqueous phase of the crude oil can range from 4.5-113 kg/tb of crude (Gary et al., 2007), predominantly in the form of sodium, magnesium, and calcium chlorides.

The desalting process involves injecting wash water, usually heated through heat exchange with the hot effluent, into the second stage of the desalter. The water from the second stage is then directed to the first stage, where it comes into contact with the incoming crude oil. The resulting hot brine, around 150°C, is subsequently cooled and discharged to the wastewater treatment plant (Mokif et al., 2022).

The optimal pH range for desalting is between 6-7, as it minimises emulsion formation and facilitates effective separation of oil and water. The pH level is influenced by the source of the wash water and considerations related to corrosion in the crude tower system. Drilling muds, which can accumulate in the desalter, need to be periodically or continuously removed. Some refineries employ a continuous mud washing system to prevent mud accumulation, while others perform intermittent washing, typically once per shift, by temporarily increasing the wash water flow to the mud washing nozzles located at the bottom of the desalter. However, this operation may result in increased discharge of hydrocarbons to the wastewater treatment system (Speight, 2014). Proper control of the oil/water interface helps minimise or eliminate unintentional discharges of hydrocarbons into the wastewater treatment systems.

The quantity of wash water used in desalters is typically around 5-8% of the crude oil throughput (Mokif et al., 2022). The source of wash water and thus level of contaminants present can vary significantly among refineries, depending on factors such as the operating pH of the desalter (higher pH resulting in more emulsions), the effectiveness of the interface control device, and the frequency and effectiveness of mud washing (Gary et al., 2007).

3.3.2 Sour water

Sour water is a by-product of refinery processes that utilise steam as a stripping medium and diluent, such as distillation and catalytic cracking. During these processes, steam condenses in the presence of hydrocarbons, which contain hydrogen sulphide (H_2S) and ammonia (NH_3). As a result, these compounds are absorbed into the water, requiring treatment (Gary et al., 2007).

The conventional treatment method for sour water involves sending it to a stripper to remove H_2S and NH_3. Heat is introduced into the stripper using steam injection. High-performance strippers can achieve H_2S levels below 1 ppm and NH_3 levels below 30 ppm in the stripped sour water, making it suitable for recycling and reuse within the refinery. This minimises the need for disposal and reduces the overall environmental impact (Gary et al., 2007).

A typical configuration of a sour water stripper involves several key components. First, all the sour water produced in the refinery is flashed in a drum, and any separated oil is directed to refinery slops. The resulting vapours from the drum are sent to the flare for safe disposal. The sour water from the drum is then stored in a tank, which provides surge capacity for the system. Subsequently, the sour water passes through a feed/bottom's exchanger, where it is heated, before being sent to the stripper. Steam is used in the reboiler to heat the bottoms and generate vapor traffic within the tower. The separated vapours, containing H_2S and NH_3, are typically sent to a sulphur plant for further processing. The stripped water is then routed back through the feed/bottom's exchanger and a trim cooler for reuse within the refinery. Any excess water that cannot be reused is directed to a wastewater treatment plant for appropriate treatment (Gary et al., 2007).

Refineries with process units such as catalytic crackers and delayed cokers produce larger volumes of sour water compared to less complex refineries (Mokif et al., 2022). Additionally, the sour water from these units may contain additional contaminants such as phenols and cyanides. It is advisable to segregate this specific sour water from the rest of the sour water produced in the refinery. Dedicated sour water strippers can be employed to process this water, and the resulting stripped sour water should be preferentially reused as wash water for the desalters. This approach enables the extraction of a significant portion (up to 90%) of the phenols contained in this sour water, effectively reducing the phenol load on the wastewater treatment system, and improving overall treatment efficiency (Gary et al., 2007).

3.3.3 Tank bottom draws

Tank bottom draws are commonly performed in refineries for various types of tanks, including crude tanks, petrol tanks, and slop tanks. When crude oil is received at refineries, it typically contains water and sediments, collectively known as bottom sediment and water, which are acquired during the extraction process. Upon storage in large tanks, it settles at the bottom and needs to be periodically removed to prevent storage capacity loss. The water drawn from these tanks is typically directed to either the wastewater treatment system or a separate tank where the solids can be separated from the oil and water phases (Gary, 2007; Speight, 2014).

A typical configuration for a crude tank draw involves several components. The crude tank is usually located within a berm, providing secondary containment. It is equipped with a valved drain line that leads to a sump situated outside the berm. During the draining operation, the operator opens the valve and uses an interface level indicator to ensure that only the bottom sediment and water is drained, while hydrocarbons are not inadvertently discharged. It is common practice for an operator to monitor the draining process continuously to prevent any unintentional loss of hydrocarbons. Although variations exist, the underlying principle of operation remains similar (Gary, 2007; Speight, 2014).

The choice of interface indicator is an important consideration in crude tanks. Some tanks employ probes that utilise high-frequency electromagnetic measurement to detect the interface between the oil and water phases. These probes provide accurate and reliable readings, aiding in the precise control of the draining operation (Mokif et al., 2022; Speight, 2014).

3.3.4 Spent caustic

Spent caustic is generated during the process of extracting acidic components from hydrocarbon streams. This includes acidic compounds such as residual H_2S, phenols, organic acids, hydrogen cyanide, and carbon dioxide. These acidic compounds are absorbed into the caustic solution, rendering it spent and unable to be regenerated. Consequently, the absorbed acidic compounds must be periodically or continuously purged from the caustic treating system and replaced with fresh caustic solution. As the caustic solution settles, it separates into a distinct aqueous phase in intermediate or product storage tanks, requiring subsequent drawdown and discharge from these tanks. Typically, the discharge of spent caustic occurs to the sewer system, often on a batch basis, which can pose challenges for wastewater treatment plants (Gary, 2007; Speight, 2014).

Traditionally, various methods have been employed for the disposal of spent caustic in refineries. Discharging it into the sewer system is a common practice, although not necessarily the most optimal solution. An alternative option is off-site disposal of phenolic spent caustics, allowing for the recovery of organic components present in the solution. However, the off-site disposal of sulphidic spent caustics, which typically comprise a significant portion of refinery spent caustic, is more challenging due to the limited reprocessing options available for this stream (Gary, 2007; Speight, 2014).

In addressing the issue of spent caustic, refineries can adopt two strategies: in-process abatement and end-of-pipe treatment. In-process abatement involves implementing measures within the refining process to minimise the formation or release of spent caustic, thereby reducing its quantity and potential environmental impact. On the other hand, end-of-pipe treatment focuses on treating the spent caustic prior to its discharge to the environment, aiming to remove or neutralise the acidic compounds and other contaminants present. Both approaches have their advantages and should be considered based on the specific circumstances and requirements of the refinery (Gary, 2007; Speight, 2014).

3.3.5 Cooling water

Cooling water plays a crucial role in refinery operations, particularly in the process of fractional distillation. To maintain an overall heat balance, the excess heat introduced into the system through fuel combustion or steam injection needs to be removed or "rejected." This heat rejection is achieved through various methods, including heat exchange with boiler feedwater, other process streams, air coolers, and cooling water systems (Svrcek and Svrcek, 2014; Ludwig, 2018).

The preheating of crude oil occurs through heat exchange with another process stream, after which the partially vaporised products are directed to a distillation tower. Different side streams are withdrawn based on their boiling point range, and these streams are further treated in distillation columns with the addition of steam to adjust their boiling point range. The cooled bottoms product from these distillation columns is then sent to storage, while the vapours are returned to the main tower. The overhead vapours from the main tower are condensed first using an air-cooled exchanger and then further cooled through a cooling water heat exchanger (Svrcek and Svrcek, 2014; Ludwig, 2018).

There are three primary types of cooling water systems commonly used in refineries:

1. Once-through cooling water system: In this system, water is withdrawn from a surface water source, such as a lake, river, or estuary, and used for cooling without contacting the fluid or vapor being cooled. The water is then typically returned to the same source (Abdelal and Al-Hajri, 2013).

2. Closed-loop cooling water system: This system involves circulating water in a closed-loop piping system, subjecting it to cooling and heating without evaporation or air contact. Heat absorbed by the water in the closed-loop system is typically rejected to a once-through cooling system using a heat exchanger (Cameron and Mohammed, 2015).

3. Evaporative cooling water system: In an evaporative cooling water system, recirculating cooling water absorbs heat and is then rejected in a cooling tower through evaporation. The hot water is sprayed against a rising stream of atmospheric air, allowing heat transfer through air heating and water evaporation (Speight, 2014).

To prevent the accumulation of dissolved solids, a portion of the circulating water in a cooling tower system is removed as blowdown. The required blowdown quantity depends on the makeup water quality and the number of concentrations cycles the cooling tower operates at, typically ranging from four to seven cycles. In refineries, cooling tower blowdown is usually directed to the wastewater treatment system via the sewer. This practice is adopted to avoid contamination of the cooling water with hydrocarbons in case of leaks in heat exchangers, as the pressure on the process side of heat exchangers is often higher than that of the cooling water. However, this practice adds a hydraulic load to the wastewater treatment system, and its overall impact should be evaluated on a case-by-case basis (Svrcek and Svrcek, 2014; Ludwig, 2018).

3.3.6 Condensate blowdown

In a refinery setting, condensate blowdown water is commonly generated from processes such as steam generation, heat exchangers, and air coolers (Kang and Yoo, 2017). The condensate water is typically contaminated with impurities picked up during the heat exchange or cooling processes. The presence of these impurities can have detrimental effects on equipment performance, corrosion rates, and overall process efficiency. Therefore, it is essential to properly manage and treat condensate blowdown water to meet regulatory requirements and minimise environmental impact.

Common treatment methods include filtration, chemical treatment, ion exchange, and membrane processes (Lee and Jeon, 2015). It is worth noting that the specific composition and treatment requirements of condensate blowdown water can vary depending on the refinery configuration, process units, and the type of hydrocarbons being processed (Hegazi, 2019). Therefore, a comprehensive understanding of the specific refinery's operational conditions and the characteristics of the condensate water is crucial in designing an effective treatment strategy.

In a refinery, condensate losses can occur from various sources including blowdown from the plant boiler system, blowdown from steam generators, and unrecovered condensate from steam traps and steam tracing (Choudhary et al., 2016). Boiler blowdown involves purging a portion of the boiler feedwater and condensate to maintain acceptable dissolved solids levels in the system. Steam generator blowdown is similar but occurs in systems where the heat source is a process heat exchanger that needs to reject heat.

Efficient condensate recovery in refineries is important for several reasons. It leads to energy savings and reduces the quantity of boiler feedwater makeup required, resulting in lower operating costs. Additionally, any condensate lost to the sewer increases the temperature of the wastewater and imposes a heat load on wastewater treatment systems (Choudhary et al., 2016).

3.3.7 Steam Methane Reforming

Steam Methane Reforming is a widely used method for producing hydrogen from natural gas. It involves the reaction of methane (the primary component of natural gas) with steam in the presence of a catalyst to produce hydrogen, carbon monoxide, and a relatively small amount of carbon dioxide.

The chemical equation for Steam Methane Reforming is:

$$CH_4+H_2O \rightarrow CO+3H_2 \qquad \text{Eq. 1}$$

This process is a crucial part of hydrogen production in the petrochemical industry and is often used to provide hydrogen for various applications within a refinery, such as hydrotreating and hydrocracking reactions. The hydrogen produced through SMR is essential for various refining processes that require a source of high-purity hydrogen.

As you can see in Eq. 1, water (H_2O) is one of the reactants in this process. The water is typically supplied as steam to facilitate the reaction and promote the production of hydrogen. While water is consumed in the reaction, it's important to note that it is often a carefully managed input, and the water consumption is considered as part of the overall process design and optimization.

Refineries employing SMR technology often implement water management practices to minimise waste and ensure sustainability. The water used in SMR may be sourced from various places, including freshwater or treated water from other refinery processes, and efforts are made to recycle and reuse water where possible.

3.3.8 Stormwater

Stormwater effluent in refineries is generated during precipitation events and can collect pollutants as it flows over various surfaces within the refinery. This effluent may contain sediment, oils, heavy metals, chemicals, and other contaminants. To effectively manage stormwater effluent and comply with environmental regulations, refineries employ a combination of structural and non-structural best management practices (BMPs).

Structural BMPs include the use of retention and detention ponds, constructed wetlands, oil-water separators, and sedimentation basins. These systems are designed to capture and treat stormwater runoff, removing contaminants and sediment before discharge or reuse. Non-structural BMPs focus on pollution prevention strategies, regular maintenance, spill response plans, employee training, and erosion and sediment control measures (USEPA, 2008; Wanielista et al., 2012).

Treatment of stormwater effluent involves physical, chemical, and biological processes. Physical processes like sedimentation, filtration, and adsorption separate or trap pollutants. Chemical processes utilise coagulants, flocculants, and sorbents to enhance pollutant removal. Biological processes rely on natural organisms and microbial activity to degrade or transform pollutants. Advanced treatment technologies, such as constructed wetlands, biofiltration systems, and permeable pavement, offer additional capacity for pollutant removal (Fletcher et al., 2018).

In terms of stormwater management, segregating non-process area stormwater from process area stormwater is important. Non-process area stormwater, which is typically clean, can be discharged without treatment if permitted by local regulations. Proper segregation can be achieved through curbing, grading, and selecting collection points. Contaminated stormwater from process areas should be collected separately and treated in storage tanks or impoundment basins to reduce hydraulic loading on the treatment plant. Determining the required storage volume for stormwater depends on factors like rainfall intensity and the drainage area of the refinery (USEPA, 2008).

CHAPTER 4: WATER USE

To evaluate the current water usage and management practices in the oil refining industry, a data collection process was initiated, asking the refineries to provide information on their source water, production volumes, water quality, and average water consumption per unit production for various products. The objective was to compare these data with the first edition of NATSURV 15 and global benchmarks to assess the refineries' effectiveness and efficiency in water utilisation.

4.1 SOURCES OF WATER

The South African refinery industry uses water from three of the four possible large sources available. Figure 10 shows that the three operational refineries obtained water from municipal sources primarily for potable purposes and sanitation. This means that on-site pre-treatment is not necessary for this water. Additionally, one refinery relied on surface water from a dam located on their site for 100% of their production process water, while 100% of their purchased municipal water was used for potable purposes. Another refinery sourced 52% of its water from surface water abstracted from a river, 33% from purchased demineralised water, and the remaining 15% from municipal supplies. The third refinery utilised treated wastewater from sewage works for its industrial processes, with the percentage varying from 0% to 98% depending on quality and availability, and the balance being sourced from municipal supplies.

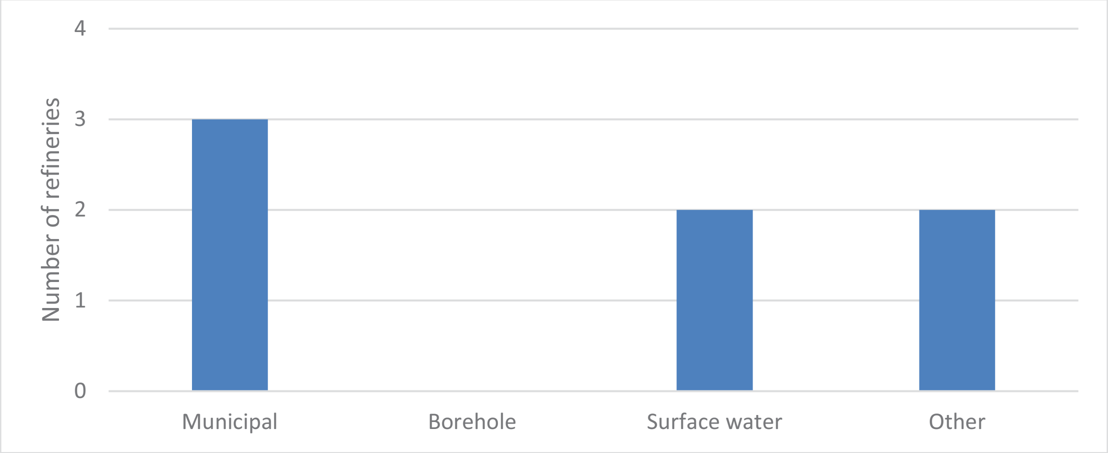

Figure 10: Water sources utilised by participating refineries

The utilization of municipal water is widespread due to its relatively low cost compared to other regions such as Europe and the U.S. (Statista, 2021). For the South African refineries, the cost of municipal water ranged between R16.46/Kℓ - R28.39/Kℓ. The affordability of water can be seen as a contributing factor to the slower adoption of water efficiency measures in various industries within the country. However, it is important to note that water prices in South Africa have been subject to inflation. According to Business Tech (2020), water consumer price inflation has increased by 213% since 2010, and projections indicate further price increases in the future.

Of the seven asset owners, two (Sasol and TotalEnergies) had submitted CDP water security questionnaires in 2023 or 2022. TotalEnergies has drilled wells to provide borehole water to their site and surrounding communities to alleviate water insecurity problems (TotalEnergies, 2023).

The primary source of supply to Sasol’s Secunda CTL is surface water from the Grootdraai Dam, within the Integrated Vaal River System, and associated transfer system. Grootdraai Dam water quality has been progressively deteriorating and reached conductivity levels above 300 µS/cm. The required water quality for

Secunda is conductivity below 240 µS/cm. This deteriorating water quality has resulted in an increase in Secunda's demand for river water due to reduced boiler efficiencies and to manage an increase in the salt loading capacity on site (Sasol, 2022).

The historical water consumption for the four crude oil refineries from the first edition (2005) to date are shown in Figure 11. All four crude oil refineries were operating until 2019. The drop in water consumption in 2020 results from the COVID-19 pandemic, and the further drop in 2021 was a result of Astron's and Engen's shutdowns. The graph clearly illustrates the fact that most of all of the water in use at these refineries was purchased from municipal supplies.

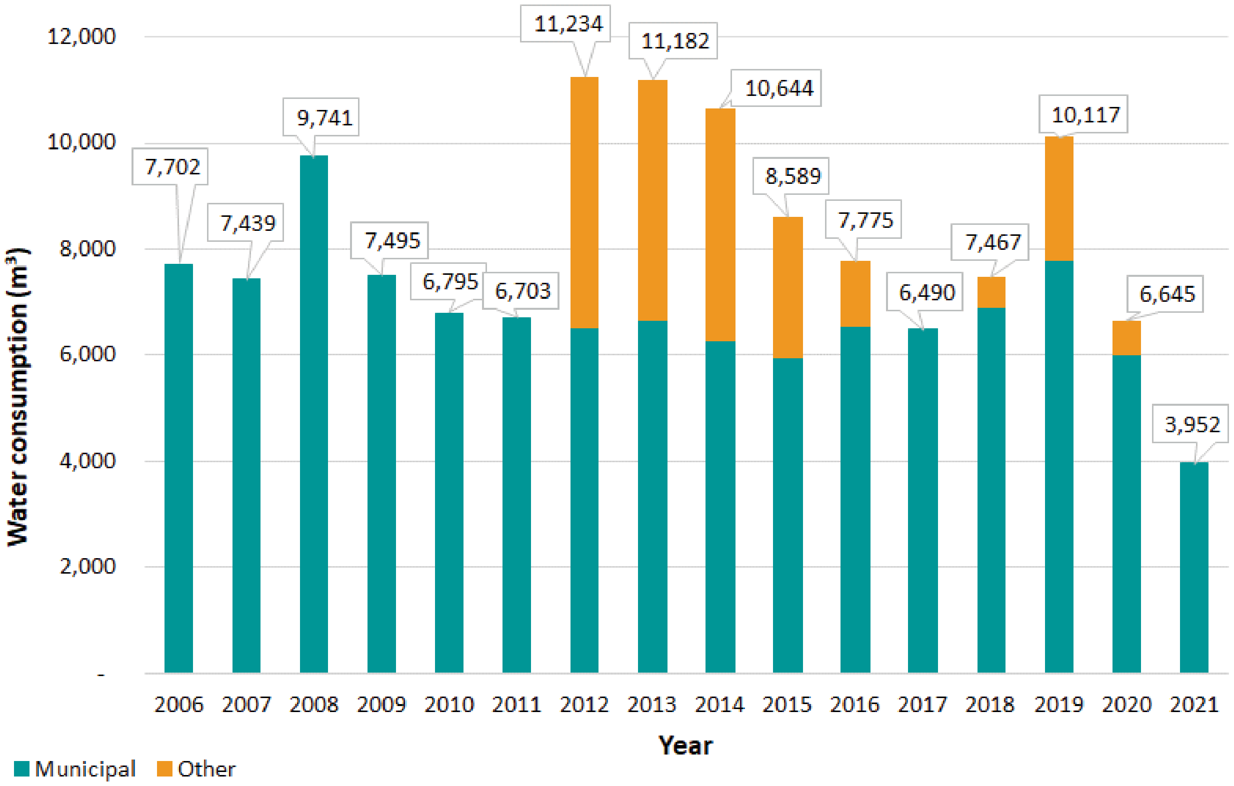

Figure 11: Crude refineries' combined annual water consumption from 2006 to 2021, showing total consumption (data callouts) and the volumes obtained from municipal supplies versus other sources (SAPIA, 2013; 2022)

Table 4 summarises the typical water sources utilised by refineries internationally and provides descriptions of each. Of this list of possibilities, South African refineries used four: surface water, municipal water, borehole water, and recycled water in 2023.

To address rising water costs and promote sustainable practices, some of the South African refineries had implemented water efficiency measures. These measures included the recovery of condensate and boiler water, increasing cooling tower cycles, and implementing water recycling in process units that do not require high-quality water. The use of reclaimed or recycled water necessitates on-site water treatment.

