"MERCURY FROM OIL AND GAS" -UNEP GLOBAL MERCURY PARTNERSHIP STUDY REPORT
Draft – 7 March 2022

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ABOUT THE STUDY REPORT

The present study report has been developed in the context of the UNEP Global Mercury Partnership (hereinafter referred to as "the Partnership"). Initiated in 2005, the Partnership aims to protect human health and the environment from the releases of mercury and its compounds to air, water and land. With over 200 partners to date from Governments, intergovernmental and non-governmental organizations, industry and academia, the Partnership focuses its work on supporting the implementation of the Minamata Convention on Mercury, on providing state of the art knowledge and science and on raising awareness towards global action on mercury[1].

The Partnership Advisory Group (PAG) decided at its tenth meeting (Geneva, 23 November 2019) to initiate work on the topic of mercury from oil and gas, which it had identified as cross-cutting amongst different Partnership areas. In follow up to expert consultations in April 2020, Partnership area leads agreed to guide a process for developing a study report, with the aim to better understand potential releases of mercury, as well as possibly how wastes are treated and accounted for and may be entering the market for other uses. As per the leads guidance, the report could also distinguish the key differences between oil and natural gas related information, and therefore address them separately; identify the differences in the presence and management of mercury in the respective sectors.

The guidance provided also indicated that the report could include: a review of existing knowledge and gaps in understanding mercury content, emissions and releases; relative geographic mercury concentrations; waste flows and treatment during the respective stages of the oil and gas processes, including decommissioning of their infrastructures of both offshore and onshore sites; and available information on the potential avenues through which mercury from the sector may be entering the market for other uses; if available, information related to quantities of mercury that are possibly entering the market; information related to how mercury is present in new techniques such as non-conventional gas (fracking, shale gas), and how it is extracted; a review of the different methods used, highlighting best practices for mercury releases reduction and waste treatment (including the treatment at dismantling yards for the decommissioned infrastructures that may contain mercury), and for detecting or monitoring mercury releases; and finally initial ideas for further research and cooperation.

The International Society of Doctors for the Environment (ISDE) was commissioned to draft the report, under the overall coordination of Lilian Corra (ISDE). The report also benefitted from the input of partners of the Global Mercury Partnership as well as experts and stakeholders from various organizations and background. The study report indeed benefitted from a consultative process, involving experts from governments, the private sector, civil society, academia and intergovernmental organizations, members of the Partnership, as well as from other relevant organizations. Experts provided input to the preparation of the study report and gave feedback on the draft study report and its annotated outline, including through open call for comments and an expert consultation held in May 2021. Finally, UNEP would like to acknowledge the financial contribution from the Government of Sweden for the development of this work.

[1]For more information, please visit: www.unep.org/globalmercurypartnership

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EXECUTIVE SUMMARY– KEY HIGHLIGHTS

The present study report has been developed in the context of the UNEP Global Mercury Partnership (hereinafter referred to as "the Partnership"). Initiated in 2005, the Partnership aims to protect human health and the environment from the releases of mercury and its compounds to air, water and land.

Mercury is an extremely harmful pollutant, which due to its toxicity, long range mobility, and persistence poses a global threat to human health and the environment. Mercury can not only cause localized harm, to which children and pregnant women are especially vulnerable, through airborne emissions or soil and water contamination, but also travel long distances through the air that can reach around the globe. Mercury is a trace element in the earth's crust, often found as cinnabar (mercuric sulfide), which may be found in all fossil fuels, including oil and natural gas at varying concentrations. Mercury contained in oil and gas may enter the environment through various pathways and at different stages of the process, including the decommissioning of oil and gas infrastructure. A significant fraction of mercury releases may be captured, including for operational, health and environmental reasons, and subsequently treated as waste. However, practices around the world vary and a comprehensive overview of the extent of uncontrolled releases to the environment is still lacking.

The present report aims to present a compilation of available knowledge on the life cycle of mercury in crude oil and natural gas, to better understand its behavior and its emission and release pathways, particularly during the extraction, processing, management and waste disposal stages, and illustrate various technologies for controlling them. It has been compiled from expert consultations, and open access sources of information to present a critical review of existing knowledge and information gaps concerning mercury from oil and gas, showcase the different reduction methods, and provide relevant suggestions for further work including research and cooperation.

Key highlights:

Crude oil and natural gas are composed of hydrocarbons and contain various elements, including mercury, which may be emitted and released at various stages of oil and gas processing and use. In the absence of adequate control measures, mercury may not only impact processing systems (e.g. by damaging equipment and contaminating chemical processes and wastewater) but also pose serious health risks to operators exposed to elemental mercury vapor or organic mercury in the workplace.

In crude oil, mercury can be emitted and/or released at various stages of the life cycle. During extraction, it is mainly wastewater that may contain mercury. IPIECA estimated in 2016 that 13.5 t/year of mercury were released to the environment from extraction water. Mercury can also accumulate with sludge in crude oil storage tanks. During processing, the fate of mercury varies, among other things, depending on the type of facility, the composition of the crude oil and the processing methodology adopted. Mercury concentrations in crude oil and natural gas also vary according to the timeline of the analysis: an analysis on site after gas removal would show a much higher concentration of mercury than a sample taken after transporting the oil onshore to a laboratory, due to evaporation or precipitation of some of the mercury.

According to the 2018 UNEP Global Mercury Assessment, 0.1%, i.e. 0.56 tonnes, of the total mercury released into aquatic ecosystems and 0.65% (14.4 tonnes) of the mercury emitted into the atmosphere come from crude oil refining, while domestic inputs accounts for 0,12%, industrial combustion 0,06% (1,4 tonnes) and combustion in power plants 0,11% (2,45 tonnes). The report however highlighted that oil and gas extraction, along other sources of mercury, is one that is currently difficult to quantify at the global scale, largely due to the lack of comprehensive activity data as well as the lack of emission factors for highly variable process technologies. The report further indicated a general lack of knowledge on mercury content, removal efficiency as well as risk of releases to the environment.

For natural gas, there is a significant risk of mercury release to the environment during extraction due to the injection of low pH water that induces the dissolution of heavy metal salts. This subsequently extracted water has been identified as rich in heavy metals, including mercury. Mercury can also be released during the transport of natural gas or form mercury sulphide on the internal surface of the pipeline. This accumulation of mercury during transport is a source of contamination for the equipment but also for the workers in charge of the pipeline and the waste produced. Also, during processing, elemental mercury may be emitted into the atmosphere or dissolved in the wastewater produced. Finally, mercury may also be emitted and/or released during the use of the finished product.

Mercury distribution, emissions and releases at various stages of oil and gas refining depends on several physical-chemical conditions such as temperature, pressure and reactivity with other chemicals in presence. Accumulation of mercury and/or its amalgams (with other metals) in internal surfaces of processing equipment may result in the reduction of the processes' efficiency due to the corrosion and embrittlement of the equipment. Therefore, equipment used becomes mercury contaminated waste that requires appropriate management.

Based on current knowledge, the following recommendations were formulated:

- Progress still needs to be made regarding mercury removal from crude oil. According to IPIECA, Good practices include the removal of mercury before refining stage for concentrations below 100 ppb and during refining for concentrations exceeding 100 ppb. As for natural gas, mercury removal could be implemented before the cryogenic distillation stage to avoid its deposition in the cryogenic equipment. Existing technologies for mercury removal in crude oil include MRUs (on condensates), filtration, chemical addition and filtration (MERCAWAY), as well as decomposition and adsorption.
- Reducing mercury emissions and releases from crude oil and natural gas processing would require strengthening human and technical capacities of facilities for a sound processing, as well as appropriate management and disposal of mercury containing waste.
- Maintenance and inspection steps should be carefully planned to limit the emission and release of mercury accumulated in separators and heat exchangers.

Finally, a number of priority areas would benefit from further research for a better understanding of mercury fate in crude oil and natural gas. These relate in particular to (i) the monitoring of mercury in both life cycles; (ii) more clarifications on the mass balance ; (iii) the identification and promotion of best available methodologies for sampling and determination of mercury concentrations ; (iv) additional information on the production and fate of mercury waste and mercury containing waste flows in regions where mercury concentrations are estimated to be higher in crude oil and natural gas and (v) enhanced access to information on mercury containing waste resulting from crude oil and natural gas deposits.

