Waste Management in the Oil & Gas Industry

June - 2020

Sustainability
Report

The Abdullah Bin Hamad Al-Attiyah International Foundation for
Energy & Sustainable Development

INTRODUCTION

WASTE MANAGEMENT IN THE OIL & GAS INDUSTRY

Managing waste from oil and gas operations is a topic of growing importance, with emerging strategies and innovative approaches to limit both waste and its impact, as it poses a significant cost to operations, and in many cases, a loss of potential revenues.

This report looks into how the industry can engage proactively and constructively, through various existing coalitions and industry associations, with government, environmental groups, and civil society. And further, how it can employ new technologies to improve the ability to monitor, reduce and dispose of waste appropriately.

Sustainability Report

This research paper is part of a 12-month series published by the Al-Attiyah Foundation every year. Each in-depth research paper focuses on a prevalent sustainable development topic that is of interest to the Foundation's members and partners. The 12 technical papers are distributed to members, partners and universities, as well as made available online to all Foundation members.

EXECUTIVE SUMMARY

- A wide range of wastes in the form of gases, liquid, solid, and heat are produced from oil and gas operations.
- These wastes, often in large volumes, have varying levels of environmental and safety hazard.
- Due to its environmental impacts and greenhouse pollution, waste constitutes a major threat to the industry's public image and licence to operate.
- Produced water is the largest waste volumetrically and by treatment expenditure, at approximately $30-200 billion annually.
- Carbon dioxide and methane attract the most policy attention and are the greatest long-term threat to the industry.
- The 'circular economy' framework that follows a Reduce-Reuse-Recycle approach, is becoming popular with companies that wish to maximise the sustainability and profitability that such framework offers.
- Active engagement and collaboration with government, environmental groups, and civil society, is essential for the establishment of improved, reasonable, workable, and comprehensive regulations, that are consistent across different industry sectors.

OIL AND GAS OPERATIONS PRODUCE A WIDE RANGE OF WASTE FROM DIVERSE SOURCES

Waste from the upstream oil and gas industry includes gaseous, liquid, and solid wastes, and heat. These cover an enormous range of types and volumes. Some are toxic or flammable, some detrimental to the environment, while others are relatively innocuous. Some may be more strictly regulated because they come from the oil industry, whereas another activity producing the same waste would not be so regulated. Some wastes, such as produced water, methane and heat, are almost ubiquitous to operations. Some are only produced during the drilling and completions phase, others occur through a whole field life-cycle, and some (such as offshore platforms) only become waste when a field is decommissioned. Some, such as hydrogen sulphide and sulphur, only occur in certain fields.

Gaseous

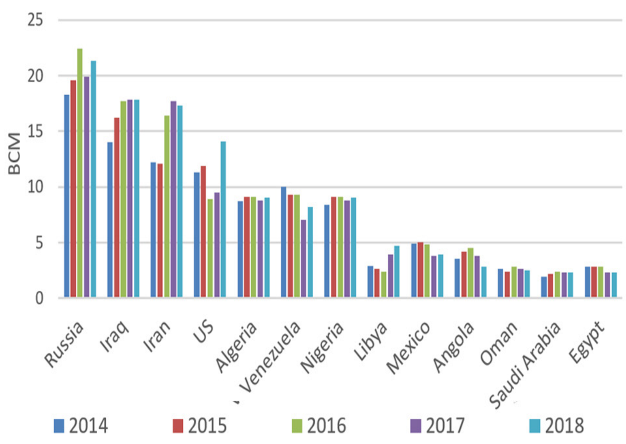
Gas flares, as a source of wastes such as carbon dioxide (CO_2), methane (CH_4), volatile organic compounds (VOCs), sulphur dioxide (SO_2), soot and heat, are produced mainly from oil and gas exploration and production facilities, refineries, industrial sites, and liquified natural gas terminals.

According to the Permian Methane Analysis Project (PermianMAP), around 11% of gas flares in the Permian Basin of Texas and New Mexico are either unlit or malfunctioning, 5% of which vent methane and the remaining 6% are lit but malfunctioning, signifying inefficient combustion.

Permian gas flares enter the atmosphere, which contradicts the Environmental Protection Agency (EPA)'s assumed 98% combustion efficiency. Extensive flaring is not only a primary source of CO_2 emissions but also a significant source of methane emissions. Both PermianMAP and a peer-reviewed study consisting of individual satellite readings from Tropospheric Monitoring Instrument (TROPOMI) found high methane leakage rates from the Permian basin.