Table 4: Typical water sources utilised by international refineries

Source water type	Description
Surface water*	These water sources include rivers, lakes, and in some cases, the sea or brackish water. Each water source has unique characteristics, such as total suspended solids (TSS), total dissolved solids (TDS), and turbidity, which may require treatment before use in the refinery, depending on the intended application and process compatibility (Reed et al., 2016).
Municipal water*	The water supplied and purchased from municipalities generally provide potable water for drinking and sanitation, although some refineries may utilise alternative sources for potable use if available. Municipalities may also supply treated effluent sources that can be used for industrial purposes or reuse (Thorat and Sonwani, 2022).
Borehole*	This source of water refers to water stored underground in aquifers and is commonly accessed in refineries through the process of drilling wells or boreholes. Groundwater is considered a valuable water source for refineries due to its relatively stable quantity and quality compared to surface water sources. It offers a consistent and reliable supply of water that can be utilised for various applications within the refinery, such as cooling, steam generation, and general process needs (IPIECA, 2010).
Water in crude	Crude oil received at a refinery may contain entrained water as a result of the upstream extraction process or during trans-shipment. This water is typically separated and removed as storage tank bottom sediment and water or through the desalter unit in the crude unit. The separated water is then directed to wastewater treatment (Reed et al., 2016).
Rainwater	Uncontaminated rainwater collected through stormwater harvesting techniques in non-industrial areas of the refinery may be used for certain processes such as equipment washing and general sanitation if it is properly stored and meets the required quality standards (IPIECA, 2010).
Recycled or reclaimed water*	Refineries often implement water recycling and reclamation systems to minimise freshwater consumption. Treated wastewater from various refinery processes, such as sour water strippers, desalter effluents, and cooling tower blowdown, can be recycled and reused for non-potable applications within the refinery (Thorat and Sonwani, 2022).

* water resources used in South African refineries.

4.1.1 Water treatment

In petroleum refineries, the quality of source water plays a crucial role in the overall efficiency and performance of various processes. Before being utilised in different operations, source water typically undergoes treatment to ensure its suitability. The treatment required depends on the characteristics of the source water and its intended use within the refinery (Reed et al., 2016). Table 5 provides an example of common treatment methods that are typically employed at internationally based on the characteristics of their source water.

In accordance with the stringent standards and regulations governing water sources and pre-treatment in the South African oil refining industry, the participating refineries had implemented some of these approaches to ensure compliance and maintain water quality (Figure 12), including demineralisation as the most common process. Notably, one refinery relied exclusively on demineralisation as its primary pre-treatment process. This refinery procures demineralised and municipal water extensively, with only the surface water sourced from a river requiring on-site treatment to meet the required standards.

Table 5: Common raw water contaminants and removal approaches (IPIECA, 2010)

Contaminant	Problem created	Removal approach
Turbidity	Deposition in water lines and process equipment	Coagulation, settling and filtration
Suspended solids	Clogging water lines and deposition in process equipment	Coagulation, settling, filtration, and sedimentation
Oil	Scaling, sludge, and foaming in boilers. Impedes processing efficiency	Coagulation, filtration, and oil/water separators
Iron and magnesium	Precipitation in water lines and process equipment	Coagulation, filtration, aeration, lime softening, and cation exchange
Dissolved solids	High concentrations lead to process inefficiencies and foaming in boilers	Lime softening, cation exchange, demineralisation, and distillation
Hardness	Scale formation in pipelines and heat exchangers	Softening, distillation, and surfactants
Alkalinity	Foaming in steam systems and steel boiler tank corrosion	Lime and zeolite softening, and anion exchange
Conductivity	High conductivity increases corrosivity of process water	Demineralisation and lime softening
Sulphate	Combines with calcium to form scale	Demineralisation and distillation
Chloride	Increases corrosivity of process water	Demineralisation and distillation
Silica	Scale formation in pipelines and process equipment	Distillation and anion exchange resins
Oxygen	Increases corrosivity of process water	Deaeration, sodium sulphite, and corrosion inhibitors
Hydrogen sulphide	Causes unpleasant odour, increases corrosivity and toxicity of process water	Aeration, chlorination, and highly basic anion exchange

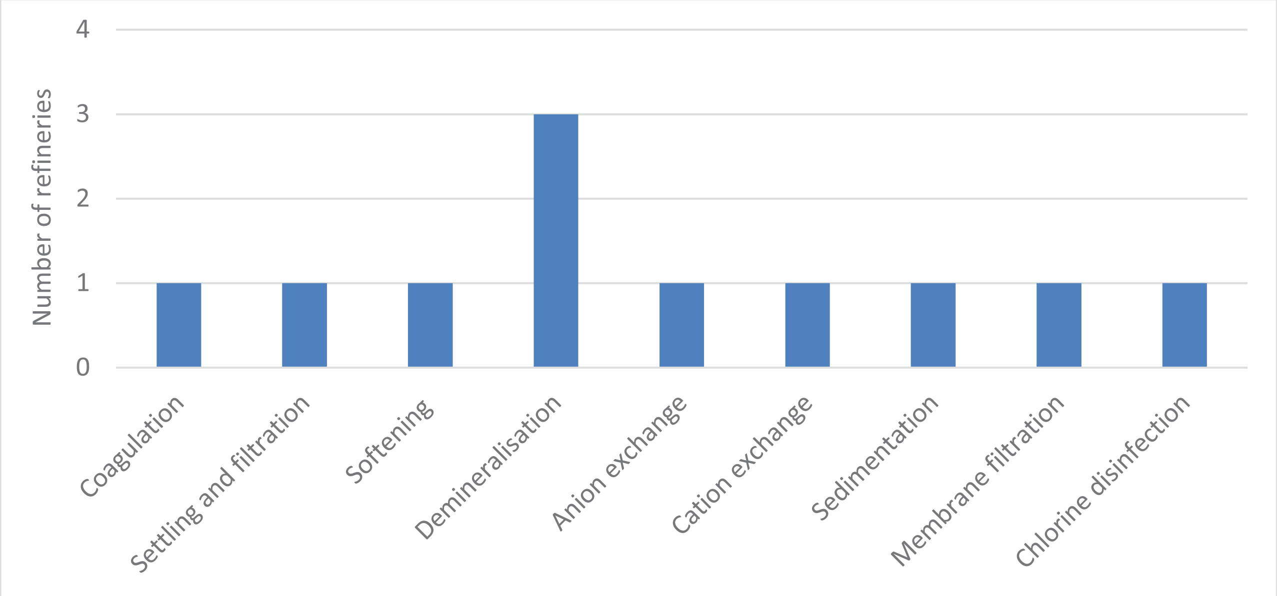

Figure 12: Water-treatment processes used by South African refineries

Another refinery combined demineralisation with membrane filtration to tailor the treatment process according to the specific and variable quality characteristics of water received from a treated wastewater source. By leveraging both demineralisation and membrane filtration, this refinery optimised the quality of its incoming water.

Lastly, the third refinery relied entirely on an on-site dam as its water source for refining processes. In order to ensure acceptable water quality, this refinery implemented a range of treatment processes, including coagulation, settling and filtration, softening, demineralisation, anion and cation exchange, sedimentation, and lastly chlorine disinfection. The adoption of multiple treatment methods enabled this refinery to meet the required standards for various refining processes, safeguarding the integrity of their operations. These treatment methods are rooted in the regulatory framework set forth by the National Water Act (NWA), South African National Standard (SANS) 241 for potable water, the general effluent standards, and the need to obtain discharge authorisations.

4.2 WATER CONSUMPTION AND SPECIFIC WATER INTAKE (SWI)

For oil refining products, specific water intake (SWI) refers to the amount of water required per unit of product created in the refining industry, or per unit of feedstock processed. The SWI can vary depending on several factors, including the complexity of the refining processes, the type of crude oil being processed, the refined products being generated, and the efficiency of water management practices within the refinery. Water usage in the oil refining industry per process unit can also vary considerably based on factors such as refinery size, products being refined, process complexity, and refining technology employed (Otts,1963).

The SWI is usually reported in the oil refining and re-refining industry as the ratio of water consumption to crude oil throughput. This ratio can vary depending on the type and quality of crude oil, the refinery configuration, and the water management practices. For example, cracking, light coking, and heavy coking are typical refinery configurations that process different qualities of crude oil, with historic water consumption of 0.34, 0.44, and 0.47 m^3 water per m^3 of crude oil, respectively (Otts, 1963). However, no South African oil refinery has a coker, and only one had a hydrocracker therefore this ratio does not reflect the actual water use efficiency in South Africa. Further, some refineries may reuse or recycle water within their processes or export treated water to other users and therefore, some sources also report the net water intake or the fresh water intake, which are the difference between the total water intake and the water reuse or recycle, or the amount of water taken from fresh water sources, respectively. For example, Shell (2019) states that their fresh water intake in 2019 was 192 million m^3, which was equivalent to 0.24 m^3 fresh water per m^3 of oil equivalent production.

The participating refineries could not provide submetering data for the water consumption of individual production process steps, however the 2005 data (Pearce and Whyte, 2005) can be compared with more recent SWI estimates. The volumes and types of refined products generated are not comparable between refineries, therefore the SWI has been expressed as a function of the volume of feedstock processed instead of the volume of product refined. This is consistent with the first edition (Pearce and Whyte, 2005). The updated estimated values have been calculated from the most recent publicly available data from the refineries' operational periods, using assumptions which may not be correct but were the best available data as follows:

- Astron consumed about 1.4 million m^3 of water in 2020 (Worldometers, 2022), which was equivalent to 0.11 m^3 of water per barrel of crude oil processed (Table 1) This was a 10% reduction from the previous year, as the refinery reduced its water losses and increased its use of alternative water sources (Worldometers, 2022).

- Enref consumed approximately 3.7 million m^3 of water in 2018-19 (Engen, 2020), or 0.1 m^3 of water per barrel of crude oil processed (Table 1). This was a 5% reduction from the previous year, as the refinery implemented water-saving measures, such as cooling tower blowdown recovery, and stormwater harvesting (Engen, 2020).

- Natref consumed 3.95 million m³ of water in 2021 (SAPIA, 2022), which was equivalent to 0.96 m³ of water per barrel of crude oil processed (Table 1). This was a 4% increase from the previous year, as the refinery faced operational challenges and water quality issues (Ritchie et al., 2022).

- PetroSA GTL consumed 2.6 million m³ of water in 2020, or 0.16 m³ of water per barrel of synthetic fuel produced. This was a 13% reduction from the previous year, as the plant optimized its water consumption and reuse (DMRE, 2021).

- Sapref consumed approximately 5.6 million m³ of water in 2019, equates to 0.34 m³ of water per barrel of crude oil processed (Table 1). This was a 7% reduction from 2018, as the refinery implemented water-saving initiatives, such as rainwater harvesting, leak detection, and reuse of treated effluent (Ratshomo, 2019).

- Secunda CTL consumed approximately 17.4 million m³ of water in 2017, 0.3 m³ of water per barrel of synthetic fuel produced (Sasol, 2022). This was a 2% reduction from the previous year, as the plant improved its water efficiency and recycling rates (Competition Commission, 2018). Water intensity targets of 11.49 m³ /ton saleable product were set for Secunda (Sasol, 2022).

To provide comparable information to NATSURV 15 edition 1, it is necessary to convert the units of measurement from barrels of oil to tons. One barrel of crude oil weighs 0.136 tons. Using this conversion factor and assuming the production figures in Table 1, we can calculate estimates of recent SWI for each refinery in South Africa as shown in Table 6.

Table 6: Average SWI from the first edition of NATSURV 15, compared to estimated recent SWI values calculated from public data

Feedstock	Refinery	Average SWI 2005 (m³/t)	Recent SWI estimates
Crude oil	Astron	0.51 - 0.67	0.8
	Enref		0.7
	Natref		0.7
	Sapref		2.5
Gas	PetroSA	2.9 (synfuels average)	1.2
Coal	Secunda		2.2

Clearly, the actual water intake values in 2023 are incorrect for the refineries that were not operating.

Pearce and Whyte (2005) commented that the range of monthly SWI data was 2.32-4.61 m³ water / ton oil equivalent processes in the synfuels refineries in edition 1, a range with which the estimated updated data are consistent.

The 2005 data for the crude oil refineries fell into the range 0.42 to 0.78 m³ water / ton feedstock. Our estimates for Astron, Enref, and Natref are consistent with that range, but our estimate for Sapref is considerably higher and should be treated with caution owing to the lack of real data available for the actual feedstock amounts refined for the specific periods, and the water consumption data sources being secondary in nature.

Although submetering data per product refined were not available, public literature indicates that petrol production has the highest SWI at 0.60-0.71 m^3 of water per ton of petrol produced, with jet fuel the lowest at 0.09 m^3 per ton (Sun et al., 2018). Table 7 provides an overview of water utilisation for different refinery purposes, along with descriptions and treatment requirements. Cooling water and boiler feed water are the primary water users in refineries (Wu and Chiu, 2011)

Table 7: Water consumed throughout the refining process

Water type	Description
Process water	Water commonly in close contact with hydrocarbons and is usually softened before use (Gary et al., 2007; Wu and Chiu, 2011).
Steam Methane Reforming	Steam Methane Reforming (SMR) consumes water as part of the reaction. In the process of SMR, methane (CH_4) reacts with steam (H_2O) to produce carbon monoxide (CO) and hydrogen (H_2).
Boiler feedwater	Water required for steam generation, needs to be treated prior to use. The purity requirements increase with higher steam pressures. Purge streams are removed from the water purification systems to prevent the build-up of contaminants, and these streams are sent to wastewater treatment while fresh makeup water is introduced (Gary et al., 2007; Wu and Chiu, 2011).
Cooling water	Extensively used in refineries for equipment such as condensers and heat exchangers. Air coolers, once-through systems, and circulating systems are employed depending on water availability and requirements. Seawater is sometimes used as cooling water in coastal areas with freshwater shortages (Gary et al., 2007; Speight, 2015).
Potable water	Potable water is required for various purposes in refineries, such as kitchens and wash areas. It can be sourced from city water supplies, treated groundwater, or a portion of the treated water from the plant's softening unit. Chlorination is typically applied to ensure its safety (Gary et al., 2007; Wu and Chiu, 2011).
Fire water	Fire water demands in refineries can be intermittent but involve large flow rates. Stormwater from non-process areas is often collected and stored for fire water use. Seawater or brackish water is sometimes used as fire water in coastal plants (Gary et al., 2007; Wu and Chiu, 2011).
Utility water	Utility water in refineries is used for miscellaneous washing operations and does not require extensive treatment beyond sediment removal (Gary et al., 2007).

The type of cooling system employed also affects water consumption. Once-through cooling water systems, which pump water from a body of water through cooling exchangers and then back into the water body, tend to have larger withdrawals but lower consumption compared to recirculating cooling tower systems. Once-through systems reject heat to a large thermal mass (e.g. a river or lake), resulting in lower net evaporative losses compared to cooling towers (Sun et al., 2018).

In the case of a closed-loop cooling tower, a significant amount of water, 3654 ℓ/s, circulates, with 231.8 ℓ/s withdrawn for makeup purposes (Figure 13). Of the makeup water, 61.7 ℓ/s is lost to evaporation, while 170.1 ℓ/s is used in blowdowns to prevent mineral accumulation. However, the blowdown water is not considered consumption as it is routed to the wastewater treatment plant and ultimately returned to a surface water body. Cooling tower evaporation loss accounts for a significant portion (approximately 65-90%) of total water consumption within a refinery (Sun et al., 2018).

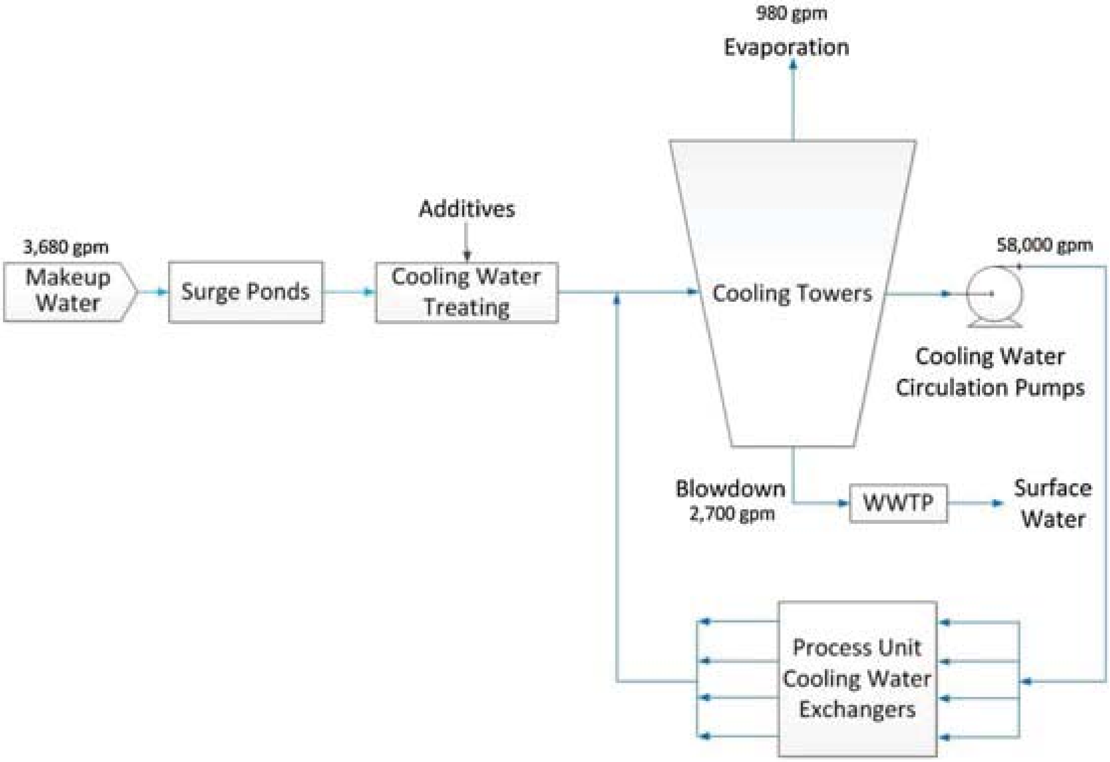

Figure 13: Refinery closed loop cooling tower water balance example (Sun et al., 2018)

Sensitivity analysis conducted by Sun et al., (2018) reveals that water consumption for petrol can range from 0.5 ℓ water/ℓ petrol with a more efficient cooling system to 1.0 ℓ water/ℓ petrol with a less efficient cooling system. Previous studies have reported varying levels of refinery water consumption per unit of product volume. For example, Wu and Chui (2011) found that U.S. refinery product water consumption averaged 1.4 ℓ water/ℓ of refined product, with a range of 0.5-2.5 ℓ water/ℓ product depending on factors such as configuration, process, and operation. The California Energy Commission reported water use intensity in Californian refineries ranging from 0.74 ℓ water/ℓ refined product to 1.41 ℓ water/ℓ refined product. These findings align with Sun et al., (2018) who estimated water consumption in the range 0.29-0.63 ℓ water/ℓ product for different refinery configurations.

Regarding specific products, propane, propylene, butanes, and jet fuel demonstrate higher sensitivity to cooling water usage changes, while petrol is less sensitive, and diesel and coke are the least sensitive. This disparity arises from the fact that petrol, diesel, and coke derive water consumption not only from cooling water evaporation losses and proportionally estimated other losses but also from the steam methane reforming plant and coker plant. Consequently, their water consumption is less influenced by sole cooling water usage and subsequent evaporation losses. Conversely, propane, propylene, butanes, and jet fuel have fewer consumption sources and are therefore more dependent on cooling water evaporation losses.

CHAPTER 5: WASTEWATER CHARACTERISTICS, TREATMENT AND DISCHARGE

5.1 WASTEWATER GENERATION

Specific effluent volume (SEV) is a measure of the amount of wastewater that is discharged from an industrial process per unit of product. In this industry, it is usually expressed volume effluent per mass of feedstock processed (m^3 water / ton oil, or oil equivalent for synfuels). Specific effluent volume can vary depending on the type and quality of the raw materials, the production technology, the water management practices, and the environmental regulations. It can also indicate the water use efficiency and the potential environmental impacts of an industrial process. The lower the specific effluent volume, the less water is wasted and the less pollution is generated. Specific effluent volume can be calculated by dividing the total effluent discharge by the total product output in a given period.

The participating refineries were asked to provide information regarding their on-site wastewater generation, including the volume for each refined product, typical pollutant loads, and the treatment methods employed before discharge. Without exception, they were either not permitted to share their effluent volumes and characteristics, or the data did not exist. As a result, the SEV associated with these refineries could not be confidently reported.

However, based on some information from the public domain, some personal communications, and the assumptions stated below, we can estimate the range of the specific effluent volumes for the two operational crude oil refineries.

Astron: On their website, Engen stated that their SEV when they were operating was 0.8 ℓ water / ℓ product. Astron and Engen's product ranges are similar (gasoline, diesel, jet fuel, LPG, bitumen, and fuel oil) and the refineries fall into the same size category. Therefore, we assumed that Astron has a similar SEV as Engen's in ℓ water / ℓ product, in which case the estimated SEV for Astron per tonne of oil refined can be provided:

- 1 barrel = 0.159 m^3
- 1 barrel = 0.136 tons
- 1 ℓ = 0.001 m^3

$$\text{SEV} = 0.8\ \ell/\ell \times 0.001\ \text{m}^3/\ell \times 100{,}000\ \text{bpd} / (0.136\ \text{t/b} \times 0.159\ \text{m}^3/\text{b}) = 2.97\ \text{m}^3/\text{t}$$

Natref: Sasol stated that Natref processes crude oil with a conversion rate of more than 90%, which led us to expect that Natref refinery had a lower SEV than other refineries in South Africa. TotalEnergies stated that Natref has achieved a 20% reduction in its SEV due to its waste reduction programme and ISO certification. Using the same conversion factors as above, we can calculate the predicted SEV as follows:

$$\text{SEV} = 0.8\ \ell/\ell \times (1-0.2) \times 0.001\ \text{m}^3/\ell \times 110{,}000\ \text{bpd} / (0.136\ \text{t/b} \times 0.159\ \text{m}^3/\text{b}) = 2.38\ \text{m}^3/\text{t}$$

Therefore, the estimated SEV of Natref refinery is about 2.38 m^3 /ton of crude oil processed.

Please note that these are only estimates based on the assumptions stated here and may not reflect the true specific effluent volumes of the refineries or plants. For example Astron has two crude distillation trains, while Engen has one, meaning that while they are similar sizes, their configurations differ and the assumption of applying Engen's 0.8 ℓ/ℓ is not completely accurate.

Pearce and Whyte (2005) reported in the first edition of the NATSURV 15 that the SEV based on the volume of water discharged per mass of feedstock processed varied from 0.26-0.41 m^3/t in the crude oil refineries to 0.57-2.34 m^3/t in the synfuels refineries. Our calculations result in SEVs approximately an order of magnitude higher than the 2005 data. This is unlikely to be realistic.