1. INTRODUCTION

"Mercury is a chemical of global concern owing to its long-range atmospheric transport, its persistence in the environment once anthropogenically introduced, its availability to bioaccumulate in ecosystems and its significant negative effects on human health and the environment". (first preamble of the Minamata Convention on Mercury).

Initiated in 2005 by a decision of the United Nations Environment Programme (UNEP) Governing Council, the UNEP Global Mercury Partnership aims to protect human health and the environment from the release of mercury and its compounds to air, water and land by minimizing and, where feasible, ultimately eliminating global, anthropogenic mercury releases. The goals of the Partnership are consistent with Article 1 of the Minamata Convention on Mercury, which states that the objective of the Convention is "to protect human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds. With over 200 partners to date from Governments, intergovernmental and non-governmental organizations, industry and academia, the Partnership focuses on supporting timely and effective implementation of the Minamata Convention on Mercury, providing state of the art knowledge and science and raising awareness towards global action on mercury.

Report Development Process

At its ninth meeting (Geneva, 18 November 2018), the Global Mercury Partnership Advisory Group (PAG) agreed to examine issues of potential interest, and to make an analysis of the level of concern, available data and possible contribution of the Partnership and agreed to initiate work on mercury from the oil and gas sector.

At its tenth meeting (Geneva, 23 November 2019), the PAG requested the Secretariat of the Partnership to convene targeted discussions with interested partners and stakeholders on the issue of mercury from oil and gas, which it had identified as cross-cutting, i.e., where the collaboration of Partnership areas of work would facilitate the development of needed information, interventions and projects, and for which the need for further information was recognized.

In response to this request, expert consultations were launched on in April 2020, with the overall objective to identify potential useful contributions from the Partnership, within the context of its mission and its existing areas of work. The meeting was attended by approximately 65 participants, both partners and non-partners, and included representatives from governments, intergovernmental and nongovernmental organizations (academia, scientific community and private sector).

Experts explored the following three aspects in their discussions:

(1) Needs and challenges associated with the management of mercury from oil and gas production, distribution and infrastructure decommissioning,

(2) Existing relevant work and guidance on best practices and

(3) Possible contribution of the Partnership to support the promotion of best practices and support moving the issue forward.

The discussions highlighted the cross-cutting nature of the topic, which could benefit from the complementarity and cooperation of several Partnership Areas, including on "mercury air transport and fate research", "mercury supply and storage" and "mercury waste management".

Several avenues were suggested as possible contributions of the Partnership, including an enhanced overview of mercury along the different stages of the oil and gas value chains, including its fate and transport, measurement techniques and the species of mercury found; and facilitating information and experience sharing on the topic of mercury from oil and gas and best practices for its environmentally sound management.

Interested Partnership area leads subsequently agreed to guide a process for developing a study report on the topic of Mercury in Oil and Gas.

Objective of the report

The objective of the present report is to analyze the life cycle of mercury in the oil and natural gas value chains and understand how this heavy metal, naturally present in oil and natural gas, may be released to the environment at different stages of the process (including the decommissioning of oil and gas infrastructure), and increase mercury concentrations in the environment, presenting therefore risks to human health and ecosystems.

It also aims at identifying and analyzing the management of waste from the sector, in terms of quantities produced, potential mercury emissions from the treatment phase, disposal, and where applicable, impacts of mercury recovery and reuse in the market.

2. MERCURY IN OIL AND NATURAL GAS

Current knowledge

The possible emissions and releases of mercury to the environment from crude oil and natural gas processing and uses were discussed during the preparatory process of the Minamata Convention.[2]

The limited available information (e.g. in terms of comprehensiveness or availability publicly) on the potential releases and emissions of mercury from the different processes and uses of crude oil and natural gas may be impeding a good understanding of:

- emissions and releases to the environment along the extraction/production and decommissioning phases;
- mercury or mercury containing waste from extraction or processing;
- occupational exposure;
- human exposure (even low chronic exposure may be particularly dangerous in early human development stages)[3].

Emissions and releases of mercury can be harmful to human health and the environment. Due to mercury's persistence, it remains in the environment and contributes to increasing the environmental pool of mercury.

Once present in the different media (air, water or soil) mercury can be transported long distances and penetrate the food chain, becoming part of all living things, affecting humans and biodiversity's health and quality of life.

Mercury is considered by WHO[4] as one of the top ten chemicals or groups of chemicals of major public health concern.

It is well known that heavy metals are present in crude oil and natural gas at varying concentrations depending on the geological formation of the producing reservoir.[5]

The presence of mercury in crude oil and natural gas poses problems for the industry operators and can have detrimental impacts on processing operations, the environment and human health.

While it is widely recognized that mercury may impact the process operations and affect the health of workers in the absence of adequate control measures[6], there are few (but an increasing number of) publications/investigations that go into the details of the question.

The processing of most crude oil is directed to maximize gasoline manufacture while for natural gas it aims to separate methane from other components. Both steps depend on the composition of the hydrocarbon mix and the market objectives.

Mercury is nowadays recognized as posing challenges to the processing of oil and gas, such as its ability to form amalgams with other metals, to poison catalysts, as well as to accumulate in processing equipment[7].

The management of mercury containing waste from petroleum processing can be a complex process, including in terms of separation, storage and disposal.[8]

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[2] UNEP(DTIE)/Hg/INC.3/5.
[3] https://www.who.int/news-room/fact-sheets/detail/mercury-and-health
[4] https://www.who.int/news-room/fact-sheets/detail/mercury-and-health
[5] https://www.who.int/news-room/fact-sheets/detail/mercury-and-health
[6] Mercury management in petroleum refining, An IPIECA Good Practice Guide, 2014.
[7]https://www.thermofisher.com/blog/metals/xrf-and-the-impact-of-mercury-in-the-oil-and-gas-industry/
[8] Mercury management in petroleum refining, An IPIECA Good Practice Guide, 2014.

It is important to take into consideration the difficulties of treating sludge deposits with hazardous content, contaminated liquids and sludge containing mercury from water treatment systems, and mercury sorbent materials. There are also challenges associated with storing and processing for disposal. It is reported that storage or burial of such waste material containing mercury are common practices in many remote locations even if these are not recognized best practices and have high environmental impacts.[9]

To understand the context of the mercury in oil and gas situation, the magnitude and importance of the oil and gas industry should be considered: over 85% of the world's energy comes from hydrocarbon resources which include coal, crude oil, natural gas, the latter two contributing to approximately 55% of the global energy consumption. The level of production reached an all-time high in 2019, with around 95.2 million barrels of oil produced daily. This quantity includes crude oil, shale oil, oil sands and NGLs (the liquid content of natural gas, where this is recovered separately), but not liquid fuels from biomass and coal derivatives.[10]

Mercury affecting the oil and gas processing systems

The contribution of the oil and gas sector to global mercury emissions was considered to be very limited. [11] However, mercury has been receiving growing attention, and the optimization of the efficiency of oil and gas plants, as well as the tightening of environmental and health laws, has made mercury an important consideration for many oil and gas process engineers.[12] In its 2014 Good Practice Guide "Mercury management in petroleum refining", IPIECA noted that "although mercury releases from refining are small, it is still important to ensure that mercury releases are properly monitored and controlled."[13]

Crude oil and natural gas are naturally primarily composed of hydrocarbons and contain as well as a wide spectrum of elements such as mercury, arsenic and vanadium in concentrations that vary in every basin and at each stage of the different processes and uses.

Mercury may be present in three different chemical forms: elemental mercury, organic mercury and inorganic, which can be found dissolved, suspended or adsorbed to particulate material. These are present in crude oil and natural gas in low concentrations (between 0.1 and 20,000 ppb in crude oil and between 0.05 and 5,000 µg/Nm3 in natural gas) according to D. Lang.[14]

As a natural constituent of crude oil and natural gas, mercury is detrimental to petroleum processing systems, and in certain circumstances may expose workers to mercury concentrations that are dangerous to health.

In gas processing, mercury may contaminate and damage certain equipment like cryogenic heat exchangers. In chemical manufacturing and refining, it may poison certain catalysts, contaminate process chemicals (like triethyleneglycol or TEG, that can be reused in gas processes) and may also partition into wastewater.