Worldwide, over 140 billion cubic metres (BCM) of natural gas is burnt in oil production sites annually, resulting in almost 300 million tonnes equivalent of carbon dioxide ($MtCO_2e$) emissions. Flaring combustion products contain over 250 toxins, which cause acidity and affect human health and plant growth[i]. As Figure 1 shows, emissions from gas flaring are generated mainly from Russia, Iraq, Iran, and the US, with most emissions emanating from upstream sites.

FIGURE 1 GAS FLARING VOLUMES, 2014-18[ii]



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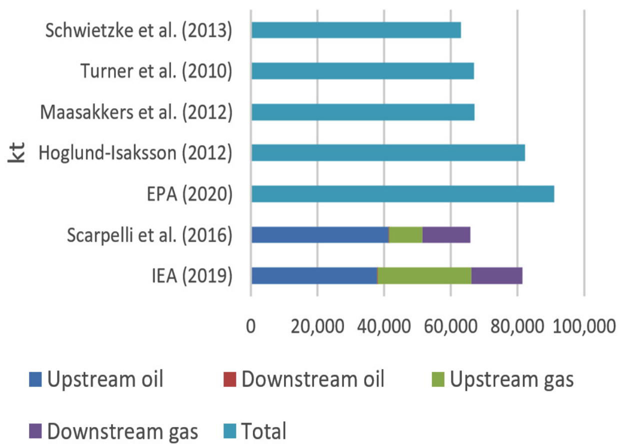
Although natural gas is viewed as the main 'bridge fuel' to a lower-carbon future energy system, methane leakage from natural gas has 28-36 times the climate warming impact of CO_2 in a 100-year period[iii], and 80 times the climate warming impact of CO_2 over a 20-year period. The US Environmental Protection Agency estimates methane emissions from oil and gas in 2020 at 91 Mt Figure 2. International Energy Agency's (IEA) estimates show a slight increase of methane emissions in 2019, but there is much uncertainty about 2020's figures due to the global slump in output caused by Covid-19. A decline in revenues implies that companies will be less inclined to spend on methane emissions reduction. In addition, low natural gas prices are likely to result in an increase in flaring as it becomes uneconomic to invest in infrastructure to bring associated gas to market.

FIGURE 2 METHANE EMISSIONS FROM OIL AND GAS, COMPARISON OF IEA AND OTHER ESTIMATES[iv]



In addition to emissions from current operations, more than 3.2 million abandoned oil and gas wells exist in the US alone, leaking 281 kilotonnes of methane in 2018. On a global scale, abandoned oil and gas wells are estimated at more than 29 million, with an estimated 2.5 million tonnes of methane emissions per year.

CO_2, nitrous oxide (N_2O), oxides of nitrogen (NOx), ammonia (NH_3), and organic compounds can also be generated from waste incineration. The incineration of one tonne of waste generates about 0.7-1.2 tonnes of CO_2[v].

Volatile organic compounds (VOCs) contribute to smog and ozone formation, as well as containing carcinogens such as benzene. They are released from the evaporation of lighter hydrocarbon fractions[vi], including ethane, propane, butane, ethylene and many other products.

Hydrogen sulphide (H_2S) is a dangerous by-product formed through several industry activities. Oil and gas extraction and petrochemical processes are two of the most significant sources of this gas, which causes a wide range of health effects. Exposure to high concentrations of H_2S can lead to death. The gas is corrosive to non-stainless steels in combination with water, causing the risk of leaks from equipment.

Sour gas contains up to 30% H_2S along with CH_4 and CO_2 and requires expensive and energy-intensive clean-up. Mixed CH_4/H_2S flames result in H_2S oxidation into sulphur dioxide (SO_2)[vii]. Along with NOx generated from gas turbines, SO_2 contributes to acid rain, which has harmful effects on soil, forests, lakes, and streams.

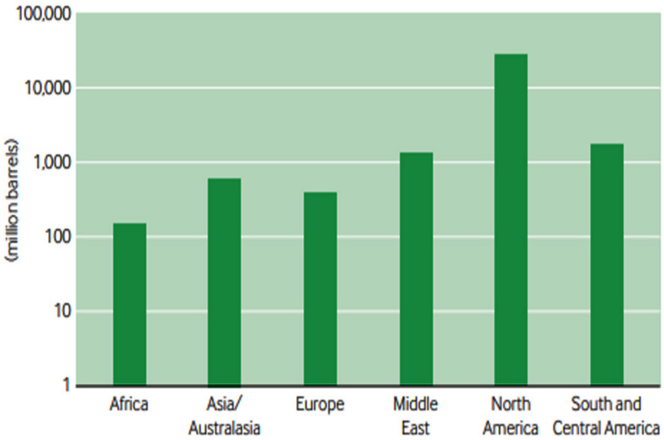
Liquid

Liquid wastes include oil, various types of wastewater, and waste materials in suspension or solution.

