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Author: Katherine Amanda Dzifa Achije

Faculty Supervisor: Mohammad Mansouri

External Supervisor: Halvor Hodnefjell

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Stavanger, June 12th, 2022

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Katherine Amanda Dzifa Achije

Abstract

The energy industry- particularly the oil and gas- is facing unprecedented times to supply global energy resources to drive economic progression and reduce greenhouse gas emissions to limit global warming. As alternative low carbon or greener energy resources are being developed and commercialised, it is important the transition is seamless. Effective energy management and adoption of sustainable low energy intensive technologies need make-up today's solutions. Not only will it bridge us over to the future energy industry, but also play in securing today's planet.

In this work, the offshore thermochemical cuttings cleaner (TCC) is assessed as a potential viable technology towards drilling and wells operations decarbonization. A multifaceted approach was adopted to determine prevailing environmental regulations, drilling waste management techniques, and understanding the as-is situation in Norway for treatment and disposal of oil-based mud cuttings. Exploring the technology from a sustainability framework was key to present an enlightened across the view findings and recommendations.

In light of Neptune Energy Norway data and findings presented in this master thesis, there exists a tangible 28% potential supply vessels fuel and eventual carbon dioxide emission reductions for supply vessels by adopting this offshore TCC technology. For yearly operations, there exists a strong potential for precisely field development drilling operations. Evidently presented, the technology has progressively improved, and simulated tests/studies demonstrates likened environmental impact on the aquatic ecosystem as from offshore discharge of water-based mud cuttings.

Further due diligence is recommended to undertake an in-depth tailored environmental risk assessment, especially for adoption of the offshore TCC technology on a mobile drilling rig. Attention is also required to finding alternative yellow chemicals to red chemicals currently in the oil-based mud. Undertaking a wholistic life cycle assessment covering the current onshore TCC treatment of oil-based mud cuttings reduce further concerns and increases confidence in potentially switching current operational procedures.

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Abbreviations

BAT	Best Available Technology
BEP	Best Environmental Practices
CCB	Cleancut Cuttings Blower
CLP	Classification, Labelling and Packaging of substances and mixtures
CO_2	Carbon Dioxide
COP	Conference of the Parties
CRI	Cuttings Re-Injection
CST	Cuttings Storage Tank
DST	Drill Stem Test
DSY	Deepsea Yantai
D&W	Drilling and Wells
ESG	Environmental, Social and Governance
EU	European Union
GHGs	Greenhouse Gases
HSE	Health, Safety and Environment
HT	High Temperature
IOGP	International Association of Oil and Gas Producers
LCPA	List of Chemicals for Priority Action
MD	Measured Depth
MGO	Marine Gas Oil
NADF	Non-Aqueous Drilling Fluids
NCS	Norwegian Continental Shelf
NEA	Norwegian Environment Agency
NDC	Nationally Determined Contribution
NIVA	Norsk institutt for vannforskning

NOK	Norwegian kroner
NPD	Norwegian Petroleum Directorate
NPT	Non-Productive Time
OBM	Oil-Based Mud
OECD	Organisation for Economic Co-operations and Development
OIC	Offshore Industry Committee
ODF	Organic-phase Drilling Fluids
O&G	Oil and Gas
PDO	Plan for Development and Operation
PCA	Pollution Control Act
PL	Production License
PSV	Platform Supply Vessel
PLONOR	Pose Little or No Risk to the Environment
REACH	Registration, Evaluation, Authorisation, and restriction of Chemicals
ROC	Residual Oil Content
ROP	Rate of Penetration
SBM	Synthetic-Based Mud
TCC	Thermochemical Cuttings Cleaner
WBM	Water-Based Mud
UNFCCC	United Nations Framework Convention on Climate Change

1. Introduction

1.1 Background information

Global surface temperature induced by human activities (relative to years 1850-1900)- represented in Figure 1 is sharply increasing. Fast and high emissions of greenhouse gases (GHGs) from industrialisation and economic growth, has created the urgent need to set ambitions- yet -achievable emission reduction levels to limit the irreversible threat to human societies and planet from climate change with a sense of urgency (Konkraft, 2021).

This climate crisis jeopardises the livelihood of present and future generations ranging from:

- food and water insecurity.
- loss of valuable lives and worsening inequality.
- more frequent and intense extreme weather conditions such as heatwaves, hurricanes, typhoons, and deep freeze.
- rising sea levels from fast melting glaciers displacing low-lying communities, island, and coasts.

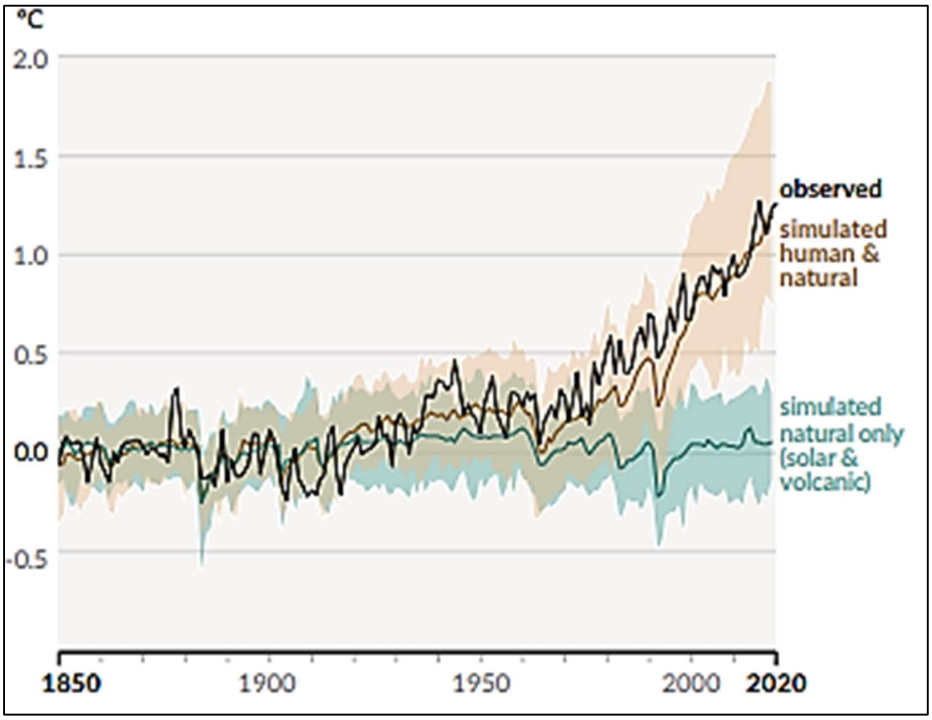


Figure 1: Change in global surface temperature (annual average) as observed using human & natural and only natural factors (both 1850-2020) (IPCC, 2021)

Furthermore, an increasing global population growth projected to reach 9.7 billion by 2050 compared to a current approximation of 7.9 billion, loudly echoes a dire need to change trajectory and re-envision energy for all (United Nations, 2019). Majority of this high growth rate is projected in developing countries already lacking access to equitable, secured and environmentally sustainable energy systems- commonly referred to as the energy trilemma (United Nations, 2019).

The Paris Agreement- a legally binding international treaty on climate change adopted by 196 Parties at Conference of the Parties (COP 21 in Paris, on 12th December 2015) - has trickled down from a high-level delegation treaty to a near tangible agreement for countries, business organisations, institutions, communities, and all. A goal to limit global warming well below 2 °C, preferably to 1.5 °C – compared to pre-industrial levels (UNFCC) - translates to 50% GHG emissions reduction by mid-21st century and (net) zero GHG emission by 2050 (UNFCC, 2021).

Norway- as a party to the Paris Agreement- committed to a target by at least 50% and towards 55% reduction in GHG emissions levels compared to 1990 base year emission of 52Mt carbon dioxide (CO_2)-equivalent effective January 2021 by 2030 (Government of Norway, 2021). This has some implications in the sector that accounts for GHGs emission in Norway. For examples, the Norwegian O&G industry together with other carbon intensive industries.

Norwegian O&G industry in January 2020 launched their climate goals- further revised in 2021- to reduce GHG emissions levels by 50% compared to 2005 levels of 13.5Mt CO_2 equivalent to 6.75Mt CO_2 equivalent by 2030 (a reduction of 6,95Mt CO_2-equivalent) and near zero by 2050 (Konkraft, 2021). It is worth mentioning since discovery of petroleum resources in the late 1960s, the oil and gas industry has contributed directly to economic growth of Norway. In 2020 Norwegian gas provided 20% to 25% of European Union (EU) gas demand-contributing to energy security in Europe- aside other petroleum products traded in global markets (NPD, 2021).

According to data from Statistics Norway, a total of 14,867 million tonnes of CO_2 equivalent was emitted from oil and gas extraction in 2019 accounting for a quarter of Norway’s total emissions. This is inclusive to service activities and transport via pipelines giving a higher value than in the Norwegian Oil and Gas Association 2005 stated level levels of 13.5 million tonnes CO_2. Furthermore, emissions from Norwegian economic activity (change in emission per produced Norwegian kroner) have decreased by 49.2% since 1990- demonstrating a country that is committed to reducing its GHG emissions footprint; exploring multiple pathways such as energy efficiency, research and development of alternative energy sources, innovation, policies, tax incentives, etc. to actively support economies, and participation towards the energy transition (Statistics Norway, 2021).

For energy companies in Norway with portfolios of O&G assets, balancing meeting EU energy supply security and driving down greenhouse emissions requires specific business data and market-driven transformation, coupled with innovation and a genuine zeal to being a multi-solution provider. Not neglecting balancing other multiple arenas such as, global energy demand, revamping of economies from the COVID-19 pandemic disruption, generational climate anxiety from slow progress, and securing their future license to operate.

1.2 Objectives

Current global state of affairs- ongoing Ukraine war, multiple sanctions on Russian, and impact on securing European oil and gas supplies, while advancing towards a carbon neutral economy, amongst several other consideration requires an evolving approach. It is imperative to examine adaptation of new less-energy intensive technologies to current drilling operations to foster meeting Norwegian O&G industry's set emission reduction targets in line with the Paris agreement by 2030. Of which some can be low hanging fruits on a case-by-case basis. Adaptation of offshore thermochemical cuttings cleaner (TCC) as a potential viable technology towards decarbonization of the petroleum industry is perceived as a potential low hanging fruit. This master thesis has a goal to highlight opportunities to deploy the offshore TCC, - considering the perceived risks and further scope of work to make an informative decision going forward. Currently, the practice involves shipping oil-based mud cuttings (OBM) to land for onshore treatment and eventual disposal.

1.3 Methodology

Combination of analytical, qualitative research, meetings and interviews held with industrial experts and targeted contracted vendors formed the basis for conduction of this master thesis, and the information and the data compiled in this report.

On the qualitative research side, scientific articles from databases, such as OnePetro, Neptune Energy Norway internal documents, together with other relevant industry articles were leveraged on to attain a comprehensive overview and relevant insight. The in-depth knowledge and experience of Neptune Energy employees and contractors furthermore facilitated the qualitative research. Open-sourced information from industry governing bodies such as Norwegian Oil and Gas Association, Norwegian Petroleum Directorate, Norwegian

Environment Agency and OSPAR Commission to mention a few, were also deciphered- of which some data is captured and presented in this report.

Specific quantitative data was retrieved from NEMS (original product full name)- environmental management software for the oil and gas-, and analysed accordingly for drilled depth, drilling mud, drill cuttings, and other general drilling information.

Maress- a web-based application for supply vessel fleet decarbonization- together with logistic information captured in WELS (original product full name)- utilised for oil and gas industry logistic- were pillars to build on potential opportunities by adopting the offshore TCC technology and present standpoint at the drilling and well (D&W) business unit in Neptune Energy, Norway. In WELS, backload and loadout excel-based tickets were downloaded and analysed according to OBM drilling dates derived from NEMS, to accurately determine actual OBM cuttings sent onshore against NEMS captured OBM cuttings generated on the drilling rig.

Majority of these data appeared in silos- some unstructured-, requiring an intelligent wholistic approach to gather and analyse these data. It was therefore a challenging and time-consuming activity. Calculations for data presented in Section 4- results & discussions- of this thesis were populated and computed in Microsoft Excel spreadsheet software.

1.4 Scope

Justification for adaptation of offshore TCC technology by Neptune Energy, Norway, D&W operational activities directly on the drilling rig against the current practice of shipping OBM cuttings to land for treatment and disposal, is the backdrop for this thesis. Precisely the framework is built on environmental considerations, governing regulations, and industry best practices.

To derive a good framework, historical D&W operations undertaken from November, 2019 to December, 2022 were analysed. It should be noted that information pertaining some field related information were unclear and assumptions were therefore taken or entirely excluded. These are communicated in Section 4 of the thesis- results and discussion- as applicable. Challenges pertaining retrieving treatment facility specific information such as electricity consumption for treating OBM cuttings on land was difficult to retrieve, and detailed treatment facility process were not included in the scope of this work. Findings presented in this thesis report are based on general internal non-confidential information available to

Neptune Energy Norway D&W business unit and other industry insights to map the entire process from cuttings generation to final delivery at quayside. As this is an open access report, cost comparison of available solutions for OBM cuttings handling and treatment was not included in this report to maintain confidentiality agreements between multiple parties.

1.5 Thesis outline

This thesis has been organised in four main parts in subsequent chapters:

Chapter 2 presents background information on generation of drilling waste from petroleum activities with industry perspective and focus on Norway, and related European Union and Norway chemical regulations applicable to offshore operations. The reader should expect information on OSPAR commission and Norwegian authorities' regulations for petroleum activities offshore discharges and general drilling waste management techniques.

In Chapter 3, Neptune Energy group company is introduced with focus on the company's environmental, social and governance strategy and operated asset in Norway. Total carbon dioxide emissions for 2020 and 2021 based on operations conducted by the drilling and well business unit in Norway is presented to demonstrate a multi-dimensional emission reduction approach. Description of 2019 to 2021 field operations conducted by the drilling and well business unit in Norway is also presented for an enlightened overview.

Results and discussions pertaining informative data related to total drilled water-based mud and oil-based mud sections, associated cuttings and utilised drilling chemicals for 2019 to 2021 yearly field operations are presented from different aspects in Chapter 4. Data based on current waste management practices adopted by the said business unit is also presented. This is later cross-examined against potentially adopting the offshore thermochemical cuttings cleaner.

Concluding remarks based on information and data present in Chapters 1- 4 is harmonised in Chapter 5.

2. Drilling waste, regulations, and management

2.1 Drilling waste

Production of oil and gas resources to meet energy demand generates significant waste. Focussing on drilling waste, according to (Svensen and Taugbøl 2011), the amount generated is highly dependent on type of drilling fluid and prevailing regulations for drilling waste handling, treatment, and disposal. Drilling waste includes utilised drilling fluid, drill cuttings, oil, and water emulsions- referred to as oil slop and oil contaminated mass (DNV, 2013).

2.1.1. Drilling fluid

Drilling fluids are vital for successful drilling of exploration, appraisal, or even completion wells and selection of the right drilling fluid- aside tools deployed in the wellbore- helps to potentially reduce the total well cost from undesired drilling related incidences downhole- such as stuck pipe incidents and loss of circulation. During drilling operations, drilling fluids are pumped down the drill string to remove drill cuttings from the borehole to surface and maintain wellbore stability. Subsequently, drill cuttings and drilling fluid are recuperated at surface through the annulus- i.e., the space between drill string and casing or drill string and open wellbore. Pathway showing drill cuttings and drilling fluid is illustrated in Figure 2.

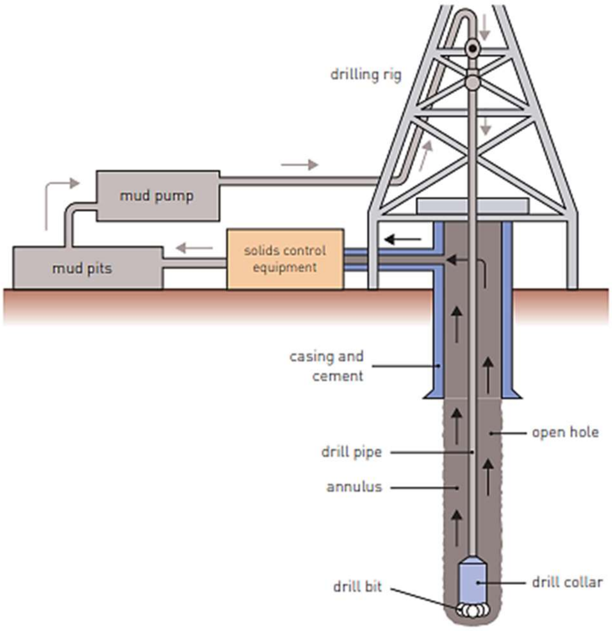


Figure 2: Illustration of drilling fluid circulation system on a drilling rig (IOGP, 2016)

Furthermore, the drilling fluid is designed to lubricate and cool both the drill bit and string, control formation pressure, and send drilling information back to surface- aside other selection criteria to limit skin damage and subsequent well productivity (Bridges and Robinson, 2020).

Drilling fluids are classified into three categories- according to type of base fluid utilised (Caenn et al., 2011):

- Gaseous
- Aqueous drilling fluids
- Non-aqueous drilling fluids (NADF)

These categories will be used to depict the type of drill cuttings excluding subsurface geology. For both aqueous and non-aqueous drilling fluids, the constituents alter depending on multiple variables such as type of formation being drilled, and drilling fluid weight required at various specific depth along the wellbore trajectory (Stantec, 2009). It is undesirable for uncontrolled inflow of formation fluid into the wellbore and eventually at surface during drilling. Hence, a drilling fluid with density equivalent between formation pore pressure and fracture pressure is optimum for wellbore control.

2.1.1.1. Gaseous drilling fluids

According to Caenn et al. 2011, gaseous drilling fluid can exist as dry air, mist, foam or stable foam and selection choice is dependent on subsurface formation. Air (the most common gaseous drilling fluid), or natural gas, or nitrogen can be used for such gaseous drilling fluids (ASME Shale Shaker Committee, 2005). In stable foam mud, air bubbles are surrounded by a film of water containing a foam-stabilizing substance or film-strengthening material, such as organic polymer or bentonite. For reduced pressure drilling, i.e., underbalanced drilling, stable foam is suited best for improve hole stability in caving formations (Caenn et al., 2011).

2.1.1.2. Aqueous drilling fluids

Commonly referred to as water-based mud (WBM), it is the most common and varied drilling fluid amongst the three types of drilling fluid (Schlumberger, 2013). The continuous- or prevalent- phase constitutes freshwater or seawater (Caenn et al., 2011). Typical composition of WBM includes solid particles- usually clay and/or organic colloids-, surfactants (Caenn et al., 2011), mineral weighting agents, and other additives suspended in the continuous phase (IOGP, 2016). Solids are added for required viscous and filtration properties of the WBM.

WBM have low initial cost compared to oil-based mud (Abduo, Dahab et al. 2016) and offers quicker detection of gas kick for better safety and well integrity management (Growcock and Patel, 2011). Table 1 shows examples of additives to improve the technical performance WMBs for improved drilling performance. Selection is dependent on geologic formations and bottomhole conditions to be encountered during drilling operations.

Table 1: Functional categories of additives examples used in aqueous drilling fluids to improve drilling performance (IOGP, 2006)

Functional category additives	**Examples**
Weighing materials	Barite, calcium carbonate, ilmenite, or hematite
Thinners	Lignite, lignosulfonates, polymers
Filtrate reducers	Clay, lignite, polymers, starch
Lost circulation	Inert soluble solids (e.g., calcium carbonate, ground nut shells, graphite, mica, and cellulose fibres)
Shale control	Soluble salts (e.g. KCL), mines, glycols
Bactericides	Glutaraldehyde, triazine disinfectants
Pipe-freezing agents	Water-based lubricants, enzymes, surfactants
Corrosion inhibitors	Amines, phosphates
Viscosifiers	Clay, organic polymers
Temperature stability	Acrylic or sulfonated polymers, lignite, lignosulfonate
Calcium reducers	Sodium carbonate, bicarbonate, polyphosphate
Defoamers	Alcohols, silicon, aluminium stearate, alkyl phosphates
Emulsifiers, surfactants	Detergents, soaps, organic fatty acids
Lubricants	Water-based lubricants, glycol, and beads
pH control	Inorganic acids and bases (caustic soda)
Flocculants	Inorganic salts, acrylamide polymers

2.1.1.3. Non-aqueous drilling fluids

Non-aqueous drilling fluids (NADF) are prepared as water phase emulsified in a continuous phase of oil or synthetic based fluid (Baker Hughes, 2006), termed as invert emulsion. Two types of NADF exists: oil-based mud (OBM) or synthetic-based mud (SBM) (ASME Shale Shaker Committee, 2005). Hydrocarbon oils are the continuous phase for OBMs and synthetic type materials for SBMs. Aside the continuous phase, NADFs composition includes emulsifiers, dissolved salts (calcium chloride the most common or sodium chloride, seawater of other brines) and colloids- such as organophilic clay, polymers, and lime (Baker Hughes, 2006). Additives present in Table 1 above can also be added to NADFs (IOGP, 2006).

SBMs are derived from polymerized ethylene (Baker Hughes, 2006) into products such as olefins, biodegradable esters, and synthetic linear paraffins (ASME Shale Shaker Committee, 2005). Ethylene has a lower toxicity level compared to aromatics, making SBM a relatively environmentally safer alternative to OBM (Baker Hughes, 2006)- should regulations approve disposal of SBMs cuttings offshore. Growcock and Patel, highlights the general ease of controlling and monitoring SBM, - having a single or fewer compounds- unlike OBM (Growcock and Patel, 2011). According to the Norwegian Oil and Gas Association Climate and Environmental Report 2021, SBMs in recent years are less often used on the Norwegian Continental Shelf (NCS).

OBMs are derived from distilled crude oil including refined linear paraffins, diesel oil and mineral oil (ASME Shale Shaker Committee, 2005). Properties of hydrocarbon oil such as non-polar, low-surface energy/tension and weak interaction with mineral, gives it a higher edge as a non-reactive, inert drilling fluid (Baker Hughes, 2006). Various health, safety, and environment (HSE) consideration have influenced development and consumption of base oils used for drilling. Historical perspective of base oils for drilling activities is summarized in Table 2. Today, OBMs usually contain base oil which are low-aromatic petroleum distillate based on paraffins with a carbon-chain length of C_{18}-C_{22} (AquateamCOWI, 2014).

Table 2: Overview of drilling base oils from a historical perspective (Aarrestad, 2013)

Description	Specification	Year
Diesel oil	High content of aromatics High volatility Dries out and irritates the skin	Pre-1984
Mineral oil	HDF 200 Relatively high volatility Lower aromatic content	1995
Mineral oil	EDC 95/11 or equivalent oils Zero aromatics Low volatility	1998
Low-viscosity oils	Sipfrill 2.0 (paraffin) EDC 99 (mineral-oil based) Zero aromatics High volatility	2002

NADFs offer advantages comprising; minimal effect on shale formation stability, temperature stability for application in high temperature (HT) wells, reduced formation damage as filtrate travels shorter distance into formation production zone, high stability and solids tolerance allowing it to be re-used on multiple wells (Baker Hughes, 2006). In comparison to WBM, NADFs have high lubricity for faster drilling and are less corrosive (Growcock and Patel, 2011).

As the initial cost of NADF is higher than WBM, - as price is pegged to oil price (Baker Hughes, 2006)- the industry norm is rental contracts between service company and well operator for NADF provided. Cost for mud losses due to loss circulation, left in well, and residual NADF on cuttings is covered by the operator. Alternatively, buyback option contracts also exist between operator and service provider with percentage buyback influenced by percentage of low-gravity solids and ratio of volume percent of oil to volume percent of water in backloaded oil mud. The NADF sent onshore is re-conditioned and re-used (Growcock and Patel, 2011).

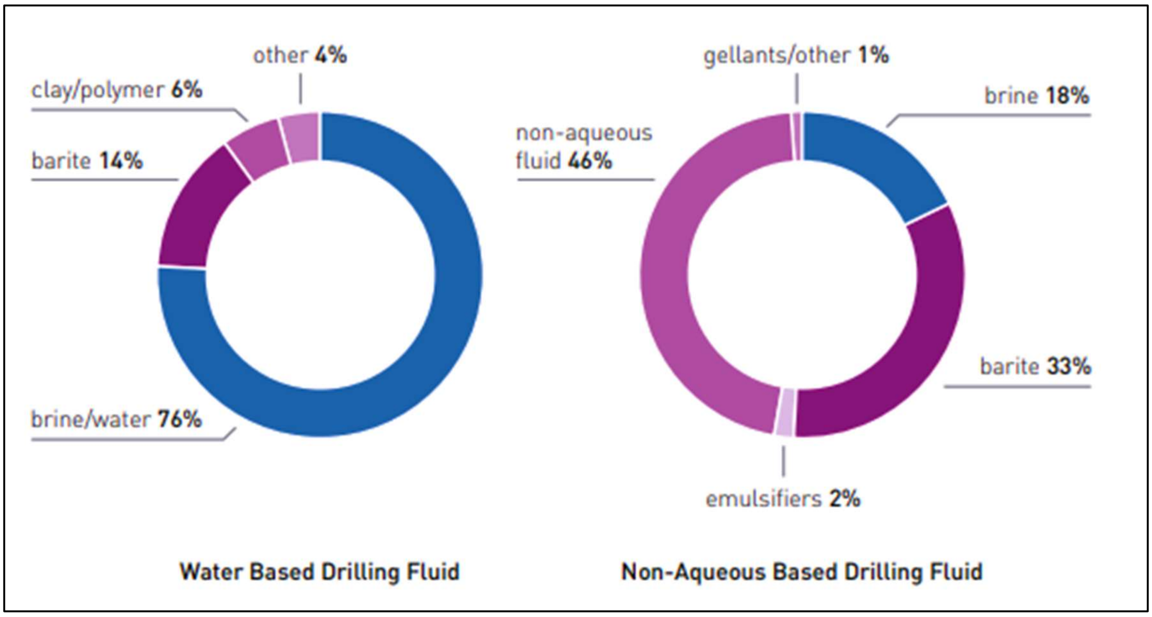


Figure 3: Composition in weight percent of typical ADFs and NADFs (IOGP, 2009)

In both WBMs and NADFs typical composition in Figure 3, barite is the next predominant component as this heavy mineral is typically added to increase the density of both drilling muds for technical and safety operational purposes (Caenn et al., 2011).

2.1.1.4. Drilling fluid development and utilization on NCS

Consumption of WBM, OBM, SBM on the NCS between 2004 and 2020 is captured in Table 2 and Figure 4 below. WBM accounts for an average of 65% of drilling fluid within this timeframe and is the most utilised drilling mud on the NCS. As earlier stated in paragraphs above, Table 3 visually confirms minimal usage of SBM in the NCS over a 16-year duration (Norwegian Environment Agency, 2021).

OBM is the next utilised drilling fluid in well section/formations and/or environments in which WBM has limiting properties, making it an inadequate drilling fluid (referring to advantages of OBM over WBM). It is common for OBM to be the preferred drilling mud in long and deviated wells due to improved well stability (Svensen and Taugbøl 2011). Norwegian Environment Agency- NEA (NEA, 2021) reports preference of OBM in the deeper section of wells to limit skin damage to reservoir formation and eventual initial production (Baker Hughes, 2006), amongst others.