Technical difficulties posed by mercury in refineries are today well known and include equipment degradation, toxic waste generation, or poisoning of catalysts. These are linked to mercury's

[9] A. Chalkidis et al. Mercury in natural gas streams: A review of materials and processes for abatement and remediation, Centre for Advanced Materials & Industrial Chemistry (CAMIC), School of Science, RMIT University, GPO Box 2476, Melbourne, VIC, 3001, Australia, b. CSIRO Energy, Private Bag 10, Clayton South, VIC, 3169, Australia. 2019.
[10] Oil - global production 1998-2019. Published by M. Garside, Sep 30, 2020
https://www.statista.com/statistics/265203/global-oil-production-since-in-barrels-per-day/
[11] IPIECA Annual Review 2013-2014
[12] Subirachs Sanchez, Mercury in extraction and refining process of crude oil and natural gas, University of Aberdeen, 2013.
[13] Mercury management in petroleum refining, An IPIECA Good Practice Guide, 2014.
[14] D. Lang. et al., Mercury arising from oil and gas production in the United Kingdom and UK continental shelf. IMKIP Oxford. 2012

unequal distribution among vapor, condensate and aqueous phases, depending on the pressure and temperature.[15]

Occupational exposure

Workers may be exposed to mercury in particular through inhalation of mercury vapors and dermal absorption of mercury during maintenance work, inspection activities and decontamination during turnaround in the petroleum industry.

According to Qa[3], "The biggest potential risk to workers arises during plant shutdowns or during service/maintenance work when mercury that has accumulated onto the internal surface of processing equipment via adsorption/chemisorption can be released to the atmosphere. This process of releasing mercury is accelerated if any hot work is carried out and can be particularly problematic in confined spaces where the mercury concentration could potentially rise above the OEL (occupational exposure limit). OELs for mercury vary from region to region but are typically in the range 20 - 50 $\mu g/m^3$."[16]

When processed hydrocarbons contain mercury (total mercury above a few ppb[17]), cleaning and inspections activities must be carefully planned due the accumulation of mercury deposits in equipment such as separators and heat exchangers.

Mercury concentrations in vapor can be much higher in the vessels than in the process stream due to the accumulation mechanisms that include adsorption on equipment surfaces and dissolution in sludge.

Chemical exposure during maintenance could be several times higher than normal work routines and during the comprehensive turnaround (TA) workers could have significant exposure.[18] Based on the review of the existing literature, the example cited is not an isolated case but rather is representative of concerns about occupational chemical exposure during maintenance routines of equipment.

Other potential exposure sources could be the decontaminated units (when measuring toxic chemical concentrations) and the wastewater drained in the water treatment system [19] Publications noted cases where mercury exposure was several times higher than the threshold limit value (TLV), with the highest levels found among steam decontamination workers. [20]

Based on the existing literature review, the examples cited are not isolated cases, but rather representative of concerns about occupational exposures.

Organic mercury (especially dialkylmercury) is estimated to be many times more toxic than elemental mercury on an equivalent weight dose basis. Dermal absorption efficiencies for elemental mercury in vapor are typically lower than 3% of the absorbed dose but nonetheless, must be strictly avoided.[21]

[15] Fabian G. Lombardi, AXION ENERGY SA, Procesamiento de crudos con mercurio, Petrotecnia.5, 2018.
[16] Qa3. Unconsidered Mercury Emissions from the Oil and Gas Industry. ANNUAL BUYERS GUIDE 2016.
[17] Maytiya Muadchim, et al. Case study of occupational mercury exposure during decontamination of turnaround in refinery plant. Published online 2018.
[18] Maytiya Muadchim, et al. Case study of occupational mercury exposure during decontamination of turnaround in refinery plant. Published online 2018
[19] Turnaround (TA) shutdown of refineries to allow for decontamination, repairs, replacements, inspections, and overhauls to increase equipment reliability to maintain production integrity and reduce the risk of catastrophic failures
[20] Maytiya Muadchim,et al. Case study of occupational mercury exposure during decontamination of turnaround in refinery plant. Published online 2018
[21] WHO. Elemental mercury and inorganic mercury compounds: Human health aspects. Geneva 2003. https://www.who.int/ipcs/publications/cicad/en/cicad50.pdf

In working areas, mercury presence in vapor suffers considerable variation (depending on the temperature and convection), highlighting the importance of monitoring as part of an overall monitoring program for chemicals of concern to understand the source and concentration.[22]

The combination of dietary, environmental and occupational mercury can cause total exposure to exceed the threshold for chronic detriment. Analysis of blood and urine are the most common diagnostic tools for the discovery and quantification of occupational exposure as conclusive symptomatic diagnosis of neuralgic impairment is usually at an advanced stage (and therapies are mostly palliatives).

Prevention is hence critical, along with raising awareness on the issue by promoting *"the development and implementation of science-based educational and preventive programmes on occupational exposure to mercury and mercury compounds;"* as called for under the Minamata Convention (article 16, paragraph 1).

Case study 1: "Escalante crude", Argentina[23]

South America has the second highest regional mercury concentrations in crude oil after Asia, with 11% of crudes over 15 ppb.

Petroleum crudes have been identified in the Fueguina basin as containing mercury in high concentrations, up to 80 ppb.

The Campana refinery, in Argentina, was warned by crude assays usually performed on crude oil (as well as by external alerts)[24] about the possible presence of mercury in crude oil since 2009. High levels of mercury were detected in "Escalante" crude (the leading exported crude from Argentina).

This refining plant installed a low concentration mercury detection equipment in order to monitor mercury levels during the process and in commercial products.

According to the monitoring outcomes, mercury average concentrations (with predominance of Escalante crude) increased up to 25 ppb.

According to the publication consulted, trace mercury in the crude oil to be refined must be studied, with a special emphasis in the crudes of Argentina as the local crudes have increased their mercury concentration over time.

This article also highlights that mercury tends to be present in all the cuts, with a high occurrence in lighter ones (like LPG and naphtha). It further strongly recommends studying mercury levels in order to prevent workers and environmental exposure, ensure the quality of the products and protect the equipment.

Finally, the article points to unanswered questions: Is mercury accumulating? Where? In which cuts? How can the effects be predicted? What actions have to be taken?

[22] Gasmet, Emissions Monitoring Handbook.
[23] Fabian G. Lombardi, Axion Energy SA, Procesamiento de crudos con mercurio, Petrotecnia.5, 2018.
[24] Fabian G. Lombardi, Axion Energy SA, Procesamiento de crudos con mercurio, Petrotecnia.5, 2018.

3. MERCURY CONTENT IN OIL AND GAS DEPOSITS

Mercury occurs naturally in oil and gas deposits, probably as the product of primary geological processes as well as secondary ones mobilizing mercury into reservoirs. Even though not comprehensive, wide-ranging research has been published on the origin of this metal.

Standards for the determination of mercury in crude oils were first developed by the American Society for Testing and Materials (ASTM International Standards) in 2010, providing the means to quantitatively determine the amounts of mercury in crude oils.[25]

Different forms of mercury in deposits (chemical speciation)

In natural gas, mercury is mostly present in its elemental form.

Several forms of mercury have been described in gas condensate, the liquid steam separated from natural gas, and in crude oil: mainly elemental mercury and inorganic compounds (like, HgS, HgK2, HgK, HgSe and other salts), but also organic compounds (mainly Hg thiols), all of them with different chemical and physical properties.[26]

These forms of mercury may be dissolved, suspended or adsorbed on inert particles like sand or wax.

Geographical distribution of the presence of mercury in crude oil and natural gas

It is important to clarify that gas condensates as well as crude oil are usually referred to in the consulted bibliography under the general denomination of “oil”, “crude” or “crude oil”.

Mercury levels in crude oil can vary significantly depending on the origin and geological factors, such as: regional tectonic position, structural features of the deposit and seismic activities. Levels can also depend on the operation conditions.[27] Consequently, mercury concentrations may vary in a short period of time influenced by these processes.

According to IPIECA’s (International Petroleum Industry Environmental Conservation Association) database, mercury levels in crude oils can vary between 0.1 and 1,000 ppb. It should be noted that the documented maximum levels in crude oil also vary greatly in the existing literature: IPIECA’s database does not register levels over 1,000 ppb but other texts such as US EPA 2001[28] mentions 20,000 ppb. IPIECA attributes this difference to old and non-comparable analytical techniques.[29]

It is important to highlight that global multicentric harmonized studies using comparable analytical techniques and data analysis have not been implemented. Also, due to possible variations of the concentrations, it is desirable to keep the concentration mapping updated.