The industry produces several wastewater streams that have to be treated separately. Volumetrically, produced water is by far the largest waste stream from upstream oil and gas operations. Fields produce water with oil, particularly as they become more mature or when water injection is employed for secondary recovery. It is not uncommon for water-cuts to reach 99% of the produced fluid[viii]. Produced water is typically highly saline (more than seawater) and may contain metals, suspended solids, oil and other hydrocarbons such as toxic BTX (benzene, toluene, xylene). However, some fields produce relatively fresh water.

Figure 3 shows the volume of onshore produced water as reported by 44 of the 56 International Association of Oil and Gas Producers (IOGP) member companies, representing 27% of 2017's

FIGURE 3 ONSHORE PRODUCED WATER IN 2017 ACROSS REGIONS[ix]

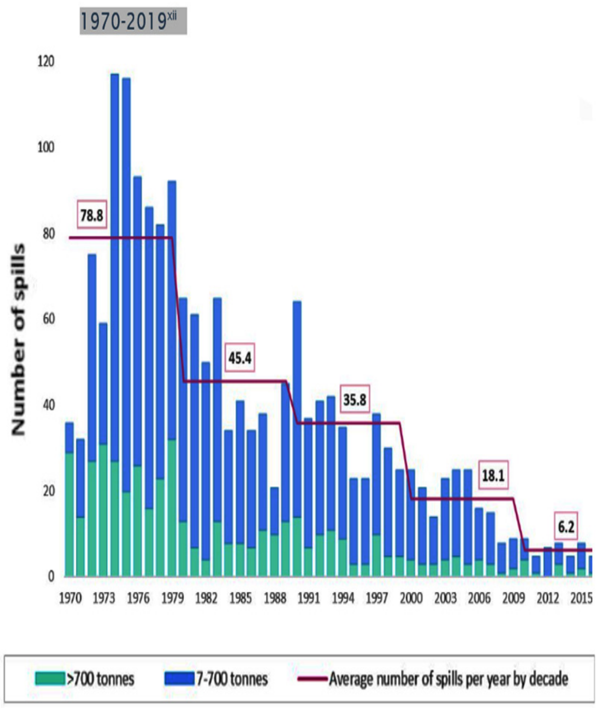


world production.
The oil and gas industry uses hydraulic fracturing following the drilling of a well to increase the subsequent production rate of oil and gas. This involves the injection of sand and water combined with hydraulic fracturing fluids (HFFs). While more than 90% of fracking fluids may remain underground, some of the HFFs return to the surface after completion of fracturing as flowback. The latter may contain wastewater, sand and proppants, and potentially toxic chemicals including acid inhibitors, friction reducers, metals, sodium salts,

sulphates, biocides, chlorides, and bromides. Between 70-140 billion gallons of water were used to fracture 35,000 wells per year in the US, according to the Environmental Protection Agency in 2010. A four-million-gallon fracturing operation would include 80-330 tons of chemicals. The transportation of between two and five million gallons of wastewater requires over 1,400 truck trips, signifying that fracking does not only deplete fresh water supply and affect aquatic environments but also creates transportation costs along with air quality, noise pollution, safety and road repair issues[x].

Oil spills can take place both in oceans and on land, damaging ecosystems as well as parts of the food chain. The number of large spills (>700 tonnes) has diminished significantly over the last decades and especially since 2010, averaging 1.8 spills per year. The quantity of oil spilled has also decreased significantly over the same period. In 2010, around 164,000 tonnes

FIGURE 4 NUMBER OF SPILLS FROM TANKERS (>7 TONNES), 1970-2019[xii]



of oil were spilled from tankers in spills of seven tonnes and above each, down 95% from 1970s levels Figure 4. Note this does not include spills from pipelines or upstream operations, such as BP's Macondo blowout in the Gulf of Mexico in 2010, which spilled four million barrels[xi] (about 550,000 tonnes).

Oil sands tailings ponds contain the waste by-product of the extraction and upgrading of oil sands, carried out primarily in western Canada. These ponds contain toxic and harmful chemicals including ammonia, mercury and naphthenic acids, endangering animals and aquatic organisms. Canada holds the largest tailings ponds in the world with one trillion litres of sludge Figure 5 [xiii].

FIGURE 5 OIL SANDS TAILINGS POND IN FORT MCMURRAY, ALBERTA[xiv]

Solid

Sand production can occur in weakly consolidated sandstone reservoirs if fluid flow exceeds a certain threshold of strength in the reservoir rock. As sand production increases, operating expenses also rise due to frequent shut-ins and clean out operations[xv]. Produced sand is considered by OSHA (US's Occupational Safety and Health Administration) a hazardous waste since it can produce respirable crystalline silica, threatening workers' health[xvi].