Table 3: Drilling mud consumption on NCS in 2004-2020 (NEA, 2021)

Year	Oil-based mud (tonnes)	Synthetic-based mud (tonnes)	Water-based mud (tonnes)	Water-based mud (%)
2004	132 062	2 298	239 889	0,64
2005	217 852	5 303	219 126	0,50
2006	183 702	0	267 310	0,59
2007	182 381	0	270 999	0,60
2008	185 891	968	274 337	0,59
2009	219 217	0	412 719	0,65
2010	147 447	0	290 684	0,66
2011	118 305	2 888	316 379	0,72
2012	117 308	0	331 820	0,74
2013	147 487	1 444	387 426	0,72
2014	128 187	816	388 739	0,75
2015	171 386	0	328 851	0,66
2016	162 460	0	314 729	0,66
2017	127 693	0	275 906	0,68
2018	145 138	0	227 743	0,61
2019	142 489	0	282 881	0,67
2020	168 608	143	278 189	0,62

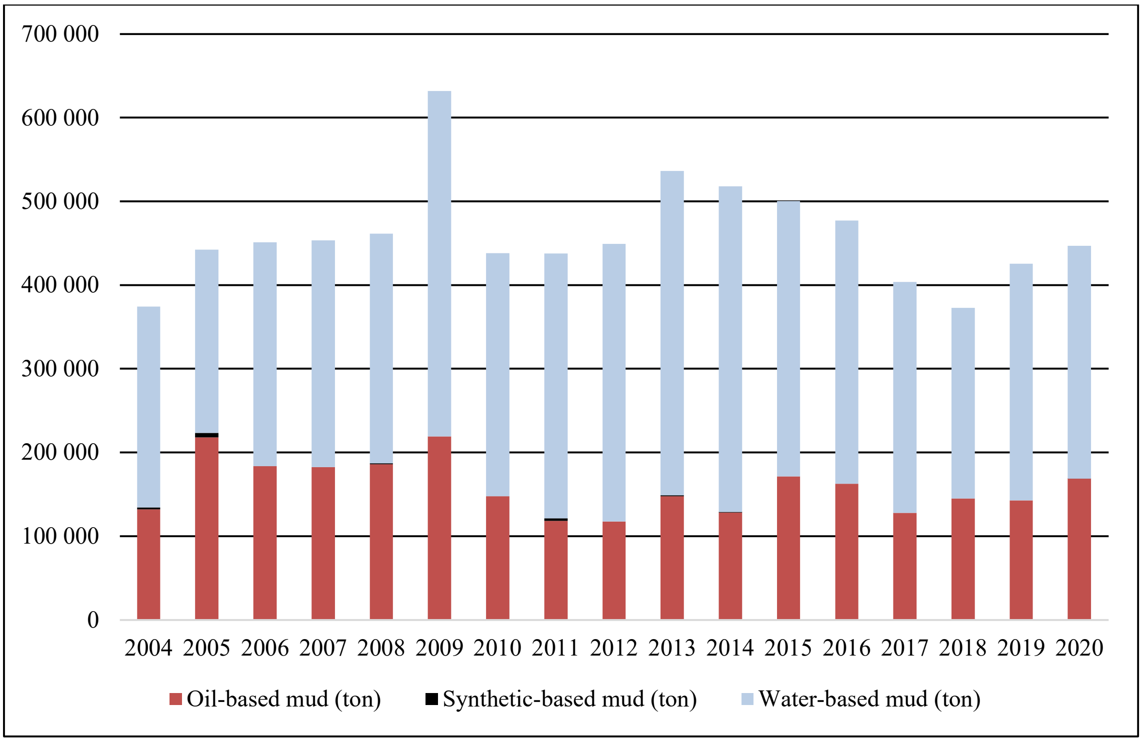


Figure 4: Drilling mud consumption on NCS, 2004-2020 (NEA, 2021)

2.1.2. Drill cuttings

Exploration of oil and gas deposit, and eventual development requires the use of rotating drilling bits attached at the tail end of a drill string to crush through the sub-surface formation- creating a wellbore- to required depths of interest (Schlumberger, 2022). This operation generates drill cuttings ranging from clay-sized particles to coarse gravels (Neff et al., 2000). These dislodged rocks pieces are removed from under the drill bit and circulated to surface with the aid of drilling fluid (Schlumberger, 2022). Type of drilling fluids used, according to subcategories listed in Sub-section 2.1.1- drilling fluids-, will be used to depict the type of drill cuttings. I.e., oil-based, water-based, and synthetic based mud drill cuttings. Drill cuttings contain formation rock, water, oil and other drilling chemicals components/additives (Stephenson, Seaton et al. 2004). Throughout this report, drill cuttings are also referred to as cuttings by the writer.

On the NCS, as shown in Figure 5, from 2000 to 2020, majority of total wells drilled were developmental wells against a smaller segment of exploration wells. Each year,163 developmental wells and 40 exploration wells were drilled averagely between 2000 and 2020. Drill cuttings generated on the NCS within the aforementioned timeframe were predominantly related to field developmental operations. In 2020, 180 development wells-accounting for approximately 85% of drilling activity were drilled against 31 exploration wells- amidst the Covid-19 pandemic (Norwegian Oil and Gas Association, 2021). Field development phase is accompanied by drilling of multiple wells; combinations of oil- and/or gas-producers, and gas/water-injection well-as required- for reservoir pressure maintenance.

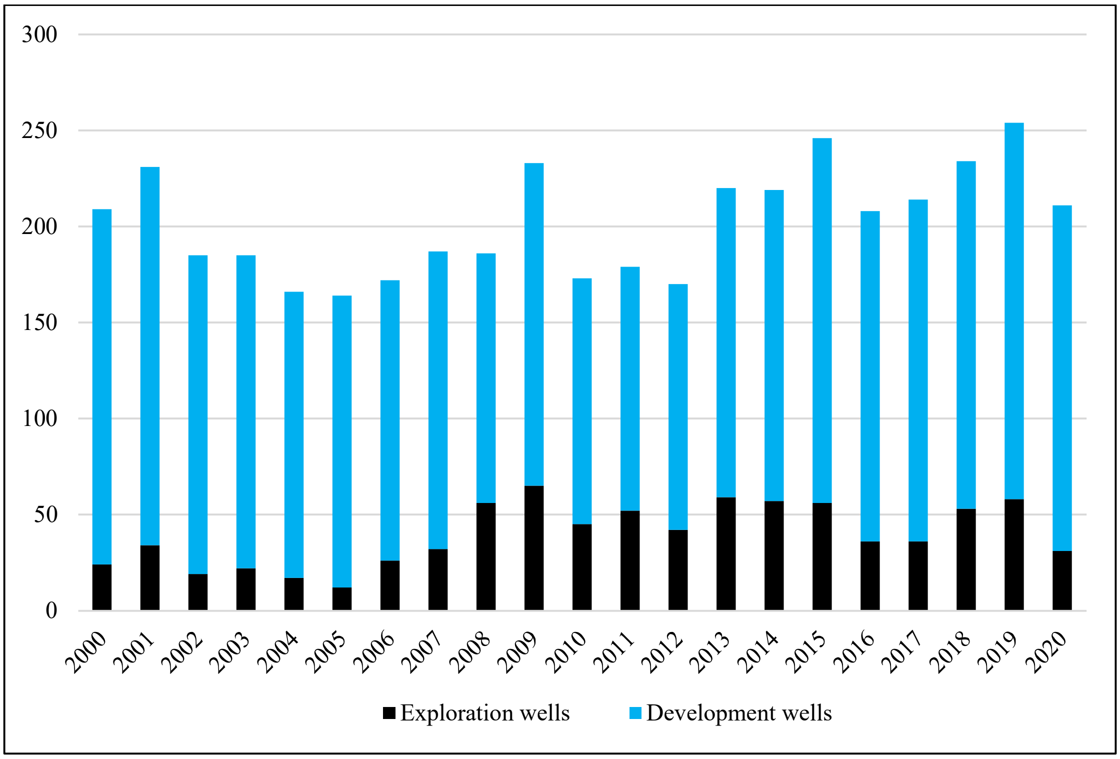


Figure 5: Total wells drilled on NCS in 2000- 2020 (Norwegian Oil and Gas Association, Climate and Environment Report, 2021)

Drill cuttings generated on the NCS from 2004 and 2020 complied from Norwegian Oil and Gas Association 2020 Climate and Environmental Report is visually displayed in Figure 6. Cumulative water- and oil-based cuttings vary year-over-year and respective amounts generated depends on diverse factors. Amongst these factors, level of yearly drilling activity, designated wellbore trajectory, geological formation encountered along wellbore trajectory to specified geological and drillers target, reservoir considerations and optimized well design play a huge role in the quantity of respective cuttings generated. In 2010, oil-based cuttings quantity increased sharply triggered by re-injected cuttings leakage problems on identified fields, leading to shut down of those re-injection wells. On affected fields, OBM cuttings was shipped onshore for treatment and disposal instead of re-injection. OBM cuttings are subjected to stricter environmental regulations than WBM cuttings and are typically treated and disposed onshore as hazardous waste (Caenn et al., 2011).

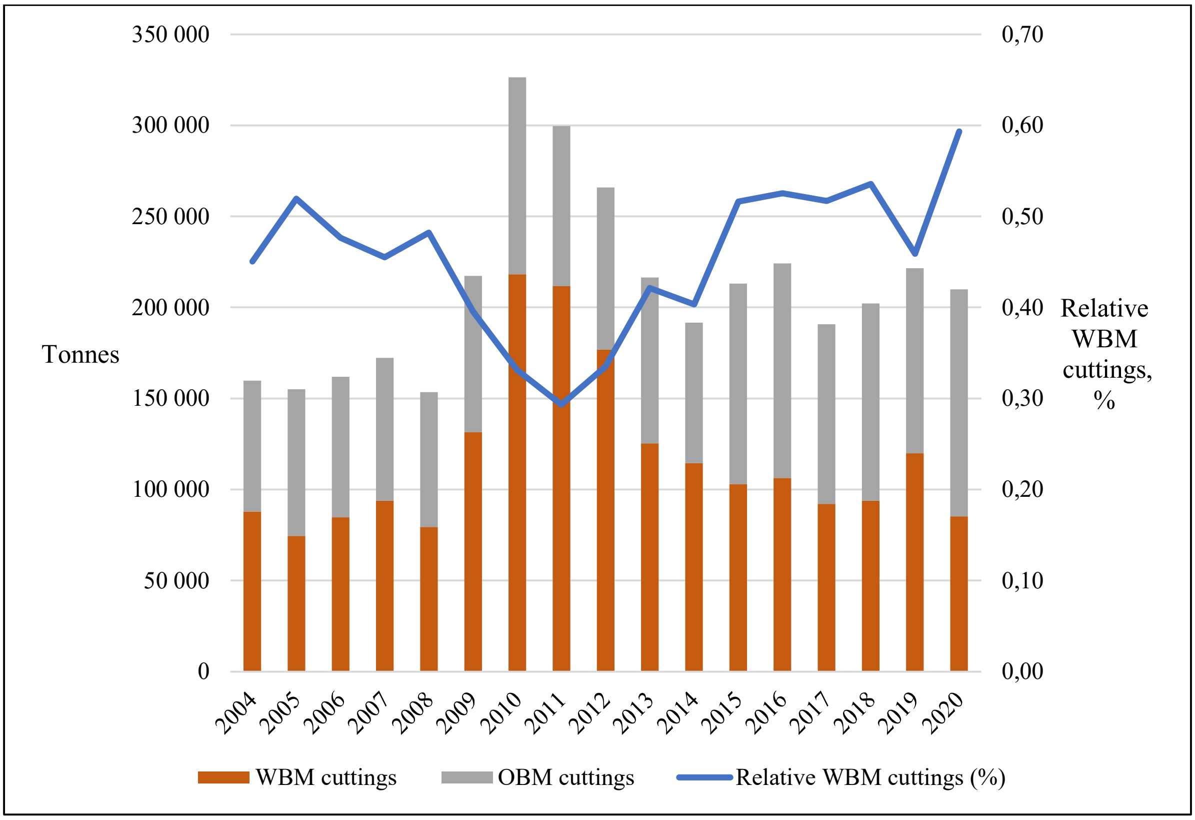


Figure 6: Water- and oil- based cuttings generated on NCS, 2004-2020 (Norwegian Oil and Gas Association's Environment and Climate Report, 2021)

2.1.3. Slop

Slop commonly refers to oily water and oil emulsions and can exists in multiple locations onboard an offshore installation or mobile drilling rig (DNV, 2013). Generation sources can include deck drainage, wellbore cleanup operations, surface tanks and pits cleaning operations (Massam, Andrade et al. 2013). Offshore treatment facilities exist to treat slops, and water with oil content of 30mg per litre of water as a weighted average for a calendar month is permitted for discharge offshore (Lovdata, 2022). Residual oily waste after treatment is shipped onshore for disposal. Effective slop management is paramount to ensure chemicals prohibited from discharge is not dumped to sea together with the treated water.

2.1.4. Oil contaminated mass

This drilling waste comprises of different oily solids waste primarily from production and maintenance operational activities offshore. The range is wide and includes oil filter, gloves, mixed waste from oil/water separators, sludge deposits in tanks and filter clothes from cleaning units (DNV, 2013).

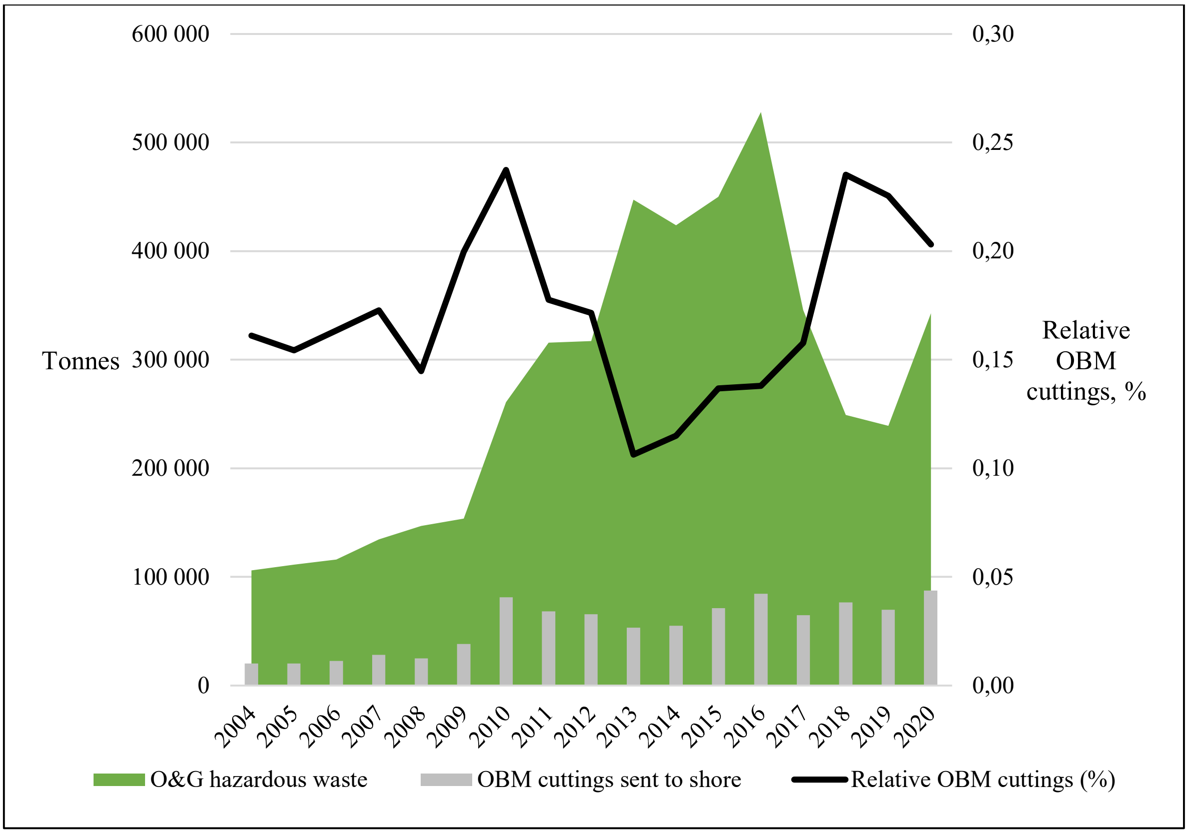


Figure 7: Offshore petroleum industry hazardous waste (NEA, 2021 & Norwegian Oil and Gas Association's Environment and Climate Report, 2021)

Norwegian Environment Agency defines hazardous waste as waste that contains health and environmentally dangerous content that can cause serious pollution or danger on people and animals (Environmental status, NEA, 2020). These wastes are sent onshore for treatment and disposal. Hazardous waste generated from the offshore petroleum industry on the NCS is represented in Figure 7. Amongst hazardous waste generated over the 16-years duration are drill cuttings, oily slop, and oil contaminated mass inclusive. In 2020, 342 700 tonnes of dangerous goods were treated onshore, of which 295 500 tonnes were declared as drilling related waste. For that same year, tank washing, and oily waste generated 19 000 tonnes and 13 000 tonnes respectively (Norwegian Oil and Gas Association, 2021).

2.2 Discharge regulations for drilling mud and cuttings on NCS

Petroleum activities on the NCS that pollutes or has the potential to pollute must secure an approval permit from the Norwegian Environment Agency- NEA. Issuance of permits are granted on the Pollution Control Act § 11 (Forurensningloven- special permit for polluting measures). Activities requiring such permits cover operations across the upstream O&G lifecycle, ranging from exploration through to decommissioning.

As pollution is an HSE related issue, HSE regulations are anchored in both the Petroleum Act, - Act of 29th November 1996 No.72 relating to petroleum activities (NPD, 2021)- and Pollution Control Act (PCA). Operator requirements include the need for adequate management systems, risk reduction, use of best available technique (BAT) and best environmental practices (BEP) (NEA, 2021). According to Chapter 36 of the Pollution Control Regulations, BAT shall be the basis for formulating conditions in permits pursuant to PCA.

2.2.1. Chemical regulations applicable to offshore operations in Norway

2.2.1.1. Registration, evaluation, authorization, and restriction of chemicals regulation

Chemical produced, imported, traded, and used within EU are subject to the Registration, Evaluation, Authorization, and restriction of Chemicals (REACH) regulation (Regulation (EC) No 1907/2006, European Commission). According to the Directorate-General for Environment of the European Commission, overall aim of REACH is protection of human health and environment from chemical substance utilization and promote innovation of safer alternative chemical. REACH sets the basic and comprehensive rules for the identification and regulation of chemicals. Regulations apply to substance alone, in mixtures and in solid products. Great responsibilities and duties are placed on companies throughout the supply chain to document and publicly declare chemicals produced, sold, and used. Norway is a member state to REACH and abides by these regulations.

2.2.1.2. Classification, Labelling and Packaging regulation

In addition to the REACH regulation, EU has regulation on Classification, Labelling and Packaging of substances and mixtures (CLP) regulation (Regulation (EC) No 1272/2008, European Commission). Suppliers have responsibility to classify and label such substances and/or mixtures for physical, health and environmental hazard. Hazardous labelling is fused on labels and accompanying safety data sheets (European Chemicals Agency). Essence of CLP is to communicate and provide knowledge for adequate risk management on inherent hazardous chemicals, to prevent and/or minimize detriment on health and environment. It safeguards personnel and end users exposed to chemicals through awareness and accessible visible information (NEA, 2021).

2.2.2. OSPAR Commission's link to Norway

On 15th February 1972, the Oslo Convention for prevention of marine pollution against dumping from ships and aircraft was signed and became effect in 1974. Over time, it extended to land-based sources of marine pollution and the offshore industry by the Paris Convention of 1974. Both Oslo- and Paris Convention were unified, up-dated and extended by the 1992 OSPAR Convention signed on 22nd September 1992- reflecting the name OSPAR derived from both cities- and entered into force on 25th March, 1998. Sixteen contracting parties (i.e., fifteen European countries and European Union) legally adopted the OSPAR convention for the protection of marine environment in the North-East Atlantic, covering five distinct areas/regions demonstrated in Figure 8. These include Region I- Artic Waters, Region II- Greater North Sea, Region III- Celtic Seas, Region IV- Bay of Biscay and Iberian Cost, and Region V- Wider Atlantic (OSPAR, 2022). Norway is one of the contracting parties to ratify this convention from the previous Oslo- and Paris- Conventions.

Comparing Figure 8 to petroleum activity area status on the NCS as of June, 2021 in Figure 9, Norway's maritime boundary and areas for petroleum activity on the NCS lies within OSPARs defined Regions I and II.

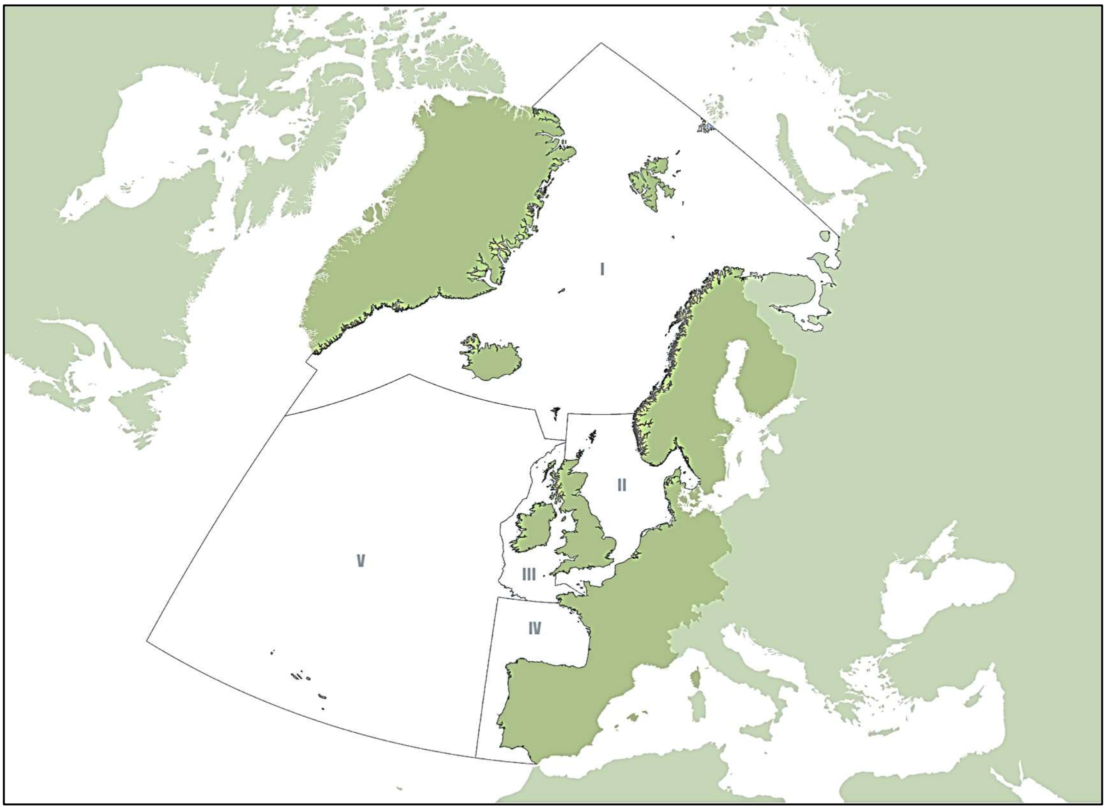


Figure 8: OSPAR North-East Atlantic Regions (OSPAR Commission, 2021)

OSPARs work is guided by the ecosystem approach- integrating conservation and management approaches-, together with other existing national, international policy and legal frameworks backed by best available scientific knowledge. Contracting parties are to use the precautionary principle, polluter pays principle, BAT and BEP, together with clean technology to support commitment towards the ecosystem approach. Use of BAT and BEP is clearly communicated in Annex III of the OSPAR convention text on prevention and elimination of pollution from offshore sources states. Adoption of Annex III is visible through the Norwegian industry HSE regulations such as the Pollution Control Act.

Appendix 1 of the OSPAR convention defines BAT as "*the latest stage of development (state of the art) of processes, of facilities or of methods of operation which indicate the practical suitability of a particular measure for limiting discharges, emissions, and waste".* Referencing the same source, Appendix 1 defines BEP as *"the application of the most appropriate combination of environmental control measures and strategies"* (OSPAR, 2022).

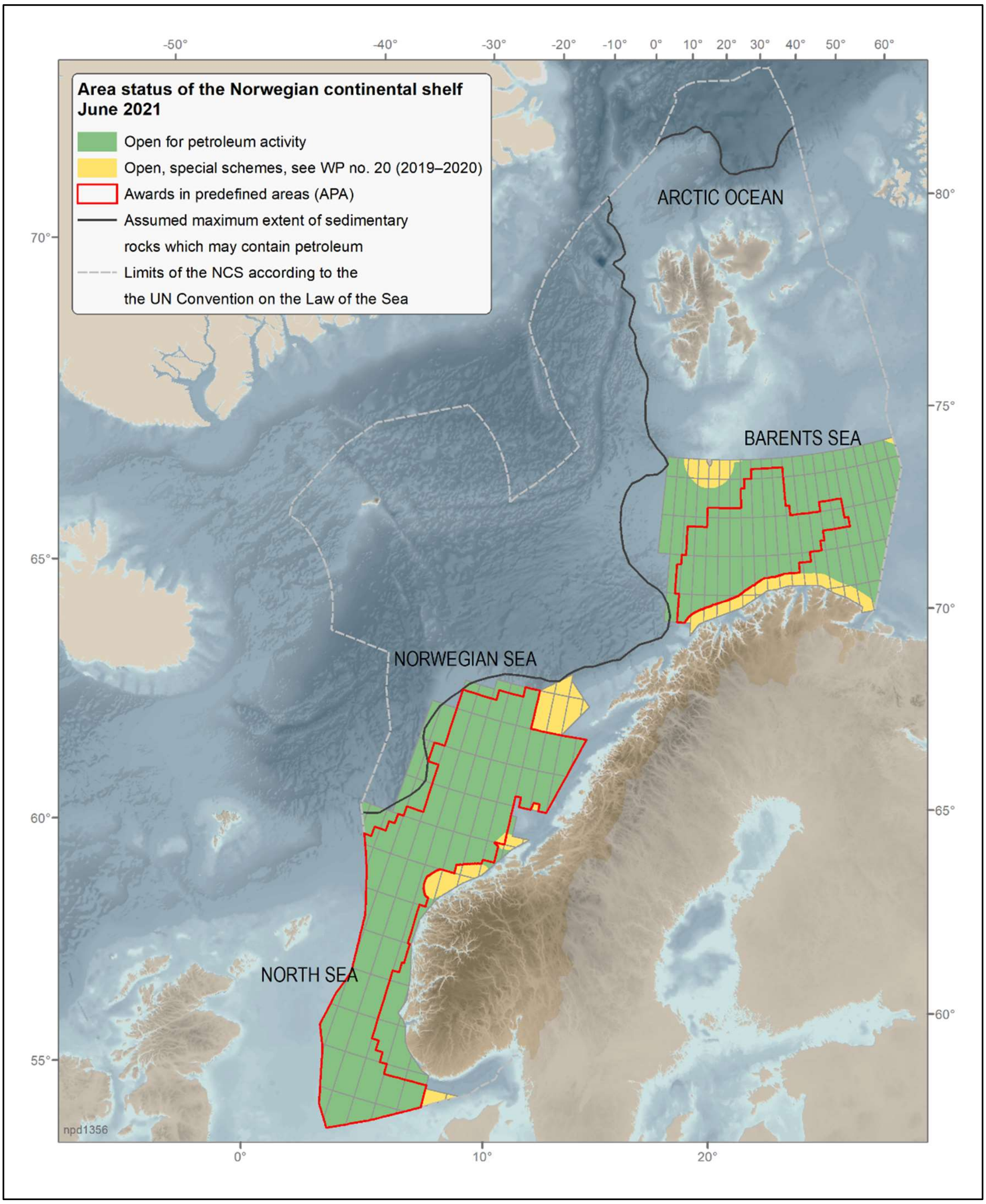


Figure 9: Area status of petroleum activities on NCS (Norwegian Petroleum Directorate, 2022)

As scientific knowledge is often limited or incomplete in marine management, application of precautionary principles is key to the ecosystem approach. Preventive measures are to be exerted on reasonable grounds to safeguard human health, marine ecosystems and living species from harmful human activities that could compromise future generations. Under polluter pay principle, cost of pollution prevention, control and reduction measures is bore by the polluter.

OSPAR's Offshore Industry Committee (OIC) leads enactment of agreements, assessment, recommendation, and decisions pertaining to the offshore oil and gas industry. According to NEA, Norway typically decides to fulfil its OSPAR commitments (adhering to OSPAR Convention Article 2 (4)- general obligations-) through issuance and amendment to HSE regulations covering industrial activities, inclusive the oil and gas industry.

2.2.2.1. OSPAR Convention articles of interest

The OSPAR Convention comprises a preamble, thirty-four articles, four annexes, three appendices, declarations accompanying selected Contracting Parties, and footnotes.

For the topic of interest in this report, emphasis is placed on the following within the OSPAR Convention to further guide the decision-making process (OSPAR, 2022):

Article 2 (3) of the OSPAR Convention requires Contracting Parties to continuously access latest technological developments and practices when adopting Programmes and Measures.