A simple mass balance between the mercury content in crude oil and natural gas and mercury waste or mercury containing waste is difficult to obtain due to the uncertainties on the origin of the mercury in the deposits and the important variation in the concentration of mercury levels in crude oil and natural gas in the basins and deposits.

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[25] Determination of Mercury in Crude Oil Is Covered in New ASTM Petroleum Standards
[26] Wilhelm et al., Mercury in crude oil processed in the United States, 2004.
[27] Subirachs Sanchez, Mercury in extraction and refining process of crude oil and natural gas, University of Aberdeen, 2013.
[28] Office of Air Quality Planning and Standards (EPA). Research and Development. Mercury in petroleum and natural gas: estimation of emissions from production, processing and combustion. 2001.
[29] IPIECA. Mercury management in petroleum refining An IPIECA Good Practice Guide. 2015.

Methodologies for estimating the concentration of mercury in crude oil

In general, as a first approach to calculate the amounts of mercury present in the crude oil, the information is presented as the average concentrations per region, which can be a good indicator to evaluate the releases and emissions according to the source of the crude oil.

To estimate the average concentration per region, Wilhelm et al. 2004 uses the average of the values obtained for total mercury in different crudes, weighted by the amount of oil produced by country.

Table 1: *Mercury concentration in crude oil by region, calculated as the average of total mercury in different crude oils weighted by production by country.*[30]

Region	Hg Concentration (weight-average, wt. ppb)
Middle East	0.8
Africa	2.7
North America	3.2
South America	5.3
Europe	8.7
Asia	220.1
Global	3.5

Another way of estimating regional average is to take the median of the results of the total mercury analysis in different deposits. This methodology has been used by IPIECA in the calculations presented in table 2 below.

When higher levels of mercury (over 100 ppb) are considered extraordinary events, this can be a more robust methodology to estimate a global average, but the estimation tends to show lower averages in regional levels as shown in the table below.

Table 2: *Total Mercury by Region Calculated as The Median Of The Results By Country*[31]

Region	Hg Concentration (median, wt. ppb)
Middle East	1.0
Africa	1.0
North America	1.2
Eurasia	1.2
South America	1.4
Pacific and Indian Ocean	3.0
Global (average weighted by production)	7.5

The results of the tables are not directly comparable because different regions, as different analytical techniques and data processing were used, although in both tables it can be observed that the results presented are similar for the zones with the lowest mercury concentration and

[30] Wilhelm et al., Mercury in crude oil processed in the United States, 2004.
[31] Mercury management in petroleum refining, An IPIECA Good Practice Guide, 2014.

with the least data dispersion. For example, in the Middle East, the averages in both tables are alike as no results are above 15 ppb of mercury.

On the other hand, for regions with a wider dispersion of the data on concentration of mercury among deposits (very low and very high presence of mercury), the results can differ significantly within estimation methodologies.

As an example, IPIECA reports an average of 3 ppb of mercury for the region identified as "Pacific and Indian Ocean" (table 2) while Wilhelm et al. reports 220.1 ppb for the region identified as "Asia" (table 1).

Even when using a data analysis similar to Wilhelm et al., the unweighted simple average of mercury levels for IPIECA dataset[32] results in 51 ppb for the "Pacific and Indian Ocean" region, still far from the 220.1 ppb mentioned by Wilhelm et al. in his publication. The difference may be due to the number of samples studied, their origin or the analytical techniques.

In addition, the timeline of analysis for the crude oil will have a significant influence over the result. A crude oil that is analyzed on-site immediately after the gas is removed, will in most cases, contain more mercury than the same crude when analyzed after transport onshore/to a laboratory. Volatile mercury can be lost from the oil, and mercury can precipitate from the oil and may then not get included in the analysis. This process can occur in pipelines, storage tanks as well as sampling bottles.[33] In any case, systematic comparable methods would be useful for a better comprehension of the global situation.

Methodologies for estimating the presence of mercury in natural gas

Like crude oil, natural gas deposits can show an important variation in the concentration of mercury, ranging from 0.05 to 9,000 µg/Nm3, depending on the source.[34] [35]

Almost all the mercury present in natural gas is elemental mercury, and only a little fraction, in low and difficult to measure concentrations, can be in a more bioavailable form like dialkylmercury.[36]

The same regions that have higher mercury in oil tend also to have higher mercury in natural gas, because in most cases crude oil and natural gas come from the same deposits.

The available information published on well-head levels of mercury in natural gas in different areas and countries shows the lowest average values for Middle East and North America, and high average values for Indonesia and South America (where the lowest measured levels are 200 µg/Nm3 and 69 µg/Nm3):

[32] B. Doll et al. (IPIECA) Industry Input to the UN Global Mercury Treaty Negotiations Focus on Oil and Gas. SPE/APPEA International Conference on health, Safety and Environment. 2012.

[33] Qa3 during document consultation. May 2021.

[34] D. Lang. et al., Mercury arising from oil and gas production in the United Kingdom and UK continental shelf. IMKIP Oxford. 2012

[35] Information provided by Qa3 during first draft consultation, November 2020.

[36] Office of Air Quality Planning and Standards (EPA). Research and Development. Mercury in petroleum and natural gas: estimation of emissions from production, processing and combustion. 2001.

Table 3: *Well-head levels of mercury in gas in different areas*[37]

Region/Country	Mercury Concentration (µg/Nm3)
Algeria	50 - 80
Eastern Europe	1 – 2,000
Far East	0.02 - 193
Germany (Northern)	15 - 450
Germany (Southern)	<0.1 - 0.3
Indonesia (Sumatra)	200 - 300
Middle East	1 - 9
North America	0.005 - 40
South America	69 - 119

Although the highest well-head levels were found in Eastern Europe this does not imply that the region has a high average concentration (the lowest levels were 1 µg/Nm3) but it indicates the presence of deposits with high mercury concentrations.

Notably natural gas (also referred in the publications as "non-condensates") shows a slightly lower concentration of mercury compared with crude oil. This difference is shown in Table 4, which compares median mercury level measured in crude oil and natural gas.

Table 4: *Mercury in oil vs gas (IPIECA)*[38]

	Median Hg level (ppb)	Percentage of crudes and condensates containing specific ranges of mercury (ppb)					
		<2	*2-5*	*5-15*	*15-50*	*50-100*	*>100*
Oil	2.4	48%	14%	14%	12%	8%	4%
Gas	1.3	65%	15%	9%	7%	1%	3%

Other publications and consulted experts [39] also highlighted that estimating mercury concentrations in gas at the well-head is potentially as difficult as in crude oil. The following table shows some examples of mercury concentrations in oil and gas from the same source. In most of the cases, the mercury levels are in the same order of magnitude in oil and natural gas while in a few cases, mercury levels in natural gas are considerably higher than in crude oil.

Table 5: *Examples of concentrations measured by Qa3 in oil and gas from the same source* (information provided by Qa3 during first draft consultation, November 2020).

Region	Hg in oil (ppb)	Hg in natural gas (ppb)
Thailand	~80	~9,000
UK	~80	~110
Norway	~12	~12

[37] D. Lang. et al., Mercury arising from oil and gas production in the United Kingdom and UK continental shelf. IMKIP Oxford. 2012

[38] Mercury management in petroleum refining, An IPIECA Good Practice Guide, 2014.

[39] Qa3 and Guia Morelli (PhD Environmental Geochemistry Researcher. Consiglio Nazionale delle Ricerche-CNR. Instituto di Geoscienze e Georisorse-IGG) consultation, November 2020.

Vietnam	~90	~560
Algeria	< 1	~14
Azerbaijan	< 1	~9
Australia	~2	~25
Oman	~20	~130
Tunisia	~38	~30

Regional content of mercury in crude oil and natural gas as an indicator

If a precise analysis has not been carried out, regional averages of mercury concentration are necessary to understand mercury emissions and releases to the environment in a location (region or country) where crude oil and natural gas is going to be processed or used and the origin of the crude oil is known.