In drilling operations, drilling fluid/mud is usually pumped down the drill string to raise drill cuttings to the surface. When discharged to the ocean, cuttings accumulate on the sea floor. This accumulation on seafloor sediments leads to changes in the physical properties and chemical composition of the sediments[xvii].

Drilling waste is often contaminated with oil and contains barite and ilmenite which can incorporate lead as an impurity[xviii]. In the US, drilling waste amounts to four barrels for every metre drilled, with 22 million m3 having accumulated in temporary disposal.

The petroleum processing and refining industries produce large amounts of waste including tank bottoms, slop oil emulsion solids, and sludges (oil, water, solids). Sludge combines hydrocarbons, sediment, heavy metals, and water. The formation of sludge at the bottom of storage tanks can cause a reduction in tank storage capacity, oil contamination, environmental pollution, corrosion, and repair costs[xix].

Apart from tank bottoms, the refining industries also use asbestos as a thermal insulator for fire retardation. Inhalation of dust created from asbestos-containing material can lead to the development of cancer and other related illnesses.

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Other solid wastes which can be found on the inside of piping and tubing are scales, which can have high concentrations of radioactivity. Over 100 tonnes of scale per oil well are produced per year in the US[xx].

The geological formations that contain oil and gas deposits also contain Naturally Occurring Radioactive Materials (NORMs). These include uranium, thorium, and radium along with their decay products. NORM can accumulate as solid scales deposited from solution. It poses a major problem especially to workers during periods of maintenance, waste transport, processing, and decommissioning.

Other solid wastes include: used equipment; decommissioned field installations; and construction wastes. The safe and environmentally responsible removal of offshore installations is a growing issue in the North Sea, as fields there are decommissioned.

FIGURE 6 SULPHUR BY-PRODUCT OF NATURAL GAS PRODUCTION, SOUTHERN ALBERTA, CANADA[xxi]

Heat

The oil industry generates heat from its operations, particularly from operations involving combustion such as boilers and generators. This heat is discharged either in air or coolant water. Produced fluids also have above-ambient temperatures because of geothermal heat. This waste heat can affect local ecosystems, for instance if discharged into water bodies.

THE CHOICE OF WASTE MANAGEMENT DEPENDS ON SEVERAL FACTORS

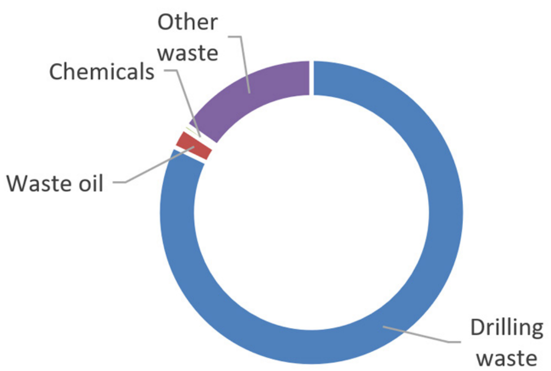
With such a wide range of wastes, appropriate waste management depends on the nature and volume of the waste, the local situation, company philosophy, and applicable laws and regulations. Special attention should be paid to:

- Regulations: classification of waste needs to be performed according to the local regulatory requirements which assign the treatment/disposal technique for specific waste streams. Regulatory bodies often classify waste by properties (solid, liquid, gaseous) and hazardous characteristics (flammable, ignitable corrosive, toxic, etc.) to determine how it should be disposed or handled.
- Source of waste: categorisation of waste by source is necessary to determine the type of waste generated by each activity/source along with its potential treatment technology and transport.

- Chemical and physical properties: waste must be classified to determine its hazardous characteristics and environmental impeccability. The steps to assess waste consist of determining the chemical composition of the waste, identifying if the substances in the waste are hazardous or organic, assigning a classification code, and describing the code for documentation purposes.
- Area of coverage: in the case of disposal, it is necessary to assess the geology and hydrology of the landfill as well as site characteristics (climatology, topography, and suitability of landfarming/landfilling).

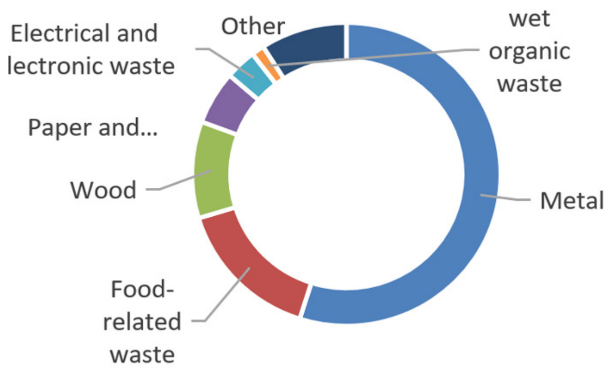
In Norway, for example, the Norwegian Environment Agency breaks down offshore well drilling waste into hazardous and non-hazardous, with industrial processes generating the most hazardous waste – about 465,000 tons of hazardous waste was taken ashore in 2015 Figure 7.