Article 5 of the OSPAR Convention requires all Contracting Parties to be proactive-individually and jointly- in preventing and eliminating pollution from offshore sources in accordance with the provision of the Convention, in particular as provided in Annex III of the Convention.

Article 3 of OSPAR Convention Annex III states: "Dumping of waste or other matter from offshore installations is prohibited and does not relate to discharges or emissions from offshore sources." Special exemption exists for carbon dioxide streams from carbon dioxide carbon capture processes for storage.

Article 2 of Annex III states: "*When adopting programme and purpose of Annex III, the contracting parties will require individually or jointly, the use of BAT-, BET- technologies and where appropriate, clean technology*".

Article 4 of Annex III states: "Use, or discharge, or emission from, offshore sources of substances which may reach and affect the maritime area shall be strictly subject to authorization or regulation by competent authorities of the Contracting Parties. Particularly, through the implementation of applicable decision, recommendation and all other agreements adopted under the Convention. The competent authority of the Contracting Parties shall provide a system for monitoring and inspection to assess compliance with authorization or regulations."

2.2.2.2. OSPAR Convention pertaining drilling fluids and discharge of drill cuttings

Commencement of the ban of OBM fluids and cuttings into the North-East Atlantic came into effect through the PARCOM Decision 92/2 on the use of Oil-Based Muds.

OSPAR Decision 2000/03 on the use of Organic-Phase Drilling Fluids (OPF) and the discharge of OPF-contaminated cuttings superseded PARCOM Decision 92/2 and PARCOM Decision on the Notification of Chemicals Used Offshore, 1981. OSPAR Decision 2000/03 recalls and places further emphasis on the management of waste and discharges offshore. Discharge of OPF- OBM and SBM- into maritime environment are prohibited and discharge of OBM cuttings were limited to maximum oil concentrations of 1% weight on dry cuttings. In exceptional circumstances, discharge of SBM cuttings to sea can be authorised, evaluating in light of BET and BAT (OSPAR, 2002).

OSPAR Recommendation 2006/5 on a Management Regime for Offshore Cuttings Piles aims to significantly reduce pollution impact from cuttings piles contaminated with oil and other substances. The offshore cutting piles management regime targeted addressing concerns from potential release of oil and other substances into marine environment from remobilization of cuttings piles from activities such as offshore installation decommissioning- creating disturbances to in situ cuttings piles. Within this recommendation, no action was required for screening of water-based drilling fluid cutting piles discharges, but requirements existed for NADFs contaminated cutting piles (OSPAR, 2006).

However, in 2009 an implementation report on OSPAR Recommendation 2006/5 evaluating disturbance of cutting piles from dredging activities found no major impacts on marine environment. A declaration of no further action was agreed upon for old cuttings discharged offshore, and decision taken for cuttings piles to be left in situ for natural degradation (OSPAR, 2009).

Bakke, Klungsøyr et al. 2013, summarised findings from research papers noting the slow anaerobic degradation of hydrocarbons in NADF contaminated cutting piles occurs within 20-50 cm from the surface of deep cuttings piles discharged several years ago. Chemical alterations of such cuttings are relatively non-existence, but physical disturbances to their resting place and erosion can slowly cause great concern for deeply covered oil-contaminated cuttings discharged several years ago (Bakke, Klungsøyr et al. 2013).

2.2.2.3. OSPAR Convention pertaining offshore chemicals

Consumption and discharge of chemicals offshore is of great concern for OSPAR, to safeguard and limit the overall impact of hazardous chemicals on marine environment.

OSPAR Decision 2000/2 aimed to encourage the continued use and transition to less hazardous substances, to minimize the overall environmental footprint and effect from use, and discharge of offshore chemicals. Reference is made to the OSPAR list of chemicals for priority action- discontinuing its use-, appraising chemicals against EU regulations. Decision 2000/2 was amended through OSPAR Decision 2005/01 on a Harmonized Mandatory Control System for the Use and Reduction of the Discharge of Offshore Chemicals, reflecting updates on the OSPAR hazardous substance strategy (OSPAR, 2005).

An OSPAR Pose Little or No Risk to the Environment (PLONOR) list of substances utilised and discharged offshore exists, and do not require strong regulations. As implied by the list, substances on this PLONOR list can be directly discharged offshore. NEA reports WBM to primarily cost of water and substances on the OSPAR PLONOR list. Inorganic salts, soluble organic substances- salts, acids, glycol, and alcohols-, insoluble man-made organic substances, minerals, insoluble man-made organic substances, and REACH Annex IV and V substances are listed on the PLONOR list (OSPAR Agreement 2013-06). In consideration to composition of WBM, WBM cuttings are permitted disposal offshore- oil contamination must however lie below OSPAR and local regulations. Responsible local government appointed environmental regulator may have other additional conditions.

Guidelines are set by OSPAR for toxicity testing of substances, chemicals used, and chemicals discharged offshore. An OSPAR protocol exists on methods for the testing of chemicals used in the offshore industry. The chemical supplier has obligations to follow these guidelines and protocol set by OSPAR, and if applicable Organization for Economic Co-operation and Development (OECD) guidance document on aquatic toxicity testing of difficult substances and mixtures. Testing and reporting are to be conducted according to OECD Good Laboratory Practices or other approved national authority quality assurance systems (OSPAR Agreement 2021-07).

2.2.3. Use of chemicals in the NCS oil and gas industry

Chemical utilization in the oil and gas industry cover operations such as drilling activities, well testing operation, produced waste treatment, reservoir production enhancement, production, and processing of well stream on platforms and transportation through pipelines to designated delivery points, amongst others. NEA reported in 2020 around 400 000 to 500 000 tonnes of chemical were used on NCS, and 14 800 discharge of permitted chemicals (Norwegian Oil and Gas Association, 2021) - approximately 60% connected to drilling and well operations compared to other sources in Figure 10.

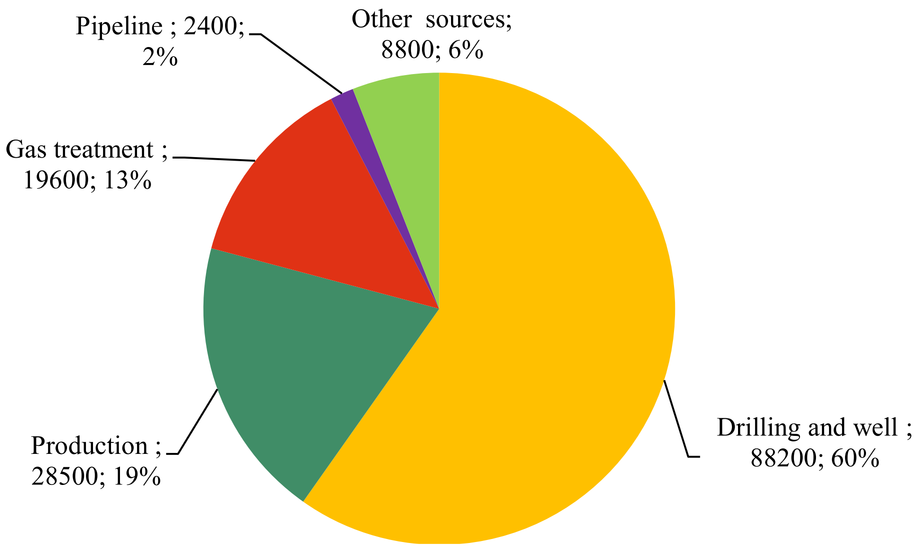


Figure 10: Discharges of chemicals from petroleum activities in 2020, by source in tonnes (NPD, 2021)

Consumption of chemicals for oil and gas activities on the Norwegian shelf has followed a similar trend to the level of drilling activity in Figure 11 below. Some exceptional years- 2012 to 2014 and 2020-, deviated from this trend and could potentially reflect well treatment operations on production facilities or other entirely different operations. Discharged chemicals to sea has remained fairly stable from 2010 to 2020 and do not follow the drilling activity trend. Strict discharge regulations are the success for observed trend. Chemicals not discharged to sea appear along other value chains e.g., dissolve in export oil, treated as hazardous waste and shipped onshore, or injected into subsurface formations (NEA, 2021).

Aktivitetsforskriften § 62-ecotoxicological testing of chemicals- mandates operators to ensure chemical utilisation and discharges on the NCS are assessed accordingly to stipulated OSPAR and OECD regulations. Responsibility lies on the operator to use chemicals posing lowest risk for environmental damage (Aktivitetsforskriften, § 65).

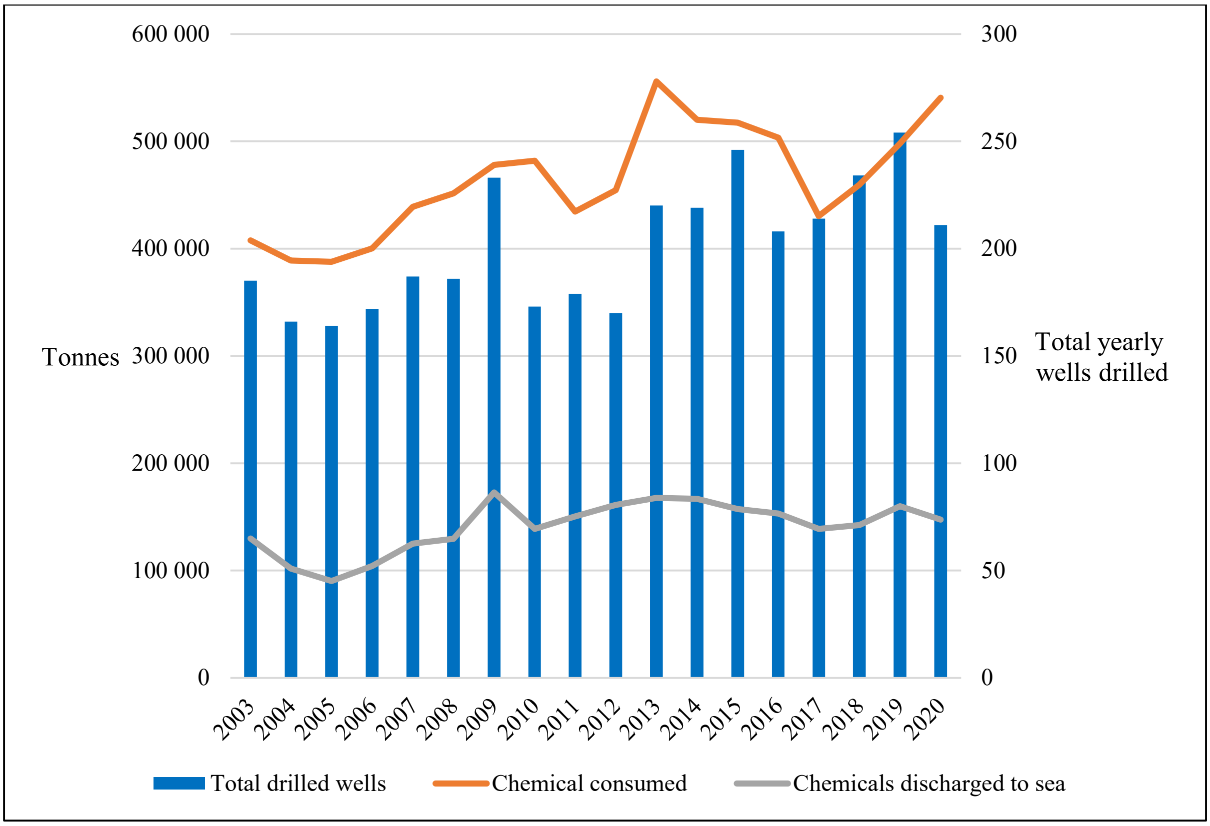


Figure 11: Development in chemical consumed and discharged from oil and gas activity against yearly drilled wells on Norwegian shelf (NEA, 2021 and Norwegian Oil and Gas Industry, 2021)

2.2.3.1. Norway zero-discharge to sea policy

Norway's petroleum industry is recognized for its stringent and high ranking environmental and climate considerations to protect the environment and has firm policies to deliver on its commitments. A zero-discharge target for hazardous substances was established in Norway to preserve the environment from adverse effect of petroleum activities in 1997. Through this initiative/policy environmentally hazardous substances irrespective of whether naturally occurring or otherwise, were prohibited from discharging to sea. Norwegian Petroleum Directorate lists the main components of discharges to sea as; drill cutting contaminated with residual chemicals, produced water and cement from drilling operations – all considering national and OSPAR accepted compositions and levels (NPD, 2021). Permitted chemicals can be discharges offshore to sea and restricted chemicals are injected downhole or treated as hazardous chemicals (NPD, 2021). In 2019, 23% of all generated hazardous waste in Norway was generated by the petroleum/mining industry alone (NEA, 2019).

2.2.3.2. Categorising of substances and chemicals on NCS petroleum industry

According to aktivitetsforskriften § 63, categorising of substances and chemicals is vested on the operator. There are four defined colour categories- bulleted below on decreasing level of severity on the environment- based on composition:

- **Black category:** Chemicals in this category contain substances with a high potential for bioaccumulation, are mutagenic, reprotoxic, and are listed on OSPARs List of Chemicals for Priority Action (LCPA), Norway's List of Priority Substance, or on REACH candidate list (Aktivitetsforskriften § 63, 2021). Special permits for utilisation and discharge are only issued on warranted technical or safety reasons (NEA, 2021). Reportedly, increase from 2019 to 2020 was due to thruster technical issues and new reporting requirements for chemicals used in freshwater generation. On the NCS, consumption of black category chemicals is minimal and trend from 2003 to 2020 is represented in Figure 12. In 2020, 7 tonnes of black category chemicals were used on NCS.

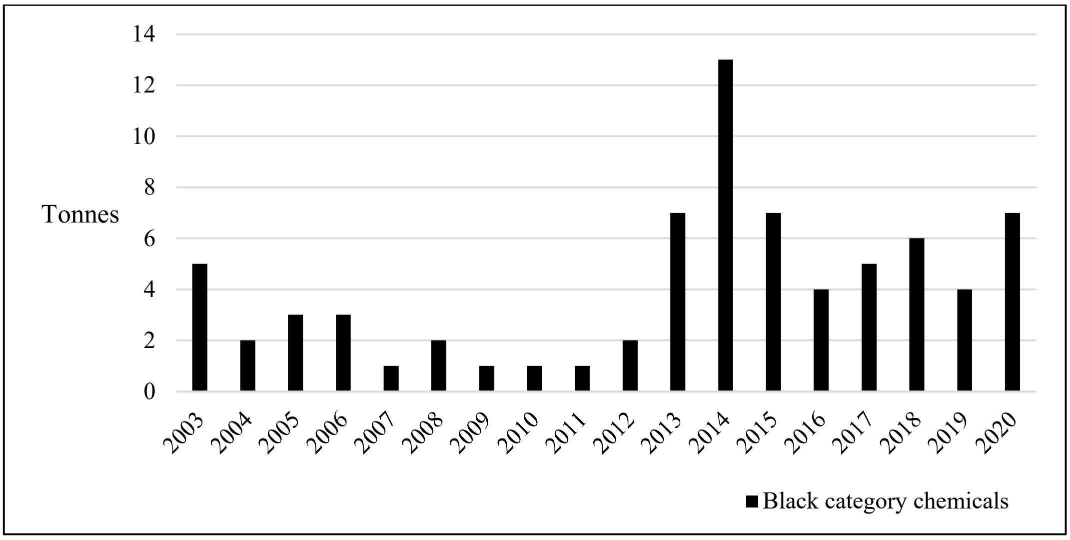


Figure 12: Black category chemical consumption on NCS from 2003 to 2020 (Norwegian Oil and Gas Association, Environment and Climate Report, 2021)

- **Red category:** Chemicals in the red category fulfil one or more of the following criteria: inorganic substances and aquatic toxicity C50 ≤ 1 mg/l, and substances with biodegradation less than 20%. Aktivitetsforskriften § 63 lists other criteria. Substitution of this category equivalent yellow or green category chemicals is uppermost priority (NEA, 2021). Critical technical or safety factors influences issuance of red category chemical utilisation and discharge permits by Norwegian

Environment Agency. Figure 13 demonstrates utilisation of red category chemicals on NCS between 2003 and 2020. Consumption from 2015 onwards increased due to reporting requirements adjustments, and reclassification of sodium hypochlorite- an antifouling agent- used in drinking water treatment from yellow to red category (NEA, 2021).

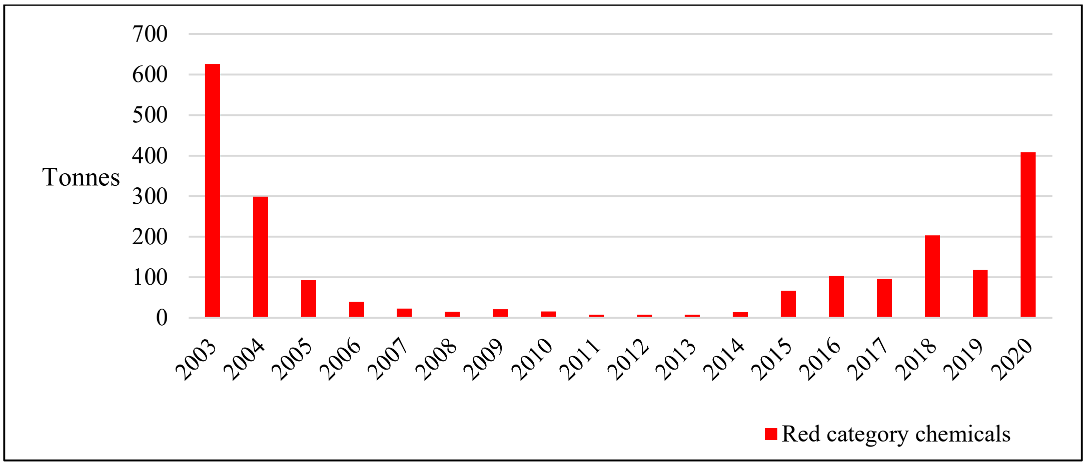


Figure 13: Red category chemical consumption on NCS from 2003 to 2020 (Norwegian Oil and Gas Association, Environment and Climate Report, 2021)

- **Yellow category:** Chemicals with mandatory testing requirements are listed in the yellow category. Substances with biodegradation ≥20% and <60% are in this category (Aktivitetsforskriften § 63). In 2020, approximately 15 000 tonnes of yellow chemicals were discharged offshore and yearly amounts from 2003 to 2020 are shown in Figure 14. Norwegian Environment Agency issues utilisation and discharge permits related to chemicals in this category.

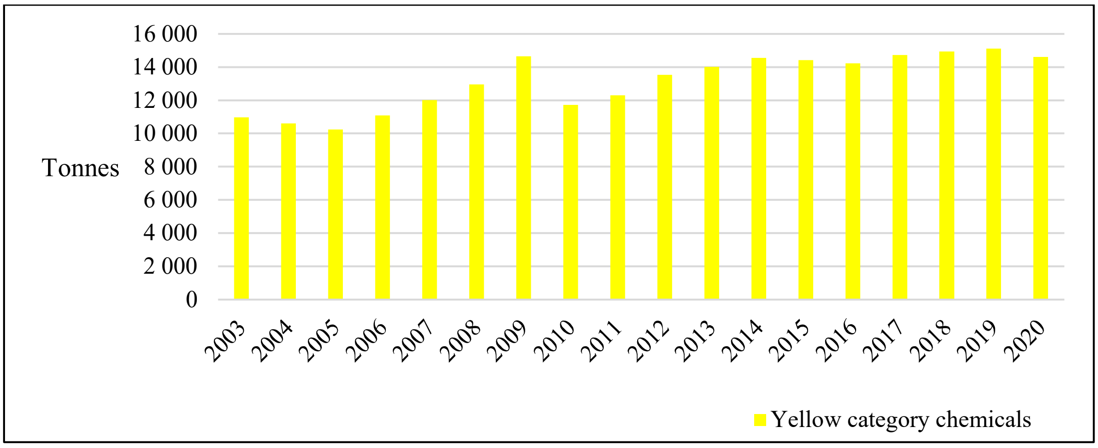


Figure 14: Yellow category chemical consumption on NCS from 2003 to 2020 (Norwegian Oil and Gas Association, Environment and Climate Report, 2021)

- **Green category:** Substances on OSPAR PLONOR list, REACH Annex IV and V list (Aktivitetsforskriften § 63), and water (NEA, 2021) are classified as green chemicals. These substances possess no, or minor negative effect on the environment. Discharging these chemicals offshore is permitted without special conditions. Figure 15 show yearly tonnes of green chemicals consumed for offshore operations on the NCS from 2003 to 2020.

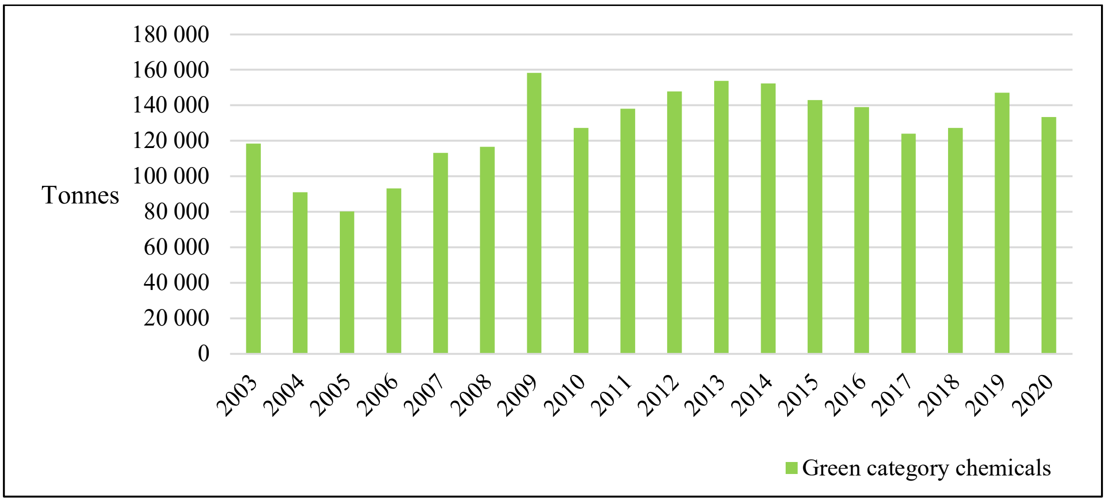


Figure 15: Green category chemical consumption on NCS from 2003 to 2020 (Norwegian Oil and Gas Association, Environment and Climate Report, 2021)

Relative yearly comparison of different chemical colours is displayed in Figure 16. Green chemicals are the most employed chemicals on the NCS year-over-year, yellow chemicals ranking second, red chemicals ranking third and black chemicals minimally used. In year 2020, 133 273 tonnes of green chemicals- representing 89.97%-, 14 605 tonnes of yellow chemicals- representing 9.85%-, 408 tonnes of red chemicals- representing 0.275%- and 7 tonnes of black chemicals- representing 0.005%- were consumed on the NCS.

Respective amounts consumed and corresponding percentages reflect compliance to Norwegian regulation, Norwegian Environment Association, OSPAR Commission environmental considerations and EU regulations like REACH, amongst others.

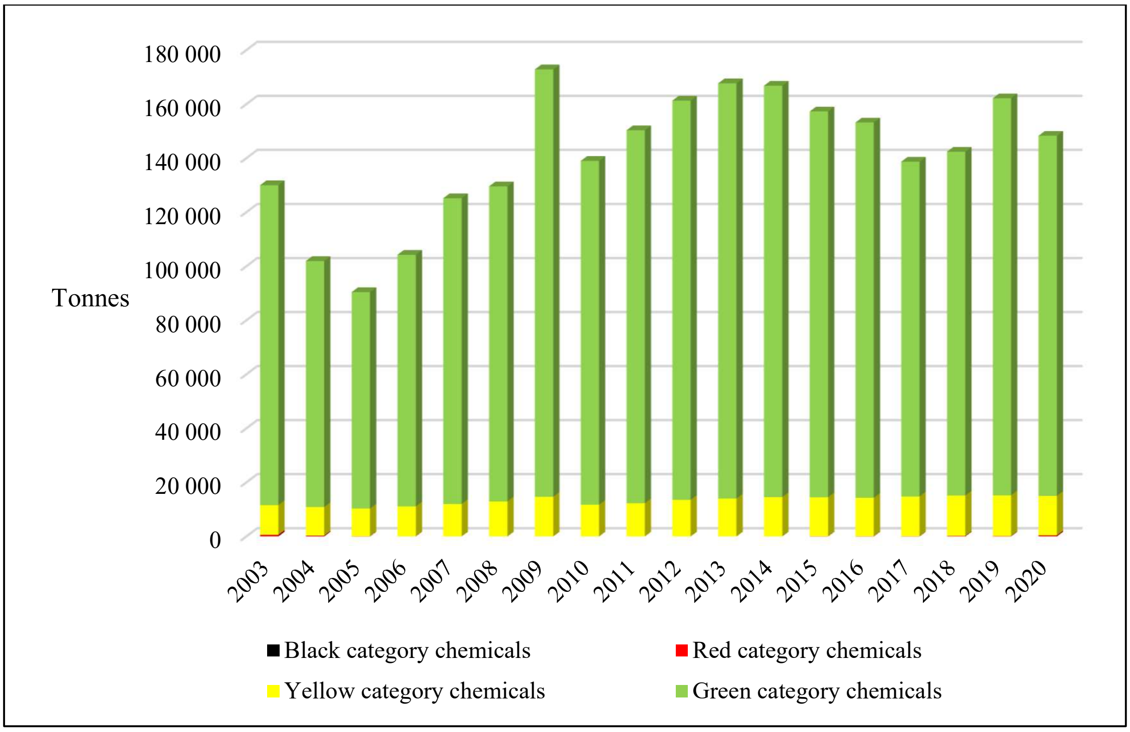


Figure 16: Yearly category chemicals consumption on NCS from 2003 to 2020 (Norwegian Oil and Gas Association, Environment and Climate Report, 2021)

2.2.3.3. Regulation pertaining disposal of drill cuttings offshore on NCS

Aktivitetsforskriften § 68, explicitly states drill cuttings contaminated with NADF or formations oil of more than 10g/kg dry mass is prohibited from offshore discharges. Likewise, WBM drill cuttings is permitted for discharge offshore if formation oil <= 10g/kg dry mass. Irrespectively, operator must apply for discharge permits if NADF contaminated drill cuttings is <= 10g/kg of dry mass. Regardless of drill cuttings contamination level, the drilling mud/fluid chemical compositions- according to chemical colour category listed in Sub-section 2.3.1- influences offshore discharge permit issuance. To protect damage to vulnerable benthic fauna in certain areas, NEA can set addition discharge conditions for even normally disposed WBM drill cuttings offshore (Norwegian Environment Agency, 2021).

For applications to discharge OBM cuttings offshore, the operator’s application must contain description of the treatment technology, degree of purification and estimated total discharge of OBM accompanying the treated OBM cuttings. Additionally, an assessment of the environmental impacts compared to alternative solutions must accompany the application (Norwegian Environment Agency, 2021).

2.3 Drilling waste management

PCA § 27 defines waste as objects, goods, or substances someone has discarded, intends to discard, or is obliged to discard. Wastewater and exhaust gases are not deemed as waste (Lovdata, 2022). In light of this, drilling fluids, treatment and disposal of drill cuttings are regulated by the PCA.

Norwegian Oil and Gas Association Report 093 on recommended guidelines for waste management in the offshore industry was created in 2019 with an objective to provide common ground for a shared waste management standard (Norwegian Oil and Gas, 2019). Waste reductions must be applied through the value chain to effectively use resources- in a more sustainable way. In this recommendation, the waste triangle shown in Figure 17 illustrates waste prevention as the most sustainable approach to manage resources and protect the environment.