While the specific data regarding average feedstock consumption and SEV for the refineries in recent years is not available, it is reasonable to assume that these results would not have changed significantly since 2005. The nature of refinery operations has generally remained consistent over the years, with periodic upgrades and maintenance to meet regulatory requirements and improve efficiency. Advancements in technology and evolving environmental standards may have influenced some refineries to adopt more sustainable practices, potentially *lowering* SEVs over the past ten to twenty years. Therefore, we turn to published literature.

According to the literature, the wastewater generated during the crude oil refining process typically ranges from 0.4 to 1.6 times the volume of the crude oil being processed (Aljuboury et al., 2019). The results of this analysis are summarised in Table 8, which illustrates the relationship between water consumption and effluent generation for different sizes of refinery. However, the International Energy Agency (IEA) forecast to 2028 (IEA, 2023) estimated a global average SEV of 1.38 m^3/ton feedstock processed. This is only an approximation based on assumptions and may not reflect the actual SEV of different refineries or regions.

Table 8: Water consumption and effluent generation (Smith, 2018)

Refinery Size	Total Water Consumption (Mℓ /year)	Total Annual Effluent Generated on Site (Mℓ/year)
Small - Medium	500 - 1500	150 - 300
Medium - Large	2000 - 4000	1000 - 1900

On average, in a medium to large crude refinery, approximately 40-50% of the fresh water taken in is discharged as effluent. For small to medium synthetic fuel plants, this percentage increases to about 60-70%.

The lack of consensus between Pearce and Whyte (2005), our calculated estimates, and information in the public domain indicates that only the owners of operating refineries can provide the SEV values or the actual data to calculate them with confidence.

The SEV values in the literature for crude oil refineries range from 0.14 to 1.14 m^3/t, with an average of 0.57 m^3/t (SAPIA, 2019). The values depend on the level of wastewater treatment and reuse in the refineries. For example, one study found that the SEV values for crude oil refineries in India ranged from 0.26 to 0.60 m^3/t, with an average of 0.40 m^3/t, after implementing wastewater treatment and reuse systems (Ding et al., 2022).

The literature values for synfuels refineries' SEVs are generally higher than those for crude oil refineries, due to the higher water intensity and complexity of the synfuels production processes: from 0.71 to 3.57 m^3/t, with an average of 2.14 m^3/t (SAPIA, 2019). The SEV values depend on the type of synfuels technology and feedstock used. For example, one study found that the SEV values for coal-to-liquids (CTL) refineries ranged from 1.71 to 3.57 m^3/t, while the SEV values for gas-to-liquids (GTL) refineries ranged from 0.71 to 1.71 m^3/t (U.S. Energy Information Administration, 2022).

5.1.1 Effluent characteristics (pollutant loads)

The small to medium-sized refinery identified pH, chemical oxygen demand (COD), total suspended solids (TSS), and oil content as the primary pollutants to be removed from their wastewater. The larger refineries emphasised that TSS and phenols posed the greatest problems at their facilities. These contaminants can be problematic due to various reasons. High levels of COD indicate a high organic load in the wastewater, which can lead to oxygen depletion and harm aquatic life if discharged into receiving bodies of water. Elevated TSS levels can cause sedimentation, leading to reduced light penetration and disrupted ecosystems. Oil contamination poses risks of toxicity and environmental harm, while phenols can be toxic and persistent pollutants. Non-compliance with water quality regulations can lead to legal penalties by the regulator and possible cancellation of the refineries water use licenses.

Although the South African refineries surveyed had limited and fragmented data regarding the characteristics of their effluent streams, Table 9 summarises the refineries' effluent quality prior to discharge in comparison to the data from the first edition of the NATSURV 15 published in 2005. The concentration ranges of these contaminants varied significantly between sites: pH levels were relatively stable across the board, ranging between 7 and 8. Compared to the 2005 NATSURV report, the concentrations of Oil and Grease in the small-medium and medium-large refineries were notably lower, ranging from 5-10 mg/ℓ and 1-2 mg/ℓ, respectively. This reduction in Oil and Grease levels may be attributed to improved operational practices and stricter environmental regulations implemented since 2005.

Table 9: Effluent characteristics at participating refineries

Refinery size	Total effluent volume (Mℓ/year)	Oil and Grease (mg/ℓ)	COD (mg/ℓ)	TSS (mg/ℓ)	pH	NH_3 (mg/ℓ)	Sulphide (mg/ℓ)	Phenol (mg/ℓ)
Small - Medium 2023	150 - 300	5 - 10	4000 - 6000	50 - 100	7 - 8	15 - 30	0.5 - 1.5	n.d
Medium - Large 2023	1000 - 1900	1 - 2	100 - 400	10 - 15	7 - 8	0 - 10	0 - 1	0.5 - 3
Pearce and Whyte (2005)	1145 - 3048	3.6 - 27	179 - 837	n.d.	7.2 - 9.2	1.2 - 24	0.1 - 8.8	3 - 8

The small-medium refinery exhibited higher COD levels, ranging from 4000-6000 mg/ℓ, while the medium-large refineries had lower COD levels ranging from 100-400 mg/ℓ. The 2005 NATSURV reported COD levels between 179-837 mg/ℓ.

The TSS concentrations in the small-medium refinery ranged from 50-100 mg/ℓ, while the medium-large refineries had concentrations between 10-15 mg/ℓ. The higher TSS levels in the small-medium refinery can be attributed to the nature of synthetic fuel refining processes, which generate solid by products or residues. Crude oil refining processes generally produce less solid waste, resulting in lower TSS levels.

Ammonia concentrations in the small-medium refinery wastewater ranged from 15-30 mg/ℓ, whereas the medium-large refineries had concentrations between 0-10 mg/ℓ. These ranges are quite similar to the 2005 NATSURV data, which reported concentrations ranging from 1.2-24 mg/ℓ. The observed sulphide levels were relatively similar in this study, with concentrations ranging from 0.5-1.5 mg/ℓ in the small-medium refinery and 0-1 mg/ℓ in the medium-large refinery. The 2005 data indicated average industry levels between 0.1-8.8 mg/ℓ, suggesting a considerable reduction since then, likely due to cleaner fuel regulations implemented since the last Edition of this survey was released.

Similarly, the phenol concentrations in the medium-large refineries ranged from 0.5-3 mg/ℓ, significantly lower than the values reported in the 2005 report (3-8 mg/ℓ). The decrease in phenol levels can be attributed to improvements in refining processes and the adoption of cleaner technologies.

Figure 14 shows the frequency of wastewater treatment methods reported by the refineries. All three used desalter oil/water separation, API separation (a gravity separation device designed according to API 421), and dissolved air flotation (DAF) as primary treatment processes. Additionally, two refineries employed sludge treatment to manage the solid residues generated by the treatment process.

One of the refineries specified the use of aerated lagoons for secondary treatment, which involves utilising oxygen and microbial activity to break down organic compounds further. This refinery also mentioned off-site disposal of the treated effluent, indicating that they transport the treated wastewater to an external facility for further treatment.

Another refinery uses a combination of flow and concentration equalisation to stabilise and regulate the flow and concentration of wastewater entering their treatment system. They use a moving bed bioreactor (MBBR) and clarifiers.

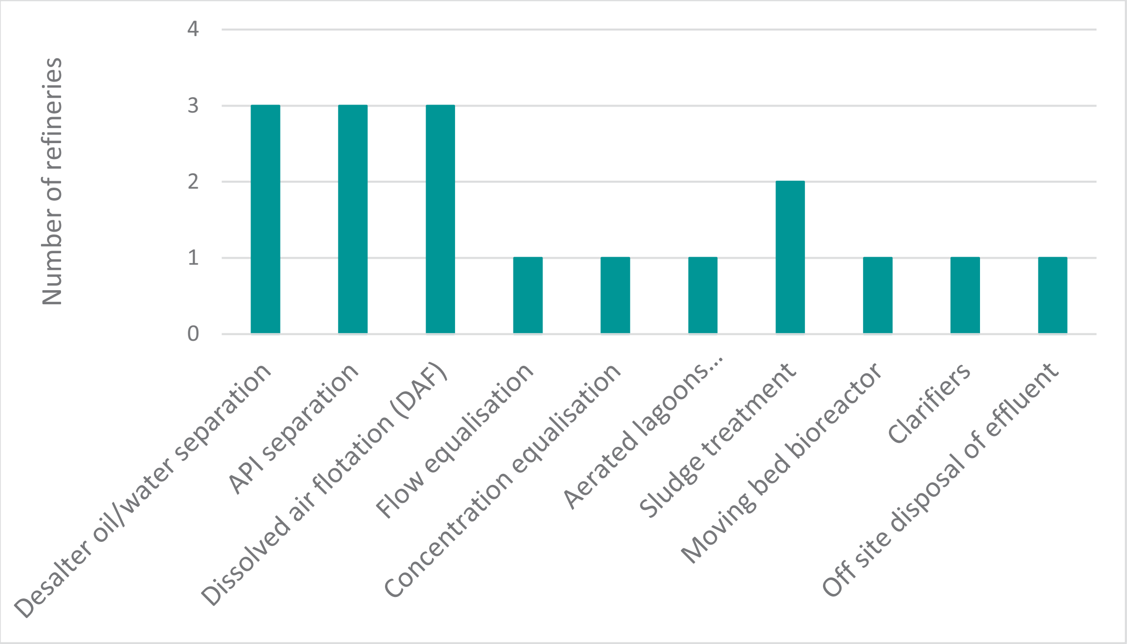

Figure 14: Wastewater treatment processes implemented at surveyed refineries

These practices are consistent with international literature, which describes two generic stages of treatment to ensure effective removal of free oil from the wastewater before entering biological treatment (Figure 15). This is achieved through the utilisation of an API separator followed by DAF or induced air flotation (IAF) unit. The wastewater then undergoes equalisation to mitigate variations in flow and concentration. Subsequently, it enters the aeration tank for biological treatment, followed by clarification. Finally, the clarified effluent proceeds to tertiary treatment (usually chlorine disinfection) before discharge.

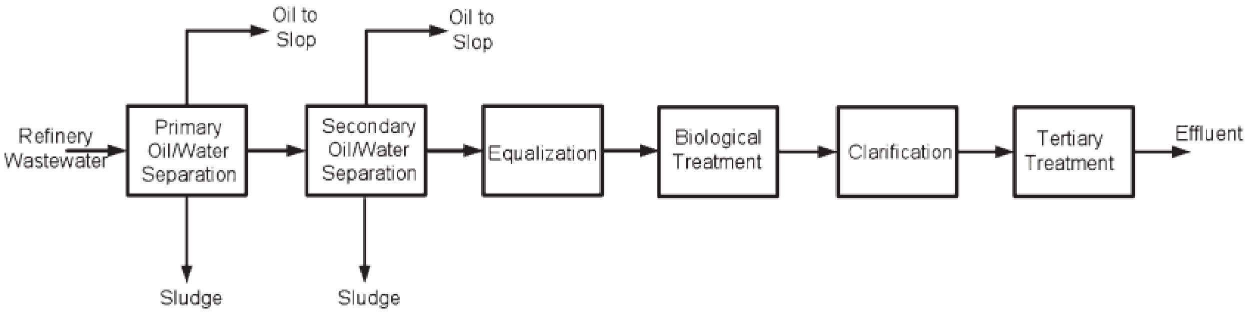

Figure 15: Typical refinery wastewater treatment processes (IPIECA, 2010)

5.2 WATER LEAVING THE REFINERY

5.2.1 Wastewater

Refinery wastewater comes into contact with hydrocarbons during the refining processes. This wastewater can also include water that is rejected from boiler feedwater pre-treatment processes or produced during regenerations. Additionally, it encompasses cooling tower blowdown and once-through cooling water that exits the refinery. Typically, once-through cooling water is discharged without undergoing treatment, while the treatment of cooling tower blowdown and wastewater from raw water treatment may vary depending on the specific refinery and its environmental regulations (Gary et al., 2007; Speight, 2015).

Contaminated wastewater is usually directed to on-site wastewater treatment plants within the refinery, or it can be pre-treated and sent to local municipal treatment works or third-party treatment facilities for further purification. On the other hand, water that has minimal or no direct contact with hydrocarbons can be considered for reuse either after undergoing treatment at the wastewater treatment plant or by implementing additional treatment processes to remove suspended solids and contaminants (Gary et al., 2007; Reed et al., 2016).

5.2.2 Steam losses

Excess low-pressure steam, generated during refinery operations, is often released to the atmosphere, while tracing steam may be vented at specific locations within the facility. Implementing efficient steam management practices can help minimise excess steam production and reduce the need for venting (Gary et al., 2007).

Blowdown is the process of releasing water from a boiler or cooling system to remove impurities or prevent the build-up of dissolved solids. The amount of water lost through blowdown can vary based on the specific refinery and its operational parameters. However, blowdown is a common practice to maintain the quality of water in the system, and it can contribute to significant water losses.

Steam traps are devices used to discharge condensate and non-condensable gases with a negligible loss of live steam. Inefficient or malfunctioning steam traps can result in the loss of valuable condensate and live steam. This can contribute to water losses, as the condensate is essentially treated water that has been heated. Properly functioning steam traps are crucial for reducing water losses and improving the overall efficiency of steam systems. Inefficient traps can lead to increased water consumption.

5.2.3 Cooling tower losses

These losses occur as a result of evaporation in cooling towers. This evaporation leads to a portion of the water being carried away by the airflow, known as cooling tower drift. When evaluating the overall water balance in a refinery, it is essential to consider these anticipated losses from steam and cooling towers (Gary et al., 2007; Speight, 2015). As a general guideline, for every 5.5°C increase in water temperature, approximately 1% of the total water mass is lost through evaporation. Cooling tower evaporation is the primary source of water loss within the refinery plant, accounting for a significant proportion (approximately 65-90%) of the total water consumption (Nabzar and Duplan, 2011).

5.2.4 Water in product

Although the amount is relatively small due to strict product quality specifications, there is still a small quantity of water that accompanies certain refinery products. This can be attributed to factors such as product formulation, storage conditions, or incidental water content during the refining process (Speight, 2015).

CHAPTER 6: IMPLEMENTATION OF WATER, WASTEWATER, AND ENERGY BEST PRACTICE

6.1 WATER AND WASTEWATER

The water, wastewater, and energy consumption best practices that have been implemented, planned, or in progress in the participating refineries are presented in Table 10. No refineries practised once-through cooling, suggesting a general preference for more efficient cooling approaches.

The first edition NATSURV 15 made no mention of the best practices employed at that time, however, Pearce and Whyte (2005) did indicate that most refineries relied on air-cooling, along with other cooling methods such as open cooling water systems.

Regarding condensate recovery, not all the refineries included in the 2005 survey had implemented such measures. Interestingly, that this trend has persisted. It appears that condensate recovery is still not widely adopted.

The recycling of treated effluent for reuse on site was not extensively implemented in 2005. However, the current survey shows that three refineries had or were in the process of implementing water recycling. This suggests a growing recognition of the importance of effluent recycling for sustainable water management in support of water security, consistent with the 2023 and 2022 CDP reports (Sasol, 2022; TotalEnergies, 2023).

Table 10: Water and wastewater practices implemented by surveyed refineries

Best practice initiative	Implemented	In progress	Planned for future
Water submetering	1	-	-
Energy submetering	1	-	-
Heat recovery	1	-	-
Water foot printing	-	-	-
Carbon foot printing	-	1	-
Water pinch analysis	-	-	-
Condensate recovery	1	-	-
Rainwater harvesting	1	-	-
Improved housekeeping (leak maintenance)	-	2	-
Marginalised cooling water sources	-	-	-
Increased cooling tower cycles	-	1	-
Water recycling	1	2	-
Reclaimed water use	1	-	-
Other	-	-	-

Although the refineries were invited to add to the list of potential best practices to be implemented via the ‘Other’ option, no additional interventions were under consideration. Further, all of the best practice adoption programmes were historical, i.e. either completed or started at the time of the survey, with no plans at any refinery to add new developments. This reflects the fundamental uncertainty around the future of the country’s refining and re-refining industries.

Higher efficiencies and improved management practices in general are largely motivated by the rising costs of water and energy, as well as the growing scarcity of freshwater resources (Wu et al., 2017) and are achieved through better monitoring. Although water and energy submetering were being implemented at one refinery in South Africa, no refineries were undertaking or planning any water pinch or water footprinting activities at all.

Several overseas refineries have successfully implemented water treatment and recycling initiatives to reduce their water consumption and enhance water quality. BP's Kwinana Refinery located in Australia, for example, achieved a 42% reduction in water demands between 1996-2014, with a substantial 93% decrease in potable water use. This achievement was made possible through the adoption of water minimisation and reuse practices within the refinery, in collaboration with partners, local water companies, and regulatory bodies (WBCSD, 2017).

The implementation of water treatment and reuse measures in refineries has yielded significant benefits. In addition to conserving potable water for societal needs, it has resulted in cost savings. These reductions in water consumption have been realised through diverse strategies, including the implementation of water minimisation measures and the utilisation of alternative water sources. As a result of these efforts, notable improvements in water efficiency metrics have been achieved, such as enhancing potable water efficiency from 0.40 m^3 water per tonne of crude oil throughput to 0.026 m^3/t (WBCSD, 2017).

Equipment upgrades and modifications also contribute to reducing water consumption in refineries. Retrofitting existing equipment with more water-efficient components, optimising process parameters, and implementing leak detection and repair programs can lead to significant water savings (Oluwoye et al., 2020; Elmobarak et al., 2021). For instance, replacing outdated heat exchangers with more efficient designs, such as plate-and-frame or shell-and-tube heat exchangers, can enhance heat transfer efficiency and minimise water requirements (Oluwoye et al., 2020).

The available international examples could be used to inspire South African future best practice adoption, if the South African industry does indeed exist in the future.

6.2 ENERGY

The petrochemical industry (e.g. Astron (Glencore, 2022) has recognised the importance of energy efficiency as a strategy for reducing emissions. Efficient technologies play a crucial role in improving the performance of petrochemical processes in terms of energy efficiency and greenhouse gas (GHG) emissions (Boulamanti and Moya, 2017). Implementing best available technology practices in core chemical production processes can result in significant energy savings ranging from 14-21% annually (Bennett and Page, 2017). These efficiency gains not only help companies reduce their exposure to fluctuating fossil fuel prices but also alleviate the burden of regulatory impacts.

Over the years, the petrochemical industry has demonstrated improvements in energy and resource consumption efficiency in response to external shocks. For example, during the oil crisis in the 1970s, the industry implemented efficiency-enhancing measures, and today, new plants are designed to consume less energy and operate more efficiently (Bennett and Page, 2017).

South Africa has implemented various energy efficiency policies to enhance energy performance. Two notable policies are the Section 12i and 12L tax incentives (McNicoll et al., 2017). The 12L tax incentive allows businesses to claim deductions against taxable income based on proven energy efficiency savings. Additionally, Eskom, the country's electricity utility, has initiated demand-side management programs since the late 1990s, providing financial and technical support to electricity consumers (McNicoll et al., 2017).

In the petrochemical sector, energy efficiency interventions have been assessed for their emissions-savings and costs. Marginal Abatement Cost Curves (MACC) analysis conducted by TIPS (2022) highlighted energy efficiency interventions with the lowest marginal abatement costs, including advanced energy management systems, steam generating boiler efficiency improvements, process heater efficiency enhancements, process control optimisation, and energy-efficient utility systems (DEFF, 2014). Some of these interventions have already been widely implemented in South Africa, but there is still room for improvement in areas such as energy monitoring and management systems, improved process control, energy-efficient utility systems, heat exchanger efficiency, and electric motor system controls (DEFF, 2014). Table 11 indicates the extent to which these energy efficiency measures can be implemented further in South Africa.

Table 11: Scope and implementation of energy efficiency measures in refineries (DEA and GIZ, 2014)

Energy efficiency measure	Extent of implementation	Scope for further implementation
Boiler and expander waste heat applied to flue gas from fluid catalytic cracking (FCC) regenerator	Extensively implemented	Limited scope for improvement
Waste heat recovery and use	Extensively implemented	Scope for improvement. Space and configuration constraints pose barriers.
Improved efficiency of steam generating boiler	Extensively implemented	Scope for 3 - 4% improvement
Improved process heater efficiency	Extensively implemented	Scope for < 5% improvement. Retrofittable poses a barrier.
Energy monitoring and management systems	Extensively implemented	Scope for improvement
Improved process control	Extensively implemented	Scope for improvement
Energy-efficient utility systems	Extensively implemented	Scope for improvement
Improved heat exchanger efficiencies	Extensively implemented	Scope for improvement
Improved electric motor system	Extensively implemented	Scope for improvement
Minimisation of flaring and utilisation of flare gas as fuel	Limited implementation	Scope for further implementation and improvement

While most energy efficiency measures have been extensively implemented in South Africa, one area that requires further attention is the minimisation of flaring and utilisation of flare gas as fuel. Other interventions such as waste heat recovery and utilisation, improving steam generating boiler efficiency, and improving process heater efficiency have limited scope for further improvement (DEFF, 2014).

CHAPTER 7: THE FUTURE OF THE INDUSTRY

In Chapter 1 it became clear that the dominating feature of oil refining and re-refining in South Africa is its disappearance. The refineries' owners were asked to provide any available information regarding the futures of the six sites. The majority of the companies did not have much information that could be disclosed, so the following summaries are based on the limited information the team was permitted to obtain from a combination of personal communications and public sources. Industry commentators suggest that 15-20% of global refining capacity will be at risk by 2030.

7.1 REFINERY SUMMARIES

Astron produces mainly gasoline and diesel. The refinery was established in 1966 and has been undergoing maintenance and periodic capacity upgrades since then. However, the refinery has been facing severe operational challenges and safety issues in recent years. In July 2020, it was shut down after an explosion that killed two workers and injured several others. Operation had resumed by December 2023. Astron Energy said that it would continue to supply its customers with refined products from its storage facilities until the refinery resumes full capacity operation.