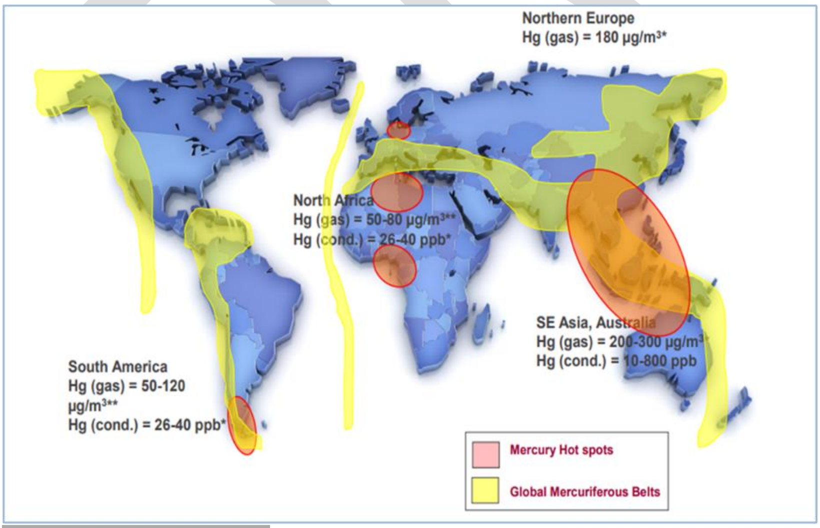
It is important to consider that in general when crude oil is imported it may be a mixture from different sources of a certain region.

To understand and make decisions on the mercury impact during the extraction processes at the local level, the regional averages are not good indicators due to the wide differences (maximum and minimum) of mercury content between deposits.

For example, even the highest level historically found in crude oil globally (higher than 10,000 ppb)[40] belongs to a deposit located in California, the North American crude oil is considered the second lowest regional average level of mercury after the Middle East, as shown in fig. 1 where there are hotspots in regions with low average regions.

In the case of natural gas, rather than regional averages, it appears more significant to consider mercury concentrations in the pipelines and deposits of origin, since natural gas is mostly commercialized inside or between neighboring regions (although this **situation is currently changing).**

Figure 1: *Mercuriferous belts and hotspots map*[41]



REDESIGN IN PROCESS

[40] S.M. Wilhelm, N. Bloom. Mercury in petroleum. Fuel Processing Technology 63, 2000.

[41] A. Chalkidis et al. Mercury in natural gas streams: A review of materials and processes for abatement and remediation, Centre for Advanced Materials & Industrial Chemistry (CAMIC), School of Science, RMIT University, GPO Box 2476, Melbourne, VIC, 3001, Australia, ᵇ. CSIRO Energy, Private Bag 10 Clayton South, VIC, 3169, Australia. 2019.

4. MASS OF MERCURY POTENTIALLY RELEASED FROM CRUDE OIL

Mercury may be found and released at different stages of the crude oil value chain, including extraction, transport, processing, and products.

Extraction

Crude oil production (extraction) systems provide limited opportunities for the loss of mercury from produced fluids, which are typically mixtures of hydrocarbon liquids, natural gas and produced water.[42] Most of the production systems separate the produced water *in situ* from the crude oil that will be transported to processing facilities.[43]

The produced wastewater obtained in this step may contain mercury, among other toxic substances, and must be managed, handled, transported and disposed of in an environmentally sound manner. There is a wide range of techniques designed to manage produced wastewater, some of which may generate hazardous sludge or solid waste with high concentrations of mercury (mercury containing waste).[44] According to a preliminary assessment by IPIECA, in 2016 13.5 t/y of mercury are released to the environment globally from produced water, about 90% of these occurring offshore.[45]

Flaring operations are very common throughout exploration and production of hydrocarbons, these operations may be carried out due to several reasons:[46]

- Initial exploration and well testing. During these activities, all of the produced oil and gas is sent to flare. This can last anywhere from a few hours to several weeks.
- During production, when it is not economically viable to export the gas.
- Operation interruptions. When gas cannot be sent to sales pipelines or into a national grid-based network. This may occur when there is no infrastructure in the region to accept the gas, or the infrastructure is under maintenance.
- Low pressure flares. During production, off-gases being sent to flare and a flare is continually kept running.
- In most cases, mercury has not been removed from gas before flaring, so that, all mercury present in the gas is emitted to the air. Regional or global estimations of mercury emissions from gas flaring have not been published yet. However, these emissions are significant and should not be overlooked.

Transport

There is a risk of accumulation of sludges with high mercury concentration in crude oil storage tanks. Crude oil is most commonly transported by oil tankers. These ships may remain active for many decades, and during those years, sludge with a high mercury concentration can accumulate at the bottom of their storage tanks.

This sludge may become an important issue during the dismantling of tankers at the end of their service life, in particular if this activity is taking place in countries that do not have the required installations for the sound management of such hazardous waste.

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[42] Produce water, definition: naturally occurring water that comes out of the ground along with oil and gas.
[43] Oil - global production 1998-2019. Published by M. Garside, Sep 30, 2020
https://www.statista.com/statistics/265203/global-oil-production-since-in-barrels-per-day/
[44] OSPAR. Background Document concerning Techniques for the Management of Produced Water from Offshore Installations. 2013.
[45] AMAP/UN Environment, 2019. Technical Background Report
for the Global Mercury Assessment 2018.
[46] Qa3. Unconsidered Mercury Emissions from the Oil and Gas Industry. Published online 2021.

In addition, in the case of spillage accidents these sludges can be an important risk of acute toxic exposure at local level due the subsequent emissions of mercury.47

Processing

Once the crude oil is extracted, it is transported to processing facilities where it is distilled to obtain fractions of different hydrocarbons, or cuts. These cuts can be chemically modified or blended to obtain commercial products.

As mentioned previously, crude oil may contain mercury, so it is relevant to know the fate of this mercury once it enters the refining process. This varies according to the design of the facility, the nature of the input crude oil, the methodology followed by the operators, the commercial needs, the environmental regulations of the country and other factors.

However, a number of common mercury out-streams can be identified, as illustrated in figure 2 below.

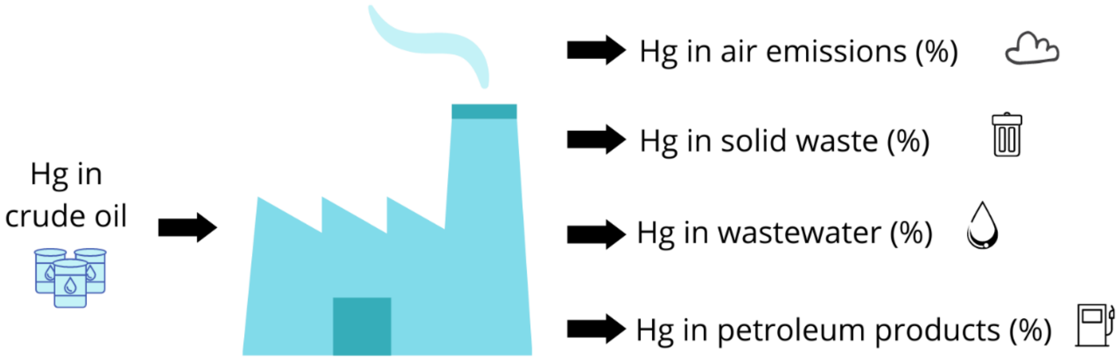

Figure 2: *Mercury in refineries mass balance*

All the out-streams of a crude oil processing facility can contain mercury in different concentrations:

- ***Mercury in wastewater***

Water is used in certain operations during the refining process, such as desalting, in steam stripping and alkylation. A typical refinery generates approximately 40–60 liters of wastewater for every barrel of oil produced. [48]

The desalination process takes place before the distillation. During this process, the crude oil and condensates are washed with water to remove undesired constituents, especially soluble salts. Elemental mercury and organic mercury are not soluble in water and remain dissolved in the crude oil.

However, other inorganic mercury species are soluble in water and are extracted from the crude oil, as well as mercury in suspension.

The US Environmental Protection Agency analyzed the total mercury in desalter sludge from four US refineries (1996) obtaining concentrations of 0.01, 4, 39 and 41 ppm.[49]

In 2019, a study calculated the mass balance of mercury on two Korean oil refineries, that did not have mercury removal systems installed, finding that 4.5% and 33.2% of the mercury that

[47] S. K. Pandey, K-H. Kim, U.-H. Yim, M-C. Jung, C-H. Kang. Journal of Hazardous Materials. 2009, 164, 380–384
[48] Wilhelm et al., Mercury in crude oil processed in the United States, 2004.
[49] Wilhelm et al., Mercury in crude oil processed in the United States, 2004.

entered these refineries ended up in the sludge out stream, whilst 3.1% and 5.6% left the facility in the wastewater effluent out stream.[50]

According to the UNEP Global Mercury Assessment 2018, 0.1% (0.56 tonnes) of the total mercury released to aquatic systems came from crude oil refining.[51]

- ***Mercury in solid waste***

Removal of mercury from black crude oil is a process with many technical difficulties and is not carried out by many companies. Where this is carried out, a chemical is added to react with elemental and/or ionic mercury and precipitate the mercury as a solid, which is then removed by centrifugation/filtration. For oils, where the predominant form of mercury is mercury sulfide (solid), centrifugation/filtration alone may be an option for reducing the mercury content. This process generates mercury-containing solid waste.[52]

Furthermore, Mercury Removal Units (MRUs) may be used in crude oil refineries to remove elemental mercury from volatile fractions. Most of these MRUs capture mercury through chemical adsorption using sulfur or other chemicals that tend to bond to mercury.