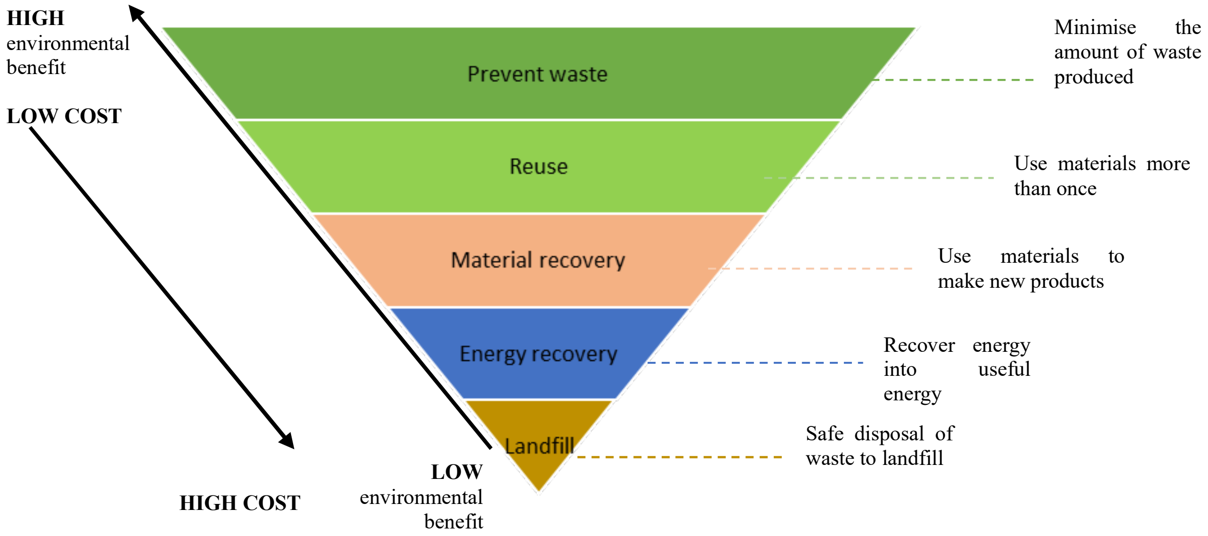


Figure 17: Waste Triangle (Norwegian Oil and Gas, 2019)

Despite waste prevention being the highest hierarchy, other significant considerations can yield both environmental and economic benefits centred on reduction, reutilisation, and recycling. In relation to the topic at heart of this master thesis, viable options include the selection of:

- products with a long lifetime
- products that can be recovered materially or energy wise
- reduction of waste with hazardous substance and substituting it with less harmful alternatives.

Effective and efficient drilling waste management is vital to minimise drilling waste from source through to handling, treatment, and disposal. Figure 18 gives an overview of drilling waste management options from retrieval of drilling fluid and cuttings to final cuttings disposal.

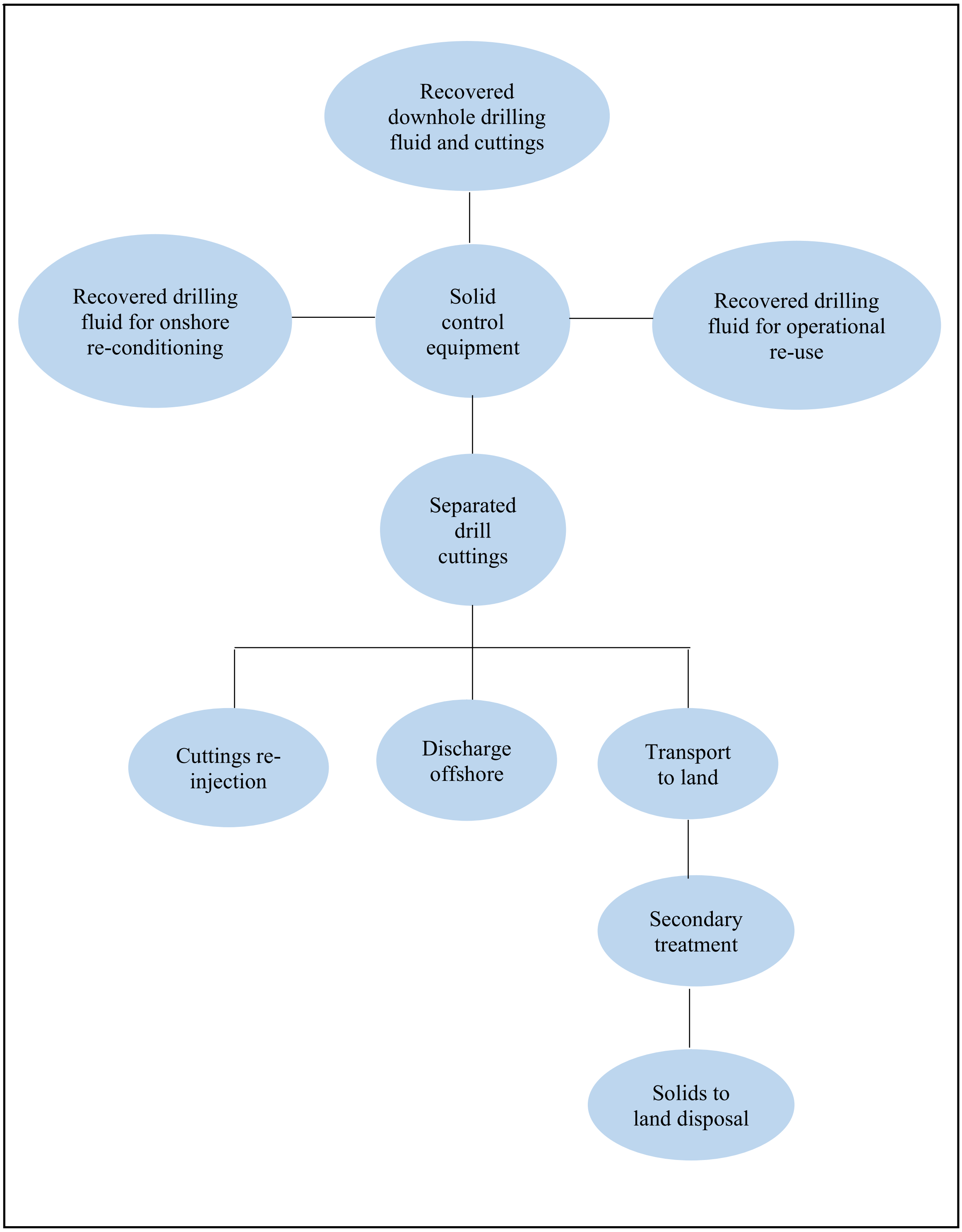


Figure 18: Offshore drilling waste management overview

2.3.1 Drilling cuttings disposal

As part of drilling waste management offshore, options available encompasses:

- drilling fluid and cuttings re-injected into sub-surface formations.
- primary treatment at source before discharge to sea – if permitted by local environmental regulation. This disposal method is best suited for WBM drill cuttings with formation oil ≤10g/kg dry mass and only WBM containing green and yellow chemicals in Norway.
- cuttings not meeting established local regulations for offshore discharge are sent onshore for further treatment and final land disposal.

2.3.1.1. Offshore cuttings re-injection

Cuttings Re-injection (CRI) is a waste disposal process wherein cuttings are ground into smaller particles. Resulting stabilised slurry- combination of grinded cuttings, slop, or sea water and viscosifiers -, is injected into a subsurface geological formation that is impermeable (Svensen and Taugbøl 2011). This disposal method is executed in proximity to generation source. Chosen formation must permanently store cuttings to avoid leakage to surface and creating undesirable catastrophic environmental incidences. A dedicated injection well, or annulus of a well being drilled- or a producing well-, and or injection into a depleted well, are employed methods for CRI (IOGP, 2003).

On the NCS, CRI was first used by BP on the Gyda field in 1991 (Willson, Rylance et al. 1993). CRI gained popularity and capitalised on for most platform drilling operations employing extensive utilization of OBM (Saasen, Jødestøl et al. 2014). Annulus re-injection is reportedly no longer used due to only one barrier existing between the pressurised injection area and surface (Taghiyev, Hodne et al. 2015).

Operational and economic considerations influence the injection method to be adopted offshore. Approaches for slurries injection into formation can be executed above the fracture pressure to crack and fracture the formation, or below fracture pressure into naturally cracked formations (Veil 2002). CRI process typically features real-time injection while drilling, so system reliability is a critical factor for operational progression (Chauvin 2018).

Generally, a CRI package comprises three principal components (Alba Rodriguez, Fragachan et al. 2007);

- cuttings transport system: to transport cuttings from source location to CRI injection well. e.g., gravity collecting system, vacuum transport system, augers or belt conveyor system, or pneumatic bulk transfer and storage system.
- slurrification system: transported cuttings are blended with seawater by circulation with centrifugal degradation pumps in a coarse tank forming a slurry. This operation partly degrades the solids from impact forces. Resulting slurry is then transferred to the classification shaker and grinder to ensure proper slurry particle size. Desired particle sizes from the shaker fall into the fines tank and slurry conditioned as required with stabilizing additives.
- re-injection system: conditioned slurry from fines tanks is received into an agitated holding tank and ready for injection downhole using a high-pressure injection pump. Data acquisition and monitoring of injection parameters provides the best operational risk mitigation and management tool.

CRI reduces associated crane lifts, OBM cuttings logistic to shore and eliminates use of landfill space. It provides a comprehensive solution for drilling waste management and adherence to zero discharge policies offshore. Issues with slurry leakage as reported by Offshore Magazine, 2010 demonstrated a potential weakness to this disposal technique and unintentional environmental regulations violation. An adequate well monitoring and verification program is therefore vital throughout the cutting's re-injection lifecycle. Referring to waste diagram in Figure 17, recovery of energy or material from the drilling cuttings /fluids is unachievable with CRI method of cuttings disposal. It is approximated CRI process emits 205 kg CO_2/tonne of cuttings to be injected (Innes, Gareth et al. 2021).

2.3.1.2. Cuttings ship-to-shore

As not every drilling rig, well or field is equipped to undertake CRI- reference made to mobile floating drilling rig and limited formation knowledge on exploration wells. Other environmentally safe drilling waste management options for cuttings disposal are explored in such scenarios. For offshore operation, two common options exist to ship cuttings to onshore processing facilities:

- **Skip & Ship**

Skip & ship is a well-known cuttings transport method- proven over several years- where cuttings are transported for treatment and final disposal onshore (Svensen and Taugbøl 2011). Drilling rigs are primarily designed with dedicated skip stations to dump cuttings into allocated skips and transported for subsequent treatment and disposal. Reportedly, it is a simple operation wherein cuttings are dumped into skips- directly from the auger feeder, or alternatively transported from the chute via blowers into skips. Filled skips are crane lifted from designed slots and replaced by empty skips as drilling operations progresses. Skip coordination required constant crane and deck crew allocation. Inability to maintain skip management pace with drilling operations can potentially result in reduced drilling rate of penetration (ROP) or rig non-productive time (NPT). This method of cuttings transport creates a handful of potential HSE risks- such as dropped objects hazards, pinch points, and requirement of effective communication between transport zones- onboard the rig, supply vessel and final treatment destination. Therefore, it is an undesired transport medium targeting small volumes of cuttings per high potential risk with crane lifts.

- **Bulk Transfer**

Bulk transportation of drill cuttings involves using large holding tanks/cuttings storage tanks (CST). Drill cuttings from the shale shaker are transferred mechanically or pneumatically to CST onboard the rig for intermediate storage and subsequently transported to CSTs onboard a supply vessel via hoses (TWMA, 2021). This system is perceived as robust, an environmentally friendly solution, and offers greater drilling waste storage at source- per square meter (m^2) space- to enable faster drilling. TWMA CST units have capacity up to 100 metric tonnes. Crane lifts are only required during mobilization and demobilization operations and hooking up of hoses from the rig to receiving supply vessels. Proper established procedures are necessary must for transfer operations to supply vessels and ensuring transfer hose is well secured to prevent undesired spills.

In Table 4, benefits and drawbacks of the different OBM cuttings transport to land mechanisms are summarised.

Table 4: Summary of benefits and drawbacks of cuttings transport to land mechanisms.

CUTTINGS TRANSPORT TO LAND MECHANISM	BENEFITS	DRAWBACKS
SKIP & SHIP	+ Economically, a cheaper solution to transport OBM cuttings to land (Statoil, 2016). + Relatively dry cuttings are transported as additional mud is not needed for lubrication.	– Greater manual intervention required per skip (levelling of cuttings heap, locking of skip lids, etc.). Additionally, considerable operation risk emerges for both rig and supply vessel personnel. – Weather sensitive operation places limitation on skip transfer from rig to supply vessel and vice versa. – Skips are associated with high number of -average five during drilling operations- crane lifts from mobilization to rig, onboard the rig, and demobilization to authorised treatment facility onshore (Svensen and Taugbøl 2011). – Volume limitations per skip- 4 m^3- implies enormous quantities required onboard drilling rig, occupying large useful rig deck space.
BULK TRANSFER	+ Reduced crane lifts in comparison to skip & ship. + Reduced manual intervention and HSE risks for rig and supply vessel personnel. + Bulk tanks can receive larger volumes- 23 m^3 (Statoil, 2016)	– Depending on cuttings dryness, additional lubrications- e.g.: Drilling mud- is needed to prevent flowline plugging or clogging (Svensen and Taugbøl 2011). – Per Equinor 2016 document, it is an expensive market solution based on equipment rental, and addition of lubrication mud that potentially can be re-used/ re-conditioned. – Weather sensitive operation. – Reduced drilling rate based on Equinor's experience from relatively low transfer rate from platform to supply vessel via hoses (Statoil, 2016)

2.3.2. Drilling fluid and cuttings treatment

There are various viable techniques to treat drilling fluids and cuttings, but selection is based on prevailing local environmental regulations, industry recommended guidelines and practices, BAT, BEP, operator preference aligned towards HSE standards, cost, and desired results.

Recirculated drilling fluid and accompanying cuttings undergo treatment to separate the cuttings- now waste-, from the drilling fluid. Treatment occurs in two stages: primary and secondary treatment. Primary treatment is the first waste management practice in any drilling operation and employs the utilisation of solid control equipment to remove drill cuttings from recovered drilling mud pumped into the wellbore (Zhiqiang Huang, Xu et al. 2018). Apart from removing drill cuttings, solid control equipment is used to remove other contaminants in addition to entrapped gas in the mud. Undertaking these fosters drilling mud recovery for potential reutilization, according to desired technical performance. A process embedded on foundation of reusing hierarchy level introduced in the waste triangle of Figure 17 and contributing to reduction in overall drilling costs.

Secondary treatment is typically performed onshore on NADFs or reservoir hydrocarbon contaminated cuttings to further recover retained NADFs, and also adhere to local environmental regulations prior drill cuttings disposal. Commercial technology to undertake secondary treatment offshore exists, eliminating OBM cuttings transport onshore for treatment and eventual disposal.

2.3.2.1. Primary treatment

Primary treatment of drilling cuttings and drilling mud is performed at the wellsite. An optimal solid control package offshore offers an operational edge, reducing potential costly NPT whiles meeting stringent environmental regulations, and recuperation of drilling fluid for reutilisation. Different technologies exist and typical solid control equipment includes shale shaker, hydro cyclones, and centrifuges. Factors such as type of drilling fluid used, available rig equipment, country specific disposal options, and sub-surface formations being drilled influences the choice of solid control equipment.

The shale shaker mounted with vibrating screens is the first and critical solid control equipment on the rig. Screen selection is a compromise between solids removal, circulating rate and screen life expectancy (Bridges and Robinson, 2020). According to OIGP 2016, the shale shaker removes the coarser, sand/gravel sized cuttings particles. If separated mud contains entrained gas from the formations, it will be passed through a degasser to remove the gas. Recovered drilling mud is subsequently passed through a hydro cyclone or centrifuge, if the drilling mud contains high concentrations of clay-sized/finer cuttings particles, to maintain performance of recycled drilling mud or prevent drilling fluid flow properties degradation (IOGP,2003). A hydro cyclone works on the principle of centrifugal forces and gravity to separate the liquid and solid phase based on density difference (Zhiqiang Huang, Xu et al. 2018). Desilter- removes solids in the range of 15μm and larger- and desanders are both hydro cyclones with increasing cone size in the respective order listed. The smaller cones recuperate finer particles from the drilling mud (Bridges and Robinson, 2020). These finer particles can accumulate in the drilling fluid thereby increasing the drilling fluid solids concentrations and degrading the rheological properties of the drilling mud (IOGP, 2016). Centrifuges further removes the finest silt from the residual drilling mud by generation of large centrifugal force (over 2000G). It is used to maintain mud weight and also control accumulation of low gravity solids for drilling mud recycling during operations (Zhiqiang Huang, Xu et al. 2018).

After primary treatment, resulting solid waste stream includes the drill cuttings (varying combination of sand, shale, clay, and small pieces of stone), other adhered solids from the drilling fluids (such as barite and clays) (IOGP, 2003).

2.3.2.2. Secondary treatment

Secondary treatment of NADF drill cuttings onshore is well established, and commonly employed technology are cutting dryer and based on thermal treatment (desorption) (Stantec, 2009). However (Stephenson, Seaton et al. 2004), highlighted the recent development of commercial offshore thermal desorption units, whereas historically thermal desorption method was best suited onshore. Onshore units are large, and demonstrated slower processing rate relative to drilling ROP, requiring additional cuttings storage space onboard the drilling rig. Residual OBM/SBM cuttings after secondary treatment are disposed in landfills, used as construction material or for land spreading (IOGP, 2006). Other secondary treatment methods include biological treatment, chemical washing, incineration, and solidification/stabilization (Zhiqiang Huang, Xu et al. 2018).

- **Cutting dryers**

Cutting dryers work on the principles of high-speed centrifugal forces to recover additional retained NADFs on the oil-based drill cuttings. There are two categories of cutting dryer: - dependent on the centrifuge axial direction- horizontal and vertical. Cutting dryers can be installed both offshore and onshore. Offshore, OBM drill cuttings can be channelled from the shaker to a cutting's dryer unit for secondary processing- if available offshore (Stantec, 2009). Onshore it can be installed upstream of the thermal desorption unit increasing throughput to the unit, and further removes excess mud/liquid from the cuttings- requiring less energy for thermal desorption. (Pierce, Wood et al. 2006). Different studies performed revealed a varying reduction in residual oil content (ROC) on NADF drill cuttings- after shaker- from an average of 11% thereabout to a best-case lowest value of approximately 2% (Zhiqiang Huang, Xu et al. 2018). Achieving OSPARs ROC of 1% limit on drill cuttings is not possible with only cuttings dryers, and other technologies adapted in conjunction or separately.

- **Onshore thermal desorption**

Thermal desorption technology for drill cuttings has evolved along stringent environmental regulations for NADF drill cuttings since mid-1990s (Pierce, Wood et al. 2006). In Norway, thermal desorption treatment on NADF drill cuttings has be used onshore since 1992 in response to the stringent offshore regulations for disposal of OBM cutting (Svensen and Taugbøl 2011).

Thermal desorption technology separates the liquid phase in the drill cuttings under anaerobic heating conditions- typically oxygen content <8% by volume- to avoid combustion from high operating temperatures (Pierce, Wood et al. 2006). In all thermal desorption process, both oil and water are evaporated from cuttings, and each unit is equipped with two-stage condensers to remove the oil and water separately (Stephenson, Seaton et al. 2004). Firstly, water is evaporated to form steam- reducing the boiling point of the oil-, making thermal desorption occur at a temperature lower than the oil theoretical evaporation value (Zhiqiang Huang, Xu et al. 2018). As evaporation occurs, both free oil and emulsified oil are moved, as heat required for evaporation is sufficient to remove and separate emulsified oil. Removing interstitial oil- referring to naturally occurring formation hydrocarbons present in drill cuttings- proves more challenging, and additional heat is required to overcome existing molecular forces and surface tension. In Norway, the onshore thermal desorption unit is predominantly electric powered (Statoil, 2016).

Different thermal desorption technologies on the market includes:

- Drum-type indirect units: a rotating drum is heated externally by burners. These units are usually operated at 315 °C but can be operated at higher temperatures.
- Screw-type units: a hollow screw with a heated jacket is used. Hot oil- heat transfer medium- is circulated through the jacket. Theoretically these units can be operated at 315 °C - similar to the drum-type indirect units-, but usually operated at 204 to 260 °C to lengthen oil's life that can be shortened from decomposition and cracking.
- Chemical thermal desorption: cuttings are mixed with concentrated acids resulting in heat generation. Cuttings are also disintegrated by chemical oxidation and heat of solution from the acid provides the heat needed for the water separation. To derive a very fine, dry powder cement-like consistency, a base compound is added to stabilize the disintegrated cuttings and neutralise the pH (Stephenson, Seaton et al. 2004).

Recovered oil can be combusted to provide heat requirement or even reutilised in NADF drilling fluids, for both drum and screw type units.

- **Incineration**

In incineration, organic components in the NADF cuttings are oxidised by indirectly or directly heating to high temperature between 820 °C to 1600 °C (Ball, Stewart et al, 2011). This process of treatment and disposal reduced the contaminants to inert residues, disposes of large volumes of cuttings, and can dispose of a vast majority of other O&G waste. Hazardous waste incinerations are limited to two types: liquid injection and rotary kiln systems. It is a less frequently explored method to treat cuttings, and resorted to when other disposal options are unavailable or in some sensitive environment with limited preferences (Ball, Stewart et al. 2012). Incineration however destroys the soil structure and removes all natural humid components. Additionally, residues may contain high metal contents and treatment of exhaust gases is necessary to remove particulates and harmful combustion products such as nitrogen oxides, or sulphur dioxides.

- **Offshore thermal desorption**

Offshore thermal desorption units are specifically design with consideration to meet and exceed <1% hydrocarbons/NADF on drill cuttings for offshore disposal- meeting OSPAR and Norway's regulation for offshore OBM cuttings discharge. Design is based on modularization of the thermochemical cuttings cleaner (TCC) onshore plant-, operating on thermal desorption- bearing in mind drilling rig deck space, total unit weight, and meeting rig zoning requirements. Achieving a shortened processing time to sustain drilling operations at the wellsite was important for technology development success (Pond and Hinden 2017). The TCC system is a viable commercial technology for thermal desorption of cuttings both offshore and onshore. This technology was developed and patented by Thermtech AS in Norway and commonly referred to as the Hammermill system (Stantec, 2009). Halliburton and TWMA have manufacturing license for the Thermtech Hammermill system (Thermtech, 2019). Kinetic energy from a drive unit is converted to thermal energy by creating friction in the cuttings stream. Subsequent sub-section will dive more into this technology.

The iNOVaTHERM portable treatment unit by NOV is another Indirect thermal esorptiont unit for offshore treatment and disposal of OBM cuttings. Unlike the Hammermill system, the iNOVaTHERM uses non-frictional indirect heating to maintain constant temperatures. This technology has proven to deliver as low as 0.1 wt.% ROC on treated OBM cuttings for offshore discharge in the North Sea (NOV, 2022).

2.3.3. TCC Hammermill technology

2.3.3.1. *Technology overview*

Depending on the technology provider, the TCC Hammermill system can be operated at 250-300 °C–- without applying an external heat- and is considered a best available technique/technology for NADF contaminated cuttings treatment. The process is controlled by fully automatic programmed logic control (PLC) system (Mi Swaco, 2011), making it reliable for long continuous operations (Thermtech, 2014), and ensuring maintenance of optimum process conditions. TCC Hammermill technology yields three major treated products- namely recovered base oil, crushed rocks, and water. Overall process diagram for this technology is show in Figure 19, depicting the various units and trajectory of untreated NADF cuttings transformed into separate products.

NADF cuttings are feed into a feed hopper and hydraulically pumped into a stationary barrel shaped process chamber- also referred to as TCC process mill-, housing a series of shaft mounted hammer arms driven by an external drive (Kleppe, Michelsen et al. 2009). Fast rotational motion of the hammer arms crushes and forces solid particles towards the wall of the process chamber, transforming kinetic energy to heat by friction. Agitation of cuttings continuously creates frictional heat, making the solid cuttings the hottest part of the system and reducing the mean particle size of the cuttings. Heat generated is high enough to flash evaporate oil and water from the drill cuttings within few seconds, and that subsequently exits the chamber as vapour (Thermtech, 2019).

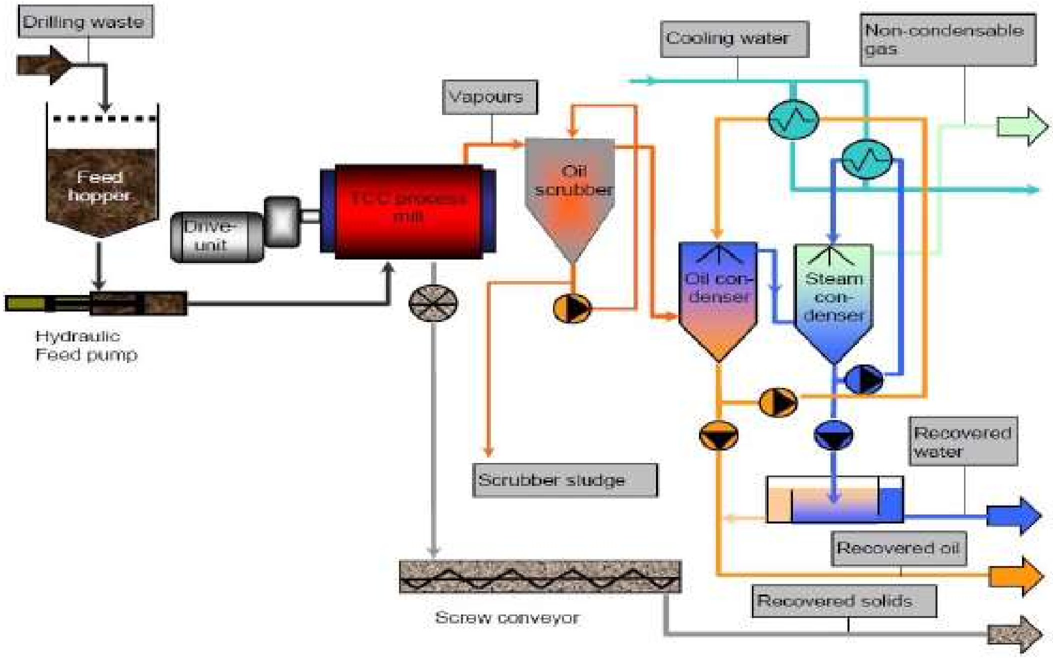


Figure 19: Process diagram for offshore thermochemical cuttings cleaner Hammermill technology (Thermtech AS, 2019)

Principle sketch of the Hammermill system, primarily focusing on activities in the process mill- ignoring ancillary and other downstream equipment for driving the unit and processing the vapour- is shown in Figure 20. Stator labelled in the diagram refers to the process mill, as rotor refers to the rotating hammer arms. Image to the left is axial cross-sectional view, and that to right is longitudinal cross-sectional view of the process mill.

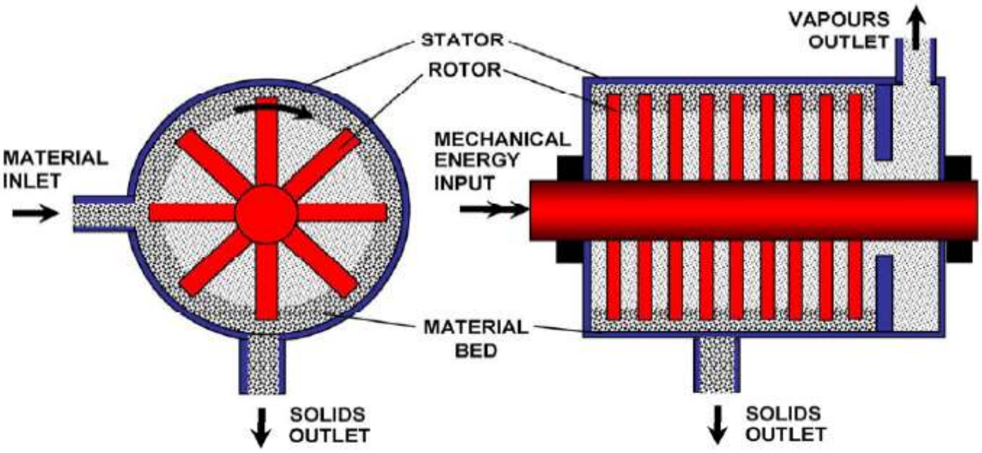


Figure 20: Sketch of offshore TCC process mill (Kleppe, Michelsen et al. 2009)

Resulting vapours exiting the process mill pass through a cyclone/oil scrubber to remove fine solid particles prior travelling to the oil and steam condenser respectively for base oil and water recovery (Kleppe, Michelsen et al. 2009). Recovered solids/sludge from oil scrubber/cyclone unit- about 30% of oil volume- is returned to the feed hopper. Retained heat in this stream heats up cuttings before entering the process chamber. Separate downstream condenser chambers convert outlet vapours to liquid water and oil. Solids in the process chamber are discharged through a cell value onto a screw conveyor.