Enref refinery was built in 1954 and has been upgraded several times since then. However, the refinery has faced environmental and social challenges in recent years. In December 2020, it was shut down after a fire and the restart date of the refinery – if any – is unknown. Engen said that it would continue to supply its customers with refined products from its other refineries or the international market. In January 2021, Engen announced that it would repurpose Enref into a fuel importation terminal by 2023, as part of its strategic review of its refining business. The company said that it would invest R1.1 billion to upgrade the site and create a world-class storage and distribution facility. The site was not expected to refine oil again. There are possible plans to import solvents for fractionation on this site to produce specialised solvents for the domestic market.

Natref is the only inland crude oil refinery in South Africa, with a current capacity of 108,500 b/d at the time of writing. It produces gasoline, diesel, jet fuel, and liquefied petroleum gas. The refinery was considered to be at the cutting edge of refining technology at its inception in 1971. However, it faces several challenges, such as aging infrastructure, low margins, competition from cheap imports, and tightening environmental regulations. The refinery relies on crude oil imports from the Middle East, which exposes it to price volatility and supply disruptions. TotalEnergies owns a 36.6% share, and Sasol holds the remaining 63.4%. In September 2020, TotalEnergies announced that as part of its plan to divest $5 billion of assets by 2025 it was considering selling its stake in the Natref refinery buyers who could invest in the refinery and upgrade it to produce low-sulphur diesel, which is required by the new South African fuel specifications. The refinery temporarily shut down in July 2022 due to supply challenges but resumed production once the issues were resolved. In 2022, TotalEnergies said that it was looking for buyers who could invest in the refinery and upgrade it to produce low-sulphur diesel, which is required by the new South African fuel specifications that were planned to take effect in 2023. In 2022 it was also announced that Natref would produce ultra-low sulphur diesel by the end of 2023. The company also said that it would continue to supply its customers in South Africa with refined products from the international market. The company plans to build a new polyethylene plant in Antwerp, Belgium and export its refined products into South Africa. The company also intends to diversify its energy portfolio to include more renewable sources, such as wind, solar, biomass, natural gas, and biofuels, and to increase its production of biofuels and bioplastics by converting the Grandpuits refinery in France into a zero-crude platform.

PetroSA's GTL plant produced fuels from natural gas: gasoline, diesel, kerosene, propane, butane, naphtha, and paraffin wax. The plant was commissioned in 1992. However, the plant has been suffering from declining gas reserves and production levels. In 2019, the plant produced only ~15% of its capacity and incurred losses of R2.2 billion. PetroSA said that it was looking for new gas sources to extend the life of the plant, as well as exploring options to convert the plant into a liquefied natural gas (LNG) import terminal, with the aim of enabling the refinery to operate again after 2026 (PetroSA, 2021; 2022).

Sapref is jointly owned by Shell and BP. It used to produce a range of products, such as LPG, gasoline, diesel, kerosene, jet fuel, fuel oil, bitumen, base oils, and solvents. The refinery faces challenges of aging infrastructure, low margins, and competition from imports. It depends on crude oil imports from the Middle East and West Africa. In February 2021, Shell announced that it planned to reduce its global refinery portfolio to six sites from 14 by 2025. The company said that it would retain only those refineries that are integrated with chemicals or trading hubs and that can produce more low-carbon fuels and specialty products and have a smaller carbon footprint (Shell, 2022a). Shell did not specify which refineries it would keep or sell, but analysts speculated that the Sapref refinery would sold following Shell's capital restructuring especially since Sapref suspended operations in April 2022 in search of a buyer. However, severe floods hindered the refinery's sale prospects, as repairing it would require extensive capital investment to reopen. BP said that it would continue to supply its customers with refined products from the international market. The future of Sapref remains uncertain as efforts continue to find a suitable buyer (News24, 2023a).

In addition to the Sapref refinery, Shell also has interests in various joint ventures and associates that operate refineries or petrochemicals plants elsewhere in Africa. Shell plans to increase its production of biofuels and low-carbon fuels from waste and biomass globally by building new biofuels plants in Rotterdam, the Netherlands and Varennes, Canada. Shell also plans to increase its investments in low-carbon energy solutions from renewables and hydrogen (Shell, 2022b).

Secunda is one of the largest CTL facilities in the world and has been operating since 1980. However, the plant is also one of the largest sources of greenhouse gas emissions in South Africa and has been under pressure to reduce its environmental impact. In 2019, Sasol announced that it would invest R2 billion to lower its emissions by at least 10% by 2030. Sasol also said that it would explore alternative feedstocks such as gas or biomass to produce low-carbon fuels in the future. Sasol is actively pursuing two projects to supply 850 GWh of green electricity, subject to regulatory approvals. In a press statement, Sasol said that these projects aim to contribute to the refinery's sustainability efforts, but their implementation depends on regulatory clearance (News24, 2023b).

7.2 FUTURE PROJECTIONS

To summarise section 7.1, the major oil companies that operate refineries in South Africa have announced their intentions to reduce their crude oil refining activities globally, and in South Africa specifically to pivot to importing refined products from other regions. This is part of their strategies to align their businesses with the global energy transition and the growing demand for low-carbon fuels.

In May 2023, speaking at the DMRE Budget Vote, the Minister of Mineral Resources and Energy, Gwede Mantashe, said that a merger between PetroSA and other Central Energy Fund (CEF) subsidiaries was progressing. Following the tabling of the Upstream Petroleum Resources Development Bill, South Africa's cabinet approved the merger of IGas, PetroSA and the Strategic Fuel Fund to form the South African National Petroleum Company (SANPC), which would allow 'the state to participate meaningfully in oil and gas developments' although the State has always participated in oil and gas.

The Upstream Petroleum Resources Development Bill details objectives concerning petroleum rights licensing, exploration of petroleum and management rights relating to petroleum. The SANPC is expected to oversee strategic planning, coordination, and governance of the country's petroleum resources, contributing to sustainable development and economic growth. The merger was designed to alleviate the unstable petroleum supply. However, in October 2023, the. Central Energy Fund (CEF) group chairperson South Africa faced a fuel crisis that it could not avert alone due to the severely constrained refining capacity and the Strategic Fuel Fund appealed to Saudi Arabia for assistance via favourable import terms (News24, 2023d).

7.2.1 Water-related impacts

The closure of refineries raises critical concerns about the environmental impact and water sector liabilities that the owners must address. This overview delves into the legal framework established by the NWA (1998), particularly sections 19 and 20, outlining the responsibilities of refinery owners during decommissioning and closure. Furthermore, it explores the potential long-term problems that the DWS may face if private sector owners fail to execute proper decommissioning procedures.

The NWA serves as the cornerstone of water resource management in the country. Sections 19 and 20 of the Act specifically address the decommissioning and closure of industrial facilities, emphasizing the need for responsible water use and environmental protection.

Section 19 of the NWA places a legal obligation on owners of industrial facilities, including oil refineries, to develop and implement decommissioning plans. These plans must outline the steps that will be taken to mitigate the environmental impact during and after closure. Refinery owners are mandated to submit these plans to the DWS for approval. The decommissioning plan should encompass various aspects, including the proper disposal of hazardous waste, restoration of affected water resources, and measures to prevent the release of pollutants into the environment. Compliance with these requirements is crucial to minimizing the long-term environmental impact and protecting the water resources surrounding the refinery.

Section 20 focuses on the responsibility of refinery owners to monitor the environmental impact post-closure. This includes ongoing monitoring of groundwater quality, surface water quality, and any potential contamination that may arise from the decommissioned site. Owners are required to submit regular reports to the DWS, ensuring transparency and accountability in the post-closure phase.

7.2.1.1 Liabilities during decommissioning and closure

The Polluter Pays principle is a fundamental environmental policy concept that holds those responsible for pollution accountable for the costs associated with its remediation and prevention. In the context of the oil refining industry in South Africa and the liabilities outlined in the NWA, the Polluter Pays principle plays a crucial role in shaping the responsibilities of refinery owners during decommissioning and closure. The closure of oil refineries brings forth a myriad of liabilities for the owners under the National Water Act.

Environmental Rehabilitation and Restoration: One of the primary liabilities lies in the proper rehabilitation and restoration of the decommissioned site. Refinery owners must undertake measures to restore the affected water resources, including wetlands, rivers, and groundwater, to their pre-closure state. Failure to do so not only violates the NWA but also poses a significant threat to the surrounding ecosystems and communities that depend on these water sources.

Hazardous Waste Management: The oil refining process generates hazardous waste that, if not managed properly, can contaminate water sources and harm ecosystems. Refinery owners bear the responsibility of safely disposing of hazardous waste in accordance with environmental regulations. Negligence in this regard not only poses immediate risks but can result in long-term water pollution, impacting aquatic life and endangering downstream users.

Prevention of Pollution: During decommissioning, refinery owners must take stringent measures to prevent the release of pollutants into the environment. This includes implementing effective containment measures, such as impermeable barriers and sedimentation ponds, to ensure that contaminants do not reach water bodies. The failure to prevent pollution during decommissioning can lead to severe consequences for water quality, aquatic ecosystems, and human health.

The Polluter Pays principle reinforces the idea that the party responsible for environmental damage, in this case, the owners of decommissioned oil refineries, should bear the financial burden of mitigating and rectifying the harm caused. The NWA aligns with this principle by placing the onus on refinery owners to develop and implement decommissioning plans, monitor post-closure impacts, and take corrective actions.

The costs associated with decommissioning and remediating a decommissioned refinery site can be substantial. The Polluter Pays principle is intended to ensure that these costs are not shifted to the public but are instead borne by the private sector entities responsible for the pollution. Refinery owners must allocate financial resources to execute proper decommissioning plans, manage hazardous waste, and address any environmental damage resulting from the refinery's operations.

By adhering to the Polluter Pays principle, the NWA creates economic incentives for refinery owners to adopt environmentally responsible practices throughout the life cycle of their operations. The prospect of shouldering the financial burden of environmental damage serves as a deterrent against negligent practices and motivates private sector entities to implement sustainable and environmentally friendly measures.

The Polluter Pays principle also helps prevent moral hazard, where companies might be inclined to neglect environmental responsibilities if they believe that the costs of pollution will be borne by society or the government. The NWA, by enforcing the Polluter Pays principle, discourages refinery owners from taking shortcuts during decommissioning and closure, promoting a culture of responsible environmental stewardship.

Adherence to the Polluter Pays principle is not only a legal requirement but also contributes to the public perception of corporate responsibility. Companies that demonstrate a commitment to environmental sustainability and actively engage in responsible decommissioning practices are likely to enhance their reputation, build trust with stakeholders, and contribute positively to their social licence to operate.

7.2.1.2 Government liabilities in the absence of proper decommissioning

If private sector owners neglect their responsibilities during decommissioning and closure, the Department of Water and Sanitation will be burdened with several long-term problems, exacerbating the challenges already faced by South Africa's water sector.

Water Resource Contamination: Improper decommissioning of refineries can result in the release of pollutants into water resources, causing contamination that persists for years. The government would then be compelled to invest substantial resources in remediation efforts to restore the affected water bodies, an undertaking that may prove both time-consuming and financially burdensome.

Public Health Risks: Contaminated water sources pose direct risks to public health. Communities relying on these water bodies for drinking water, agriculture, and other essential needs may face increased health concerns due to exposure to pollutants. The government would be forced to address the health consequences, potentially leading to increased healthcare costs and strained public resources.

Legal and Regulatory Repercussions: The Department of Water and Sanitation has the authority to enforce compliance with the National Water Act. In the absence of proper decommissioning by private sector owners, legal action may be necessary to hold them accountable. This not only consumes government resources but also contributes to prolonged environmental degradation while legal processes unfold.

Impact on Biodiversity and Ecosystems: Water pollution resulting from inadequate decommissioning can have cascading effects on biodiversity and ecosystems. Aquatic life may suffer, and the delicate balance of ecosystems can be disrupted. The government would need to implement conservation and restoration measures to mitigate these ecological impacts, requiring additional investments in biodiversity management.

It is imperative for both the private sector and the government to work collaboratively to ensure that the decommissioning of oil refineries aligns with the principles of sustainable water management. Only through adherence to the NWA and a commitment to responsible environmental stewardship can South Africa navigate the challenges posed by the declining oil refining industry while safeguarding the integrity of its water resources.

7.2.2 Other implications

There are also potential implications for the country's carbon footprint which would differ depending on the sources and types of fuels imported, the transportation and storage methods used, and the demand and consumption patterns of the domestic market. They can be summarised as follows:

Decreased carbon emissions: The closure of the refineries will reduce the direct emissions from the refining process, which accounts for about 10% of the total emissions from crude oil (Gordon and Feldman, 2016). However, this may be offset by the emissions from the production and refining of fuels in other countries, depending on their environmental standards and regulations.

The shift to cleaner fuels will also reduce the local GHG emissions from the combustion of fuels, which accounts for about 75% of the total emissions from crude oil (Gordon and Feldman, 2016). The exact effect will depend on the specifications and standards of the imported fuels, such as sulphur content, octane rating, and biofuel blending. The lower and more consistent the specifications and standards, the lower the emissions.

Increased carbon emissions: Conversely, importing refined petroleum products from abroad could increase the indirect emissions from the transportation and distribution of fuels, which accounts for about 15% of the total emissions from crude oil (Gordon and Feldman, 2016). This will depend on the distance and mode of transportation, such as pipelines, ships, trucks, or trains. The longer and more energy-intensive the transportation, the higher the emissions.

Tighter specifications require more 'intense' refining and hence higher emissions. However tighter specifications also allow for the introduction of newer transport technologies which reduce consumption and emissions with the overall effect of lower GHG emissions.

Impact on local industry: Closing refineries could have economic and social impacts on local communities and the workforce. Depending on the scale and scope of the changes, it could result in job losses and economic disruption. The conversion of refineries to import terminals will require investments in infrastructure and technology to ensure adequate storage capacity, safety, and quality of fuels. This would also entail additional emissions from construction and operation activities.

Impact on fuel demand: The change in fuel supply and prices may affect the demand and consumption patterns of the domestic market (e.g. lowers the number of non-essential personal journeys people take). This may have positive or negative effects on emissions, depending on how consumers respond to changes in fuel availability and affordability. For example, consumers may switch to more efficient or alternative vehicles, or they may drive more or less frequently.

Dependency on international suppliers: South Africa would become more dependent on international suppliers for its energy needs, which could lead to vulnerabilities in energy security and supply chain disruptions in case of global energy market fluctuations or geopolitical conflicts.

Externalising carbon penalties: South Africa has international commitments or agreements related to carbon emissions reduction, and could face penalties or fines for not meeting those targets regardless of where the refining takes place. For example, South Africa is a signatory to the Paris Agreement (UNFCC, 2015), which aims to limit global warming to well below 2°C above pre-industrial levels by 2100. Under this agreement and the Copenhagen Accord (UNFCCC, 2009), South Africa has pledged to reduce its emissions by 34% by 2020 and 42% by 2025 from a business-as-usual scenario. If South Africa does not meet these targets, it may face diplomatic pressure or sanctions from other countries or international bodies. Alternatively, it may have to purchase carbon credits or offsets from other countries or projects that reduce emissions elsewhere.

Therefore, the change of South Africa's oil refineries to import terminals will have mixed impacts on the country's carbon footprint. It could be an opportunity to reduce global emissions by importing cleaner fuels and promoting energy efficiency and diversification. However, it could also be a challenge to manage emissions from fuel transportation and storage, and to balance fuel security and affordability with environmental sustainability. The actual overall impact on the country's carbon footprint would depend on factors such as the precise energy sources used in the refining process abroad and the efficiency of transportation and distribution.

CHAPTER 8: INDUSTRY STATUS IN THE SADC

Due to the disappearing industry in South Africa, this chapter explores the situation in the industry in the Southern African Development Community (SADC) countries, to search for any illustrative examples of potential future routes the South African industry might take.

Oil and Gas Journal publishes a worldwide list of refineries annually in a country-by-country tabulation that includes for each refinery: location, crude oil daily processing capacity, and the size of each process unit in the refinery. For some countries, the refinery list is further categorized state-by-state. The information in this chapter has been sourced from the Oil and Gas Journal website.

8.1 OVERVIEW

The SADC is a Regional Economic Community comprising 16 Member States (Figure 16). It has four operational refineries outside of South Africa (Table 12).

Figure 16: Countries of the SADC (source: https://www.sadc.int/member-states)

Table 12: List of refineries in the SADC

Country	Industry / capacity overview
Angola	Luanda Refinery (Sonangol), 65,000 bbl/d (8900 m³/d)
Botswana	None
Comoros	None
Democratic Republic of Congo	None operational. Muanda Refinery (SOCIR), 15,000 bbl/d (2400 m³/d) (not in working order since 2000)
Eswatini	None
Lesotho	None
Madagascar	None operational. Tomasina Refinery (Galana), 12,000 bbl/d (1900 m³/d) destroyed in Cyclone Geralda 1994
Malawi	None
Mauritius	None
Mozambique	None
Namibia	None
Seychelles	None
Tanzania	Dar es Salaam Refinery (TIPER), 17,000 bbl/d (2700 m³/d), a storage facility only since 2004
Zambia	Indeni Petroleum Refinery, 25,000 bbl/d (4,000 m³/d)
Zimbabwe	None. Invictus Energy, an Australian company, was drilling in the Cabora Bassa Basin but stated in a news release that it had yet to retrieve any oil samples at the time of writing (ZimEye, 2023)

8.2 ANGOLA

There are four oil refineries in Angola, of which only one is operational and two are planned or under construction. The operational refinery is the Luanda Refinery, which has a capacity of 60,000 barrels per day (bpd) and is owned by Sonangol, the national oil company of Angola. The planned or under construction refineries are:

Cabinda Modular Refinery: This refinery is being developed in the Cabinda province, which produces 60% of Angola's oil. It will have a capacity of 60,000 bpd and will produce gasoline, diesel, jet fuel, LPG, bitumen, and fuel oil. It is a joint venture between Gemcorp, a UK-based investment management firm, and Sonaref, a subsidiary of Sonangol. The first phase of the refinery was expected to be commissioned in 2022, but to date has not been commissioned.

Lobito Refinery: Lobito Refinery has been in discussion and planning for ~20 years. It is planned to be built in Lobito city, on the central coast of Angola. Its planned capacity is 200,000 bpd and it is intended to produce gasoline, diesel, jet fuel, LPG, bitumen, fuel oil, and low-sulphur diesel that meets South African (and Euro V) standards. The project was launched in 2008 but suspended in 2016 due to financial constraints. The project was revived in 2019 and is expected to be completed by 2025. Sonangol, Angola’s national oil company (NOC) signed an MoU with the China National Chemical Engineering (CNCEC) to raise funds for the Lobito Refinery project in June 2023.

Soyo Refinery: Planned to be constructed in the Soyo municipality, which is located on the far north coast of Angola. Sovo has a planned capacity of 100,000 bpd and will produce gasoline, diesel, jet fuel, LPG, bitumen, and fuel oil. It will also produce low-sulphur diesel. The project was announced in 2019 and is expected to be completed by 2024.

These refineries are part of Angola's strategy to increase its domestic refining capacity and reduce its dependence on imported petroleum products. Angola currently imports about 70% of its petroleum products. By 2025, Angola could have overtaken South Africa as the region’s biggest refiner based on existing and upcoming projects (ARDA, 2023). In 2022, Angola completed the rehabilitation and expansion of its 65,000 bpd Luanda Refinery, where capacity has more than tripled. It also made progress on the construction of the Cabinda Refinery. Angola relies on the private sector to develop Soyo and Lobito. While the tender for the Soyo facility was already awarded, the one for Lobito should be announced by the end of 2023, marking the start of the country’s biggest refining venture to date. Angola intends to position itself as a regional supply hub, with several pipelines in discussions with its neighbours, including Zambia.

8.3 TANZANIA

TIPER (the acronym for Tanzania International Petroleum Reserves Limited) is a joint venture between the Government of Tanzania and Oryx Energies, a Swiss-based company that specializes in the supply, storage and distribution of oil and gas products in Africa. TIPER is not a refinery, but only a storage facility.

TIPER was born out of the AGIP Refinery, originally built in 1966 and jointly owned by the Government of Tanzania and Agip, an Italian oil company. The refinery had a capacity to process 600,000 tonnes of crude oil per year and produced 30% of the local demand for refined products. In 1999, Oryx Energies acquired Agip's assets in Tanzania and formed a joint venture with the Government of Tanzania to operate the remaining storage facilities.

Although TIPER was a refinery when it was owned by Agip, it was shut down in 2000 due to financial and technical challenges. The facilities underwent major rehabilitation and improvement and became TIPER in 2004. Since then, it has been operating as a storage facility. TIPER does not process any crude oil or produce any refined products. It only imports, stores, and distributes petroleum products to domestic or export markets.

TIPER has a storage capacity of 213,200 cubic metres and can handle gasoline, diesel, jet fuel, LPG, bitumen, and fuel oil for domestic use or export.

8.4 ZAMBIA

Indeni Petroleum Refinery Company Limited (IPRL): This refinery is located in Ndola, Zambia. It is owned by the Government of Zambia and the Government of India. It is the only crude oil refinery in Zambia. It processes light sweet crude oil imported from the Middle East through a pipeline from Dar es Salaam, Tanzania. It produces gasoline, diesel, kerosene, LPG, bitumen, and fuel oil. It does not produce low-sulphur diesel that meets the South African standards, and cannot export to South Africa. The refinery has been operating below its capacity due to frequent breakdowns and maintenance issues. In 2021 the Government of Zambia announced plans to upgrade the refinery to increase its capacity and efficiency by 2023.

8.5 SUMMARY

Several factors are driving the closures of oil refineries in Africa:

The **COVID-19 pandemic**, which temporarily reduced the global and local demand for refined petroleum products, especially in the aviation and transport sectors. This has resulted in lower margins and profitability for the oil refiners, as well as excess supply and storage constraints.

Cleaner fuels policies which are aimed at reducing the sulphur content and improving the quality of refined products. These policies require the oil refiners to upgrade their facilities and equipment, which entails high capital and operational costs. The oil refiners have been unable or reluctant to invest in these upgrades, citing low returns and lack of government support.

The **competition from imported products**, which can be cheaper and more readily available than the domestically produced products. The imported products may also meet the cleaner fuels standards and have lower environmental impacts. African oil refiners have been unable to compete with these imports, especially from Asia and the Middle East, due to their higher production costs and lower efficiency.