FIGURE 7 HAZARDOUS OFFSHORE WASTE FROM THE NORWEGIAN SHELF IN 2015, (%)[xxii]



About 37,000 tons of non-hazardous waste was produced on the Norwegian shelf in the same year Figure 8.

FIGURE 8 NON-HAZARDOUS OFFSHORE WASTE FROM THE NORWEGIAN SHELF IN 2015, (%)



Subsequently, these wastes are sent for waste treatment facilities decided by the Departments of Environmental Affairs at the County Governor's Office, signifying that each waste stream is assigned a specific waste treatment technology.

WHAT ADVANTAGES ARE THERE FOR THE INDUSTRY IN IMPROVING ITS WASTE MANAGEMENT PRACTICES?

Waste damages the oil and gas industry's reputation and long-term societal acceptance. Greenhouse gases are the most serious long-term issue, but local waste may be more visible and forms a tangible target for environmental campaigners. Incidents of water contamination have caused persistent negative media attention in the US in particular[xxiii].

Recently, Greenpeace activists boarded two Royal Dutch Shell oil platforms situated in the British North Sea, protesting over 11,000 tonnes of oil being left on the platforms, while leaving a "Clean up your Waste" banner[xxiv]. In August 2019, environmentalists were enraged by the Trump administration's announcement that it was seeking to abandon a regulation designed to stop methane leakage. Even disconcerted gas producers were concerned that such a move by the administration could cause a waning in gas appeal as a transition fuel[xxv].

Waste also harms financial returns by incurring costs and fines, affecting employee health and productivity, and missing revenue-generating opportunities. However, some forms of waste, notably methane, water, used equipment and heat, can be valuable for re-use.

The potential benefits to a company that follows circular management practices include: increased revenues; reduced costs of materials, operating, waste management and disposal, facility clean-up, and energy; reduced regulatory compliance concerns; improved operating efficiency; reduced potential for civil/criminal liability; and enhanced public perception of the company as well as the industry.

WHAT ARE THE OPTIONS FOR REDUCING, REUSING, AND RECYCLING WASTES IN THE ENERGY SECTOR?

The energy industry has tended to look at waste as an issue of disposal. Over time, the scope of appropriate disposal sites has narrowed as practices such as disposing of cuttings in the sea, or flowback water in open surface pits, have become unacceptable.

However, the industry can learn from a wider movement towards the 'circular economy' and a holistic approach to avoiding waste. Complete circularity may not be possible, but major reductions of material and energy inputs and waste outputs are achievable.

In the context of 'circular economy' framework, the following approaches are essential in waste management:

1. Reduce the amount of waste and the amount of material and energy input to a process.

In the waste management hierarchy, the highest priority is given to waste reduction since avoiding waste generation altogether, or producing the least waste possible, reduces the associated risks and costs of waste management. This can be done through product substitution, equipment modification, automation, and process changes. In some cases, waste reduction is neither technically possible nor economically feasible. Still, the lower the volume/toxicity, the more cost-effective waste management becomes.

For example, produced water, which constitute the largest volume and cost of waste management in oil and gas industry, can be reduced by using downhole oil/water separators and simultaneously injecting it underground[xxvi]; using polymer injection to reduce permeability to water in the production area[xxvii]; and reducing leaks and drips by practicing preventive maintenance.

There are major gains to be made in reducing greenhouse gases by cutting down on methane leaks via ‘green completions’, replacing hydraulic valves, and monitoring systematically with automatic sensors, drones and satellites. This boosts revenues by allowing sale of the captured methane. The IEA has reported extensively on methane reduction opportunities[xxviii].

2. Re-use equipment and materials as far as possible.

Reusing preserves some or all of the energy and materials used in operations. It also includes reusing materials and equipment by finding alternate uses for them rather than disposing or recycling them. This method is considered one of the most efficient to avoid land filling. Waste re-use also includes recovery of waste heat through capturing heat exhausted by a reclamation unit and, then, reused as thermal energy recovery or power generation[xxix]. Repsol applies, for instance, thermal desorption to treat drilling mud. This was used at the Caipipendi field in Bolivia to obtain fuel and water, reducing the amount of waste and virgin raw materials used in the processes. About 15,000 tons of drilling muds were treated and 2,000 m3 of diesel recovered[xxx].