Treating cuttings offshore with the TCC treatment unit enables the recovery of >99% synthetic oil, base oil, or other low toxicity mineral oil for immediate formulation of new OBM onboard the drilling rig (Mi-Swaco, 2011). In most cases, the final boiling point of base oil lies around 300 °C at atmospheric pressure (Kleppe, Michelsen et al. 2009). Short processing time and low operational temperatures compared to onshore thermal desorption technology ensures an output base oil of high quality (Murray, Kapila et al. 2008). Presence of steam from the water lowers the actual evaporation temperature of the base oil than the maximum evaporation temperature by as much as 50 °C, yielding recovery of a high quality base oil (Kleppe, Michelsen et al. 2009). Recovered base oil solid contamination can vary between 0.1% to <1%- dependent on technology provider.

Base oil for drilling has carbon numbers typically in the C_{12} to C_{18} range. A gas chromatography mass spectrometry scan of a Hammermill recovered base oil from an Mi-Swaco site in Bautino, Kazakhstan displayed similar footprint as a virgin base oil. Aside base oil quality specification such as density and flash point, other HSE requirements can be met by adoption of the offshore TCC OBM cuttings treatment for further utilisation of recovered base oil in drilling mud. Amongst these includes reduction of benzene, toluene, ethyl-benzene and xylenes (BTEX) which are highly volatile and potentially affect personnel health, and removal of oil fractions outside the virgin base oil specification (Kleppe, Michelsen et al. 2009). It is important to maintain a good flash point of the recovered base oil as a low flash point makes it more easily ignited deeming it unfit for re-use. Summing up, recovered base oil is appropriate for directly re-use in new drilling mud.

Cleaned cuttings can be used in manufacturing of cementitious material and various construction applications. Focusing on the master thesis topic, treated cuttings have a documented residual oil content ≤0.5% weight on dry cuttings- well below OSPAR and NEA maximum ROC levels of 1% weight on dry cuttings (Thermtech, 2019). Assessment of the offshore TCC technology presented in the AquateamCOWI 2014 report for the Norwegian Oil and Gas Association concluded the technology cleans the OBM cuttings based on data provided by the technology provider. Analysis performed then on four different sample sets of treated OBM cuttings using the offshore TCC technology revealed an average oil content of 0.4 g/kg dry mass.

Treated water from the TCC Hammermill technology meets NEAs <30ppm oil in water- typically <20ppm- for discharge to sea (TWMA, 2021). According to Kleppe 2009, energy consumed for thermal treatment of OBM cuttings based on standard ambient conditions- composition of 70% solids, 15% water and 15% oil- is 60% on water phase, 23% on solids and 17% on oil phase. The water phase consumes the most energy.

2.3.3.2. Adoption in Norway

In Norway, Total Energies was the first operator to use the offshore TCC technology on the Martin Linge field development as a pilot project in 2015. NEA issued a permit for OBM treated cuttings offshore discharge- ROC of ≤ 0.05 wt.%- using the offshore TCC technology- for the aforementioned field project. In the event treated OBM cuttings could not meet the permit conditions, OBM cuttings had to be shipped onshore for treatment and eventual disposal. It is observed that this discharge limit was significantly low compared to limits set in the Johan Sverdrup application. Furthermore, the technology has developed and potentially deliver lower ROC on treated cuttings in the future.

An environmental audit performed revealed a breach of permit conditions, with treated OBM cuttings disposed higher than stipulated levels (NEA, 2015). Documented weighted average monthly ROC on treated cuttings- performed by a third party- were 0.35 wt.% in May, 0.58 wt.% in August, and 0.17 wt.% in September. Additionally, oil accompanying recovered water from the TCC unit was higher than weighted average monthly limits of 30 mg/l set by OSPAR and NEA. Based on these findings and others, the license was revoked. It is difficult to pinpoint reasons for the technology's inability to delivered agreed permit discharge limits, but it is important to recognise having trustworthy partners/vendors to abide with NEAs issued permit conditions.

Focusing on more recent times, Equinor applied for a OBM cuttings discharge to sea permit- 5-gram oil per kilogram cuttings, equivalent to 0.5 wt.%, in 2016 using the offshore TCC technology for Johan Sverdrup phase 1 field development. Application catered for 16 wells drilled from a permanent drilling rig on the field, and 8 production wells drilled from the Deepsea Atlantic mobile drilling rig, generating a total of 16 000 tonnes OBM cuttings and 4 000 tonnes as buffer. A total of 80 tonnes ROC on treated OBM cuttings was another basis for discharge permit issuance. Based on the type of shaker- mud cube- installed on the drilling rig, approximately 5% OBM retained on cuttings. After treatment through the offshore TCC unit, a guaranteed anticipated estimate of 0.5 wt.% or less OBM retained on the cuttings. Planned OBM comprised only green and yellow chemicals. A detailed analysis on the various outlet streams accompanied Equinor's discharge application to NEA-based on planned OBM composition. In their application, organic components such as pH regulators, barite weight material, bentonite, and additives such a calcium carbonate are some minerals remaining in the drill cuttings after treatment. Heavy organic components such as clay, graphite and asphalt-like substances are not separated during treatment and remain on the treated drill cuttings. It was also strongly believed heavy organic compounds not removed after treatment through the TCC unit remains strongly attached to the treated cuttings, remaining insoluble in seawater and inaccessible to marine organisms.

Based on accompanying analysis to the Johan Sverdrup application, the Norwegian Environment Agency issued a permit with average discharge limit of 0.3 wt.% and daily discharge limit of 0.5 wt.%- aside other conditions (Norwegian Environment Agency, 2016). More recently, adoption of the offshore TCC technology on Johan Sverdrup field yielded averagely 0.25 wt.% and 0.21 wt.% ROC per dry mass treated OBM cuttings for year 2020 and 2021. It is anticipated with the next year, a further decline in ROC on treated cuttings will be observed within the 0.1 – 0.2 wt.% range (Equinor, 2022). Baker Hughes was awarded the contract for drill cuttings destructing, amongst other services, in 2015. Johan Sverdrup offshore TCC unit for 2019 drilling operations was custom build by Thermtech AS for Baker Hughes (Statoil, 2016).

In their application, Equinor further stressed on the offshore TCC unit several years of experience- over 10 years in 2016- on the British sector and declared as BAT for treatment and disposal of OBM cuttings in the same region. Once must recall from Chapter 2, Sub-section 2.2.2- OSPAR Commission's link to Norway-, Figure 8, OSPARs jurisdiction extends over the United Kingdom maritime areas.

2.3.3.3. Environmental considerations

In comparison to untreated OBM cuttings or WBM cuttings, the offshore TCC technology reduces the OBM cuttings particle size and increases the proportion of fine powders (AquaCOWI, 2014). When discharged offshore, the fine-grained treated cuttings settle near the discharge zone in the sea and settle more faster through the water column than initially thought (Equinor, 2022). A low risk of harm exists from drill cuttings discharges on water column organism due to the rapid rate of dilution and dispersal. Turbidity of the cuttings plume decreases light penetration resulting in temporary reduction in primary production of phytoplankton and clogging of gills or digestive tract of zooplankton. It is believed there is minimum damage to mobile water column animals- such as larger crustaceans and fish-, as these usually avoid or move away from drill cuttings plumes (IOGP, 2016).

Laboratory test performed expect associated environmental risk from discharge of treated OBM cuttings offshore to liken that of permitted WBM cuttings discharges offshore with no observed adverse effects on the seafloor ecological functioning (Moodley, Austerheim et al, 2019). Levels of metal and polycyclic aromatic hydrocarbon (PAH) are anticipated to be similar to those accompanying discharged WBM cuttings. Environmental studies conducted in May 2021 by Norsk institutt for vannforskning (NIVA), NORCE Norwegian Research Center and Sintef for discharge of treated OBM from the Johan Sverdrup field confirmed evident traces of hydrocarbons and metals in mussels. No significant health indications were observed on mussels. Immaterial pH difference in discharge areas compared to other locations around the Johan Sverdrup field were observed.

These findings accompanied Equnior’s application this year 2022 to NEA for extension of the treated OBM cuttings discharged permit using the offshore TCC technology on other planned wells on the field- aside the initial 16 wells linked to the first permit.

3. Case study

3.1 Introduction to the company “Neptune Energy”

Neptune Energy is an international exploration and production company, operating in Norway, United Kingdom, Germany, Netherland, Algeria, Egypt, Indonesia, and Australia. Aside operating assets and developing projects in these locations, Neptune Energy also partners with other operators to deliver safer cost-competitive vital energy resources for global markets (Neptune Energy, 2021). As an operator, Neptune energy’s environmental, social and governance (ESG) strategy launched late 2019 has promulgated its sustainable business intentions, commitments, and actions.

Norway is strategically important to Neptune’s global asset portfolio, as approximately 40% of the Neptune Group’s total production- daily average production of 54.7kboepd (kilo barrel oil equivalent production per day) in 2020. Within the Neptune Energy group, Norway has the highest production, and proved and probable reserves (Neptune Energy, 2021).

Investment decisions made to partly electrify Gjøa semi-submersible platform- largest operated asset by Neptune since first oil production in 2020- with hydropower generated from shore, has reportedly saved 200,000 tonnes CO_2 emission annually. Directly corresponding to emission tax savings of NOK 118.2 million (2021 values of NOK 591/tonnes CO_2) and projected NOK 400 million (declared 2030 values of NOK 2000/tonnes CO_2). Neptune Energy has prided itself from a lower carbon footprint- 4.3kg CO_2/boe (barrel of oil equivalent)- compared to Norwegian industry level of 9kg CO_2/boe (Neptune Energy, 2021) in 2020 and has strategically placed Gjøa as a preferred area hub for future tie-in projects, since Plan for Development and Operation (PDO) approval in 2007 (NPD).

For a company in growth, this is accompanied by further exploration, appraisal, and development- of either operated, non-operated assets, or combination.

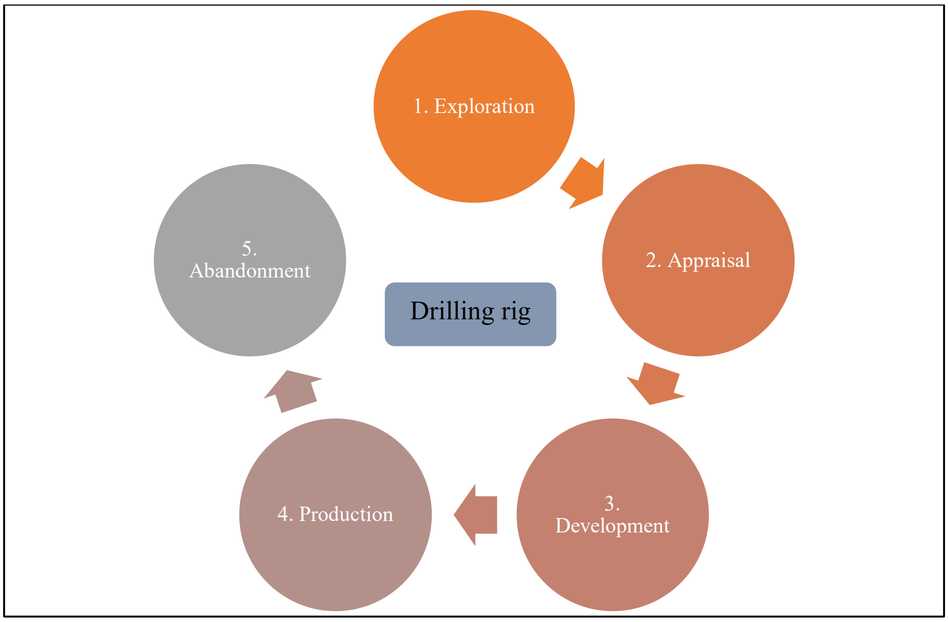
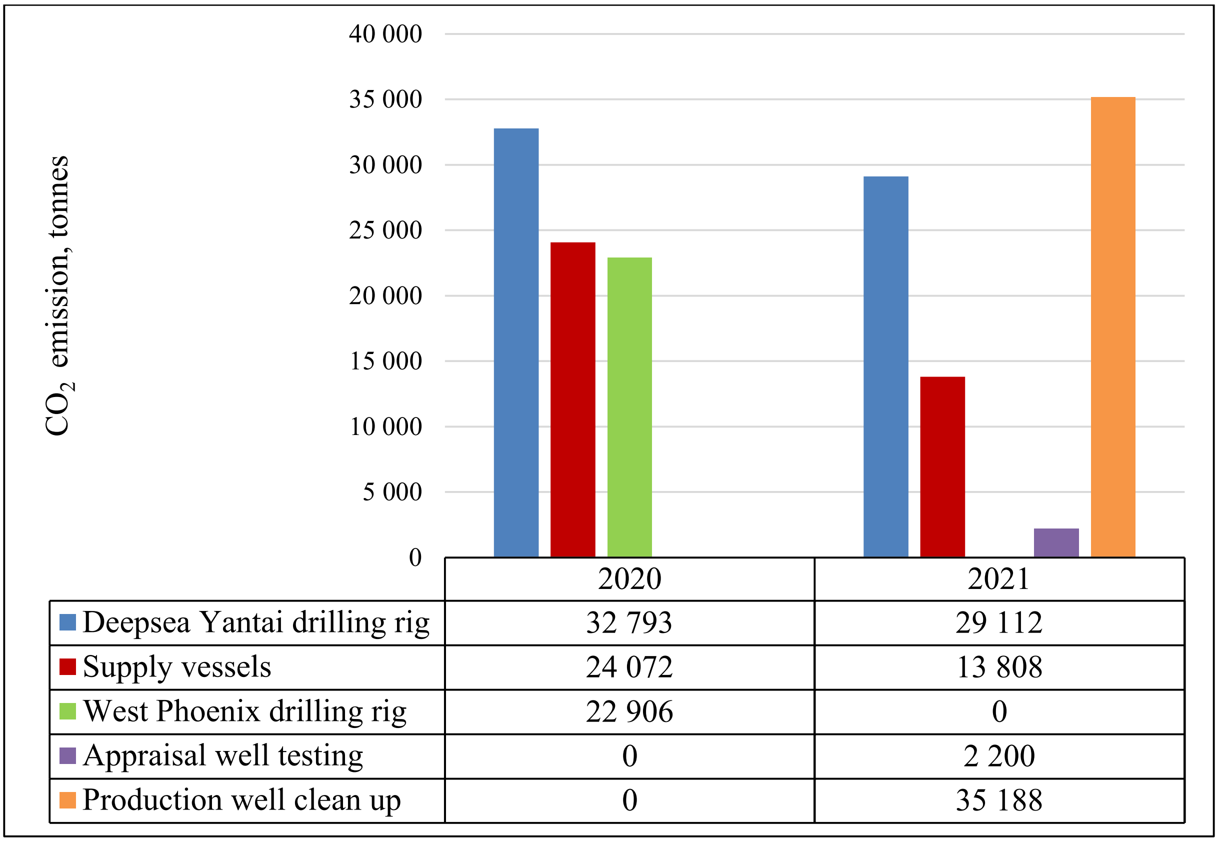


Figure 21: Upstream oil and gas lifecycle

Offshore drilling rigs- highlighted in the upstream oil and gas lifecycle in Figure 21 above- are therefore at the heart of operations pertaining new discoveries, development of long-term value at the safest quickest possible time and eventual abandonment/decommissioning of assets. Managing activities from exploration to development of such wells/fields is typically managed under the drilling & wells (D&W) business unit in an operator company- interfacing with multi- disciplines and service providers. As emission footprint reduction strategies are defined and executed for the longer-term production phases, one must not disregard the other activities in the entire value chain as we transition.

Earlier compilation of Neptune Energy D&W CO_2 emission data displayed in Figure 22 below by the writer, shows a multi-dimensional approach for potential emission reductions based on nature of operations undertaken. Interfacing with multiple suppliers has effect on the broadness and quality of data present to Neptune Energy. In Figure 22, data for 2019 operations was not included as operations commenced in November with the newly constructed first-time operated Deepsea Yantai rig. In Norway, a new organization was formed in 2019 after Neptune Energy completed the acquisition process of Engie E&P International S.A. assets. November 2019 operation was the first under Neptune Energy Norway.

As business interfaces with multiple service providers, prevailing contractual agreements, ownership and capital allocation, other technologies or innovative strategies for offshore drilling operations can potentially reduce indirect emissions. One of such technology targets drilling waste management strategies- particularly oil-based drill cuttings. Offshore treatment and disposal of oil-based mud (OBM) drill cuttings could potentially contribute towards meetings Neptune Energy Norway emission targets, amid other decarbonisation strategies.



	2020	2021
🟦 Deepsea Yantai drilling rig	32 793	29 112
🟥 Supply vessels	24 072	13 808
🟩 West Phoenix drilling rig	22 906	0
🟪 Appraisal well testing	0	2 200
🟧 Production well clean up	0	35 188

Figure 22: Neptune Energy D&W CO_2 emissions for 2020 and 2021

3.2 Drilling & Wells field operations in Neptune Energy, Norway

Neptune Energy D&W business unit in Norway undertook different scope of work in the upstream sector field life cycle. Enlightening the reader on operation undertaken in 2019 through 2021- focused years for this master thesis topic-, information pertaining fields developed, explored, or appraised, location and other general information shall accompany sub-sections below. It is worth noting the order of fields and wells presented bear no chronological representation to actual operational activities undertaken.

Table 5 gives a quick overview of Neptune Energy- Norway- field development drilling activity pertaining drilled wells and total operation days. Total operational or drilling days presented in Table 5 and Table 6 reflect associated OBM and WBM section drilling days, plug and abandon days, and completion days.

Table 5: Neptune Energy, Norway, field development drilling activity overview

Field	Oil producer well	Gas producer well	Water injector well	Appraisal well	Total operational days
Duva	3	1	0	0	247
Gjøa P1	1	1	0	3	300
Fenja	3	1	2	0	362 and on-going

Summary of exploration and appraisal wells drilled by Neptune Energy- Norway- and corresponding drilling days are present in Table 6.

Table 6: Neptune Energy, Norway, exploration, and appraisal drilling activity overview

Field	Exploration wells	Appraisal wells	Total drilling days
Dugong	3	1	128
Grind	1	0	45

Contracted drilling rig for field operations and timeframe is present in Table 7.

Table 7: Neptune Energy Norway, yearly field operations and contracted drilling rig

Field	Year	Drilling rig
Duva	2019-2021	DSY
Gjøa P1	2020-2021	DSY
Fenja	2020	West Phoenix
Grind	2020	West Phoenix
Dugong	2020-2021	DSY
Fenja	2021	DSY

A visual imprint to better comprehend field location and current preferred location of interest to Neptune Energy Norway, centred around the Gjøa field is present in Figure 23. Grind does not appear in Figure 23 as this was an unsuccessful wild cat drilling campaign.

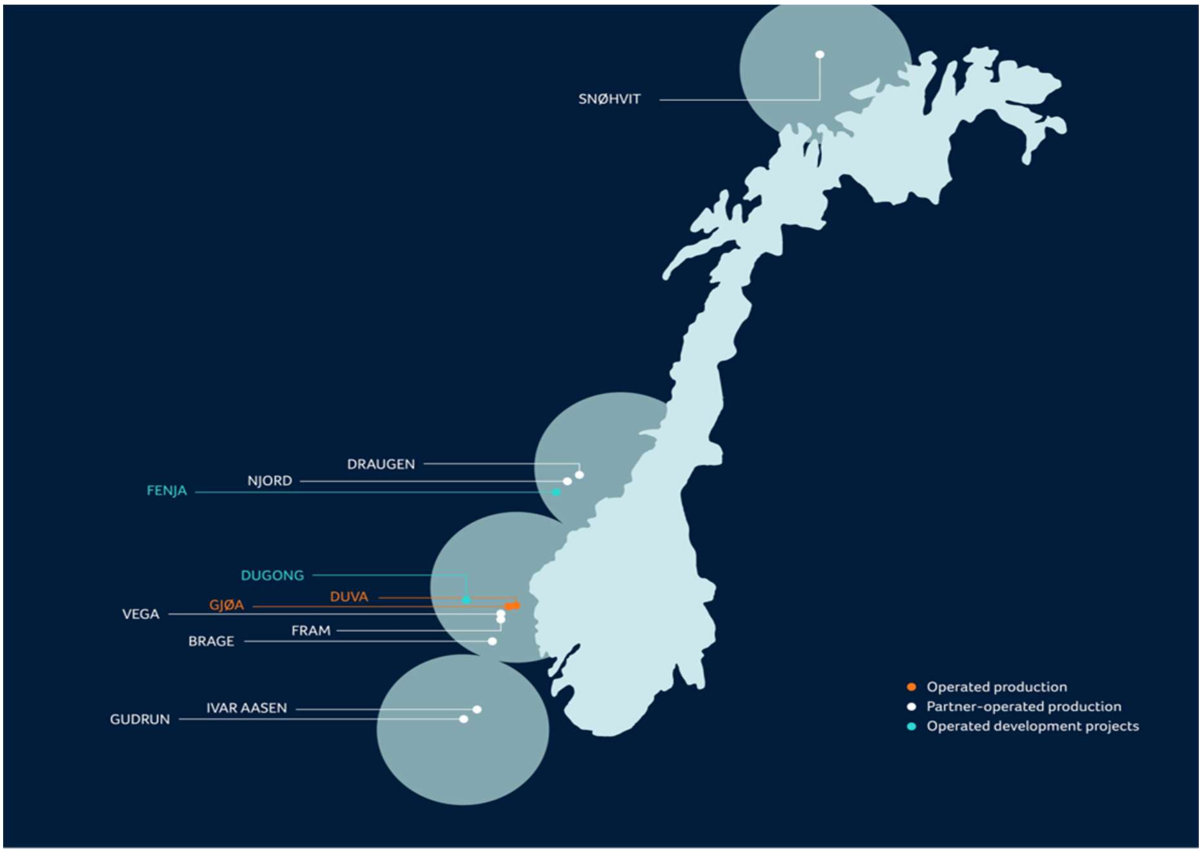


Figure 23: Visual perspective for Neptune Energy Norway field projects

Below, a short description of the field projects of Neptune Energy, Norway is presented.

3.2.1. Duva

Duva field is situated in the western part of block 36/7, approximately 14 km north-east of the Neptune Energy operated Gjøa field and 30 km west of the Norwegian coastline in the northern part of the North Sea. Duva subsea installation development plan entailed drilling three oil producer and one gas producer well in a tie-back to Gjøa platform (Neptune Energy, 2021). This developmental project was executed using the Deepsea Yantai (DSY) drilling rig in fiscal year 2019 to 2021. To maximise synergies, Duva development project was executed concurrently with Gjøa P1 redevelopment. Closest point of call logistics base is the Fjordbase located in Florø. Duva production successfully commenced in August, 2021.

For background information to the reader, Duva development- commenced November, 2019- was the first drilling campaign after acquisition formalization of Engie assets in Norway and other location by the Neptune Energy Group, forming the Norway business entity of the company.

3.2.2. Gjøa P1

Gjøa field is located in blocks 35/9 and 36/7 in the northern part of the North Sea. The field was discovered in 1989 by well 35/9-1, and oil and gas production started in November 2010. Neptune Energy operates the Gjøa semi-submersible platform. Gjøa P1 segment redevelopment plan- aimed to develop untapped reserves in the northern P1 segment- was influenced by results from drilling three appraisal wells. Drainage strategy for the already producing P1 segment entailed drilling one oil and one gas producer well in a subsea template (Neptune Energy, 2021). This scope of work was undertaken in fiscal year 2020 to 2021 by DSY drilling rig in parallel with the Duva development project. Closest logistics base is the Fjordbase located in Florø. Gjøa P1 production successfully commenced in February 2021.

3.2.3. Dugong

The Dugong 34/4-15 prospect in Production License (PL) 882 is located 158 kilometres west of Florø, close to the Snørre field. The reservoir lies at a depth of 3,250 to 3,400 meters and water depth of approximately 300 meters. Well, 34/4-15 S (main bore) and 34/4-15 A (side track) well were drilled in 2020 to validate defined objectives in pursuance of this exploration activity.

In 2021 first quarter, the Dugong Appraisal well 34/4-16 S was drilled and temporarily plugged and abandoned. However, in September 2021, activity recommenced with a planned drill-stem test to determine potential hydrocarbon commercial deliverability. To further evaluate the Dugong prospect, in third quarter of 2021, an additional exploration well referred to as the Dugong Tail, well 33/6-5 S, was drilled without finding targeted potential hydrocarbon bearing reserves (Neptune Energy, 2021).

Dugong discovery exploration wells 34/4-15 S & A, appraisal well 34/4-16 S and Tail 33/6-5 S exploration well drilling operations were all undertaken by the Deepsea Yantai (DSY) drilling rig. According to NPD, PDO is expected early 2024 and plan are underway to evaluate development strategies and solutions for the field. Based on the field’s location, Fjordbase located in Florø is the closest logistics base.

3.2.4. Fenja

Fenja is a subsea development located in the Norwegian Sea 120 kilometres north of Kristiansund operated by Neptune Energy. Initial planned developmental wells consist of two oil producers, one water injector and one gas injector- planned conversion to a gas producer towards field's life end. Two subsea templates tied back to Equinor's recently refurbished Njord A platform via a production pipeline, water and gas injection pipelines and an umbilical encompasses the development plan (Neptune Energy, 2021). Initial scope of work was undertaken by West Phoenix semi-submersible drilling rig in March to October 2020, and outstanding final drilling campaign transferred to DSY drilling rig in 2021 to 2022. Projected first oil is expected in the first quarter of 2023.

3.2.5. Grind

Exploration well 6507/8-10 S located PL 889, part of block 6507/8, was drilled 7 kilometres east of the Heidrun field in the Norwegian Sea and 216 km west of Brønnøysund (NPD, 2020). This unsuccessful wild cat drilling campaign was performed by the West Phoenix semi-submersible rig in the first quarter of 2020. Kristiansund logistics base is the closest supply base to support the rig at this location.

3.3 Drill cuttings handling and transport on DSY

Cuttings handling on DSY has undergone several modifications since Neptune Energy contracted the rig in 2019. The system onboard the rig is displayed in Figure 25 and is described in subsequent passages/texts/paragraphs that follows.

Recovered downhole drilling mud and cuttings at surface are firstly passed over the shale shakers to separate the drill cuttings from the drilling mud. Separated drill cuttings are feed into two independent auger feeders that can be operated in two directions. For WBM cuttings meeting permitted discharge regulations, these are discharged directly into the sea through a chute. Two routes exist for OBM drill cuttings: (i) directly from the auger feeder to cuttings skips (backup system) or (ii) to the Mi-Swaco Cleancut cuttings collection and transportation system (primary system). In the backup system, the cutting skips are loaded onto supply vessels and sent onshore to Franzefoss at Eide for secondary treatment of drill cuttings. A minimum of five cutting skips are constantly onboard DSY drilling rig, but during active drilling operations, the quantity increases as a buffer for operational flexibility.

In the primary system, OBM drill cuttings from the auger feeder are feed into the Mi- Swaco Cleancut Cuttings Blower (CCB) by gravity. Mi-Swaco refers to the CCB as the prime mover of the Cleancut system. It is a 0.23 m^3 pressure vessel equipped with an inlet valve conveying cuttings into the feed hopper mounted on top of the CCB, and an outlet valve to discharged cuttings to the Cleancut ISO Pumps. There are sealing mechanisms to ensure cuttings containment within a closed pressure system. Cuttings are discharged by compressed air and conveyed at rates up to 25 tonUK/hr into downstream Cleancut ISO Pumps (Mi-Swaco CCB Equipment Data Sheet). Discharged cuttings from the CCB can be conducted through a 5-in steel pipe or flexible hoses (Mi-Swaco CCB product sheet, 2019). On DSY, flexibles hoses are rigged up. Two CCBs onboard DSY offers flexibility and robustness to the system ensuring drilling operations progress as planned. As at the time of writing of this master thesis, there are four Cleancut ISO Pump units permanently onboard DSY. On a standard 20-ft (6.1-m) container dimension is built each Cleancut ISO pump unit- combination of storage vessel and individual conveying device (Mi-Swaco ISO Pump equipment data sheet).