Security and safety issues, which have exposed the oil refineries to various risks, such as fire incidents, explosions, vandalism, sabotage, and civil unrest. These incidents have caused damage to refinery infrastructure and equipment, as well as injuries and fatalities to the workers. These incidents have also disrupted the refinery operations and supply chains, leading to temporary or permanent closures.

The energy transition, which is aimed at reducing the dependence on fossil fuels and increasing the use of renewable energy sources, such as solar, wind, hydro, and biofuels. This transition is driven by global efforts to mitigate climate change and its impacts, as well as by the local initiatives to diversify the energy mix and enhance energy security.

Africa as a whole is expected to remain a net importer of refined products for the foreseeable future due to the lack of current capacity and a lack of new refining projects on the continent (ARDA, 2023); 2022 has been described as a point of no return for sub-Saharan Africa's downstream oil and gas industry. By the end of that year, Africa imported over half of the petroleum products it needed to meet the demand of its developing economies and growing populations. While large refining hubs were operational in North Africa, sub-Saharan Africa imported over 90% of its fuel by 2023.

The future of the sector the SADC is thus expected to be dominated by a shift away from refining towards import, storage and distribution of pre-refined products. Such a shift will require increased logistics and haulage capacity for flammable liquids, and strengthened transport infrastructure for road or rail distribution of pre-refined products.

CHAPTER 9: THE BRAZILIAN ENERGY INDUSTRY'S TRANSITION FROM FOSSIL FUELS TO RENEWABES

Brazil was selected as an example with regard to its oil industry's adjustment from fossil-fuel derived liquid fuels to fuels derived from renewable sources. The choice was driven by its similarities with South Africa.

Oil refining in Brazil has faced a major challenge to adapt to the shift from fossil fuels to biofuels. Brazil is one of the largest oil producers and consumers in the world, but has also developed a strong tradition of using biofuels, especially ethanol from sugarcane, as a transport fuel. Brazil has several national strategies to cope with the changing energy landscape, as follows (Szklo and Schaeffer, 2007):

- Developing new technologies and processes to produce biofuels from different feedstocks, such as cellulosic ethanol from bagasse, biodiesel from palm oil, and biogas from urban waste (IEA Bioenergy, 2021).

- Investing in research and innovation to improve the efficiency and sustainability of biofuel production and use, such as reducing greenhouse gas emissions, water consumption, and land use (BP, 2018; IEA Bioenergy, 2021).

- Expanding the domestic and international markets for biofuels, by increasing the mandatory blending of ethanol and biodiesel in gasoline and diesel, promoting the use of flex-fuel vehicles that can run on any blend of ethanol and gasoline, and exporting biofuels to other countries (BP, 2023; Duran, 2013; IEA Bioenergy, 2021).

- Diversifying the oil portfolio to include more renewable sources, such as wind, solar, and biomass power generation, as well as natural gas and biofuels (BP, 2023).

- Enhancing the regulatory framework and policy incentives over the past decade to support the development and deployment of biofuels, such as the National Biofuels Policy (RenovaBio), which aims to increase the production and consumption of biofuels in a competitive, sustainable, and predictable manner (Duran, 2013; IEA Bioenergy, 2021).

These strategies were designed to help Brazil achieve its energy security, environmental, and economic goals, while maintaining its position as a global leader in biofuels.

Brazil is now known for its biofuel industry, especially in the production of ethanol from sugarcane. Over the years, the country has made significant strides in transitioning towards liquid fuels from renewables, primarily due to a combination of economic, environmental, and policy drivers. The Brazilian government, in collaboration with oil companies, has played a pivotal role in this transition by providing drivers for change in the industry.

9.1 DRIVERS FOR TRANSITION

Seven factors have driven Brazil's transition towards renewables:

1. Economic Viability: One of the primary drivers for Brazil's transition towards renewables is the economic viability of biofuels, particularly ethanol produced from sugarcane. Sugarcane ethanol has been a cost-effective and competitive alternative to gasoline, which has driven its widespread

adoption. Additionally, Brazil's abundance of arable land and favourable climate conditions for sugarcane cultivation have contributed to the economic attractiveness of this renewable fuel.

2. Energy Security: Reducing dependence on imported fossil fuels has been a key driver for Brazil. By promoting domestically produced renewable fuels, the country has aimed to enhance its energy security, reduce trade deficits, and insulate itself from volatile international oil markets.

3. Environmental Sustainability: The environmental benefits of transitioning to renewable liquid fuels cannot be overstated. Sugarcane ethanol is considered a significantly cleaner alternative to fossil fuels, with lower greenhouse gas emissions. This aligns with global efforts to combat climate change and reduce the carbon footprint of the transportation sector.

4. National Biofuel Program (RenovaBio): The Brazilian government introduced the RenovaBio program to promote the use of biofuels, including ethanol from sugarcane. The program provides economic incentives and a certification scheme to encourage biofuel production and consumption. It has created a structured market for biofuels, stimulating investments in the sector.

5. Market Demand and Consumer Preference: As consumers become more environmentally conscious, there is a growing demand for cleaner fuels. Ethanol from sugarcane has gained popularity among Brazilian consumers, both for its lower cost and environmental benefits. The positive perception of ethanol has driven market demand and encouraged oil companies to invest in this sector.

6. Technological Advancements: Continuous research and development in the field of biofuels have resulted in improved technology and processes for biofuel production. Innovations have made it more efficient and cost-effective to produce ethanol from sugarcane, making it an attractive option for oil companies. Brazil has also implemented regulation to facilitate innovation, which could be an enabler not only for water efficiency but also energy efficiency, especially in the space of renewables.

7. Geopolitical Factors: Reducing Brazil's dependence on fossil fuel imports has geopolitical implications. By promoting the use of domestically produced renewable fuels, Brazil aims to strengthen its geopolitical position and reduce external influences on its energy security.

The primary enabling factor was that the main oil refiner in Brazil is Petrobras, the state-owned company that accounts for over 82% of Brazil's oil and gas production and owns 14 of the country’s 18 refineries (Statista, 2021b). The other four are owned and operated by Univen Petróleo, Dax-Oil, Grupo Peixoto de Castro and Refinaria Riograndense.

The creation of the SANPC provides a close parallel with Petrobras and using similar but contextualised policies could enable South Africa to make an equally successful switch to biofuel-dominate transport fuel usage over the coming decade that would moderate the effects of inflation.

9.1.1 RenovaBio

The RenovaBio programme is a national biofuels policy that was launched in 2017 by the Brazilian government. Its main objective is to ensure an adequate expansion of renewable fuels in the Brazilian energy matrix, based on more sustainable production models in line with Brazil’s Nationally Determined Contribution (NDC) under the Paris Climate Agreement. The programme is designed to support the country’s commitments to reduce greenhouse gas emissions by 43 percent by 2030 compared to 2005 levels (USDA, 2021).

The programme is guided by annual goals, which are set by Brazil's National Energy Policy Council (CNPE), based on the projections of biofuel demand and supply in the country. The goals are expressed in terms of carbon intensity reduction for the transport sector, which reflects the amount of carbon emissions per unit of energy consumed. The programme aims to achieve a 10.1 percent reduction in carbon intensity by 2028, compared to 2017 levels (Rabobank, 2017; USDA, 2021).

The programme operates through a market-based mechanism, which involves the creation and trading of decarbonization credits (CBIOs). Each CBIO represents one ton of carbon dioxide equivalent that was avoided by using biofuels instead of fossil fuels. The CBIOs are generated by biofuel producers, who must have their production process certified by an accredited entity and validated by the National Agency of Petroleum, Natural Gas and Biofuels (ANP). The certification process evaluates the energy-environmental efficiency and sustainability of the biofuel production, based on a lifecycle analysis that considers the emissions from feedstock cultivation, processing, transport, and use. The more efficient and sustainable the production, the higher the number of CBIOs generated per unit of biofuel produced.

The CBIOs are traded on the stock exchange and can be purchased by any agent, such as individuals, companies, or institutions. However, the main buyers of CBIOs are fuel distributors, who are obligated to meet individual emission reduction targets, proportional to their market share of fossil fuels. The targets are set by the CNPE and enforced by the ANP. The fuel distributors must prove their compliance with their targets by acquiring and retiring a corresponding number of CBIOs every year.

The programme is expected to prevent the release of more than 600 million tons of carbon dioxide equivalent into the atmosphere over the next 10 years, by increasing the use of renewable fuels from primary resources in the transport sector. The programme also aims to stimulate the development and innovation of the biofuel industry in Brazil, creating value addition and employment opportunities, as well as enhancing energy security and diversification.

9.2 ACTIONS TAKEN BY OIL COMPANIES

The oil companies in Brazil have taken concrete actions to transition towards renewables, particularly through the production and distribution of biofuels like sugarcane ethanol.

Diversification of Product Portfolios: Oil companies have diversified their product portfolios to include biofuels. Many have invested in building or acquiring ethanol production facilities, leveraging the expertise of Brazilian sugar and ethanol producers.

Blending Ethanol: Most gasoline sold in Brazil contains a certain percentage of ethanol (typically E27, meaning it contains 27% anhydrous ethanol), a blending strategy that reduces the carbon footprint of gasoline. Oil companies have actively engaged in ethanol blending to meet regulatory requirements.

Biofuel Partnerships: Oil companies have entered into partnerships with sugarcane producers and biofuel manufacturers to secure a reliable source of ethanol. These partnerships often involve vertical integration, with some oil companies owning and operating their own sugarcane fields and processing plants.

Investment in Refining Infrastructure: Private and public investment has gone into refining infrastructure capable of processing biofuels efficiently. This involves retrofitting refineries and upgrading them to handle the production of renewable liquid fuels.

Market Expansion: Oil companies have expanded their presence in the renewable fuel market by establishing biofuel distribution networks and opening new gas stations that exclusively sell ethanol or ethanol blends.

Certification and Compliance: Oil companies have ensured compliance with RenovaBio certification requirements, which involve reducing greenhouse gas emissions in their fuel production processes.

9.2.1 When and why oil companies took action

Oil companies in Brazil began to actively explore the transition to liquid fuels from renewables, including biofuels from sugarcane, over the last two decades. This period saw a confluence of factors that made this transition attractive. The length of time required to make the transition in Brazil demonstrates the level of commitment required to change national priorities and how long it takes to before policy impact occurs on the ground. It demonstrates the need for bold and visionary decision-making by government, and commitment on and behalf of the sector to remain sustainably and globally competitive. This is an example of a just transition from which South Africa could draw some lessons for its own TIPS.

The Brazilian government, recognizing the potential of renewable fuels, introduced programs and incentives to encourage the adoption of biofuels. These included tax benefits, regulatory mandates, and the RenovaBio program, which established a market for CBIOs to reward carbon emissions reduction in biofuel production.

The growing environmental awareness among consumers and the desire for cleaner fuels led oil companies to respond to the market demand for ethanol. Ethanol had already become a significant component of the Brazilian gasoline blend, and oil companies aimed to capitalize on this consumer preference.

Sugarcane ethanol became economically competitive with fossil fuels, thanks to advancements in sugarcane cultivation, ethanol production processes, and efficient supply chains. The cost-effectiveness of biofuels made them a viable option for oil companies to explore.

Oil companies recognized that reducing carbon emissions was a global imperative, and investments in cleaner energy sources could enhance their environmental and social responsibility credentials.

Brazil’s aim to reduce dependence on fossil fuel imports, enhance energy security, and insulate the country from international oil price fluctuations provided a strong motivation for oil companies to invest in domestic biofuel production.

While the transition to liquid fuels from renewables has been driven by these factors, certain barriers and challenges have also emerged.

9.2.2 Barriers and Challenges

The primary barrier has been investment costs. Transitioning to renewable liquid fuels requires substantial investments in refining infrastructure and technology. Oil companies needed to commit significant capital to retrofit or build new facilities for biofuel production. The production of sugarcane ethanol also involves a complex supply chain, from cultivation to processing. Managing this chain efficiently and ensuring a consistent supply of ethanol can be challenging for oil companies.

The market for biofuels in Brazil is highly competitive, with many players involved in the production and distribution of ethanol. Oil companies face competition not only from other oil majors but also from dedicated biofuel producers. While sugarcane ethanol is cost-competitive, market dynamics and fluctuations in global oil prices can impact the economic viability of biofuels. Maintaining profitability in the biofuel sector is a challenge in the face of economic uncertainties.

The environmental impact of biofuel production, particularly in terms of land use and water resources, can be a concern. Balancing the environmental benefits with potential negative effects is an ongoing challenge.

9.3 RELEVANCE TO SOUTH AFRICA

Both Brazil and South Africa are middle income countries, are members of the BRICS (Brazil, Russia, India, China, and South Africa) trade and investment bloc, are significant economies in their regions, have similar development aspirations, and grapple with social inequalities. Like South Africa, 45% of Brazil's population lives without sanitation treatment services, and both countries demonstrate a precariousness of state utilities' budgets and public investments in the water and energy utility sectors

Like South Africa, Brazil's goal is to attract foreign investment in public infrastructure through partial concessions and PPP arrangements. The Lula da Silva government is interested in attracting private investment as well as supporting state-owned utilities.

The economic conditions prior to Brazil's biofuels transition were not exactly the same as South Africa's. Brazil had excess cane sugar with no market, therefore government policy to enable the use of vehicle flex fuels with up to 80% ethanol content provided market pull for ethanol produced from sugar. Although South Africa does not have such a large sugar excess, it does have plentiful cane sugar, and the market for sugar for human consumption has been shrunk by the implementation of sugar tax on food and beverages. Current regulations limit the amount of ethanol in liquid fuels to 10%, but policy adjustments and seed investment from government may be a means by which to decouple transport costs from oil prices, and use the circular economy for some of the country's transport needs.

CHAPTER 10: CONCLUSIONS AND RECOMMENDATIONS

10.1 CONCLUSIONS

South Africa’s oil refining industry is in a probably irreversible decline. Three refineries were operational (Astron, Natref, and Secunda CTL), with three asset owners (Sasol, TotalEnergies, and Astron Energy). Their SWI and SEV values have been inferred from the limited primary data that were available plus secondary data in the public domain, but as some of the primary data required for the calculations are non-existent or not available, firm conclusions cannot be drawn.

The operational refineries have implemented water conservation and water demand measures both inside and outside their factory fences, including water submetering, condensate recovery, rainwater harvesting, increased cooling tower cycles, and water recycling. They have paid attention to energy efficiency by investing in energy submetering and heat recovery. One has embarked on carbon footprinting.

The international trend is towards a lower water demand for refined oil products, driven by a combination of rising water prices and insecurity of water supplies, and a higher energy demand, driven by more stringent environmental regulations for the quality of liquid fuels. South Africa is subject to the same drivers as the rest of the world; it is therefore reasonable to predict that lower SWI and higher energy demand in 2023 compared with when the first edition was published (2005) would be the case.

10.2 RECOMMENDATIONS FOR FUTURE WORK

At the outset of this project, we intended to conclude by provide recommendations on the best practice for this industry to adopt in the foreseeable future. With only three refineries left in operation and the futures of two of those uncertain, this section has refocused on recommendations for the next edition of NATSURV 15:

1. List South Africa’s operational crude oil refineries, CTL, and GTL refineries.

2. Provide a summary of the sources of South Africa’s liquid fuels (e.g. refined domestically, imported, produced by recycling and re-refining), including the relative proportions of the supply from each, and the expected stability of supply (based on factors such as the presence or absence of bilateral or other long term governmental trade agreements).

3. Document the processes of import, storage and distribution of refined petroleum products and the value chain's impact on water efficiencies.

Oil recycling is challenged by the lack of awareness and education among the public and stakeholders about the benefits and opportunities of oil recycling. There is a need for more innovation to improve the technologies and processes for oil recycling, as well as to develop new products and markets from recycled oils. There is also a need for more policy support and incentives to encourage oil recycling in South Africa.

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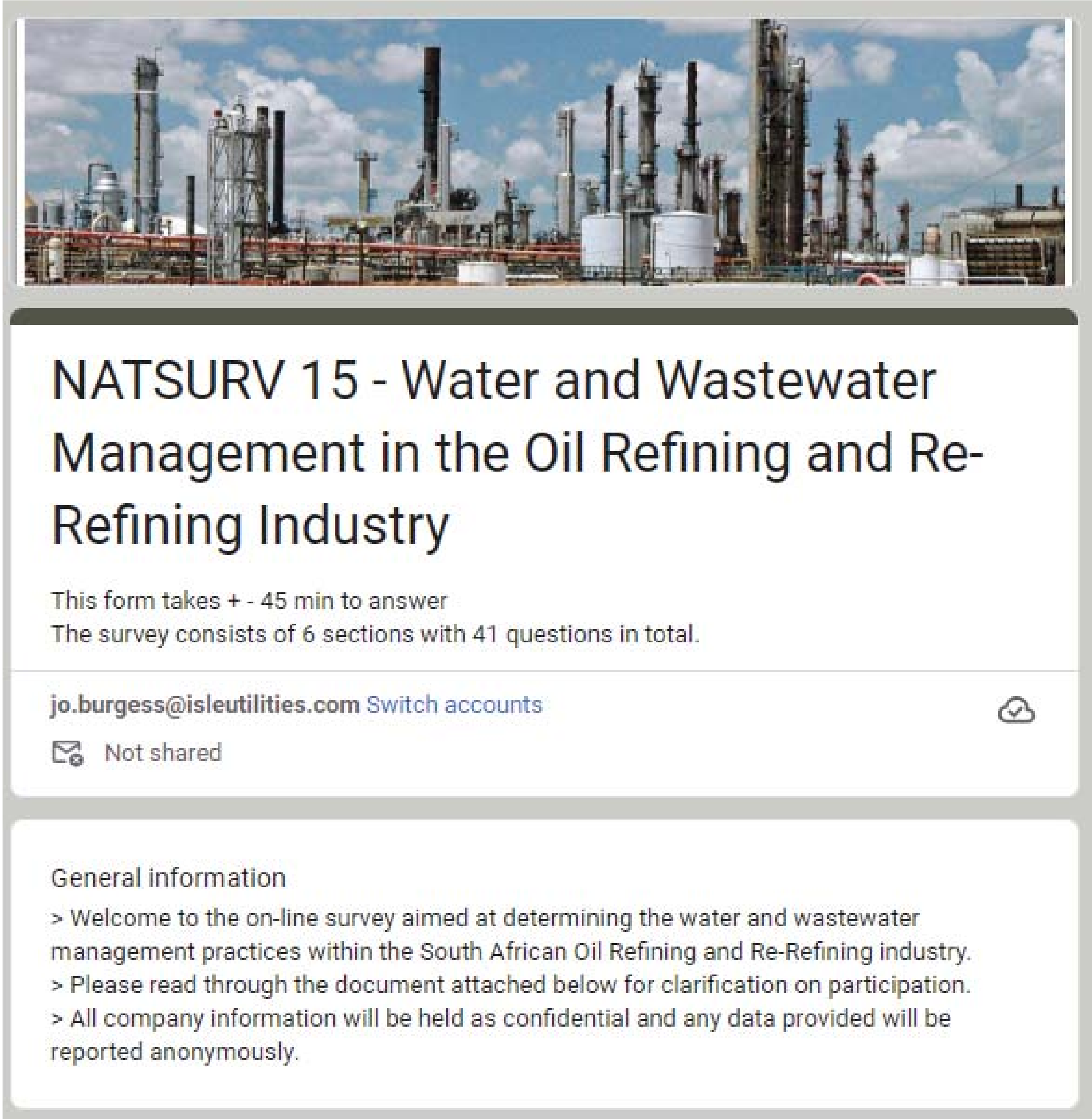
APPENDIX A: QUESTIONNAIRE



NATSURV 15 - Water and Wastewater Management in the Oil Refining and Re-Refining Industry

This form takes + - 45 min to answer
The survey consists of 6 sections with 41 questions in total.

jo.burgess@isleutilities.com Switch accounts

Not shared

General information

> Welcome to the on-line survey aimed at determining the water and wastewater management practices within the South African Oil Refining and Re-Refining industry.
> Please read through the document attached below for clarification on participation.
> All company information will be held as confidential and any data provided will be reported anonymously.

WATER
RESEARCH
COMMISSION

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11 MAY 2022

Dear Stakeholder

Request for participation: National Survey (Natsurv) research project titled "Water and wastewater management in the oil refining and re-refining industry".

In the 1980s the Water Research Commission (WRC) and Department of Water and Sanitation (DWS) embarked on a series of national surveys (Natsurvs). The purpose of the Natsurvs was to document a snapshot of current water use and wastewater generation and management within a particular industry. This project intends to update Natsurv 15 on water and wastewater management in the oil refining and re-refining industry, published in 2005.

Your organization has been identified as an important stakeholder in this industry, and we would like to humbly request for your assistance to the project team, led by Prof Joanna Burgess at Isle Utilities in collaboration with the University of Cape Town. The requested assistance will include granting permission to the project team to access your organization datasets in support of the current project.

Although the report will be published at the end of the project, it is important that you are aware that **your organization datasets will not be published**, nor even reported to the WRC. The project team will hold the information in confidence and the records will be deleted at the end of the contract.

You will also be provided with a preview of the report prior to its final copy-editing and publication.