The saturated adsorbent generates solid waste with high mercury concentrations that must be disposed of correctly.

In addition, refineries may use filters or other techniques to remove mercury and other trace contaminants from water and sludge to ensure that wastewater meets environmental standards prior to discharge or disposal.

In these cases, filters saturated with mercury or filter cake with elevated mercury concentrations also generate hazardous solid waste that contains high mercury concentrations. [53]

- ***Mercury in air emissions***

There is evidence of higher concentrations of atmospheric mercury in oil refineries and their surroundings.[54]

The study published by A.H.M. Mojammal (Atmospheric Pollution Research. 2019) calculated a mass balance of mercury on two crude oil refineries and found that 4.3% and 9.8% of the mercury that entered into these refineries was emitted to the atmosphere.[38]

According to the UNEP Global Mercury Assessment (2018), crude oil refining represented, in 2015, the 0.65% (14.4 tonnes) of the total emissions of mercury to the atmosphere.[33]

- ***Mercury in petroleum products***

Elemental mercury is a volatile compound, so it is expected to be found in the volatile fractions of the distillation.

However, inorganic mercury (that has not been removed during desalting or transformed to volatile mercury species during distillation) is expected to be found in the petroleum coke.

The previously mentioned study on two crude oil refineries in Korea (A.H.M. Mojamma, *Atmospheric Pollution Research.* 2019) calculated a mass balance of mercury and found that 42.6% and 39.5% of the mercury that entered into these refineries ended up in the products.[16] It should be remarked that these refineries did not have MRU installed.

A summary of mercury content in various oil products can be found in table 6.

[50] A.H.M. Mojammal, S-K. Back, Y-C. Seo, J-H. Kim, Atmospheric Pollution Research. 2019, 10 (1), 145 - 151
[51] AMAP/UN Environment, 2019. Technical Background Report
for the Global Mercury Assessment 2018.
https://www.unenvironment.org/resources/publication/global-mercury-assessment-2018
[52] Qa3. Unconsidered Mercury Emissions from the Oil and Gas Industry. Published online 2021.
[53] Wilhelm et al., Mercury in crude oil processed in the United States, 2004.
[54] X. Lan, R. Talbot, P. Laine, A. Torres, B. Lefer, and J. Flynn. Environ. Sci. Technol. 2015, 49, 10692−10700

A study performed in South Korea, in 2007, suggests that mercury present in gasoline and diesel is emitted into the air by motor vehicles.[55]

According to the 2018 UNEP Global Mercury Assessment, domestic combustion of oil (houses and transport) represented 0.12% (2.7 tonnes) of total emissions of mercury to air in 2015, the industrial combustion 0.06% (1.4 tonnes) and the combustion in power plants 0.11% (2.45 tonnes).[56]

Table 6: *Summary of total mercury in refining products, expressed in mass ppb*[57]

Reference	Type	Number of samples	Range (ppb)	Mean (ppb)	SD
Liang *et al.* (1996)	Gasoline	5	0.22-1.43	0.7	NR
Liang *et al.* (1996)	Gasoline	4	0.72-3.2	1.5	NR
Liang *et al.* (1996)	Diesel	1	0.4	0.4	NR
Liang *et al.* (1996)	Diesel	1	2.97	2.97	NR
Liang *et al.* (1996)	Kerosene	1	0.04	0.04	NR
Liang *et al.* (1996)	Heating Oil	1	0.59	0.59	NR
Bloom (2000)	Light distillates	14	NR	1.32	2.81
Bloom (2000)	Utility fuel	32	NR	0.67	0.96
Bloom (2000)	Asphalt	10	NR	0.27	0.32
Olsen *et al.* (1997)	Naphtha	4	3-40	15	NR
Tao *et al.* (1998)	Naphtha	3	8-60	40	NR
US EPA (2000)	Coke	1000	0-250	50	NR

- ***Mercury mass balance in crude oil distilleries***

The following Figure 3, from a IPIECA 2014 report, provides a simplified example of where diverse forms of mercury may distribute or accumulate in a crude refinery.

[55] J. H. Won, J. Y. Park, T. G. Lee. Atmospheric Environment, 2007, 41, 7547–7552.
[56] AMAP/UN Environment, 2019. Technical Background Report for the Global Mercury Assessment 2018. https://www.unenvironment.org/resources/publication/global-mercury-assessment-2018bn
[57] Wilhelm et al., Mercury in crude oil processed in the United States, 2004.

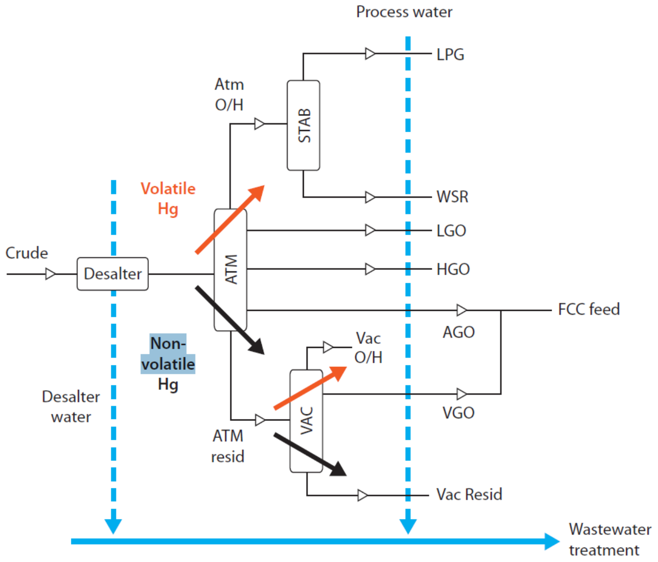

Figure 3: *The most common mercury distribution paths in hydrocarbons and water (IPIECA).* [6]

The mass balance of mercury provides information on the different fates of mercury during the distillation process, considering the concentration of mercury in the crude oil entering the refining process, the presence of mercury in the final products, the mercury waste and mercury containing waste.

Due to the chemical properties of mercury present in crude oil, like its volatile nature and tendency to damage aluminum-based equipment and form amalgams, some refineries have reported troubles[58] in closing a mercury mass balance, obtaining uncertainties of at least 30% (in other words, more than 30% of the mercury that entered the plant has an unknown fate).

Among others, one of the possible explanations for these high levels of uncertainty may be the accumulation in equipment and pipes due to adsorption processes or amalgam formation.[59] Other reasons for a poor mass balance may include different designs of sample points across the refinery, some of which may not afford representative samples and multiple sample points cannot usually be sampled simultaneously; thus, mass balance evaluations across a refinery usually take place over several days during which the crude feeding the refinery may change which can directly affect the mercury measured.[60]

In any oil refinery, the output of mercury (air, water, waste, and products) should be equal to the input. Otherwise, it is being accumulated in the systems of the installation and could cause accidents as explained in previous sections.

An estimation of the annual accumulation of mercury in refineries can be found in table 7.

Table 7: *Comparison of annual mercury accumulation for each range of concentration*[61]

Potential annual accumulation			
Mercury in crude (ppb)	1	10	200
50,000 bbls/day – "small refinery"	0.5 kg/year	5 kg/year	90 kg/year
250,000 bbls/day – "large refinery"	2.5 kg/year	25 kg/year	450 kg/year

[58] Fabian G. Lombardi, Axion Energy S.A., Procesamiento de crudos con mercurio, Petrotecnia.5, 2018.
[59] Fabian G. Lombardi, Axion Energy S.A., Procesamiento de crudos con mercurio, Petrotecnia.5, 2018.
[60] Qa3 during document consultation. May 2021.
[61] Mercury management in petroleum refining, An IPIECA Good Practice Guide, 2014.