From these four Cleancut ISO Pumps, drill cuttings are blown in batches by the individual conveying device pumps-, through flexible hoses to twenty-six ISO pumps units sea fastened onto the supply boat keeping station at either port- or starboard side of the rig. To prevent plugging the flexible hose, additional lubricant- example OBM meant for recondition onshore–- is added after the shaker. Each ISO pump can load 20 tonnes of drill cuttings. This setup is a continuous sensitive operation requiring a stationed supply vessel at location- beside the rig- when drilling planned OBM section/hole. Dependent on anticipated OBM cuttings per section, additional ISO-tanks are occasionally loaded onto another supply vessels to prevent halting drilling operations. Backloaded drill cuttings are subsequently shipped onshore for secondary treatment and disposal at Franzefoss in Eide.

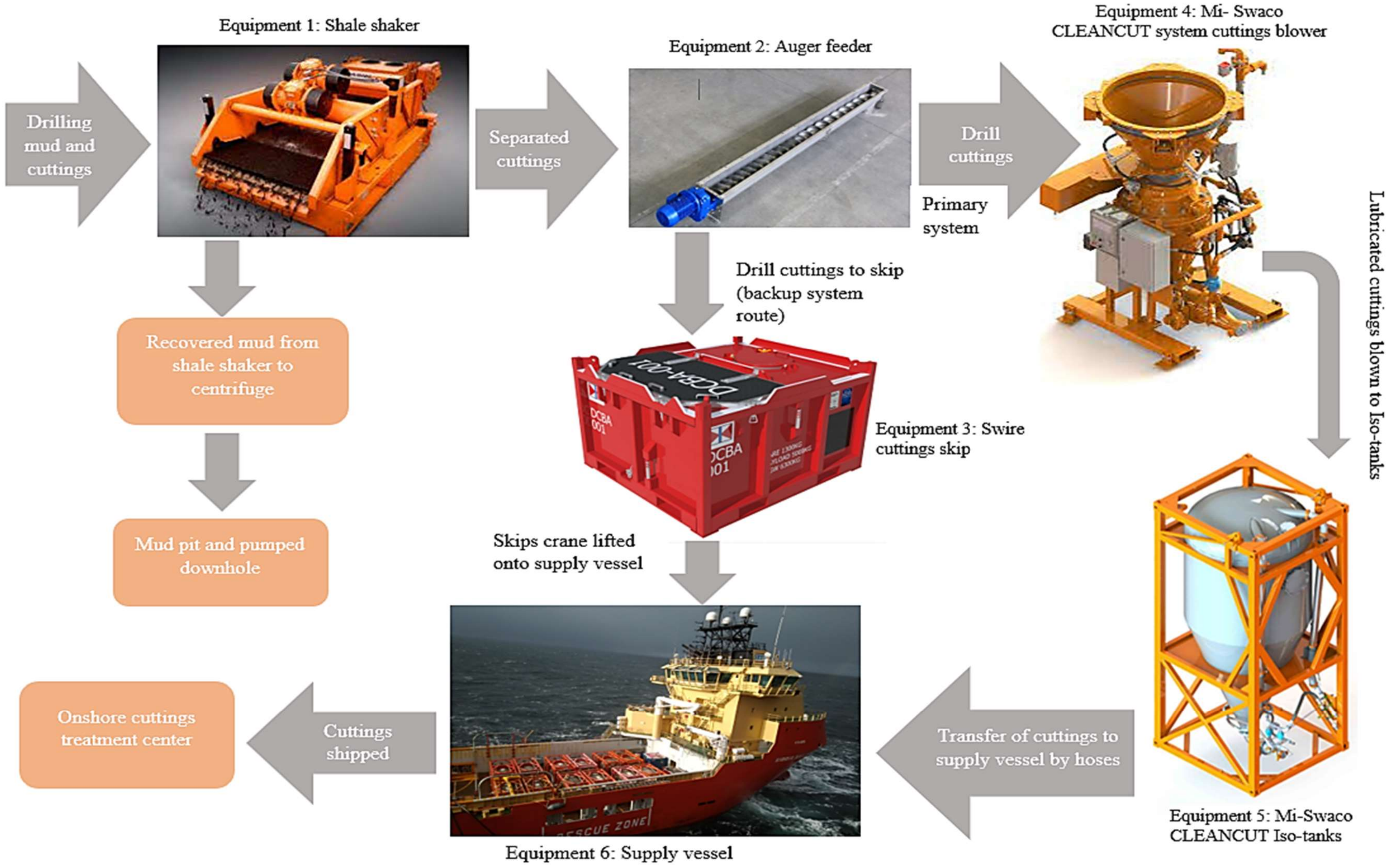


Figure 24: Drilling mud and cuttings system on DSY

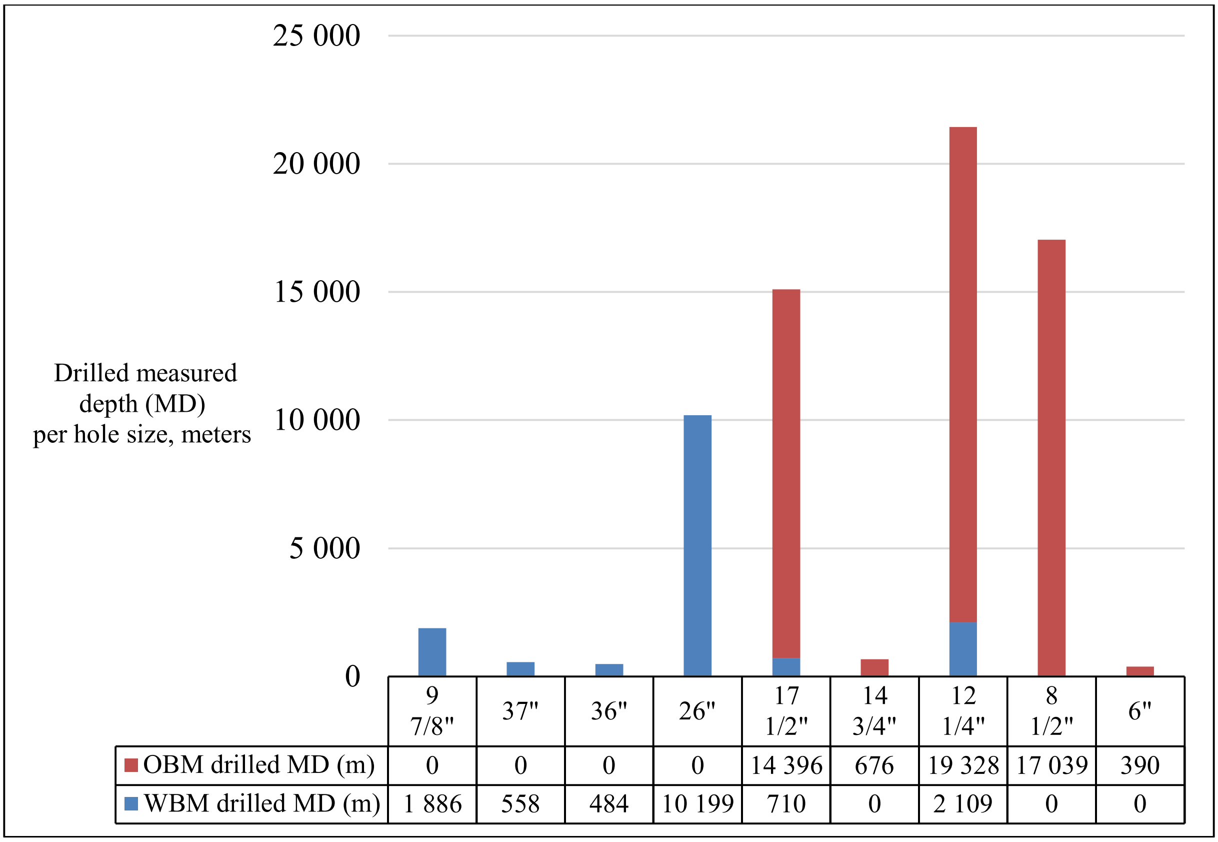
4. Results and discussion

Historical information pertaining Neptune Energy Norway’s D&W operations will be progressively dissected to provide a good foundation to base recommendations for future adoption of the offshore TCC technology for OBM cuttings treatment and disposal to sea.

4.1 Drilled hole size, measured depth, and drilling mud data

The data analysed will firstly be introduced according to drilled hole size, utilised drilling mud and resulting drilled measured depth (MD) covering November, 2019 to December, 2021 drilling activities, retrieved from NEMS. Data in Figure 25 is a cumulative sum for drilling campaigns undertaken by both the DSY and West Phoenix drilling rigs. It does not reflect only one well, but all wells drilled referenced to field operations outlined in preceding Section 3.2. As choice of drilling mud and casing setting depth is influenced by subsurface formation, technical integrity, and safety- amongst other considerations- the data presented in Figure 25 below enlightens the reader on other drilling mud data to be introduced in subsequent sub-sections.

Confirmation of suspected shallow gas or water inflow at certain fields entailed drilling a 9 7/8” hole section as a safety precaution with WBM. Hole section 37” and 36” were drilled with WBM to accommodate the 30” conductor casing- first casing- running a total length of 1 042 mMD. Accompanying 20” surface casing housed in a 26” hole section was drilled with WBM covering a total length of 10 199 mMD. Hole section 17½” accommodating 13 5/8” intermediate casing revealed combinations of WBM for a total length of 710m MD and OBM for a total length of 14 396 mMD. Hole section 14 3/4” was drilled with OBM for a total length of 676 mMD. Casing size 9 5/8”- production casing- contained in a 12¼” hole, was OBM drilled to total length of 19 710 mMD- longest OBM drilled length- and remaining 2 109 mMD by WBM. The last section- 8½” hole- for 7” liner led to the formation reservoir drilled with OBM for a total length of 17 039 mMD. The 6” hole in the reservoir section was drilled with OBM to a total length of 390 mMD.



	9 7/8"	37"	36"	26"	17 1/2"	14 3/4"	12 1/4"	8 1/2"	6"
🟥 OBM drilled MD (m)	0	0	0	0	14 396	676	19 328	17 039	390
🟦 WBM drilled MD (m)	1 886	558	484	10 199	710	0	2 109	0	0

Figure 25: Neptune Energy, Norway, D&W drilled MD reflecting drilling mud type and hole size in 2019 to 2021

Correlation of this data yields 76% of total drilled MD was attributed to OBM and remaining 24% by WBM, presented in Figure 26 below.

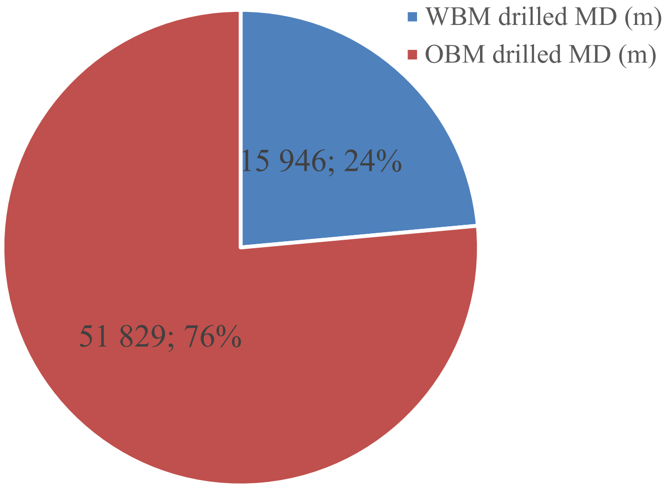
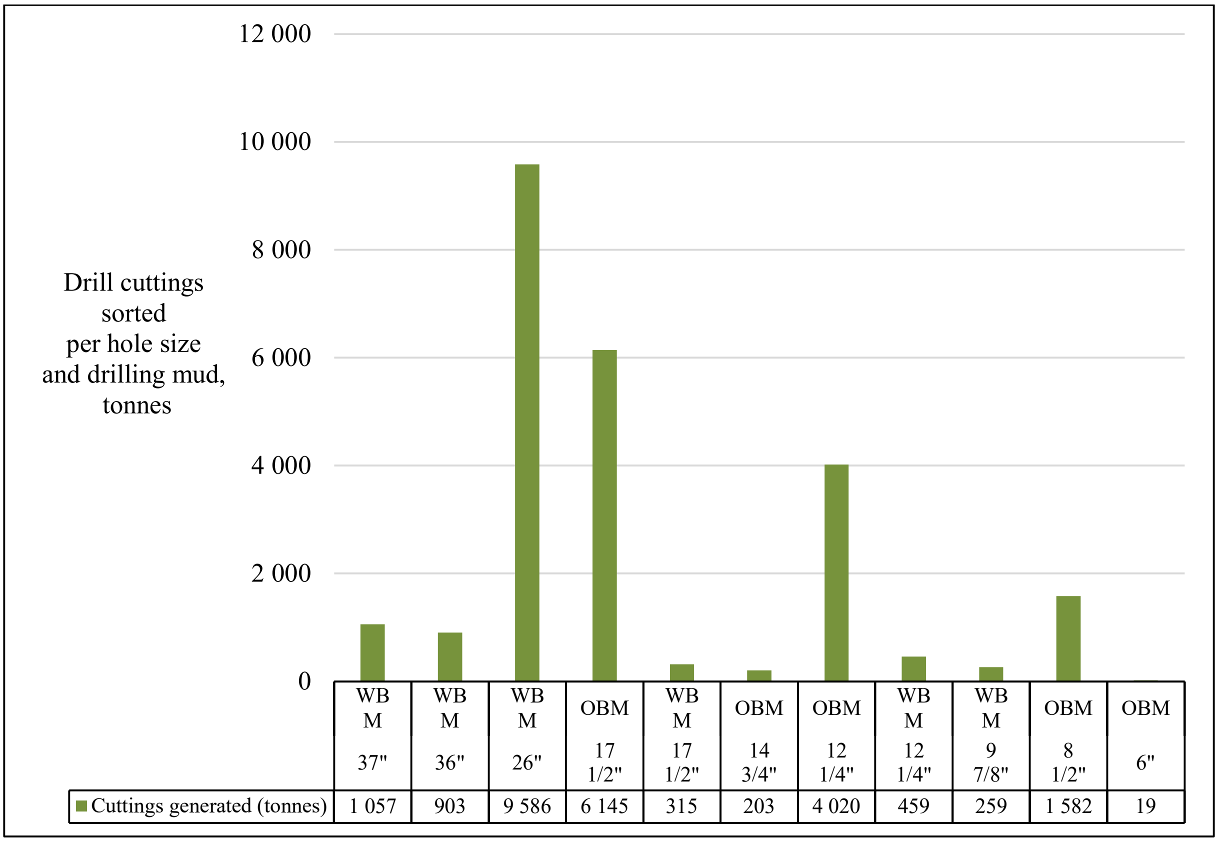


Figure 26: Neptune Energy, Norway, D&W corresponding percentages of WBM and OBM drilled length (m MD) in 2019 to 2021

Associated drill cuttings generated for drilled sections introduced in Figure 25 is presented in Figure 27. Based on hole size and total drilled length, the 26” section- previously referred to as 26” hole- generated the largest WBM cuttings of 9 586 tonnes. 12 109 tonnes generated WMB cuttings met NEA conditions for offshore discharge to sea. These WBM cuttings were not contaminated by formation/reservoir hydrocarbons. Focusing on OBM cuttings, the 17½” section generated 6 145 tonnes- the largest OBM cuttings. Despite the 12¼” and 9 7/8” sections high cumulative drilled lengths respectively, individual holes sizes influence volume of cuttings generated.

OBM cuttings handling procedure influences the ROP through the 17½” and 12¼” section. To ensure drilling operations is not stalled, a good ROP must be maintained to keep pace with OBM cuttings handling and transfer. An ROP of 80 m/hr was the highest used to drill the 17½” section and 67 m/hr for 12¼” section for 2019 to 2022 field operations. Nonetheless, weather, and subsurface requirements also influence ROP for the 17½” and 12¼” sections- sections generating the largest OBM cuttings.

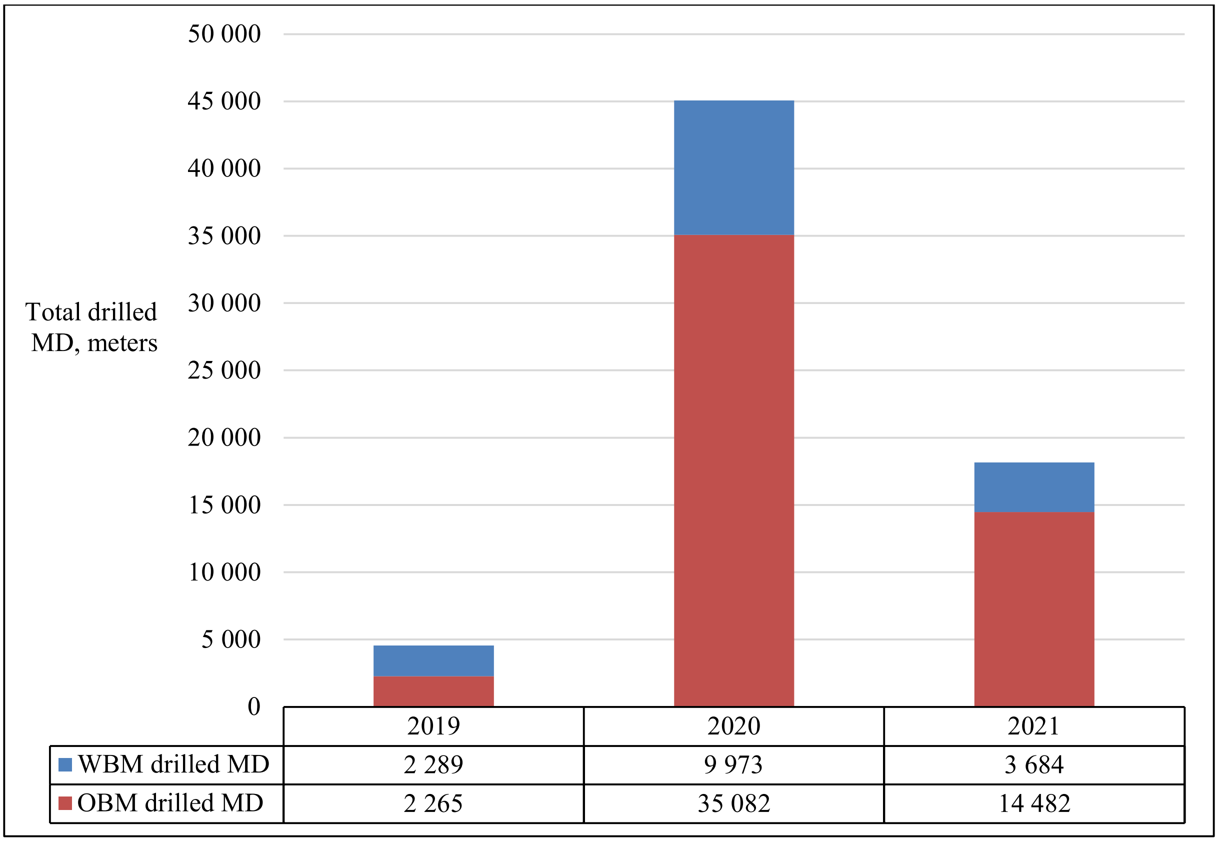


	WBM 37"	WBM 36"	WBM 26"	OBM 17 1/2"	WBM 17 1/2"	OBM 14 3/4"	OBM 12 1/4"	WBM 12 1/4"	WBM 9 7/8"	OBM 8 1/2"	OBM 6"
🟩 Cuttings generated (tonnes)	1 057	903	9 586	6 145	315	203	4 020	459	259	1 582	19

Figure 27: Neptune Energy, Norway, D&W associated drill cuttings generated per drilled section in 2019 to 2021

Examining the data presented in Figure 25- according to corresponding section and mud type drilled MD-, analysis per fiscal year gives a further enlightened reflection, displayed in Figures 28 and 29.

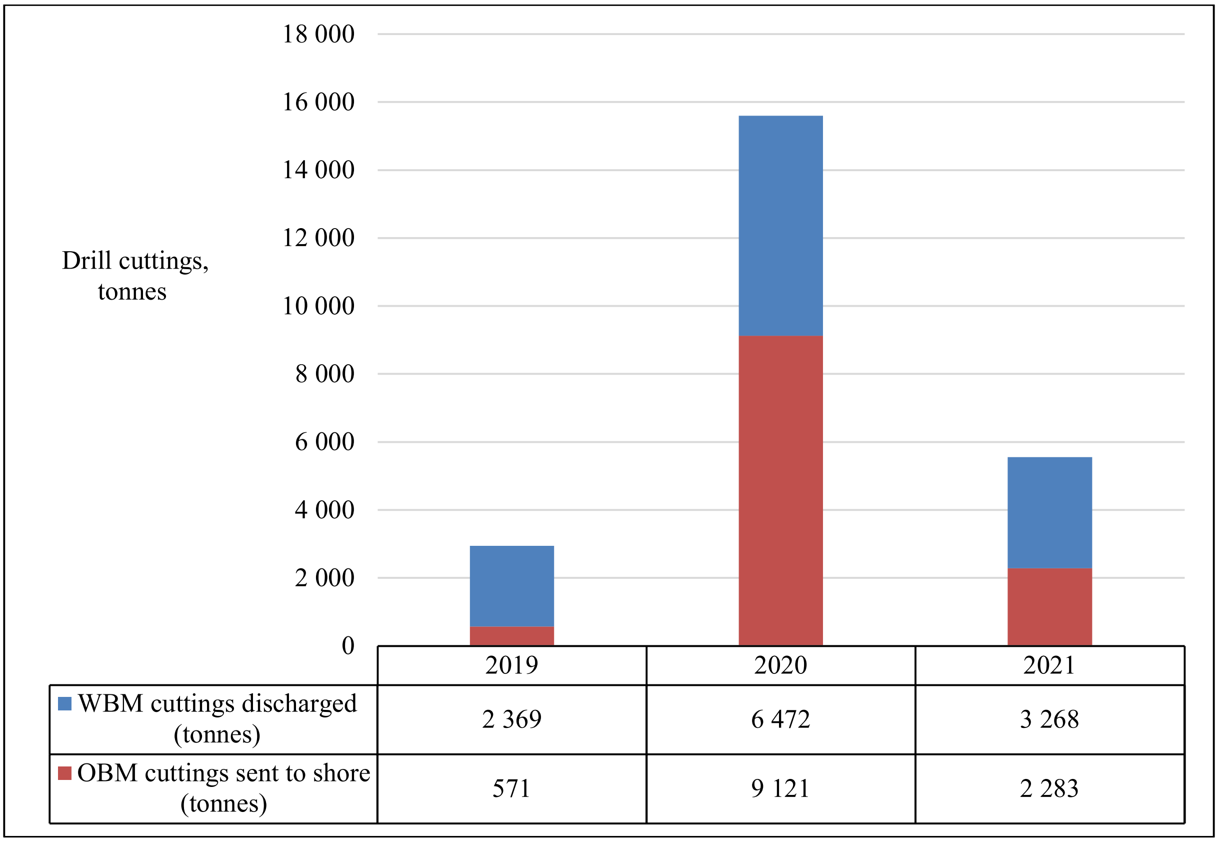
Year 2020 recorded the highest drilling activity- referenced to years 2019 to 2021 timeframe. Cumulatively, 9 973 mMD was WBM drilled, and 35 082 mMD was OBM drilled. Echoing it again, 2019 drilling activity begun in November that year and 2021 embedded several well clean-up operations and drill stem test (DST) operations. Hence, associated lower total drilled mMD in 2019 and 2021 in comparison to year 2020. In 2020, DSY drilled 2 567 mMD WBM sections and 25 143 mMD OBM sections. West Phoenix drilled 7 406 mMD WBM sections and 9 939 mMD OBM sections.



	2019	2020	2021
🟦 WBM drilled MD	2 289	9 973	3 684
🟥 OBM drilled MD	2 265	35 082	14 482

Figure 28: Neptune Energy, Norway, D&W cumulative drilled MD for year 2019 to 2021 according to drilling mud type

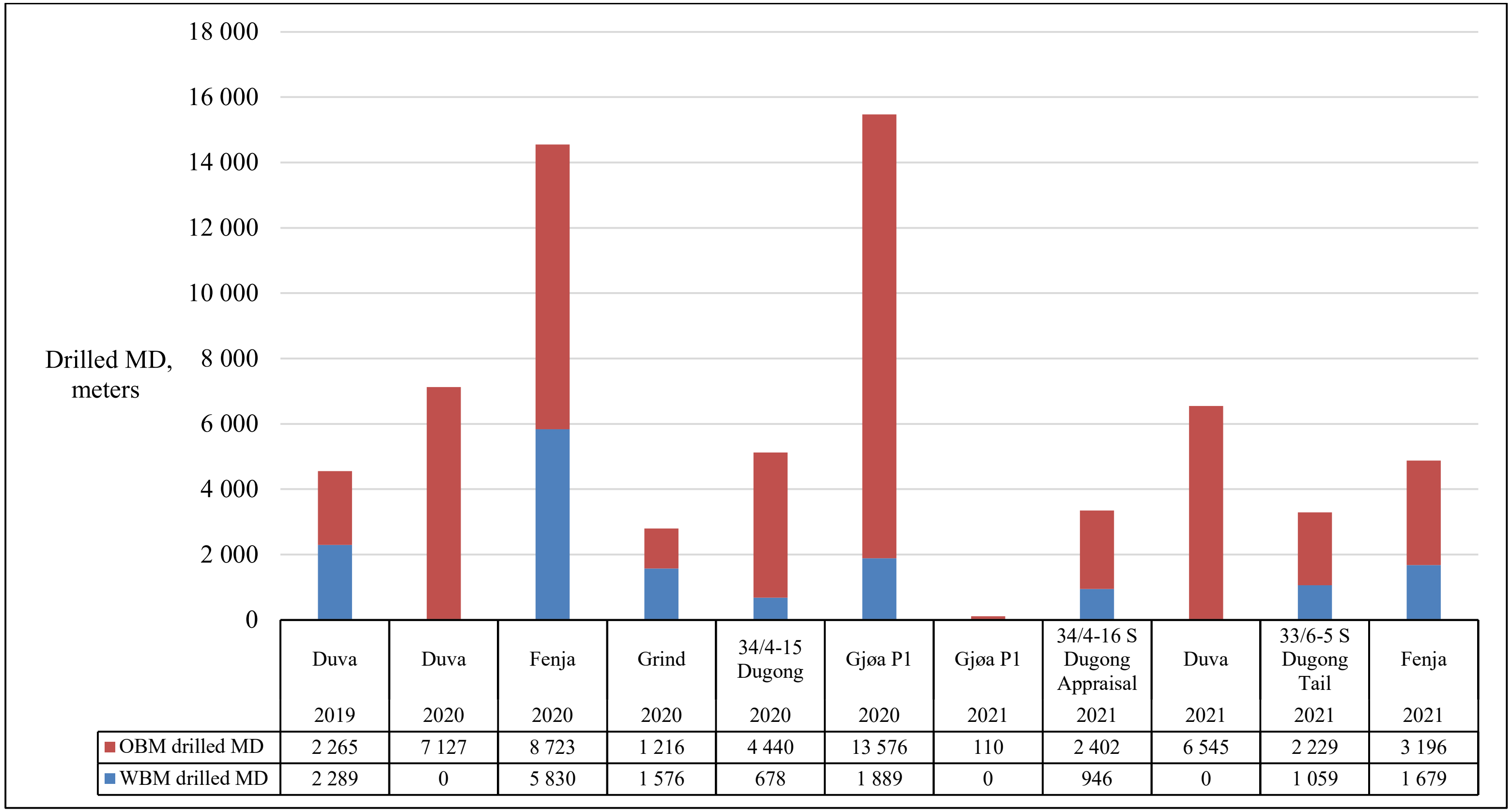
Yearly WBM cuttings discharged to sea and OBM sent to land for treatment is displayed in Figure 29. A similar trend is portrayed in Figure 29 as Figure 28. Year 2020 generated the highest OBM and WBM cuttings of 9 121 and 6 472 tonnes respectively. A shorter MD length with larger hole sized WBM sections generates greater cuttings than subsequent longer MD length having smaller hole sized OBM sections.