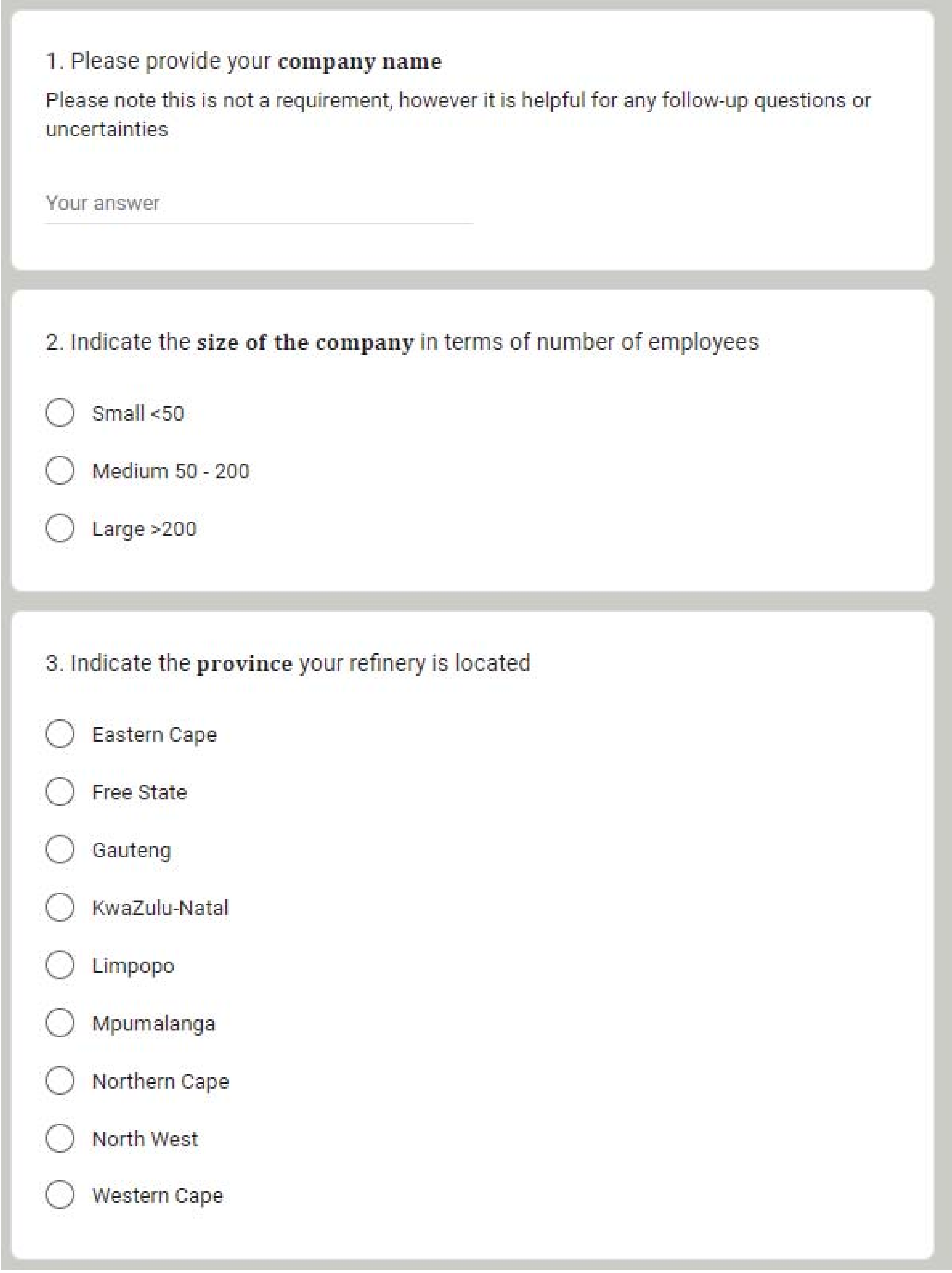
Your support of the project team as requested is appreciated in advance, and do not hesitate to contact the WRC for any further clarification regarding this request.

Yours sincerely

John Ngoni Zvimba

Prof John Ngoni Zvimba
Research Manager: Sustainable Integrated Wastewater Resources Futures
KSA3: Water Use, Wastewater and Sanitation Futures

Supporting sustainable development through research funding, knowledge creation and dissemination



1. Please provide your **company name**

Please note this is not a requirement, however it is helpful for any follow-up questions or uncertainties

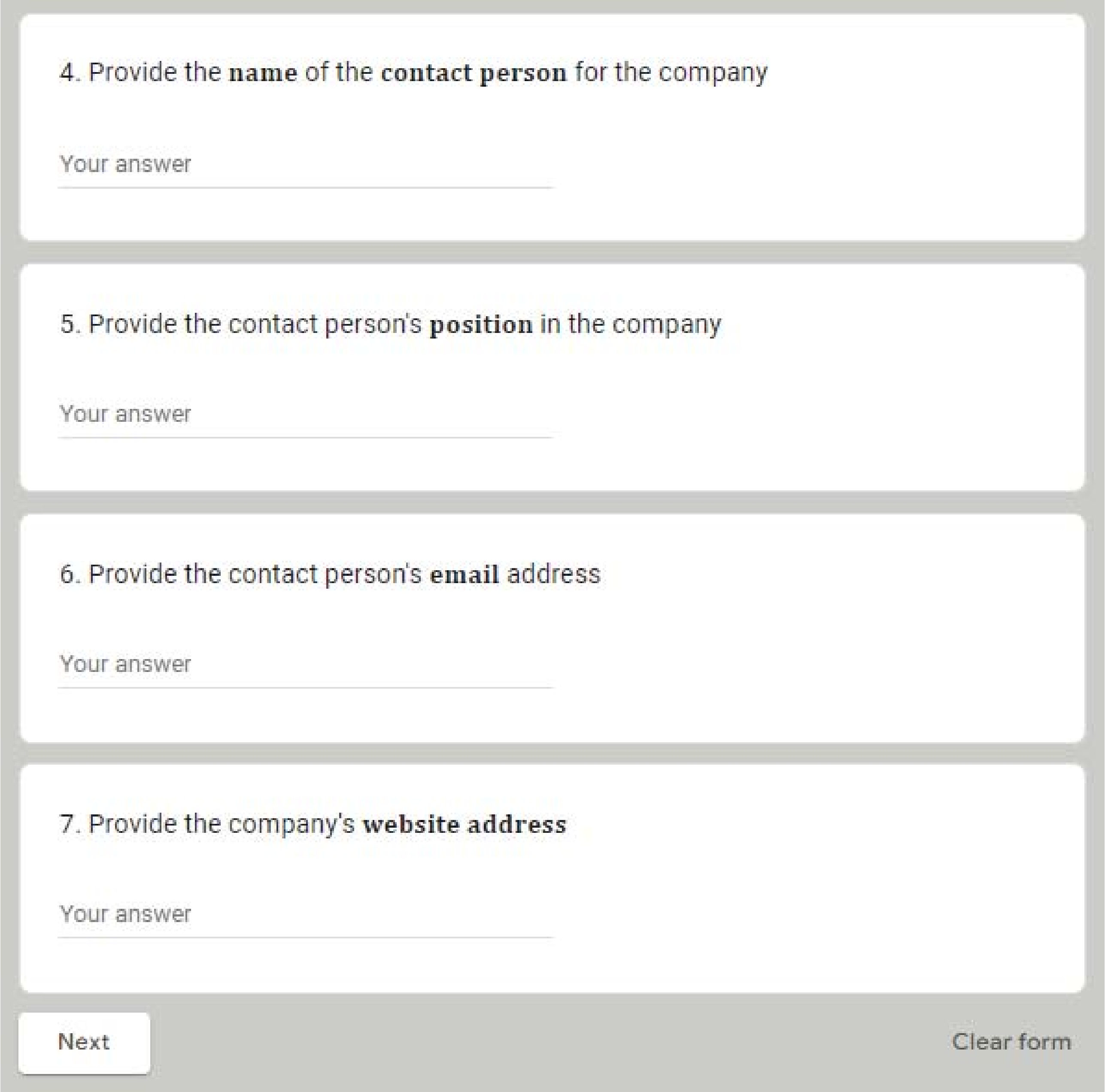
Your answer

2. Indicate the **size of the company** in terms of number of employees

- ○ Small <50
- ○ Medium 50 - 200
- ○ Large >200

3. Indicate the **province** your refinery is located

- ○ Eastern Cape
- ○ Free State
- ○ Gauteng
- ○ KwaZulu-Natal
- ○ Limpopo
- ○ Mpumalanga
- ○ Northern Cape
- ○ North West
- ○ Western Cape



4. Provide the **name** of the **contact person** for the company

Your answer

5. Provide the contact person's **position** in the company

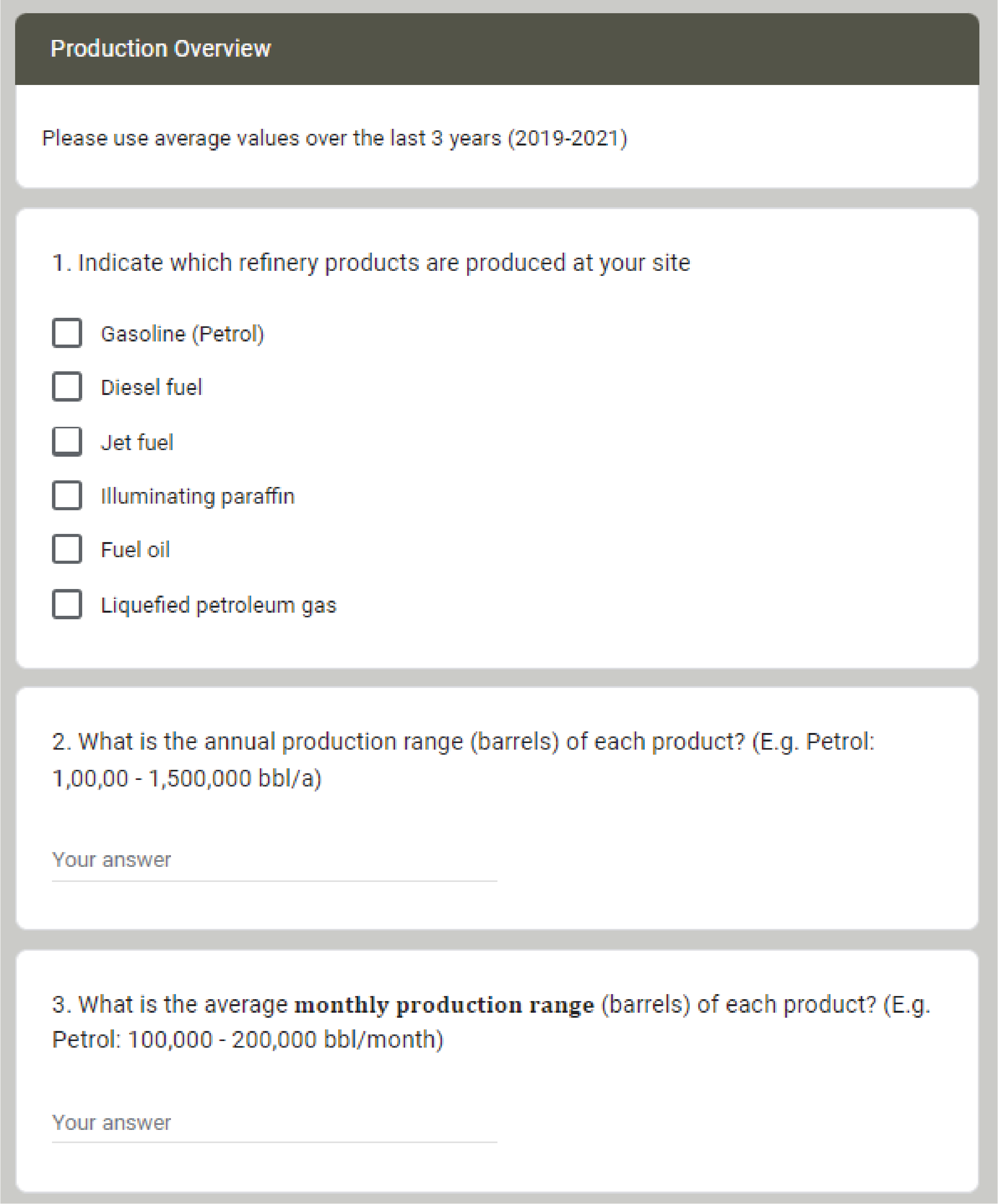
Your answer

6. Provide the contact person's **email** address

Your answer

7. Provide the company's **website address**

Your answer



Production Overview

Please use average values over the last 3 years (2019-2021)

1. Indicate which refinery products are produced at your site

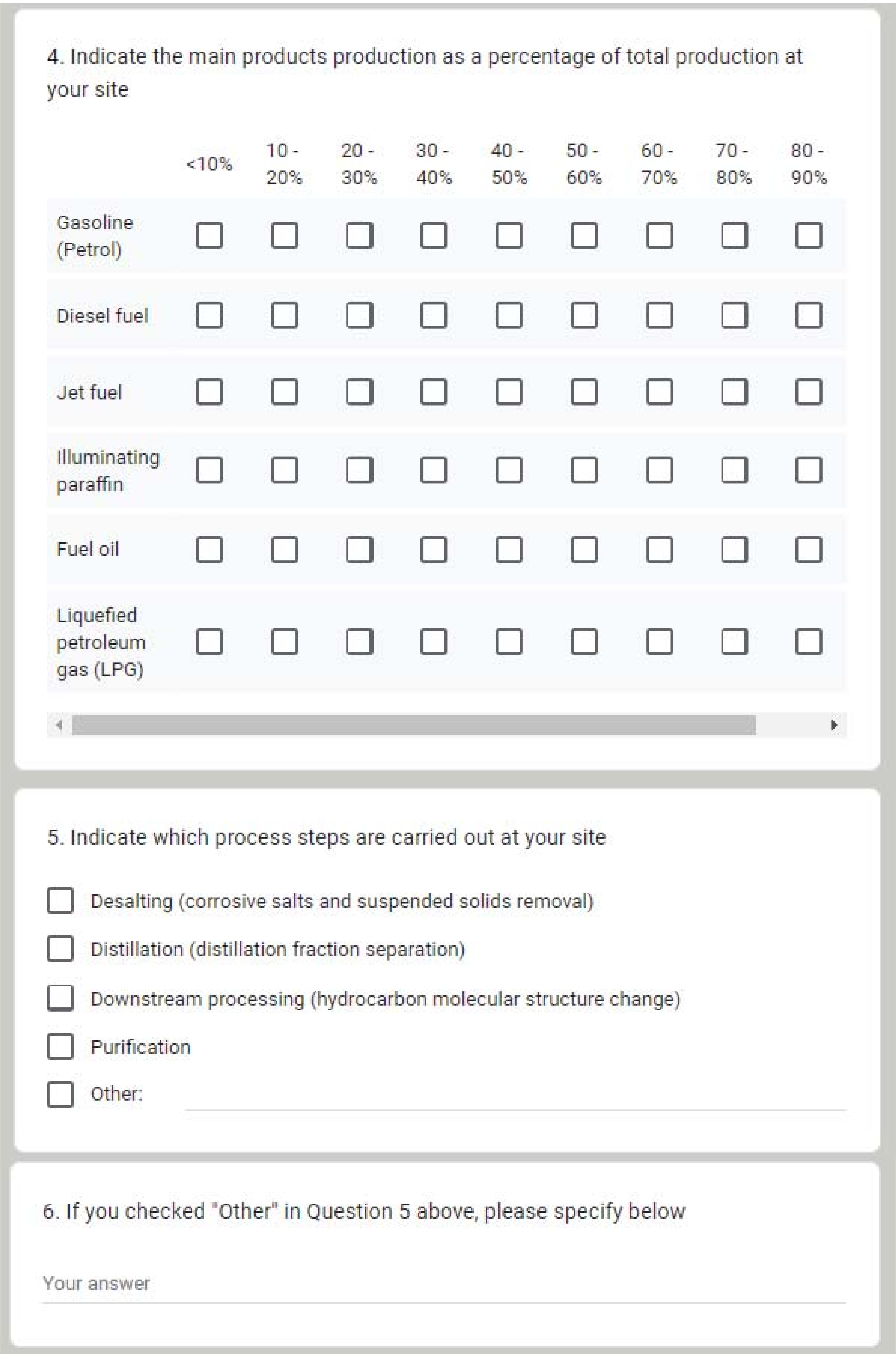
☐ Gasoline (Petrol)
☐ Diesel fuel
☐ Jet fuel
☐ Illuminating paraffin
☐ Fuel oil
☐ Liquefied petroleum gas

2. What is the annual production range (barrels) of each product? (E.g. Petrol: 1,00,00 - 1,500,000 bbl/a)

Your answer

3. What is the average **monthly production range** (barrels) of each product? (E.g. Petrol: 100,000 - 200,000 bbl/month)

Your answer



4. Indicate the main products production as a percentage of total production at your site

	<10%	10 - 20%	20 - 30%	30 - 40%	40 - 50%	50 - 60%	60 - 70%	70 - 80%	80 - 90%
Gasoline (Petrol)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Diesel fuel	☐	☐	☐	☐	☐	☐	☐	☐	☐
Jet fuel	☐	☐	☐	☐	☐	☐	☐	☐	☐
Illuminating paraffin	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fuel oil	☐	☐	☐	☐	☐	☐	☐	☐	☐
Liquefied petroleum gas (LPG)	☐	☐	☐	☐	☐	☐	☐	☐	☐

5. Indicate which process steps are carried out at your site

☐ Desalting (corrosive salts and suspended solids removal)

☐ Distillation (distillation fraction separation)

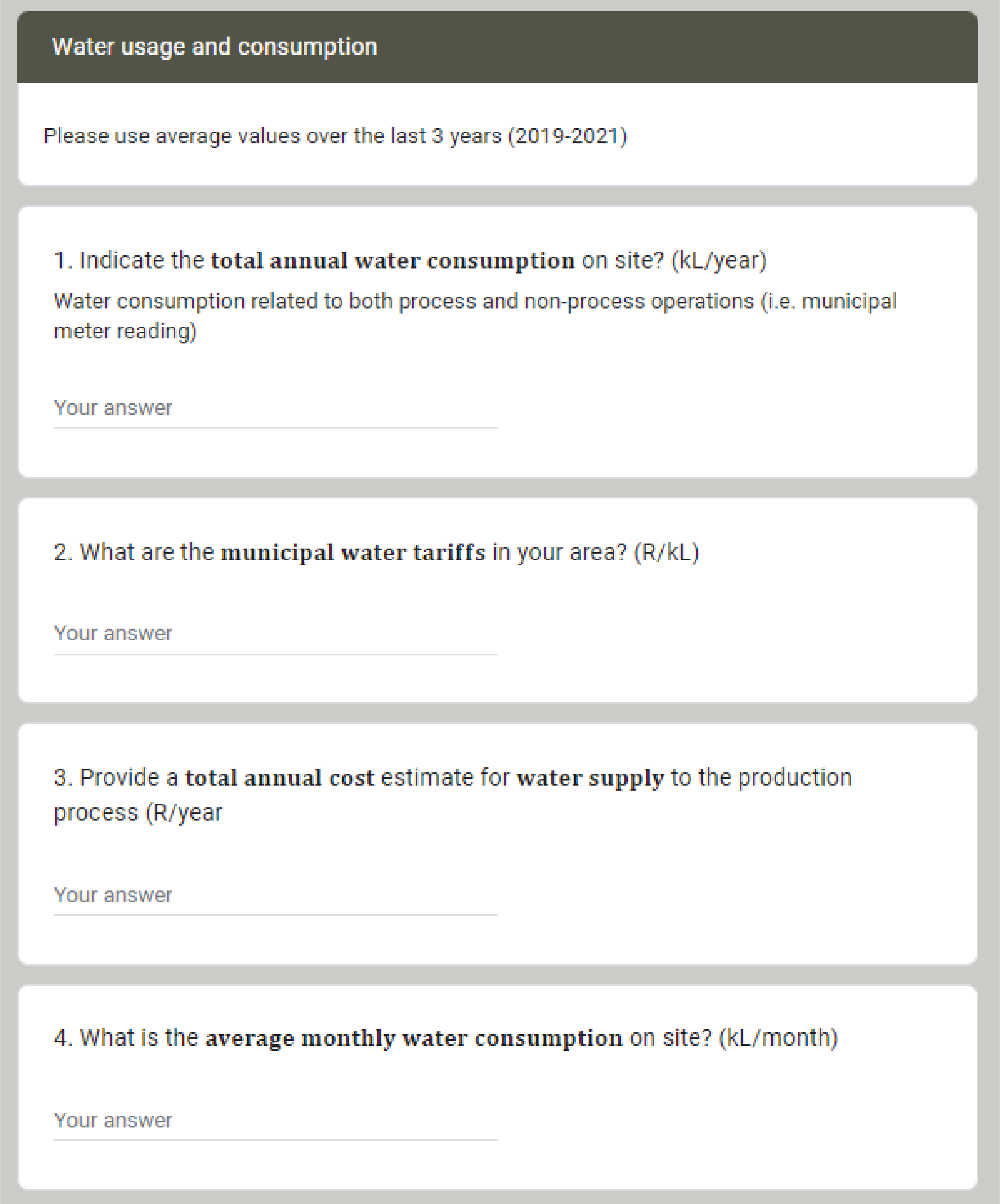
☐ Downstream processing (hydrocarbon molecular structure change)

☐ Purification

☐ Other: __________

6. If you checked "Other" in Question 5 above, please specify below

Your answer __________



Water usage and consumption

Please use average values over the last 3 years (2019-2021)

1. Indicate the **total annual water consumption** on site? (kL/year)

Water consumption related to both process and non-process operations (i.e. municipal meter reading)