According to the International Petroleum Industry Environmental Conservation Association (IPIECA), produced water can be treated and reused for drilling and completion, hydraulic fracturing, irrigation, livestock and wildlife watering, electric power industry and in other industrial and commercial applications. The Qarmat Ali water treatment plant in southern Iraq, for example, treats industrial waste-water for reinjection into fields such as Rumaila.

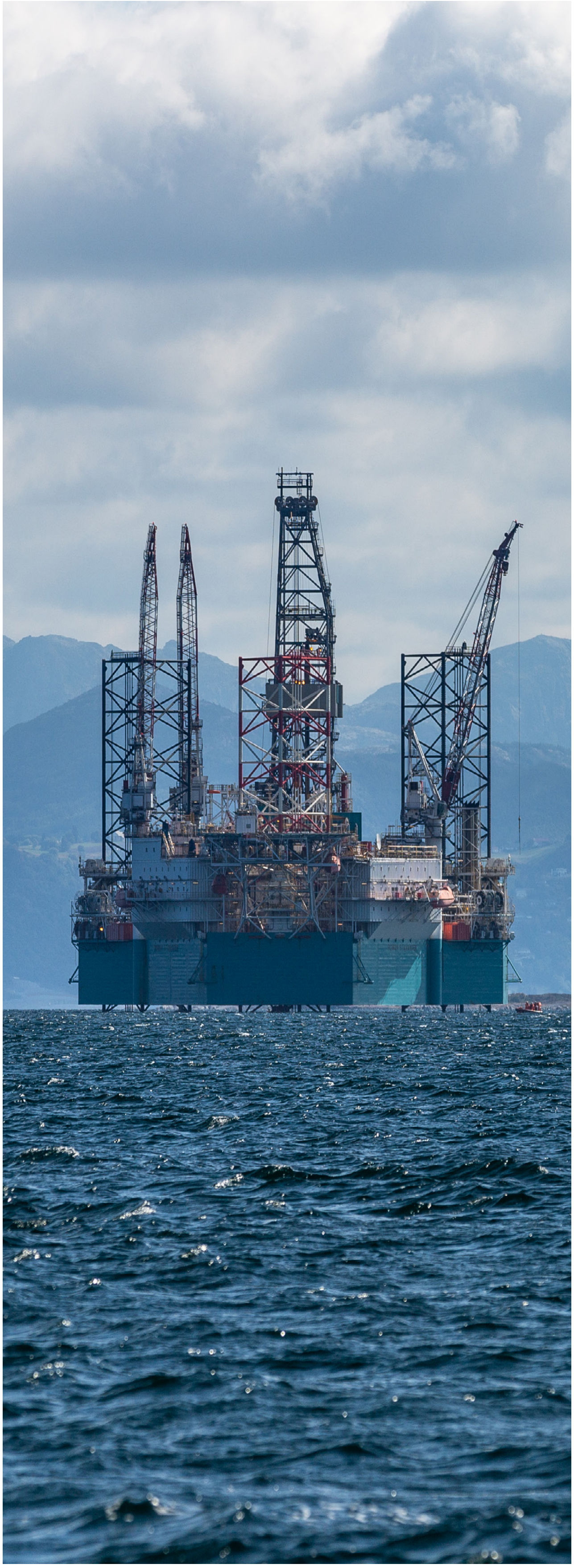
The most common way drilling fluids' waste is managed in the US is by reclaiming water from the reserve pit through a dewatering technique. The produced water is then used as rig-wash water or makeup water for the drilling fluid system[xxxi]. The US's Association of State and Territorial Solid Waste Management Officials (ASTSWMO) added that produced water can also be reused in downhole operations, road de-icing and as a dust suppressant[xxxii].

3. Recycle the components or materials for future use.

Recycling involves reclaiming useful components of a waste material or eliminating contaminants from a waste for reuse purposes. In the US, 80% of sludge volumes generated at refineries are recycled and only 20% are disposed of[xxxiii].

Apache was able to reduce its operating costs in 2016, by recycling produced water in drilling operations. It built six water recycling systems in the Alpine High oil and gas play, West Texas, with a capacity of recycling 90% of produced water[xxxiv].

The Brent Spar, a North Sea offshore oil installation operated by Shell, became the target of a Greenpeace-led campaign when it was scheduled for removal in 1995. Shell intended to sink the facility in the deep ocean. Instead, the company eventually decided to reuse some of the equipment; recycle most



of the steel, oil and wax; and send about ten tonnes of asbestos to landfill. The structure was used as the core of a new quay at Mekjarvik in Norway[xxxv].