	2019	2020	2021
🟦 WBM cuttings discharged (tonnes)	2 369	6 472	3 268
🟥 OBM cuttings sent to shore (tonnes)	571	9 121	2 283

Figure 29: Neptune Energy, Norway, D&W yearly WBM cuttings discharged to sea and OBM cuttings sent to land for treatment

Further expatiating on the data, total drilled length per corresponding field development, exploration, and appraisal well operations in each fiscal year is presented in Figure 30. Presented order per field and year is an easy means for data representation and does not capture actual operational sequence.

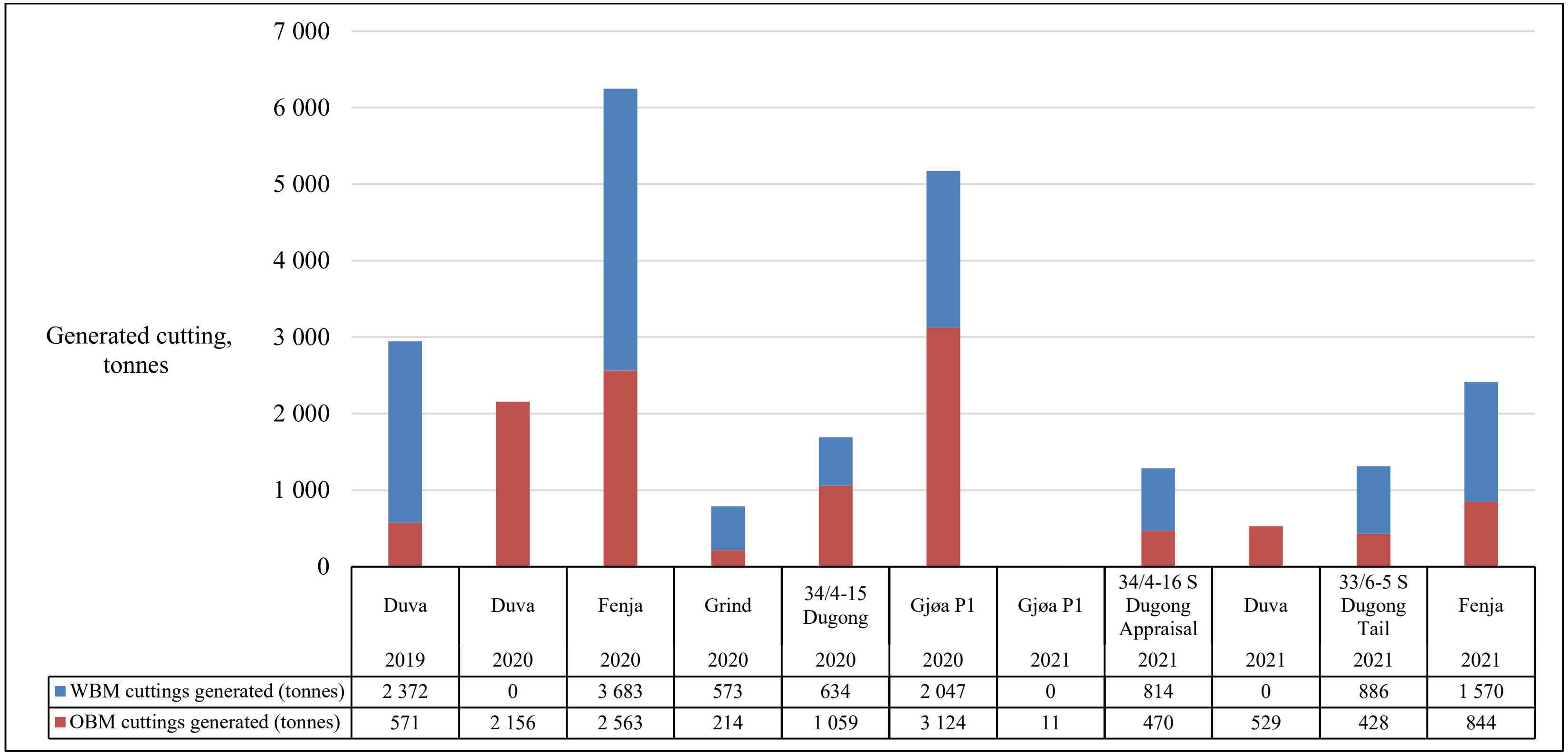


	Duva 2019	Duva 2020	Fenja 2020	Grind 2020	34/4-15 Dugong 2020	Gjøa P1 2020	Gjøa P1 2021	34/4-16 S Dugong Appraisal 2021	Duva 2021	33/6-5 S Dugong Tail 2021	Fenja 2021
🟥 OBM drilled MD	2 265	7 127	8 723	1 216	4 440	13 576	110	2 402	6 545	2 229	3 196
🟦 WBM drilled MD	2 289	0	5 830	1 576	678	1 889	0	946	0	1 059	1 679

Figure 30: Neptune Energy, Norway, D&W drilled MD per yearly drilling campaign

Fenja field development drilling in 2020 and 2021 accounted for the longest drilled length- OBM 11 919 mMD and WBM 7 509 mMD. Yet, Gjøa P1 re-development was longest drilled OBM sections summing 13 686 mMD- cumulative for 2020 and 2021.

Field development operations such as Duva, Fenja and Gjøa P1 generated tremendous cuttings versus that associated with exploration or appraisal operations for Grind, 34/4-15 Dugong, 34/4-16 S Dugong appraisal and 33/6-5 S Dugong Tail- data is presented in Figure 31. Field development operation are typically more complex unlike exploration or appraisal operations that have straighter well profiles. Fenja 2021 development generated 3407 tonnes OBM cuttings- highest amongst all Neptune Energy Norway D&W field operations. Gjøa P1 2021 re-development was the next ranked generating 3 135 tonnes.



	Duva 2019	Duva 2020	Fenja 2020	Grind 2020	34/4-15 Dugong 2020	Gjøa P1 2020	Gjøa P1 2021	34/4-16 S Dugong Appraisal 2021	Duva 2021	33/6-5 S Dugong Tail 2021	Fenja 2021
🟦 WBM cuttings generated (tonnes)	2 372	0	3 683	573	634	2 047	0	814	0	886	1 570
🟥 OBM cuttings generated (tonnes)	571	2 156	2 563	214	1 059	3 124	11	470	529	428	844

Figure 31: Neptune Energy, Norway, D&W generated cuttings per yearly drilling campaign

4.2 OBM drill cuttings offshore transport to land data

Sub-section 3.3 and Figure 24- drilling mud and cuttings system on DSY- established drill cuttings handling and subsequent current transport to land mechanism on DSY. One must recollect intended rig backload OBM meant for onshore reconditioning is added for lubrication during OBM cuttings handling and quantity utilised is dependent on nature and dryness of retrieved OBM cuttings.

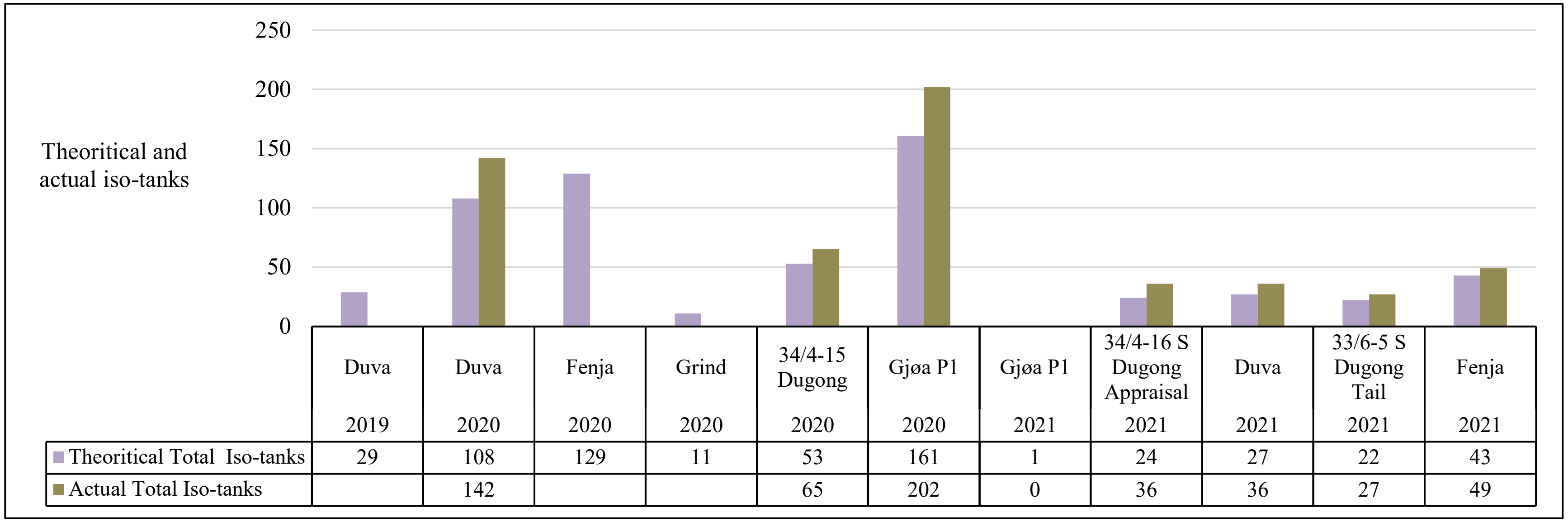
Backload and loadout data from WELS- a web-based logistical platform for the oil and gas industry- was deciphered to get concrete approximation of actual total iso-tanks backload per yearly field operation. All historical backload and loadout tickets to DSY were retrieved and data compiled according in Table 8. However, historical loadout and backload tickets for 2019 Duva on DSY, 2020 Fenja, and 2020 Grind operation on West Phoenix were unretrievable. Hence, respective columns on actual total iso-tanks left empty in Table 8 and Figure 32. OBM cuttings generated were retrieved directly from NEMS.

Table 8: Neptune Energy, Norway, D&W field operations and subsequent alternative offshore OBM cuttings transport to land mechanisms

Year	Field	Mud type	OBM cuttings generated, tonnes	Theoretical total iso-tanks, Qty	Actual total iso-tanks, Qty	Cuttings sent to shore, m^3	Skip alternative ($4m^3$ per skip), Qty
2019	Duva	Oil Based	571	29	-	209	52
2020	Duva	Oil Based	2156	108	142	790	197
2020	Fenja	Oil Based	2563	129	-	921	230
2020	Grind	Oil Based	214	11	-	75	19
2020	34/4-15 Dugong	Oil Based	1059	53	65	388	97
2020	Gjøa P1	Oil Based	3203	161	202	1173	293
2021	Gjøa P1	Oil Based	11	1	0	4	1
2021	34/4-16 S Dugong Appraisal	Oil Based	470	24	36	172	43
2021	Duva	Oil Based	529	27	36	240	60
2021	33/6-5 S Dugong Tail	Oil Based	428	22	27	157	39
2021	Fenja	Oil Based	844	43	49	309	77

Calculations for alternative transport by skip demonstrates a 40% increase- quantity wise comparison to actual iso-tanks utilised per field operation. One must note, this is to further validate preference of Mi-Swaco's Cleancut technology over skips, should skips be the preferred OBM cuttings transport to land mechanism.

Figure 32- graphical representation of theoretical and actual iso-tanks- offers a visualisation of data introduced in Table 8 above. Averagely 29% extra iso-tanks are utilised above the theoretical iso-tanks required, attributed to addition of lubricant to cuttings for Mi-Swaco Cleancut technology operational technicalities. This is calculated from percentage of extra theoretical iso-tanks utilised above actual total iso-tanks for 2019 to 2021 yearly field operations.



	Duva 2019	Duva 2020	Fenja 2020	Grind 2020	34/4-15 Dugong 2020	Gjøa P1 2020	Gjøa P1 2021	34/4-16 S Dugong Appraisal 2021	Duva 2021	33/6-5 S Dugong Tail 2021	Fenja 2021
■ Theoritical Total Iso-tanks	29	108	129	11	53	161	1	24	27	22	43
■ Actual Total Iso-tanks		142			65	202	0	36	36	27	49

Figure 32: Neptune Energy, Norway, D&W OBM cuttings theoretical and actual iso-tanks utilised

Establishing sound estimates of lubrication added by adopting the Mi-Swaco Cleancut technology, the difference between OBM generated on the rig- values captured after shaker- and calculated OBM sent in iso-tanks is presented in Table 9. An indication of potential OBM for land reconditioning is derived from this difference. Oily slops is another source of lubricant. In 2021, Gjøa P1 OBM cuttings of 11 tonnes were added to Dugong Appraisal OBM cuttings.

Table 9: Neptune Energy, Norway, D&W lubricant estimation

Year	Field	OBM cuttings generated on rig, tonnes	OBM cuttings sent in iso-tanks, tonnes	Difference, tonnes	Percentage lubrication added, weight %
2019	Duva	571	-	-	-
2020	Duva	2156	2529	373	17 wt.%
2020	Fenja	2563	-	-	-
2020	Grind	214	-	-	-
2020	34/4-15 Dugong	1059	1388	329	31 wt.%
2020	Gjøa P1	3203	3965	762	24 wt.%
2021	Gjøa P1	11	0	-	-
2021	34/4-16 S Dugong Appraisal	470	625	156	33 wt.%
2021	Duva	529	692	163	31 wt.%
2021	33/6-5 S Dugong Tail	428	550	122	29 wt.%
2021	Fenja	844	980	136	16 wt.%

Least weight percentage of lubricant added was 16 wt.% for Fenja in 2021, and highest 33 wt.% Dugong Appraisal in 2021. This is contrary to estimates of 10 wt.% lubricant added to OBM cuttings. No fast rule exists on amount of lubricant added, but purely on the discretion of the operator based on OBM cuttings appearance after the shaker.

4.3 Drilling days breakdown according to mud type

Total drilling days in drilling respective WBM and OBM sections per yearly field operation is presented in Table 10. Respective days captured is not entirely for active drilling but represents total days including waiting on the weather and other operational standbys. Field development operations as evident in total drilling days for Duva 2019 to 2021, Fenja 2020 & 2021, Gjøa P1 2020 & 2021 take tremendous time to drill and complete, unlike that of Grind 2020 and Dugong 2020 & 2021, exploration, or appraisal wells.

Table 10: Neptune Energy, Norway, D&W total drilling days per mud section

Year	Field	Drilled length (m MD)	Total drilling days	OBM drilling days	WBM drilling days
2019	Duva	4554	81	27	54
2020	Duva	7127	39	39	0
2020	Fenja	14553	308	172	136
2020	Grind	2792	45	21	24
2020	34/4-15 Dugong	5118	50	45	5
2020	Gjøa P1	15465	251	220	31
2021	Gjøa P1	110	49	12	37
2021	34/4-16 S Dugong Appraisal	3348	53	31	22
2021	Duva	6545	127	85	42
2021	33/6-5 S Dugong Tail	3288	25	18	7
2021	Fenja	4875	54	42	12

4.4 Drilling chemicals data

As preceding sub-section dived into drill cuttings specific and related data, it is timely and relevant to proceed with analysing drilling mud chemical composition, retrieved from NEMS. Sensitive information to protect the interest of Neptune Energy Norway contracted drilling mud provider will not be disclosed. Reference is made specifically to not listing drilling mud composition according to chemical function group or commercial product names. General information according to chemical colour coding will be basis for presented data- aside presenting base oil data as it is another point of interest for adoption of the offshore TCC technology.

Table 11 shows respective amount of green, yellow, red, and black chemicals composition in WBM, OBM and other drilling technical reasons. Entirely, 38 344 tonnes of chemicals were consumed for drilling operations in 2019 to 2021. One must recollect per NEA regulations, red and black chemicals- zero consumed for Neptune Energy Norway D&W related operations- are not permitted for discharge to sea. Hence, red chemicals typically occur in OBM.

Table 11: Neptune Energy, Norway, D&W yearly consumed drilling chemicals per chemical colour categories

Consumed, tonnes	**2019**	**2020**	**2021**	**Total**
Green Chemicals	3 849	16 534	8 924	29 306
Yellow Chemicals	809	5 943	2 107	8 859
Red Chemicals	13	132	34	179
Black Chemicals	0	0	0	0

Similar to chemical colour category trend on the NCS, Neptune Energy, Norway, D&W observes this industry wide trend. Total green chemical accounted for 29 306 tonnes- representing 76.4% of drilling mud composition. Total yellow chemicals accounted for 8 859 tonnes- representing 23.1% of drilling mud composition. Total red chemicals accounted for 179 tonnes- representing 0.5%. Graphical representation of these values is displayed in Figure 33.

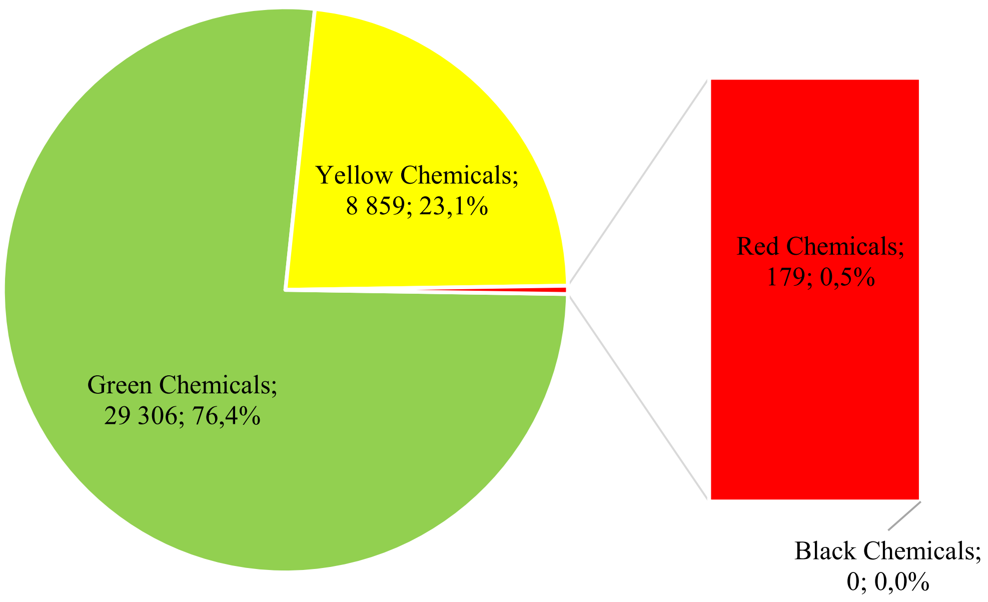


Figure 33: Neptune Energy, Norway, D&W total drilling mud composition per chemical colour categories

Enhancing this data to provide information on potential chemical composition accompanying both WBM and OBM cuttings, Table 12-14 below illustrates amount of chemicals per colour code discharged to sea, left in well and lost in well- due to operation challenges/technical reasons, respectively.

Table 12: Neptune Energy, Norway, D&W yearly drilling chemicals discharged to sea per chemical colour categories

Discharged to sea, tonnes	**2019**	**2020**	**2021**	**Total**	**% relative to total consumed**
Green Chemicals	0	4 756	2 474	7 230	25%
Yellow Chemicals	0	92	74	166	2%
Red Chemicals	0	0	0	0	-
Black Chemicals	0	0	0	0	Not applicable

Respective amount of chemicals per colour code discharged to sea are: 25% of total consumed green chemicals, 2% of total consumed yellow chemicals and no red chemical.

Table 13: Neptune Energy, Norway, D&W yearly drilling chemicals left in well per chemical colour categories

Left in well, tonnes	**2019**	**2020**	**2021**	**Total**	**% relative to total consumed**
Green Chemicals	2 197	5 039	2 219	9 454	32%
Yellow Chemicals	130	1 139	519	1 788	20%
Red Chemicals	0	26	12	37	21%
Black Chemicals	0	0	0	0	Not applicable

Respective amount of chemicals per colour code left in wells are: 32% of total consumed green chemicals, 20% of total consumed yellow chemicals and 21% of total consumed red chemical.

Table 14: Neptune Energy, Norway, D&W yearly drilling chemicals lost in well per chemical colour categories

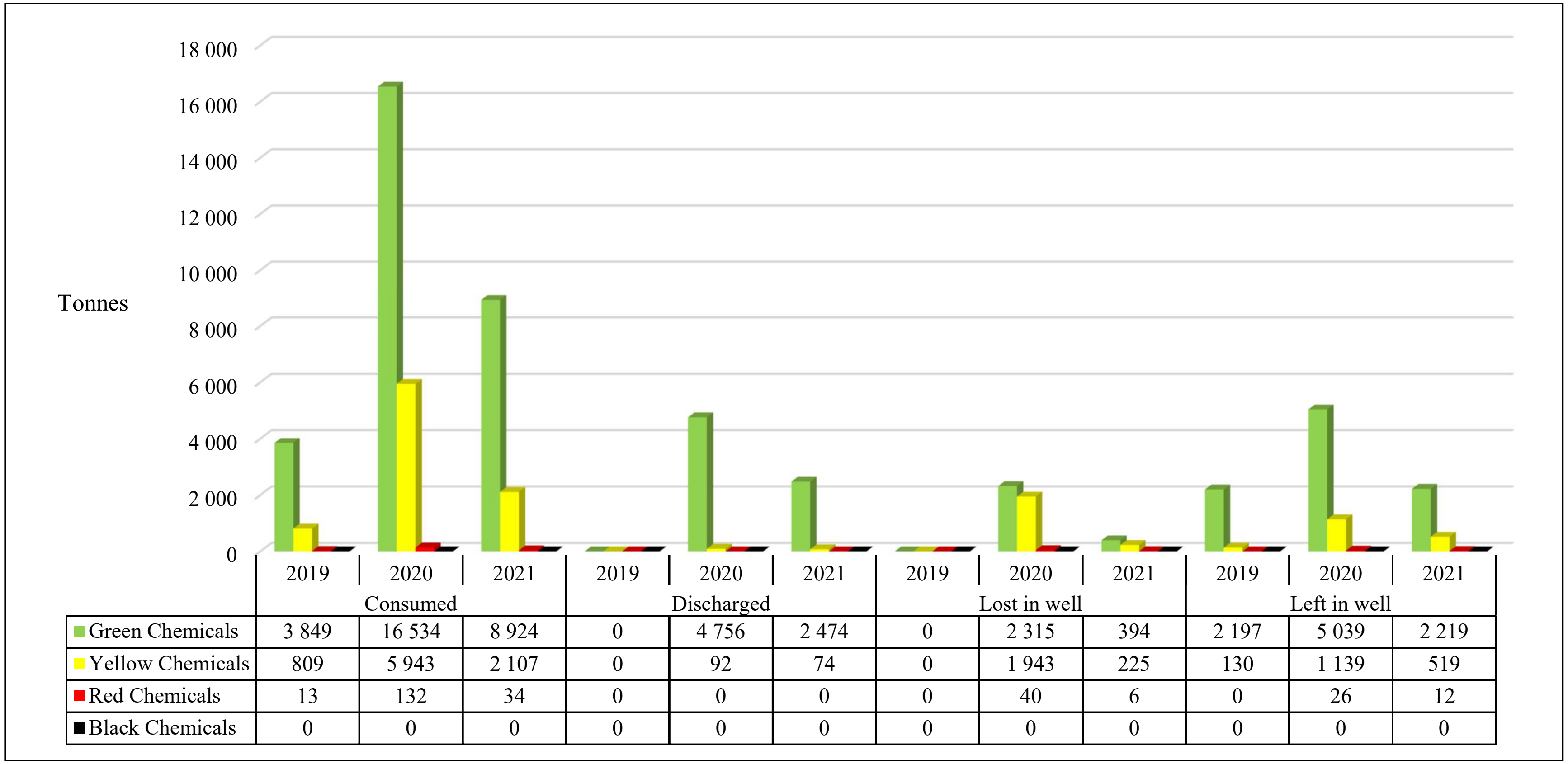
Lost in well, tonnes	**2019**	**2020**	**2021**	**Total**	**% relative to total consumed**
Green Chemicals	0	2 315	394	2 709	9%
Yellow Chemicals	0	1 943	225	2 168	24%
Red Chemicals	0	40	6	46	26%
Black Chemicals	0	0	0	0	Not applicable

Respective amount of chemicals per colour code lost in wells are: 9% of total consumed green chemicals, 24% of total consumed yellow chemicals and 26% of total consumed red chemicals.

In summary, 32% of green chemicals was left in well, 20% of yellow chemicals left in well, 21% red chemical left in wells, per chemical balancing breakdown. In 2020, Neptune Energy Norway faced operational challenges on the Gjøa P1 development resulting in significant drilling chemicals lost in well.

Approximately -34% green chemicals, 54% yellow chemicals and 47% red chemicals were retrieved- cumulatively with accompanying WBM and OBM cuttings.

Drilling chemicals breakdown compilation per colour coding is displayed in Figure 34 for total chemicals consumed, discharged to sea, left in well and lost in well, according to information presented in Tables 12-14.



	Consumed			Discharged			Lost in well			Left in well		
	2019	2020	2021	2019	2020	2021	2019	2020	2021	2019	2020	2021
🟩 Green Chemicals	3 849	16 534	8 924	0	4 756	2 474	0	2 315	394	2 197	5 039	2 219
🟨 Yellow Chemicals	809	5 943	2 107	0	92	74	0	1 943	225	130	1 139	519
🟥 Red Chemicals	13	132	34	0	0	0	0	40	6	0	26	12
■ Black Chemicals	0	0	0	0	0	0	0	0	0	0	0	0

Figure 34: Neptune Energy, Norway, D&W yearly drilling related chemicals breakdown per colour coding

Focusing on maximum potential recoverable base oil by treating OBM cuttings offshore using the TCC technology- identified as one key leverage point in favour of the technology- historical data from 2019 to 2021 field operations is presented in Table 15- excluding Fenja 2021. Recovered base oil derived as a product after OBM cuttings treatment offshore is intended to be fed back into the OBM drilling system on the rig.

Table 15: Neptune Energy, Norway, D&W highlighted base-oil balance directly related to OBM cuttings

Year	Field	Chemical function group	Total used (tonnes)	Discharged (tonnes)	Sent to slops (tonnes)	Sent to onshore disposal (tonnes)	Percentage sent to slops & onshore disposal out of total base oil used, %
2019	Duva	Base oil	619	0	0	133	22%
2020	34/4-15 Dugong	Base oil	439	0	0	266	61%
2020	Duva	Base oil	759	0	0	280	37%
2020	Grind	Base oil	155	0	141	0	0%
2020	Fenja	Base oil	1 337	0	584	266	20%
2020	Gjøa P1	Base oil	2 707	0	248	827	31%
2021	Duva	Base oil	780	0	0	571	73%
2021	Gjøa P1	Base oil	270	0	0	159	59%
2021	34/4-16 S Dugong Appraisal	Base oil	347	0	0	164	47%
2021	33/6-5 S Dugong Tail	Base oil	246	0	0	144	58%

From data presented, approximately half the amount of base oil used in OBM is sent onshore for disposal together with OBM cuttings. Using a base oil density of 814 kg/m^3 and applying a today base oil cost of 1000 USD per tonne base oil (Chemanalyst, 2022), depending on service contract, a total of approximately 35 790 000 NOK cost was most likely incurred by Neptune Energy Norway for base oil loss from OBM cuttings treatment and disposal onshore. No buy back option could be exercised by the service contractor for this lost base oil. Adopting the offshore TCC technology can potentially recover a hefty percentage of this lost base oil.

Per information gathered, the onshore cuttings treatment and disposal facility consume 25% of recovered base oil on OBM cuttings to drive their process and 75% if delivered as fuel for other industries processes. Remaining 75% energy required for the onshore treatment process is derived from electricity. Base oil retained on OBM cuttings sent onshore for treatment is therefore recovered for final destruction into energy and not recovered as a material which the offshore TCC technology provides. From Figure 17 in Sub-Section 2.3- drilling waste management- material recovery is higher up the triangle offering a higher environmental benefit.

4.5 Supply vessel data

Providing contextual information on mapping out estimated supply vessel fuel consumption & particularly carbon dioxide emissions, assigned field support logistics hub, distance to OBM cuttings delivery location and estimated sailing time at 10 knots based is captured in Table 16.