Your answer

2. What are the **municipal water tariffs** in your area? (R/kL)

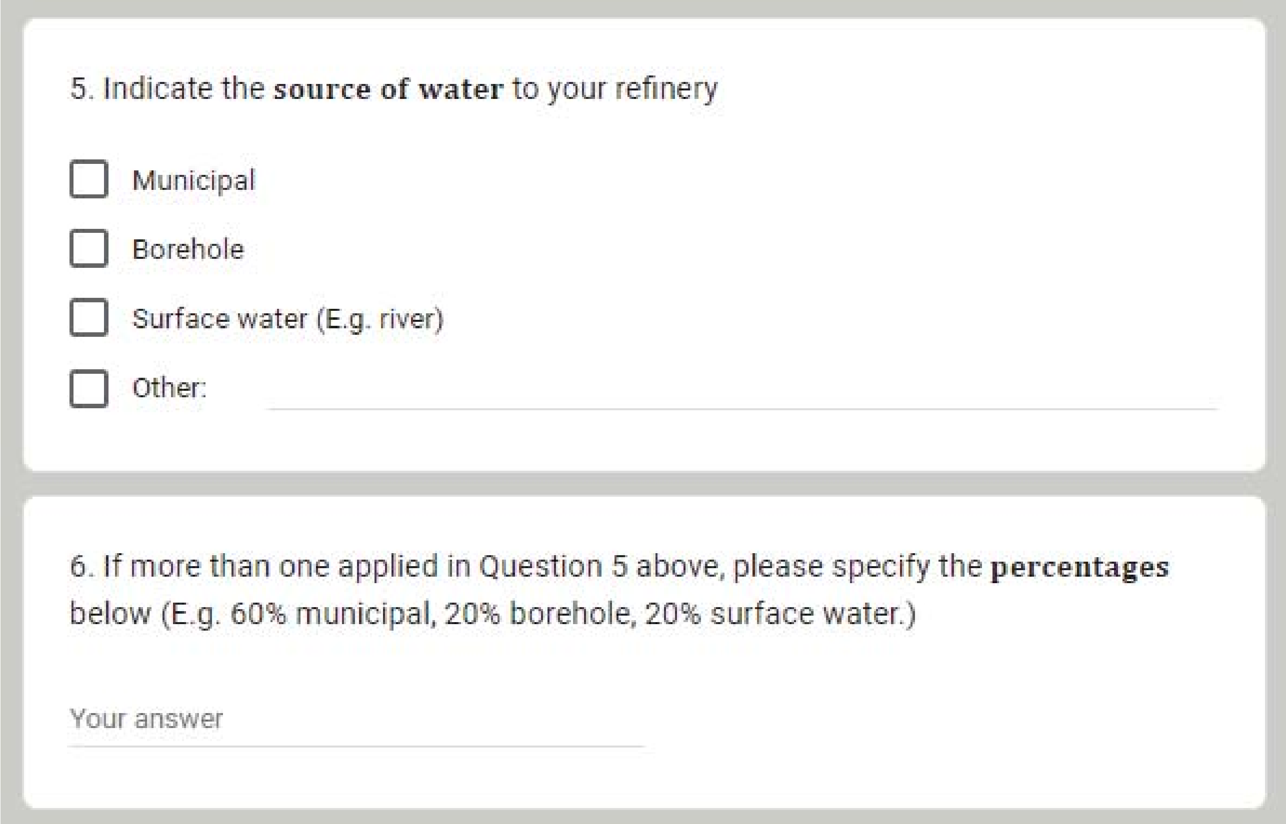
Your answer

3. Provide a **total annual cost** estimate for **water supply** to the production process (R/year

Your answer

4. What is the **average monthly water consumption** on site? (kL/month)

Your answer



5. Indicate the **source of water** to your refinery

☐ Municipal

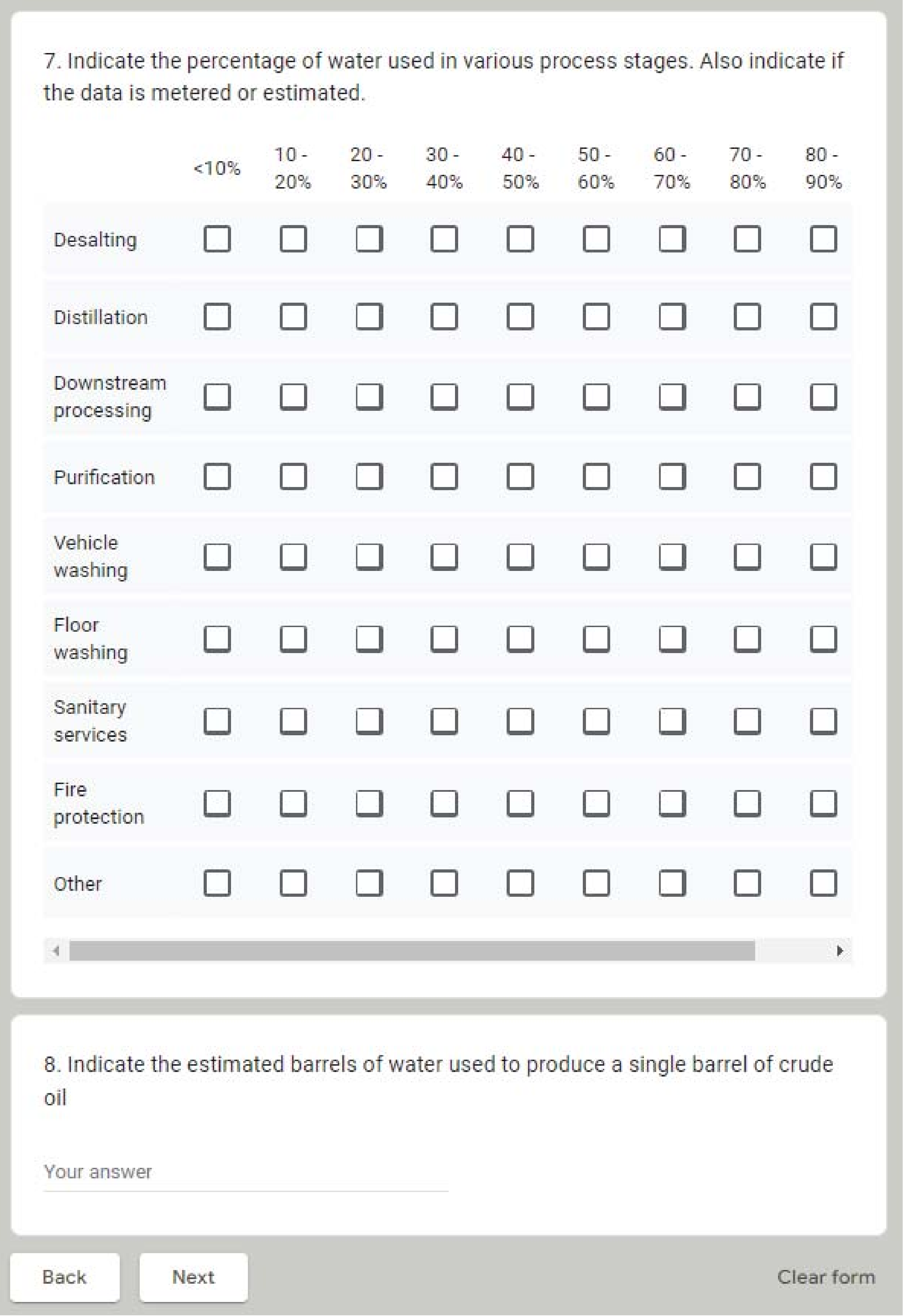
☐ Borehole

☐ Surface water (E.g. river)

☐ Other: ____________________

6. If more than one applied in Question 5 above, please specify the **percentages** below (E.g. 60% municipal, 20% borehole, 20% surface water.)

Your answer ____________________

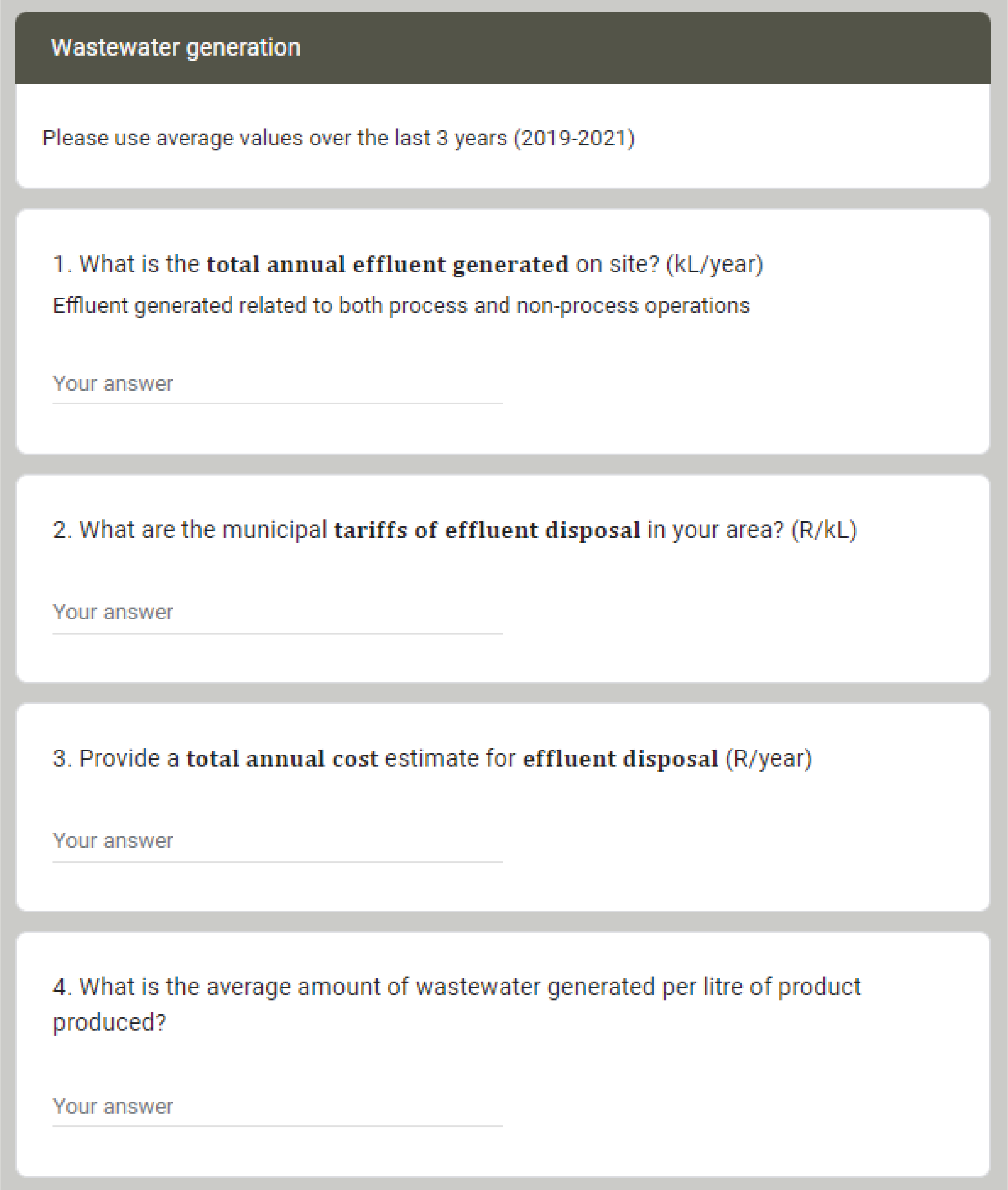


7. Indicate the percentage of water used in various process stages. Also indicate if the data is metered or estimated.

	<10%	10 - 20%	20 - 30%	30 - 40%	40 - 50%	50 - 60%	60 - 70%	70 - 80%	80 - 90%
Desalting	☐	☐	☐	☐	☐	☐	☐	☐	☐
Distillation	☐	☐	☐	☐	☐	☐	☐	☐	☐
Downstream processing	☐	☐	☐	☐	☐	☐	☐	☐	☐
Purification	☐	☐	☐	☐	☐	☐	☐	☐	☐
Vehicle washing	☐	☐	☐	☐	☐	☐	☐	☐	☐
Floor washing	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sanitary services	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fire protection	☐	☐	☐	☐	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐	☐	☐	☐	☐

8. Indicate the estimated barrels of water used to produce a single barrel of crude oil

Your answer



Wastewater generation

Please use average values over the last 3 years (2019-2021)

1. What is the **total annual effluent generated** on site? (kL/year)

Effluent generated related to both process and non-process operations

Your answer

2. What are the municipal **tariffs of effluent disposal** in your area? (R/kL)

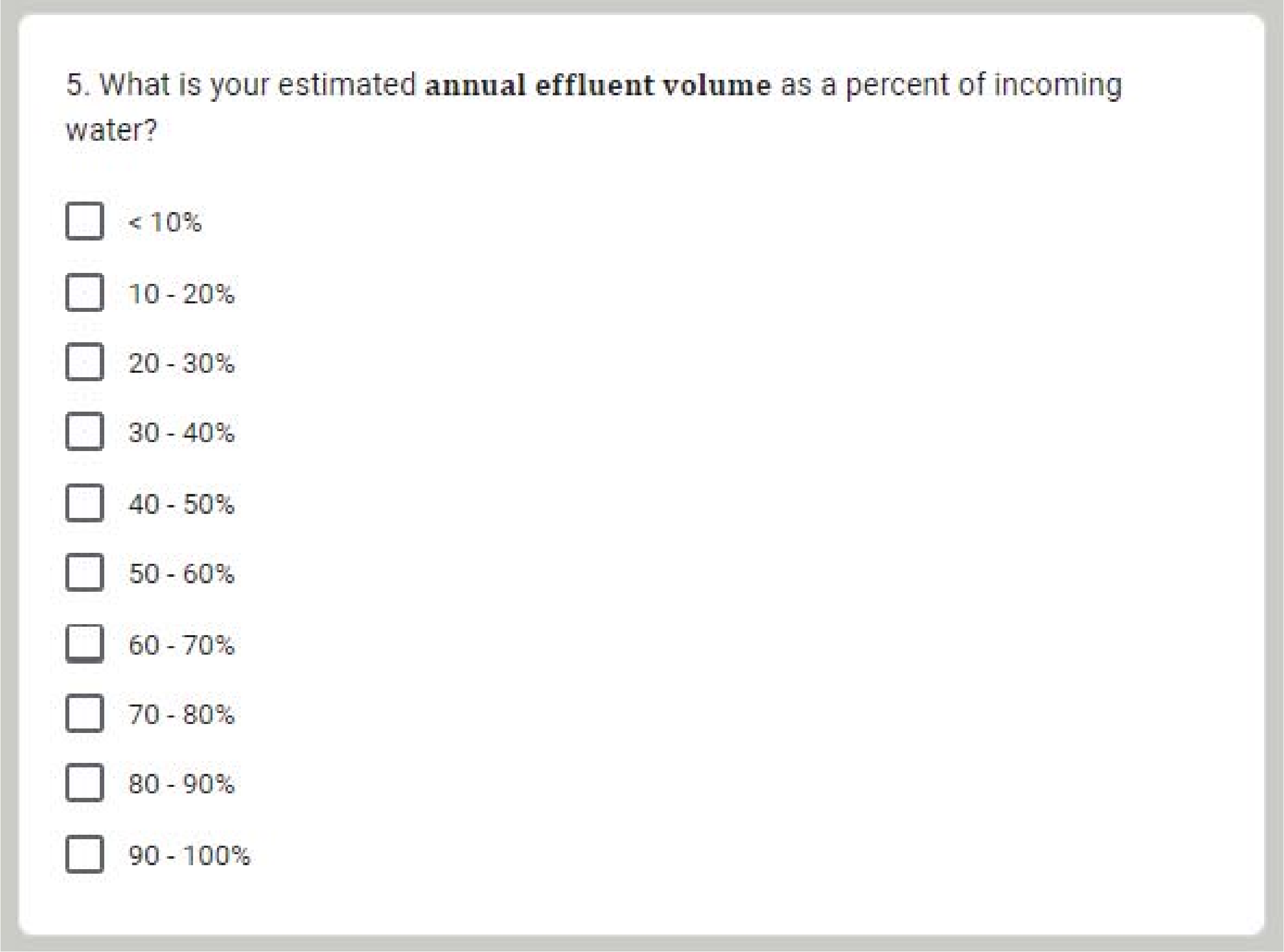
Your answer

3. Provide a **total annual cost** estimate for **effluent disposal** (R/year)

Your answer

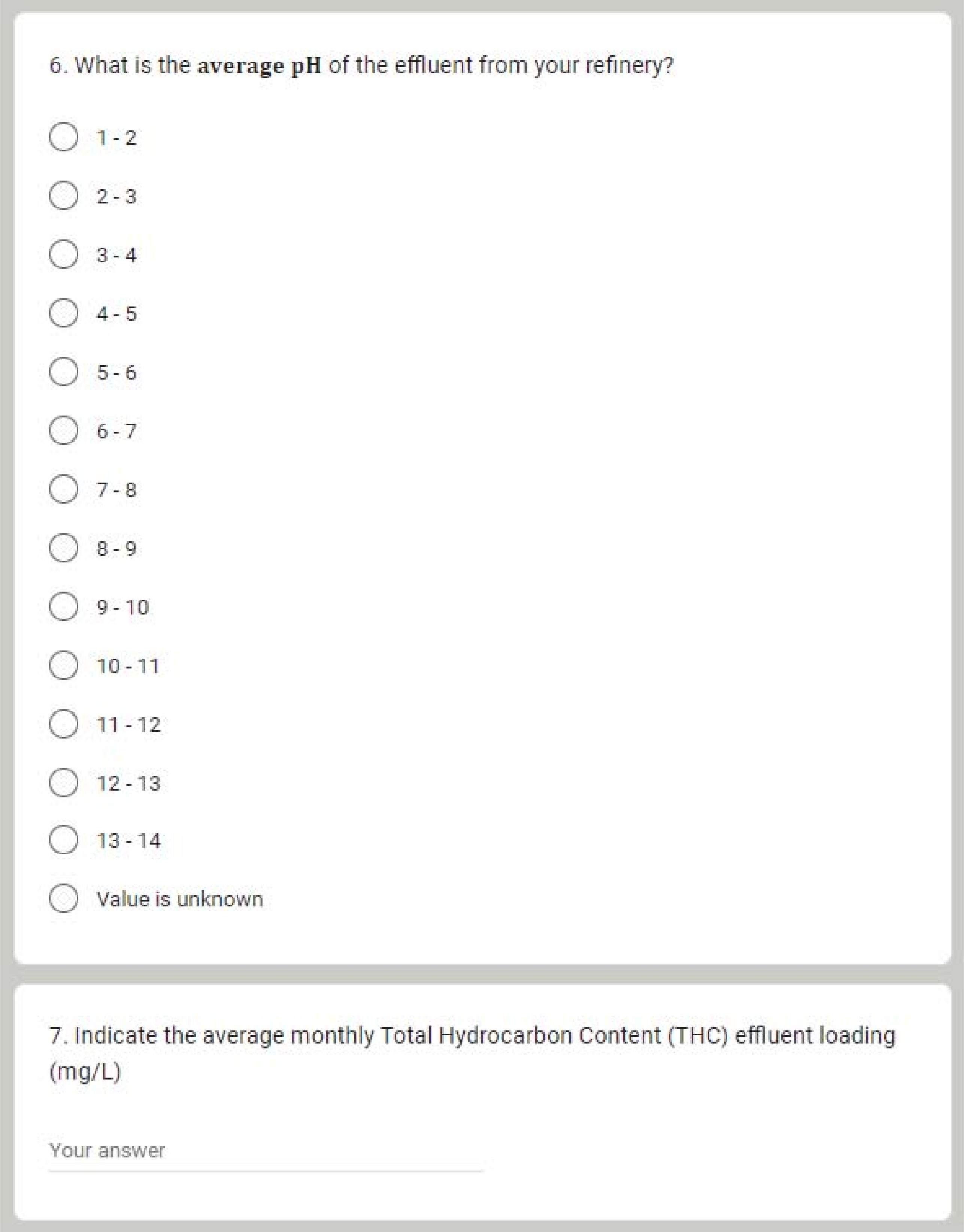
4. What is the average amount of wastewater generated per litre of product produced?

Your answer



5. What is your estimated **annual effluent volume** as a percent of incoming water?

- ☐ < 10%
- ☐ 10 - 20%
- ☐ 20 - 30%
- ☐ 30 - 40%
- ☐ 40 - 50%
- ☐ 50 - 60%
- ☐ 60 - 70%
- ☐ 70 - 80%
- ☐ 80 - 90%
- ☐ 90 - 100%

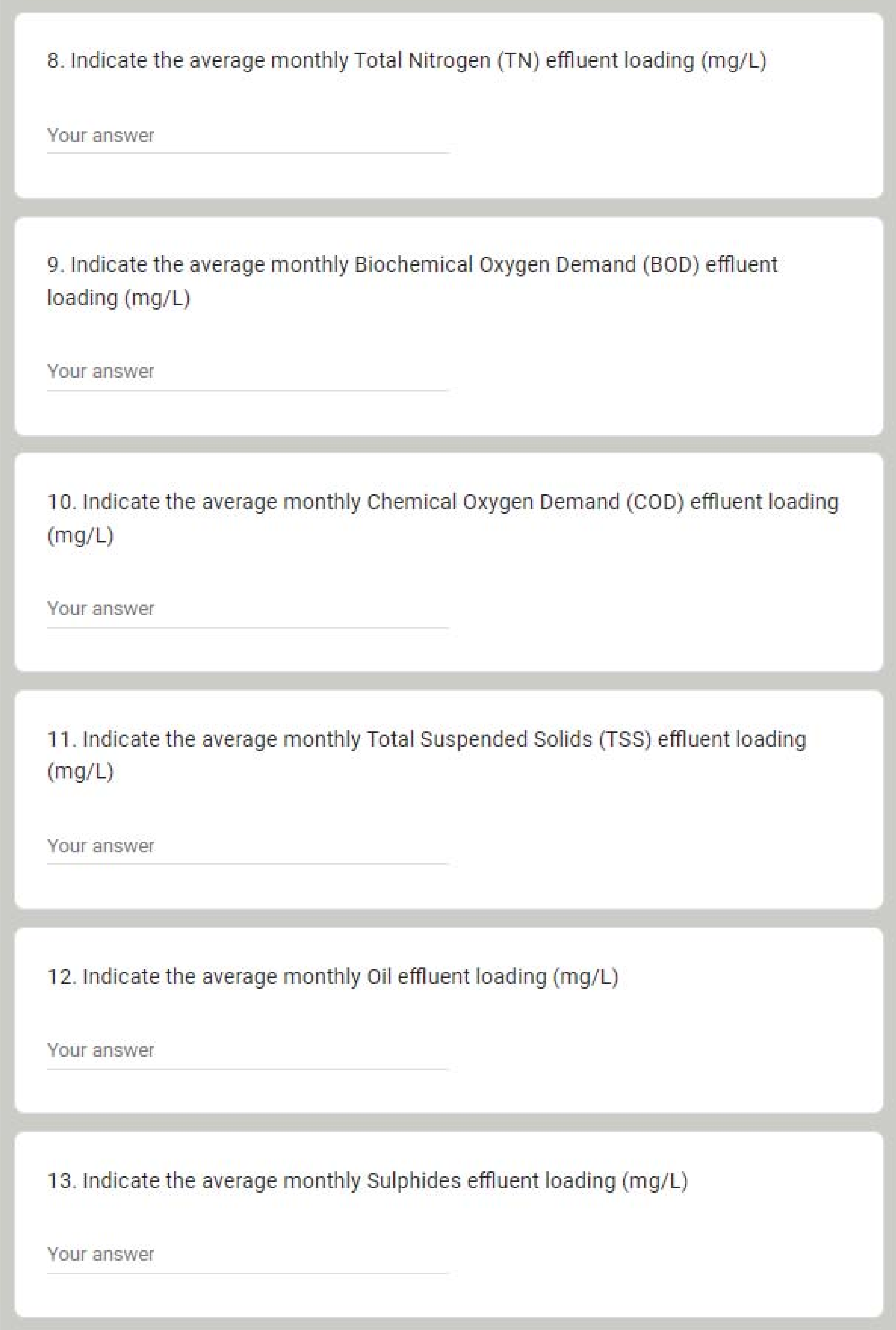


6. What is the **average pH** of the effluent from your refinery?

○ 1 - 2
○ 2 - 3
○ 3 - 4
○ 4 - 5
○ 5 - 6
○ 6 - 7
○ 7 - 8
○ 8 - 9
○ 9 - 10
○ 10 - 11
○ 11 - 12
○ 12 - 13
○ 13 - 14
○ Value is unknown