According to the publication, the accumulation estimate is based on the assumption that 20% of the mercury in the incoming crude accumulates in the process equipment or associated wastes. In addition, plants need to consider that units have been in place for many years, and may have pre-existing accumulation of mercury.

The internal surface of pipelines and process equipment in oil processing facilities are populated with active sites to which mercury may be adsorbed. The pipelines may accumulate mercury on their inner surface over the active lifetime of the plant. Upon decommissioning, if the presence of mercury is not taken into account, the regimens employed to discard old pipes and process equipment, such as heating and cutting of the metal into smaller manageable sections or smelting of the steel back into a recycled reusable form, could inadvertently release mercury into the environment.[62]

[62]Qa3. Unconsidered Mercury Emissions from the Oil and Gas Industry. ANNUAL BUYERS GUIDE 2016.

5. MASS OF MERCURY POTENTIALLY RELEASED FROM NATURAL GAS

Extraction

The extraction of natural gas by hydraulic fracture (fracking) presents a particular risk of mercury release into the environment due to the production of "flowback" water.

To facilitate the fracture of the shale and the release of natural gas, water with a low pH is injected into the ground. This acidic water facilitates the dissolution of salts that were previously trapped in the shale, including heavy metal salts.

During the extraction of natural gas, part of the injected water is also extracted, which is then called "flowback" water.[63] There is evidence in the literature that "flowback" water is rich in heavy metals and, in some cases, mercury,[64] [65] [66] [67] which may be released to the surrounding environment.

Flowback water storage tanks may not incorporate sufficient safeguards to ensure this water cannot get in contact with surface water. Although there are not many publications about mercury levels in the surroundings (surface water, soil and biota) of production sites, one study that analyzed samples from Pennsylvania found higher concentrations of mercury in water and biota close to extraction sites by fracking and suggests they could be related to the natural gas extraction.[68]

Transport

Natural gas is mostly transported by pipelines. Usually when transporting crude oil, mercury is not lost during the movement of fluid, but in the case of natural gas, elemental mercury can adsorb into the steel surface structure and react with iron sulphide to form a mercury-rich layer of mercury sulphide on the internal surfaces of pipelines.[69]

This effect increases with natural gas humidity, and also with the presence of H_2S that reacts to form an iron sulphide layer.

When natural gas is transported through long distances, an appreciable decrease in mercury concentration can be observed. The EPA 2001 report mentions the following example: "natural gas produced offshore that contains low mercury concentration (1-20 ppb) when measured at the wellhead, may not present any mercury at the processing facility initially".

The accumulation of a mercury-rich scale during transport contaminates the equipment, and may represent a risk for workers during maintenance and decommissioning activities.These activities produce significant amounts of mercury waste and mercury containing waste that must be managed in an environmentally sound manner.

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[63] C. J. Grant, A. K. Lutz, A D. Kulig and M. R. Stanton. Ecotoxicology. 2016. 25, 1739–1750.
[64] S. J. Maguire-Boylea and A. R. Barron. Environ. Sci.: Processes Impacts, 2014, 16,. 2237–2248
[65] Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe. AEA/R/ED57281 Issue Number 11 Date 28/05/2012.
[66] Leff, E. Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program, Well Permit Issuance for Horizontal Drilling and High-Volume, Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs. New York State Department of Environmental Conservation: New York, NY, 2011.
[67] N. Abualfaraj, P. L. Gurian, and M. S. Olson. Environmental Engineering Science. 2014. 31 (9).
[68] C. J. Grant, A. B. Weimer, N. K. Marks, E. S. Perow, J. M. Oster, K. M. Brubaker, R. V. Trexler, C. M. Solomo 5 and R. Lamendella. Journal of Environmental Science and Health, Part A. 2015. 50, 482–500.
[69] Wilhelm et al., Mercury in crude oil processed in the United States, 2004.

Figure 4: *Example of solid waste accumulated on the inner surface of a mismanaged pipeline* Image provided by Qa3.

Processing

Natural gas processing is typically not as complex as crude oil refining and could be defined more accurately as a treatment and separation process, since chemical transformations are not expected to happen. The treatments are designed to remove unwanted impurities like water, carbon dioxide, hydrogen sulphide, and metals.

When it is needed, H_2S and CO_2 removal are carried out with an amine absorption, this process can capture some mercury present in the gas.

Then, the dehydration of the gas is carried out. The gas passes through an adsorbent material, usually dry triethylene glycol that captures the water. After that, the adsorbent is regenerated in a continuous process by increasing the temperature and evaporating the water.

Triethylene glycol, and other dehydration systems, can capture elemental mercury present in the natural gas, which is later evaporated during the regeneration process and may be emitted into the atmosphere, if flue gas is not treated, or re-dissolved in the wastewater of the facility.

Other cleaning processes like CO_2 (when membrane technologies are used) or N_2 removals can also retain mercury in membranes and columns that can eventually be liberated to the atmosphere (case study 2).[70] If it is necessary, an MRU is used before these processes to protect the equipment.

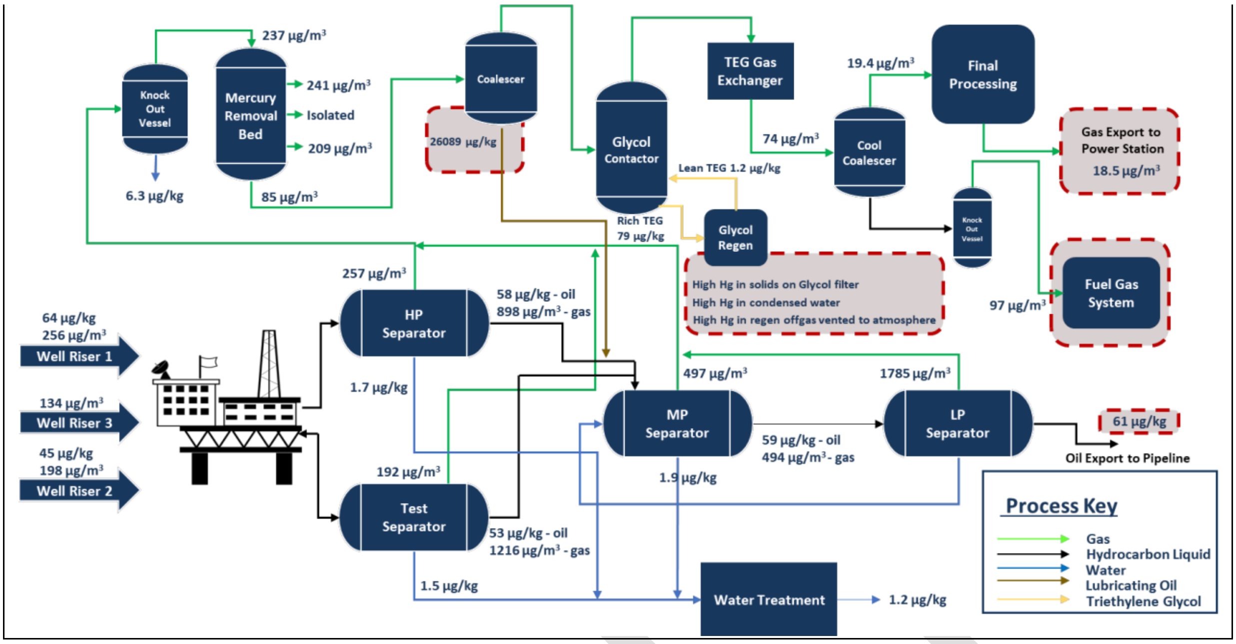
Case study 2 by Qa3[71]:

Region: South East Asia.

Type of Facility: Offshore production of oil and gas where MRU is located upstream in process.

Mercury Issues: Although this facility has the mercury removal located upstream in the process the MRB has become saturated allowing mercury to pass resulting in mercury contamination throughout the entire process leading to emissions from flaring, combustion of fuel gas and in export gas.

[70] Qa3 Unconsidered Mercury Emissions from the Oil and Gas Industry. ANNUAL BUYERS GUIDE 2016.
[71] Qa3. Unconsidered Mercury Emissions from the Oil and Gas Industry. Published online 2021.



The separation process for natural gas liquids typically takes place using cryogenic techniques, which have an inherent risk of condensing elemental mercury in the systems if the concentration of mercury is sufficiently high.[72]

Such condensation occurs in gas separation plants that have a content of mercury in feeds higher than 10–20 µg/m³.