Table 16: Neptune Energy, Norway, D&W yearly field related logistics information

Year	Field	Drilling rig	Closest logistics hub	Drilling rig distance to OBM cutting delivery location, nautical miles	Sailing time at 10 knots
2019 - 2021	Duva	Deepsea Yantai	Florø	69 nautical miles (nm) to Franzefoss, Eide	6 hrs 54 mins to Eide
2020 & 2021	Fenja	West Phoenix	Kristiansund	62 nm to Vestbase, Kristiansund	6 hrs 12 mins to Vestbase, Kristiansund
2020	Grind	Deepsea Yantai	Kristiansund	Difficult to validate	
2020	34/4-15 Dugong	Deepsea Yantai	West of Florø	112 nm to Franzefoss, Eide	9 hrs 21 mins to Eide
2020 & 2021	Gjøa P1	Deepsea Yantai	Florø	Field lies in close proximity to Duva field.	Field lies in close proximity to Duva field
2021	Dugong Appraisal & Tail	Deepsea Yantai	Florø	112.4 nm to Franzefoss, Eide	11 hrs 14 mins to Eide

In 2020, 6 443 m^3 of marine gasoil (MGO) and 2 652 tonnes of LNG was collectively consumed by all supply vessels that supported Neptune Energy Norway D&W operations. For 2021, a total of 5 148 m^3 MGO was consumed based on reported supply vessels fuel consumption for Neptune Energy Norway D&W operations.

To build potential supply vessel fuel consumption specifically for OBM cuttings reception at wellsite and transportation to land, data was extracted accordingly:

- active OBM cuttings generation dates was retrieved from NEMS to derive concrete OBM generation days.
- historical loadout and backload tickets from WELS facilitated pin-pointing exact supply vessel allocated for OBM cuttings transport, concrete days at wellsite and arrival day at OBM cuttings receiving location.
- from Maress, historical positioning of supply vessel, and estimation of supply vessel OBM cuttings related fuel consumption served as a confirmation source to data extracted and compiled in NEMS and WELS.

Supply vessel assigned to receive and transport OBM cuttings, and corresponding active OBM drilling days per yearly field operation is presented in Table 17. For 2020 Gjøa P1 operation, no OBM cuttings was sent on a dedicated supply vessel because of minute quantity generated-11 tonnes- and rather added to 2021 Dugong Appraisal OBM cuttings.

Table 17: Neptune Energy, Norway, D&W, OBM cuttings supply vessel fuel and CO_2 emission footprint

Year	Field	Supply vessel	Active OBM drilling days
2020	Duva	Siddis Mariner & Norsea Fighter	39
2020	Fenja	Siddis Mariner	151
2020	34/4-15 Dugong	Siddis Mariner	30
2020	Gjøa P1	Siddis Sailor, Siddis Mariner & Norsea Fighter	207
2021	Gjøa P1	N/A	19
2021	34/4-16 S Dugong Appraisal	Siddis Mariner & Norsea Fighter	21
2021	Duva	Siddis Mariner	85
2021	33/6-5 S Dugong Tail	Siddis Mariner & Stril Orion	12
2021	Fenja	Siddis Mariner	42

Siddis Mariner is the dedicated vessel to receive and transport OBM cuttings and is reflected in Table 17 for all yearly field operations. Siddis Mariner's top deck can accommodate 26 iso-tanks. Depending on expected OBM cutting per hole section, other PSVs can support receiving and transporting OBM cuttings if above Siddis Mariner maximum transport capacity- 520 tonnes- for drilling operations to proceed. Operational logistics planning also influences OBM cuttings supply vessel allocation in the necessity of timely key operational support.

A 100% supply vessel fuel consumption approach targets removing associated consumption for OBM cuttings receival from rig to supply vessel and transportation to land. It also includes supply vessel fuel consumption for loadout of new iso-tanks to wellsite to receive new OBM cuttings. OBM cuttings transport trips- loadout and backload of iso-tanks- represents averagely approximately 10% of total supply vessel trips per yearly field operation. Reference made to supply vessel trip used during drilling of both WBM and OBM sections.

Despite supply vessels also transporting bulk drilling chemicals and undertaking other ad-hoc wellsite support, it is challenging to allocate percentages of these other activities to translate into corresponding fuel consumption and CO_2 emissions from the 100% approach. With a degree of confidence, majority of assigned cuttings supply vessel time at the wellsite is primarily to receive OBM cuttings for drilling progression. To cater for bulk drilling chemicals transport, other ad-hoc activities, and a conservative approach, progressive 100 basis points reduction will be applied and presented in Table 18. Similar approach was employed in calculating corresponding CO_2 emissions using an average marine gas oil (MGO) density of 845 kg/m^3 with data captured in Table 19. A conversion factor of 1 kg diesel releasing 3.17 kg CO_2 is applied throughout the report, referenced against Statistisk Sentralbyrå, and year 2020 Norwegian Oil & Gas emission factor report.

Filled iso-tank housing OBM cuttings for all yearly field operations were delivered to Eide and new empty iso-tanks loadout to the rig occurred in Florø. Aside yearly Fenja field operations for which Kristiansund served as the location for both iso-tank backload from the rig and loadout to the rig. Duva 2019 and Grind 2020 operations data were not included in Table 17 due to complications in retrieving relevant information for case constructing.

Fenja 2020 and Gjøa P1 2020 operations assigned supply vessels consumed approximately 994 m^3 and 1 073 m^3 for OBM cuttings transport in the optimistic approach. Tallying with the fact that Fenja 2020 total OBM section was 8 723 mMD generating 2 563 tonnes OBM cuttings, and Gjøa 2020 total OBM section was 13 576 mMD generating 3 124 tonnes OBM cuttings. Both field operations had high active OBM drilling days displayed in Table 17 above.

As Grind 2020 OBM cuttings supply vessel fuel consumption and CO_2 emission were not presented, 33/6-5 S Dugong Tail 2021 had the lowest fuel and CO_2 footprint. Assigned supply vessels consumed approximately 74 m^3 for OBM cuttings transport in the 100% approach for OBM section totalling 2 229 mMD and 428 tonnes OBM cuttings generated.

These trends are recurrent in the progressive 100% basis point reductions of both OBM cuttings supply vessel and CO_2 emission footprint.

Table 18: Neptune Energy, Norway, D&W variations in OBM cuttings supply vessel fuel consumption

		OBM cuttings supply vessel fuel consumption, m^3									
Year	**Field**	**100%**	**90%**	**80%**	**70%**	**60%**	**50%**	**40%**	**30%**	**20%**	**10%**
2020	Duva	297	267	238	208	178	149	119	89	59	30
2020	Fenja	994	895	795	696	596	497	398	298	199	99
2020	34/4-15 Dugong	238	214	190	167	143	119	95	71	48	24
2020	Gjøa P1	1 073	966	858	751	644	537	429	322	215	107
2021	34/4-16 S Dugong Appraisal	77	69	62	54	46	39	31	23	15	8
2021	Duva	151	136	121	106	91	76	60	45	30	15
2021	33/6-5 S Dugong Tail	74	67	59	52	44	37	30	22	15	7
2021	Fenja	89	80	71	62	53	45	36	27	18	9

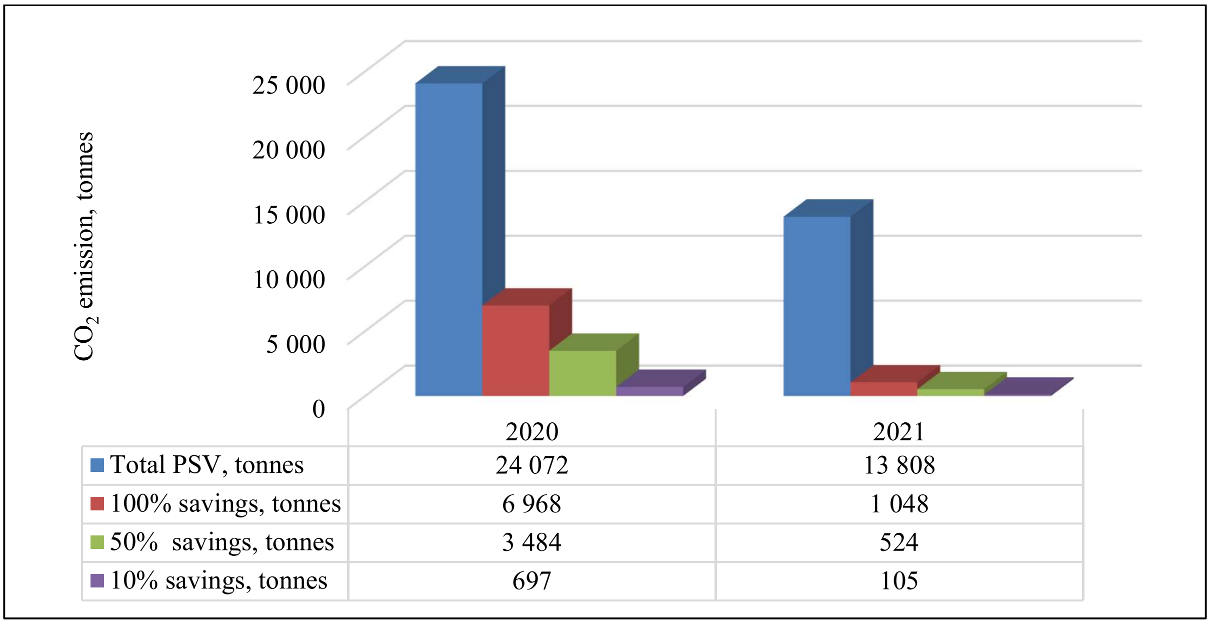
Table 19: Neptune Energy, Norway, D&W variations in OBM cuttings supply vessel CO_2 emissions

		OBM cuttings supply vessel CO_2 emissions, tonnes									
Year	**Field**	**100%**	**90%**	**80%**	**70%**	**60%**	**50%**	**40%**	**30%**	**20%**	**10%**
2020	Duva	795	716	636	557	477	398	318	239	159	80
2020	Fenja	2 662	2 396	2 130	1 863	1 597	1 331	1 065	799	532	266
2020	34/4-15 Dugong	636	572	509	445	382	318	254	191	127	64
2020	Gjøa P1	2 874	2 587	2 299	2 012	1 724	1 437	1 150	862	575	287
2021	34/4-16 S Dugong Appraisal	207	186	166	145	124	104	83	62	41	21
2021	Duva	404	364	323	283	242	202	162	121	81	40
2021	33/6-5 S Dugong Tail	198	178	158	139	119	99	79	59	40	20
2021	Fenja	239	215	191	167	143	120	96	72	48	24

Potential supply vessel CO_2 emissions savings by adopting the offshore TCC technology for 3 different scenarios are presented in Table 20: 100% savings, 50% savings and 10% savings. In Table 20, potential supply vessel savings was mapped for 2020 and 2021 operations on the DSY and West Phoenix drilling rigs. 2019 values were not included because of the short period of operations- two months- and complexities around retrieving relevant data. Based on 2020 operations a high potential of 30% existed that year, while 2021 operations had a high potential of 8%. Taking into consideration the total OBM drilled length of 2020- 35 082 mMD- was approximately 2.5 times the total 2021 OBM drilled length- 14 482 mMD, - this potential supply vessel emission saving values are valid. Furthermore, in 2021 well clean-up and testing operations were executed for Gjøa P1, Duva and Dugong 34/4-16 S appraisal well, all on the DSY drilling rig against zero in 2020. Graphical representation of Table 20 is illustrated in Figure 35.

Table 20: Neptune Energy, Norway, D&W potential supply vessel emission saving in relation to total yearly PSV CO_2 emissions by adopting offshore TCC technology

			CO_2 emissions savings, tonnes- considerations towards operations on DSY & West Phoenix			
Year	OBM drilled length, m MD	OBM cuttings generated, tonnes	Total PSV	100% savings	50% savings	10% savings
2020	35 082	9 195	24 072	6 968	3 484	697
2021	14 482	2 282	13 808	1 048	524	105



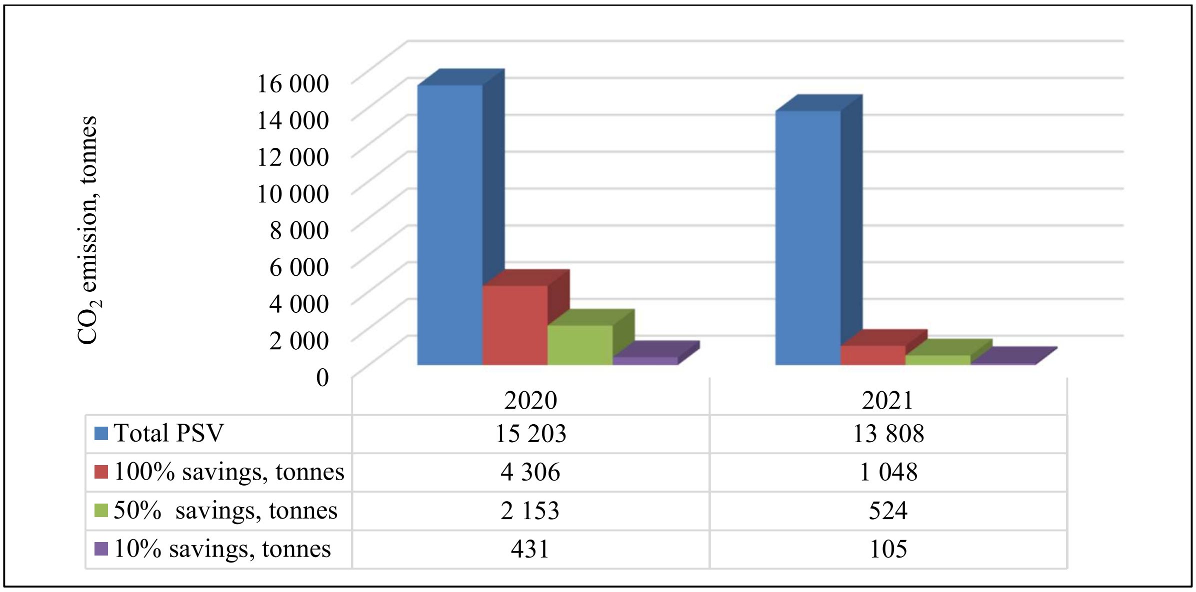
	2020	2021
🟦 Total PSV, tonnes	24 072	13 808
🟥 100% savings, tonnes	6 968	1 048
🟩 50% savings, tonnes	3 484	524
🟪 10% savings, tonnes	697	105

Figure 35: Neptune Energy, Norway, D&W potential supply vessel emission saving in relation to total yearly PSV CO_2 emissions by adopting offshore TCC technology- Deepsea Yantai and West Phoenix operations.

Since 2021, DSY was the only operational drilling rig assigned to Neptune Energy, I will present potential supply vessel CO_2 emissions savings as this better reflects potentials going forward. Similar rationale presented in Table 20 above is applied in Table 21. Based on 2020 operations a high potential of 28% existed, despite 2021 operations having a high potential of 8%. Taking into consideration total OBM drilled length of 2020- 25 143 mMD- was approximately twice the total 2021 OBM drilled length- 14 482 mMD, - this potential supply vessel emission saving values are valid. Graphical representation of Table 21 is illustrated in Figure 36.

Table 21: Neptune Energy, Norway, D&W potential supply vessel emission saving in relation to DSY yearly PSV CO2 emissions by adopting offshore TCC technology

			CO_2 emissions savings, tonnes- considerations towards operations on DSY			
Year	OBM drilled length, m MD	OBM cuttings generated, tonnes	Total PSV	100% savings	50% savings	10% savings
2020	25 143	6 339	15 203	4 306	2 153	431
2021	14 482	2 282	13 808	1 048	524	105



	2020	2021
🟦 Total PSV	15 203	13 808
🟥 100% savings, tonnes	4 306	1 048
🟩 50% savings, tonnes	2 153	524
🟪 10% savings, tonnes	431	105

Figure 36: Neptune Energy, Norway, D&W potential supply vessel emission saving in relation to total yearly PSV CO_2 emissions by adopting offshore TCC technology- Deepsea Yantai operations.

Translating these potential supply vessel savings by adopting the offshore TCC unit into potential financial gains for Neptune Energy Norway the data will be presented on these potential bases:

- supply vessel rental savings with considerations made towards removing supply vessel entire trips for OBM cuttings receival and transportation for onshore treatment and disposal. Assumption is made dedicating the entire trip for OBM cuttings.
- associated OBM cuttings related supply vessel cost savings. From Drivkraft Norge 2022, historical diesel price of 15 NOK/litre was applied to 2021 and 13.5 NOK/litre applied to 2020 values.
- CO_2 diesel tax applied for associated potential supply vessel CO_2 emission for OBM cuttings related activities. From the Norwegian Tax Administration, mineral product tax of 1.45 NOK/litre diesel in 2020 and 1.58 NOK/litre diesel in 2021.
- in all three sub-bullets above, it was presented for 100%, 50% and 10% PSV savings.
- in 2020 as supply vessels supported two drilling rigs, OBM drilling days is calculated as 287, better reflecting combined interfacing individual rig OBM drilling days.

Costs based on current DSY OBM cuttings handling setup and potential offshore TCC technology cost was not in this scope of work.

Table 22: Neptune Energy, Norway, D&W historical potential financial savings

	Year	**2021**	**2020**
	Drilling rig	Deepsea Yantai	Deepsea Yantai & West Phoenix
	OBM drilling days	160	287
	100% potential PSV rental savings (equivalent to removing 1 PSV)	NOK 16 000 000	NOK 28 700 000
Fuel savings, m^3	100% PSV saving	391	2 601
	50% PSV saving	196	1 301
	10% PSV saving	39	260
Fuel cost savings	100% PSV saving	NOK 5 870 242	NOK35 116 131
	50% PSV saving	NOK 2 935 121	NOK 17 558 066
	10% PSV saving	NOK 587 024	NOK 3 511 613
CO_2 emission, tonnes	100% PSV saving	1 048	6 968
	50% PSV saving	524	3 484
	10% PSV saving	105	697
Associated CO_2 emission cost (reference to CO2 taxed for diesel)	100% PSV saving	NOK 618 332	NOK 3 771 733
	50% PSV saving	NOK 309 166	NOK 1 885 866
	10% PSV saving	NOK 61 833	NOK 377 173

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4.6 Illustrative potential offshore TCC technology fuel consumption and CO_2 emission data

As potential supply vessel fuel consumption and CO_2 emissions data has been presented in Section 4.5- supply vessel data-, it is imperative and appropriate to constructively determine if potential adoption of the offshore TCC technology provides an upper advantage in terms of fuel consumption and CO_2 emissions.

To present data regarding potential fuel consumption, easily available information on TWMA's TCC-RotoMill communicated in the TWMA Low Carbon Drilling November, 2019 report is duplicated below:

- Type of fuel: Gasoil/MGO
- Diesel engine fuel requirement: 250 litres/hr
- Average cuttings processing rate: 5 tonnes/hr

Calculations are therefore solely aligned towards the TWMA TCC-RotoMill technology, just for illustrative purposes- as data was easily available. One must not this data is only for the TCC-Rotomill technology and does not include energy requirements for additional required support equipment. Similarly, energy consumption for the Mi-Swaco Cleancut technology onboard the rig was not calculated, only supply vessel fuel consumption was determined.

Table 23 presents associated processing time for each yearly field operation, associated fuel consumption based on the TWMA TCC-Rotomill information listed above. For all 2019 – 2021 yearly field operations, 602 m^3 of MGO could potentially treat 12 048 tonnes of OBM cuttings offshore with the TCC Rotomill technology- approximately 10% of supply vessel fleet MGO fuel consumption of 6 443 m^3 in 2020.

Table 23: Illustrative potential TWMA TCC-RotoMill fuel consumption using historically generated OBM cuttings data

Year	Field	OBM Drilling days	Cuttings sent to shore, tonnes	Average cuttings generation tonnes/hr	TCC processing time for corresponding cuttings generated @ rate of 5 tonnes/hr.	TCC fuel consumption 250ltr/hr, litres	Fuel consumption at 250ltr/hr, m^3
2019	Duva	26	571	0.92	114	28 572	29
2020	Duva	40	2 156	2.25	431	107 807	108
2020	Fenja	154	2 563	0.69	513	128 157	128
2020	Grind	21	214	0.42	43	10 696	11
2020	34/4-15 Dugong	36	1 059	1.23	212	52 945	53
2020	Gjøa P1	204	3 203	0.65	641	160 161	160
2021	Gjøa P1	7	11	0.07	2	550	1
2021	34/4-16 S Dugong Appraisal	21	470	0.93	94	23 483	23
2021	Duva	77	529	0.29	106	26 460	26
2021	33/6-5 S Dugong Tail	12	428	1.48	86	21 381	21
2021	Fenja	42	844	0.84	169	42 224	42
						Total volume, m^3	**602**
						Total mass, kg	**509 057**
						Total corresponding CO_2 emissions, tonnes	**1 614**

As supply vessel consumption for OBM cuttings transport for Duva 2019 and Grind 2020 operations could not be mapped out, focus will be on reflecting supply vessel fuel consumption- captured in Table 18- against potential TWMA TCC-Rotomill technology for remaining 2020 to 2021 yearly field operations presented in Table 24.

Table 24: Comparison of potential supply vessel fuel consumption to offshore TCC Rotomill fuel consumption for 2020 to 2021 field operations

		OBM cuttings supply vessel fuel consumption, m^3			**TCC Rotomill fuel consumption, m^3**
Year	Field	100%	50%	10%	Consumption at 0.25 m^3/hr
2020	Duva	297	149	30	108
2020	Fenja	994	497	99	128
2020	34/4-15 Dugong	238	119	24	53
2020	Gjøa P1	1 073	537	107	160
2021	34/4-16 S Dugong Appraisal	77	39	8	23
2021	Duva	151	76	15	26
2021	33/6-5 S Dugong Tail	74	37	7	21
2021	Fenja	89	45	9	42

Based on parameter listed and used for calculations, the potential TWMA TCC- Rotomill technology fuel consumption is potentially significantly less than the 50% approach for OBM cutting supply vessel fuel consumption. Further demonstrating some substantial potential fuel reductions. One must bear in mind, supply vessel fuel consumption for OBM cuttings transport is dependent on distance from wellsite to OBM cuttings receiving facility, yearly seasons, loadout of new empty iso-tanks, and supply vessel maintaining its position by the rig to receive OBM cuttings. Unlike the offshore TCC technology, fuel consumption is largely dependent on the desired maximum processing rate for OBM cuttings.

Evident from the data presented in Table 24, adoption of the offshore TCC technology for field developmental operations provides the greatest potential for potential supply vessel emission reductions. For operations aligned towards the field production phase, high number of wells drilled and longer drilled well sections generates huge volume of OBM cuttings than single exploration of appraisal well operations.

It is prudent to reflect on potential drilling rig fuel consumption increase by adoption of an offshore TCC technology- using presented TWMA Rotomill data. Data is presented in Table 25 based on historical drilling rig fuel consumption for Deepsea Yantai and West Phoenix in 2020, and Deepsea Yantai alone in 2021. Grind 2020 field operation potential OBM cuttings supply vessel consumption is not included in the total 2020 potential OBM cuttings supply vessel calculations because of data challenges. As a reminder to the reader, this projected increase is based on historical operations and without power consumption for other required support equipment to run the offshore TCC technology- such as pumps and air compressors. Should power consumption for other required support equipment to run the offshore TCC technology be similar to current power requirements to transport the OBM cuttings after the shaker to the supply vessel, then projections calculated are spot-on.

Table 25: Neptune Energy, Norway, D&W assigned drilling rig potential- West Phoenix and Deepsea Yantai- fuel consumption increase by potentially adopting offshore TCC technology for year 2020to 2021 field operations

Year	Drilling rig	OBM cuttings generated, tonnes	Drilling rig fuel consumption, m^3	Equivalent potential fuel consumption for TCC offshore technology. Processing 5 tons/hour @ 250 l/hr, m^3	% TCC onshore technology against total drilling rig fuel consumption
2020	Deepsea Yantai & West Phoenix	9 195	20 560	460	2%
2021	Deepsea Yantai	2 282	11 241	114	1%

Based on activity level with two drilling rigs in 2020, a cumulative 2% drilling rig fuel consumption increase could potentially be realised from adopting the offshore TCC technology. For 2021 activity level and nature of operations conducted with Deepsea Yantai drilling rig, the potential drilling rig fuel consumption increase is 1%. It is important to make considerations towards this especially when establishing yearly baseline fuel reduction for drilling rigs, and its’ impact on fuel reduction strategies and responsibilities.

As Deepsea Yantai is currently the only active drilling rig for Neptune Energy, Norway, D&W business unit, the respective potential increase by adopting the offshore TCC technology- based on historical operations- is illustrated in Table 26. Based on operations conducted on the Deepsea Yantai drilling rig, in 2020 and 2021, a respective 3% and 1% drilling rig fuel consumption increase could potentially be realised from adopting the offshore TCC technology.

Table 26: Neptune Energy, Norway, D&W assigned drilling rig potential- Deepsea Yantai- fuel consumption increase by potentially adopting offshore TCC technology for year 2020 to 2021 field operations

Year	Drilling rig	OBM cuttings generated, tonnes	Drilling rig fuel consumption, m^3	Equivalent potential fuel consumption for TCC offshore technology. Processing 5 tons/hour @ 250 l/hr, m^3	% TCC onshore technology against total drilling rig fuel consumption
2020	Deepsea Yantai	6 339	12 104	338	3%
2021	Deepsea Yantai	2 282	11 241	114	1%

Recalling an earlier stated information, 2020 field operations on both West Phoenix and Deepsea Yantai drilling rigs were purely for exploration, appraisal, and developmental operations. 2021 field operations on the Deepsea Yantai drilling rig were also on exploration, appraisal, and developmental operations, but with well testing and cleanup operations.

5. Concluding remarks

In light of information presented, the offshore TCC technology provides a considerable potential of yielding PSV fuel savings and CO_2 emission reduction. In 2020 with two drilling rigs in operation with Neptune Energy, Norway, D&W business unit, a 30% potential PSV fuel and CO_2 emission reduction existed. Considering only the DSY drilling rig in 2020, a 28% potential PSV fuel and CO_2 emission reduction existed. Based on the varying nature of yearly operations conducted in 2020 and 2021, 2021 data displayed a reduced potential PSV fuel and CO_2 emission reduction of 8%. Regardless, field developmental operations leading to the production phase in the O&G lifecycle provides the greatest opportunity. One must recollect approximately 10% of total supply vessel trips are linked to OBM cuttings transport to shore activities and loadout of clean ISO tanks to the wellsite. It is anticipated adoption of this offshore TCC technology will increase the DSY drilling rig total fuel consumption of approximately 3% if similar field operations activities are undertaken as in year 2020. Having a concrete overview of the total offshore TCC technology and support/downstream equipment will provide better insight towards the drilling rig energy management. However, to realise these gains, supply vessel planning, and management is critical, albeit drilling operational progression and technical safety challenges receive uttermost resolution priority.

Additional groundwork is needed to kick start this potential implementation process by firstly finding alternative technically capable yellow chemicals to replace the red chemicals present in the OBM. Secondly, the potential offshore TCC supplier must undertake some tests to identify and document various outlet streams from the offshore TCC unit to support the application process with the Norwegian Environment Agency – NEA. An assessment of the environmental impacts compared to alternative solutions must accompany the operators' application to NEA. For adoption on a mobile drilling rig on exploration, appraisal, or subsea wells, it is difficult to identify how associated environmental assessment program in the discharge area will be undertaken particularly after discharge of treated OBM cuttings has occurred. An in-depth environmental assessment tailored to the aquatic environment of the exact field location and specific OBM composition is required to accompany the application process to NEA.

As evidently presented, the successful adoption of the offshore TCC technology by Equinor on the Johan Sverdrup field, has awakened confidence in the technology. This is in light of environmental considerations and the technology's ability to deliver on NEA discharge permit limits of 0.3 wt.% ROC on treated cuttings. Even though the Johan Sverdrup field is electrified by power from shore and leveraged on in the application to NEA for adoption of the offshore TCC technology, there is an associated strong potential reduction of PSV fuel savings for OBM cuttings transport. For wellsite locations with deposits of vulnerable benthic fauna in the area, no discharge permit to sea will be issued by NEA.

For recovery of base oil with strong technical capabilities after treatment of the OBM cuttings, a good procedure must be adopted in running the offshore TCC unit to realise one of key potential of the technology.

These recommendations presented are made considering prevailing environmental regulations and information, BAT and BEP at the time of writing this master thesis. Further due diligence must be undertaken to realise full potentials and minimise associated risk from this potential implementation.

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