7. Indicate the average monthly Total Hydrocarbon Content (THC) effluent loading (mg/L)

Your answer



8. Indicate the average monthly Total Nitrogen (TN) effluent loading (mg/L)

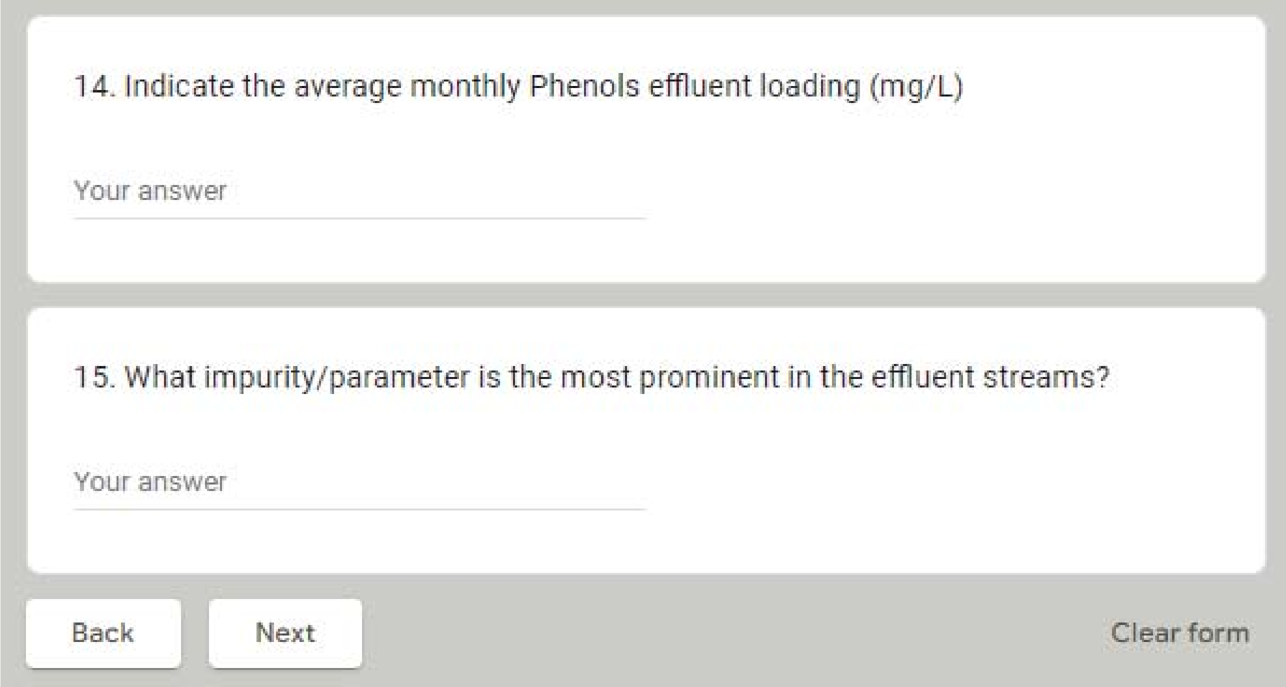
9. Indicate the average monthly Biochemical Oxygen Demand (BOD) effluent loading (mg/L)

10. Indicate the average monthly Chemical Oxygen Demand (COD) effluent loading (mg/L)

11. Indicate the average monthly Total Suspended Solids (TSS) effluent loading (mg/L)

12. Indicate the average monthly Oil effluent loading (mg/L)

13. Indicate the average monthly Sulphides effluent loading (mg/L)

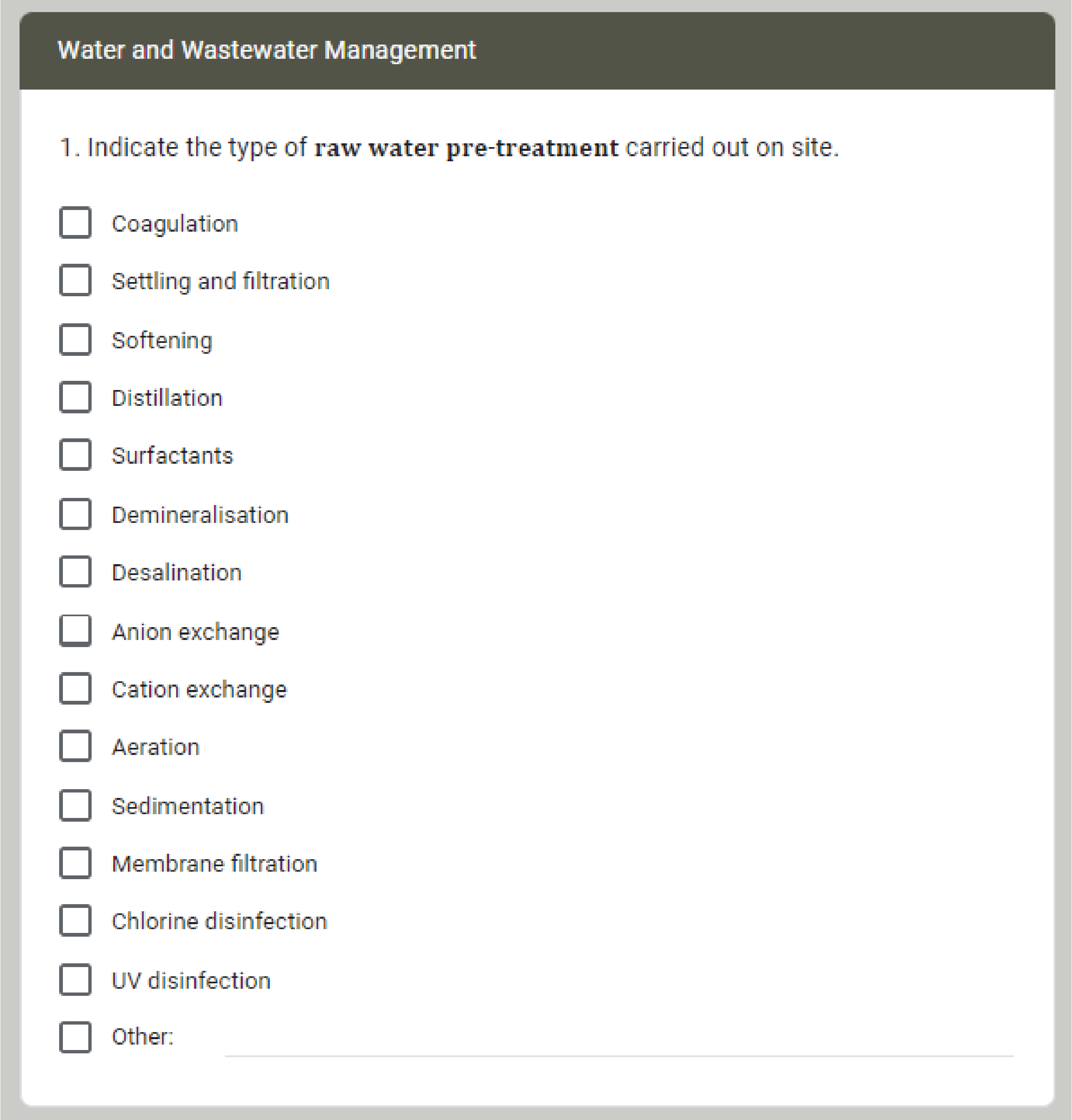


14. Indicate the average monthly Phenols effluent loading (mg/L)

Your answer

15. What impurity/parameter is the most prominent in the effluent streams?

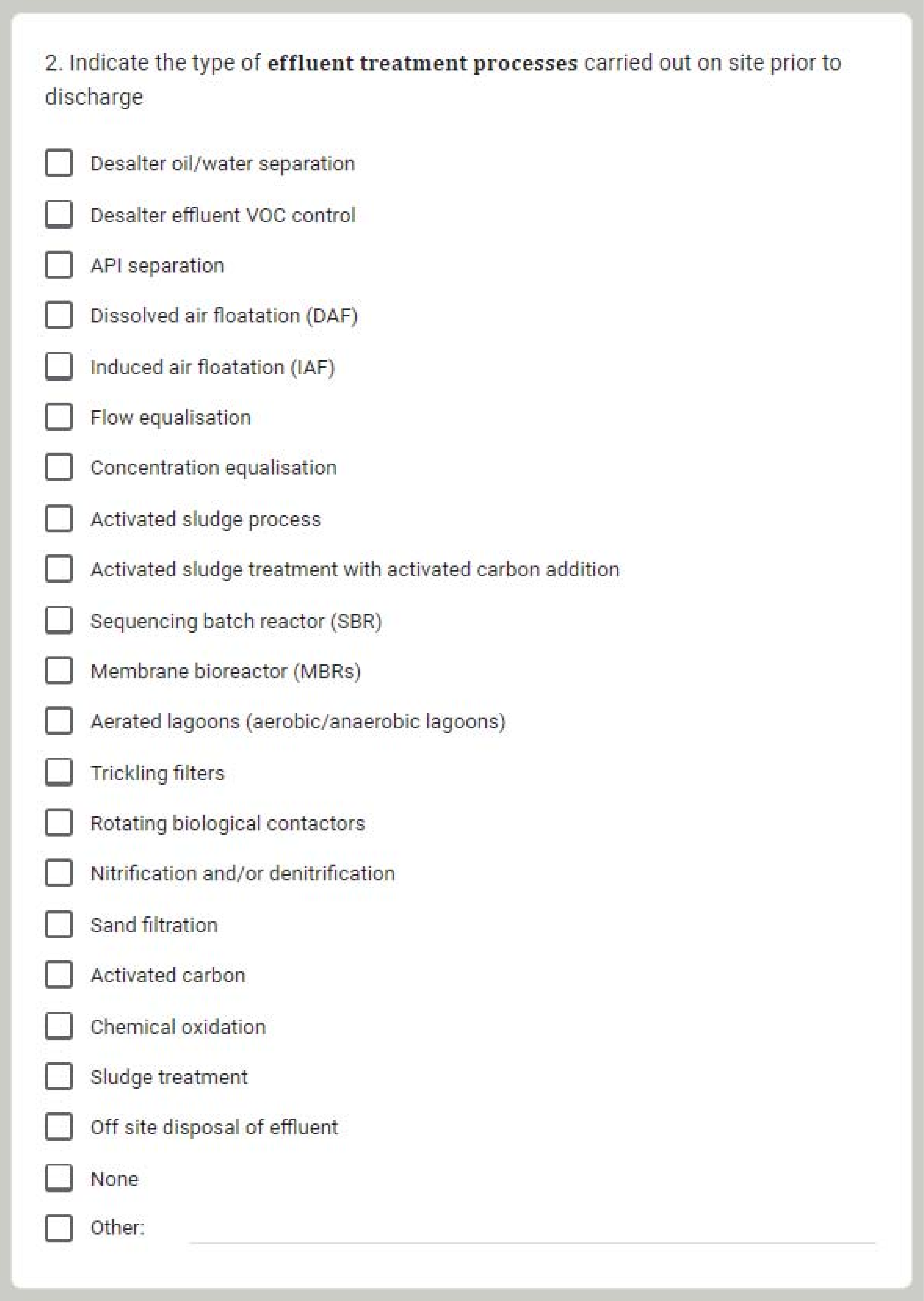
Your answer



Water and Wastewater Management

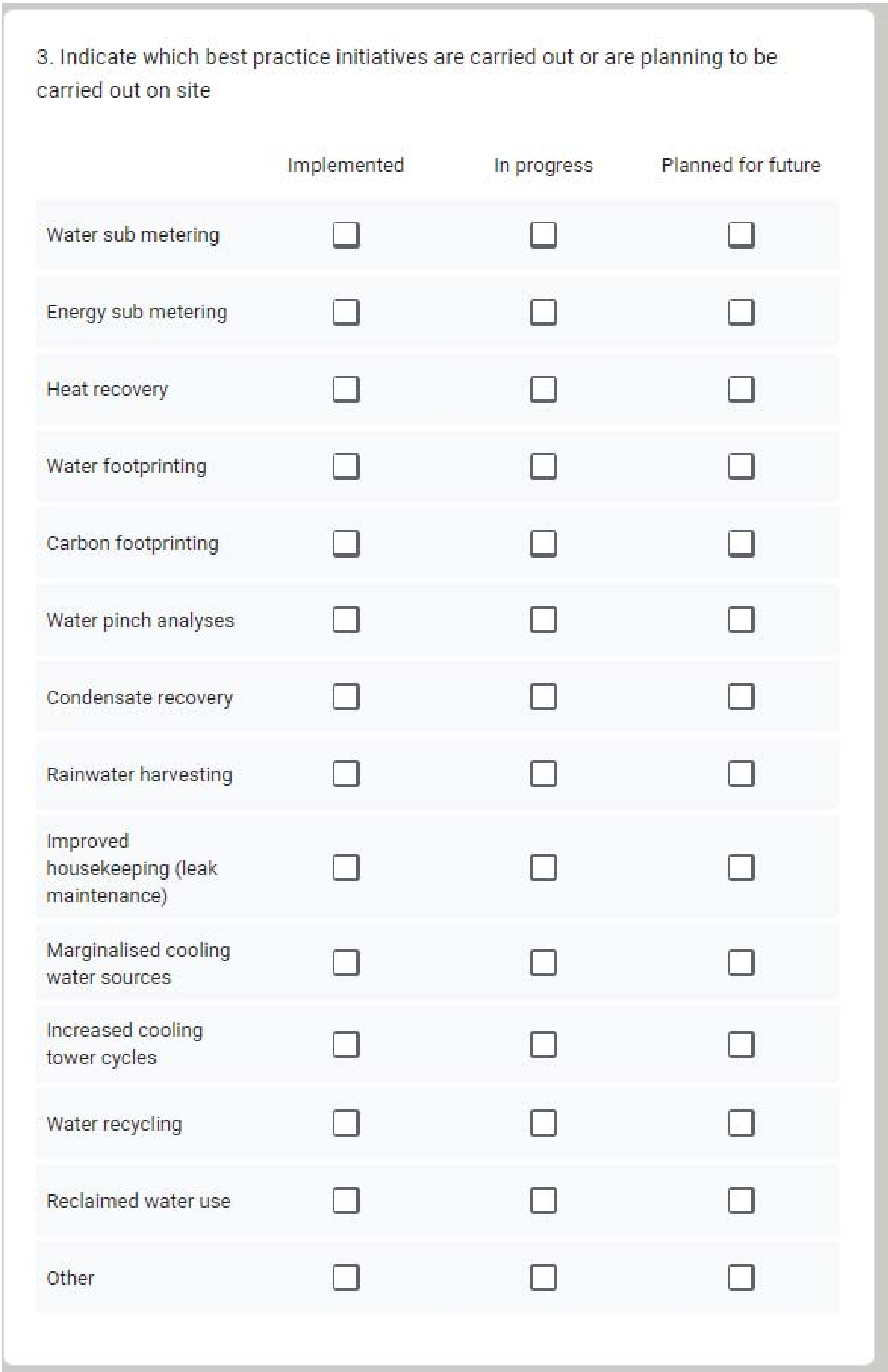
1. Indicate the type of **raw water pre-treatment** carried out on site.

☐ Coagulation
☐ Settling and filtration
☐ Softening
☐ Distillation
☐ Surfactants
☐ Demineralisation
☐ Desalination
☐ Anion exchange
☐ Cation exchange
☐ Aeration
☐ Sedimentation
☐ Membrane filtration
☐ Chlorine disinfection
☐ UV disinfection
☐ Other: ______________________



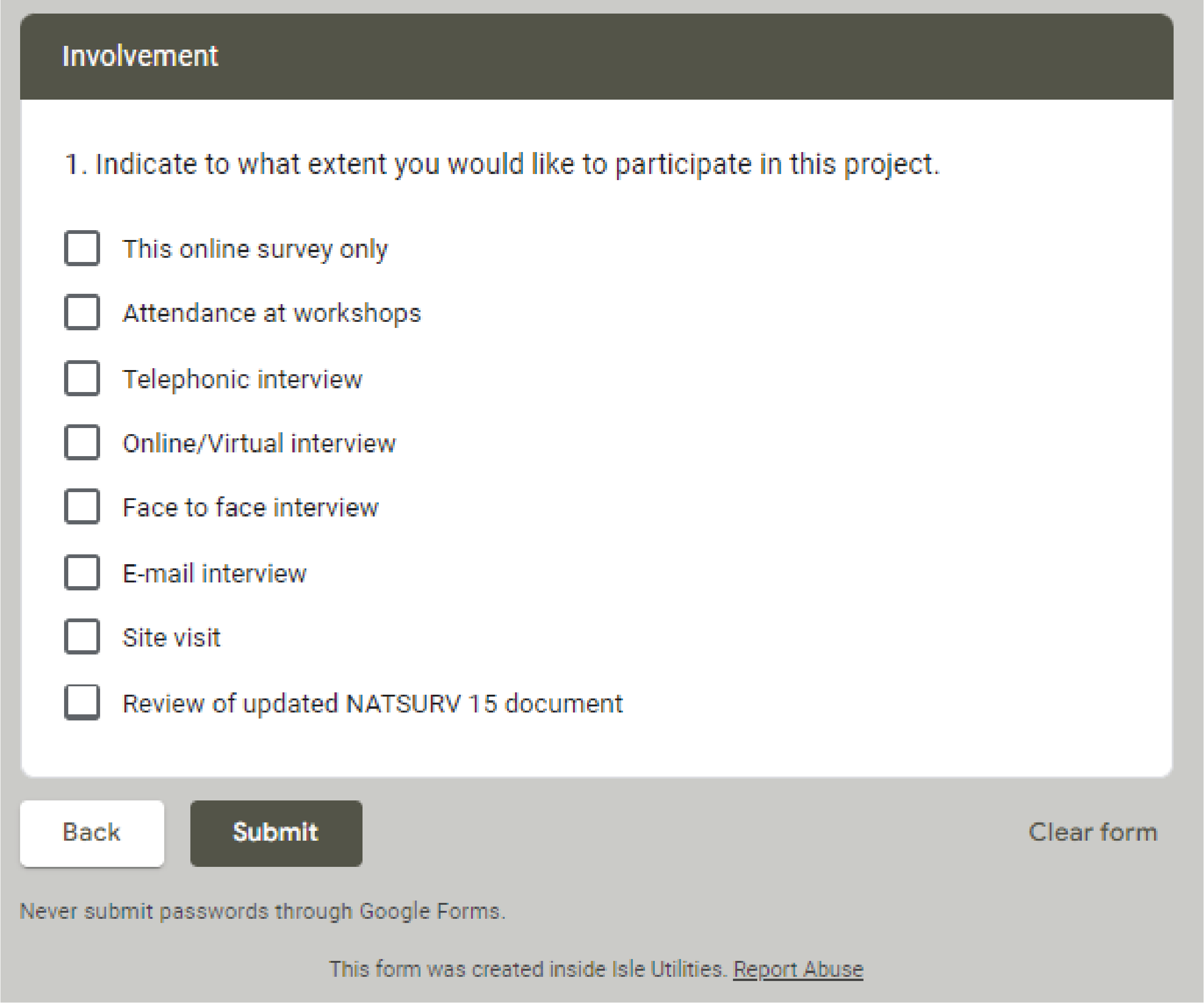
2. Indicate the type of **effluent treatment processes** carried out on site prior to discharge

- ☐ Desalter oil/water separation
- ☐ Desalter effluent VOC control
- ☐ API separation
- ☐ Dissolved air floatation (DAF)
- ☐ Induced air floatation (IAF)
- ☐ Flow equalisation
- ☐ Concentration equalisation
- ☐ Activated sludge process
- ☐ Activated sludge treatment with activated carbon addition
- ☐ Sequencing batch reactor (SBR)
- ☐ Membrane bioreactor (MBRs)
- ☐ Aerated lagoons (aerobic/anaerobic lagoons)
- ☐ Trickling filters
- ☐ Rotating biological contactors
- ☐ Nitrification and/or denitrification
- ☐ Sand filtration
- ☐ Activated carbon
- ☐ Chemical oxidation
- ☐ Sludge treatment
- ☐ Off site disposal of effluent
- ☐ None
- ☐ Other: ______



3. Indicate which best practice initiatives are carried out or are planning to be carried out on site

	Implemented	In progress	Planned for future
Water sub metering	☐	☐	☐
Energy sub metering	☐	☐	☐
Heat recovery	☐	☐	☐
Water footprinting	☐	☐	☐
Carbon footprinting	☐	☐	☐
Water pinch analyses	☐	☐	☐
Condensate recovery	☐	☐	☐
Rainwater harvesting	☐	☐	☐
Improved housekeeping (leak maintenance)	☐	☐	☐
Marginalised cooling water sources	☐	☐	☐
Increased cooling tower cycles	☐	☐	☐
Water recycling	☐	☐	☐
Reclaimed water use	☐	☐	☐
Other	☐	☐	☐



Involvement

1. Indicate to what extent you would like to participate in this project.

☐ This online survey only

☐ Attendance at workshops

☐ Telephonic interview

☐ Online/Virtual interview

☐ Face to face interview

☐ E-mail interview

☐ Site visit

☐ Review of updated NATSURV 15 document

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