Other offshore oil installations have been sunk to provide artificial reefs, as in the Gulf of Mexico and offshore California, in the 'Rigs-to-Reefs' programme. This is managed by the US's Bureau of Safety and Environmental Enforcement[xxxvi].

APPROPRIATE WASTE TREATMENT AND DISPOSAL OPTIONS

Remaining waste after due consideration of the above three steps should be treated and disposed in a safe, secure and sustainable way.

Waste treatment renders the waste less hazardous, making it safer to transport, store, and dispose of – and sometimes recycle. This can be done through stabilisation, neutralisation, evaporation, precipitation, incineration, scrubbing, among other options. The treatment of waste usually requires the use of several technologies. In the case of produced water, seven treatment technologies are commonly employed: (1) the removal of organics (including oil and grease), (2) solids removal, (3) disinfection, (4) dissolved gas removal (including light hydrocarbon gases, carbon dioxide, and hydrogen sulphide), (5) softening (removal of water hardness and reduction in scaling), (6) removal of NORM, and (7) desalination[xxxvii]. These are usually regulated by government authorities which assign specific waste streams to specific treatment facilities or disposal sites (landfills, pits, etc).

Waste-water can be disposed of by reinjection into suitable deep geological formations or into the producing reservoir (for pressure maintenance and improved oil recovery). However, this has caused problems in certain geological settings, like in Oklahoma and Kansas, by lubricating pre-existing faults and triggering earthquakes[xxxviii].

Also, waste-water can be treated for re-use, in agriculture or for other industrial uses. Petroleum Development Oman produces about one million m3 of water daily with its oil. It has experimented with using treated produced water to grow salt-tolerant crops[xxxix] and creating wetlands in the desert[xl]. In essence, wastewater is either left in evaporation ponds and the remaining solid material recovered, or is placed in aquifer storage for future use, or it can be treated and disposed of in general wastewater systems, surface water bodies or the sea. However, it should be noted that many jurisdictions do not permit disposal in surface water bodies or in the sea.

Drilling wastes are usually disposed in landfills or sent to offsite processing/treatment plants.

Disposal is sometimes limited as it requires, especially for drill cuttings, solidification. Other factors limiting disposal cover the presence of heavy metals, hydrocarbons, and radionuclides[xli].

Disposal costs vary extensively based on the location of the disposal facility, method, type of waste and the level of local competition. Table 1 shows the range of costs for the disposal of each waste. An estimated 300 million barrels of water are produced with oil every day[xlii] (compared to approximately 100 million barrels of oil – ie an average global water-cut of about 75%). The worldwide industry's costs for produced water handling could therefore be in the range of $30-200 billion annually – an enormous opportunity for savings and value creation.

APPROPRIATE WASTE TREATMENT AND DISPOSAL OPTIONS

TABLE 1 DISPOSAL COSTS BY WASTE TYPE[xliii]

Waste	Costs ($/bbl)
Produced water	0.30-10
Water-based muds and cuttings	0.50-40
Tank bottom	0.85-40
Contaminated soil	1-22
Oil-based muds and cuttings	2-40
NORM	40-300

GAS FLARING AND METHANE LEAKAGE IS AN IMPORTANT EXAMPLE OF COLLABORATION WITHIN THE INDUSTRY AND WITH GOVERNMENT

Generally, governments, whether national or local, primarily manage oil industry waste by regulation. This can be prescriptive (ie specifying precisely how waste should be dealt with), or it can be performance-based (for example setting emissions/discharge standards which companies can decide the preferred way of meeting), or a combination of the two. For example, Russian law orders companies to utilise 95% of the associated gas. Meanwhile, gas flaring is illegal in Nigeria and prohibited in Equatorial Guinea, with exemptions granted sometimes by the government.

In countries with a federal system of governance (such as the US, Canada, and Australia), there can also be differences in the standards and policies applied at the federal level and those at the provincial/state level. For instance, while flaring is still legal in the US under certain conditions, some states are enacting reporting regulations at state level.

Gas flaring reduction initiatives can also take the form of regional alliances between countries, international organisations, and oil and gas companies:

- The World Bank's Global Gas Flaring Reduction Partnership (GGFR) is a public-private initiative seeking to develop programmes and remove technical and regulatory barriers to utilising flared gas[xliv]. Partners include several national and sub-national governments, and a number of leading international and national oil companies including Shell, ExxonMobil, Equinor, Kuwait Oil Company, Qatar Petroleum and others.
- The Oil and Gas Climate Initiative (OGCI), a grouping of 12 major oil and gas companies, has set the reduction of methane emissions[xlv] as one of priority areas. The group also sees the promotion of circular carbon economy (re-use of carbon dioxide) as an important longer-term area.
- IPIECA[xlvi] has a membership of 44 oil and service companies and a number of petroleum associations. It covers a wide range of industry, environmental and social issues, with the management of greenhouse gas emissions, water and oil spills being particularly important.
- In response to the problems of flaring and methane leakage, along with increased pressure from environmental groups, the Texas Railroad Commission, the state's petroleum regulatory body, created "the Texas Methane and Flaring Commission," which aims to introduce regulatory reforms to the sector's flaring reduction practices[xlvii].

TABLE 2 EXAMPLES OF MANAGEMENT MEASURES FOR GAS FLARING AND OTHER WASTE TYPES

Country	Type of Waste	Measures
Iraq	Gas flaring	Iraq has been a longstanding member of the GGFR and made several pledges to reduce flaring. However, the country's commitments have rarely been met and the deadline to end flaring has been pushed back from 2016 to 2022. Recently, several companies announced gas capture projects that will help the country increase its associated gas capacity.
Nigeria	Gas flaring	In 2018, the Nigerian National Petroleum Corporation announced a new strategy to end routine flaring by 2020. This is applied alongside penalties that were set in the 2016 Nigeria Gas Flare Commercialization Programme.
Russia	Methane leakage	Russia accounts for ten per cent of global methane emissions. The country introduced a system taxing all "nature users" for their emissions since the 1990s. The MNRE and Cabinet of Ministers also established guidelines and rules for emission calculation methodologies according to the Scientific Research Institute on Protection of the Atmospheric Air.i
OSPAR[xlix] (15 NE Atlantic governments)	Marine environment	OSPAR regulates (inter alia) dumping waste at sea and land-based marine pollution, including offshore facilities, carbon capture & storage, chemicals, oil discharges and air pollution.

IMPLICATIONS FOR MAJOR OIL AND GAS PRODUCERS

- Oil and gas companies' regulatory compliance and waste management practices have improved greatly in recent decades. Nevertheless, waste continues to present a major cost and reputational challenge for the industry. Progress is especially required on wastewater management, greenhouse gases (CO_2 and CH_4), and decommissioning, given the growing proportion of older fields.
- National oil firms need to identify their waste management issues and how they should address them. Joining industry organisations such as IPIECA will guide them regarding best practices. These organisations are important for setting common standards and pushing for reasonable and consistent government policies across jurisdictions. OGCI, provides a platform for its members to engage actively in processes that lead to strong and appropriate climate policies, and investment in technologies to reduce CO_2 and CH_4.
- Petroleum companies should be encouraged by the economic incentives the "circular economy" framework presents and should rethink their waste management holistically in line with it, rather than treating it as an afterthought to be outsourced. The 'circular economy' framework, though not perfect, is a useful framework for managing waste systematically and moving beyond simple disposal.

IMPLICATIONS FOR MAJOR OIL AND GAS PRODUCERS

- While effective waste management may not be considered as a top business priority, it can offer cost savings and revenue gains, which in the face of current prevailing market conditions, are vital for corporate survival.
- Companies should incorporate emerging technologies – such as satellite and drone monitoring, artificial intelligence and automation, 3D printing, produced water recycling, waste-to-energy and waste heat recovery – into their operations and, where appropriate, enter industry coalitions to develop such methods further.

CONCLUSION

It is hard to give general prescriptions about oil and gas industry waste, as it varies so widely by type, sector and geography. Beyond the main liquid and gaseous wastes, there is a great variety of solids and other substances that must be dealt with appropriately.

Companies that manage waste effectively will have a competitive advantage. Cost reductions, particularly for produced water, will be increasingly important for maintaining economic viability in mature fields. Reducing greenhouse gas emissions, which is increasingly a concern for investors, is also a cost issue in jurisdictions with carbon pricing (such as the EU, UK, Norway, and Canada). Upstream greenhouse gas footprints are likely to become a focus for the EU when permitting imports of oil and gas; they therefore pose the threat of denial of market access.

Waste offers revenue streams – for instance, saving methane leaks, re-using water, employing waste heat, selling solid sulphur to chemical firms, and capturing carbon dioxide for enhanced oil recovery.

Proper management of waste is of utmost important for societal acceptance of oil and gas activities. For example, the US shale industry has faced widespread complaints (not always well-founded), over water pollution, earthquakes, noise pollution, dust, air pollution and ozone, and flaring. This has led to hydraulic fracturing and therefore shale development being banned in several states, including New York. At a time that the petroleum business faces growing political and environmental opposition over its contribution to climate change, it needs to continuously find ways to minimise its footprint and ecological impacts. New technologies combined with new business models and management frameworks allow for major advances in reducing the impact of waste, and should be a priority for the industry.

APPENDIX

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