Mercury can also react with the aluminum (liquid metal embrittlement and amalgam corrosion) present in some heat exchanger systems, altering the properties of the material.

Liquefied natural gas (LNG) plants and many natural gas separation plants may encounter problems associated with mercury condensation and reduce mercury attack of aluminum, both of which may cause serious accidents (see figure 5).[73]

They then use removal techniques, described in chapter 7.

The out-stream gas that leaves the MRUs usually has a mercury content of less than 1 µg/m³.[74] The saturated adsorbent material of the MRUs is a source of solid waste with a high mercury concentration, which must be disposed of correctly.

Figure 5: *Metallurgical failure caused by mercury in a gas processing facility (IPIECA).*

The risk of atmospheric emissions during gas processing is also present. For example, a study showed that the atmospheric mercury concentration in the surroundings of a natural gas

[72] Qa3. Unconsidered Mercury Emissions from the Oil and Gas Industry. Published online 2021.
[73] Wilhelm et al., Mercury in crude oil processed in the United States, 2004.
[74] SPE International. Mercury monitoring and removal at gas processing facilities. 2007.

processing facility in Egypt is higher than average with a maximum value of 212 ng/Sm^3 in the condensate tank area.[75]

Products

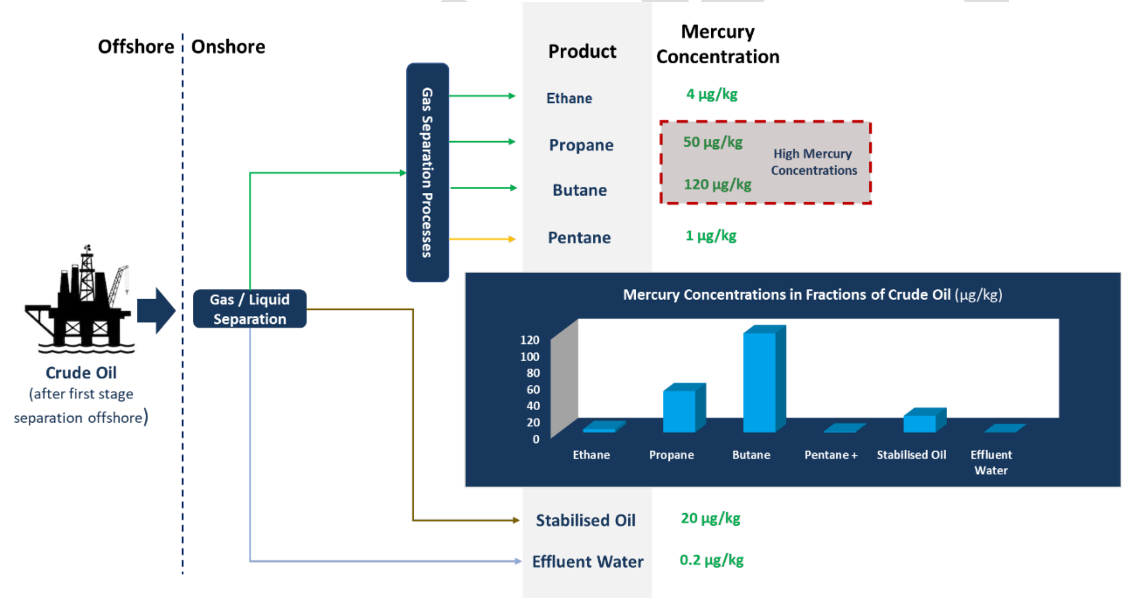
Mercury can be present in the final products derived from natural gas, as shown in the case study 3. According to the 2018 UNEP Global Mercury Assessment, the combustion of natural gas in houses and transport represented, in 2015, 0.01% (0.16 tonnes) of total emissions of mercury, industry represented 0.01% (0.16 tonnes) and power plants 0.02% (0.33 tonnes).[76]

Case study 3 by Qa3[77]:

Region: Europe

Type of Facility: Gas Separations and Fractionation Plant (methane already removed by upstream processing, remaining gas removed from oil and separated into individual products; ethane, propane, butane, pentane).

Mercury Issues: This case study demonstrates the partitioning of mercury into the LPG fraction during fractionation of gas.



[75] A.A. El-Fekya, W. El-Azaba, M.A. Ebiada, M. B. Masoda, and S. Faramawya. Journal of Natural Gas Science and Engineering. 2018. 54. 189–201

[76] UNEP. Global Mercury Assessment. 2018. https://www.unenvironment.org/resources/publication/global-mercury-assessment-2018

[77] Qa3, Mercury in the Oil and Gas Industry. Document for the UNEP Global Mercury Partnership, Sheet Reference: INF15

6. TECHNIQUES USED TO REMOVE MERCURY FROM CRUDE OIL AND NATURAL GAS

Presence of mercury in crude oil and natural gas in processing plants

As mentioned above, mercury exists in varying concentrations in natural gas and crude oils extracted from different basins in all regions around the world.

Even though mercury is present in crude oil and natural gas in trace concentrations, due to its reactivity and ability to form amalgams with some other metals, it may accumulate in process equipment (especially on internal metal surfaces).

The accumulation may cause catalyst poisoning (reducing the efficiency of some processes), corrosion and embrittlement of equipment. The latter of these may lead to industrial accidents. As a result of the accumulation of mercury over time, old equipment may become mercury containing waste streams that require adequate end of life treatment.[78]

Due to its volatile nature, elemental mercury tends to concentrate in light fractions like liquefied petroleum gas (LPG, see case study 4) and naphtha, but it also reacts with some hydrocarbon's compounds, like asphaltenes and can appear in heavier refinery cuts or fractions.

The process of producing and refining oil and gas subjects the fluids to many varying conditions, including temperature, pressure and contact with other chemicals. This results in a distribution of the mercury according to the reaction and partitioning properties of the mercury species present into the final products and waste streams produced.

The contamination of the equipment and the mercury containing remaining residues constitutes a risk for gas plant and refinery workers, in particular during a plant shutdown or maintenance procedure.

Mercury removal from crude oil

Although removal of mercury from black crude oil is not straightforward and is not carried out by many companies, mercury is sometimes monitored in crude oil when entering refineries plants. As a general rule, according to IPIECA's Good Practices Guidelines: [79]

- "The mercury content of incoming crudes to refinery will be less than 10 ppb, on a month-average basis, and no individual crude should exceed 100 ppb" in other case it is treated when it enters the refinery.

These good practice levels are significantly below the average and maximum levels of mercury content found in crude oil from certain regions, in particular for Asia and South America (see section 4), hence calling for mercury removal from such crude oils before refining.

In accordance with IPIECA, mercury removal technologies can be applied in refineries. However, they are most applicable to refinery products and effluents; there is only one proven technology for the removal of mercury directly from crude oil and condensates. This technology is in use by one IPIECA member in southern Argentina.[80]

It is not an easy process to remove mercury from crude oil and there are very few facilities operating this technology. During the refining process mercury partitions into the light fractions (predominantly the LPG) and on some refineries the mercury in the LPG is removed from crude

[78]Qa3. Unconsidered Mercury Emissions from the Oil and Gas Industry. Published online 2021.
[79] Mercury management in petroleum refining, An IPIECA Good Practice Guide, 2014.
[80] Mercury management in petroleum refining, An IPIECA Good Practice Guide, 2014.

oil entering a refining plant with gas phase "mercury removal units" (MRU, described in the next section).

Mercury removal from natural gas and LPG

As mentioned in chapter 5 processes for natural gas production are often simpler than for crude oil as it only involves a separation of the raw material into commercial products: gas and natural gas liquids' (NGLs). It can be sold as gas (transported in pipelines) or liquefied (LPG) for sea shipping.

The process can be summarized in the following steps:

1. Prior to entering the gas plant, the gas is treated to remove water using triethyleneglycol (TEG) or adsorbents.
2. The gas is cleaned through acid gas scrubbers (before water removal when H_2S is captured with amines, or after when CO_2 is captured with membranes.
3. A mercury removal process may be included, in which case it will be deployed upstream of the cryogenic distillation stage.
4. Cryogenic distillation involves cooling the gas in an aluminum heat exchanger. The gas is then progressively heated through a number of heat exchangers, allowing the individual products to be boiled off and separated in towers.
5. The liquid product streams (condensate) are sent to petrochemical manufacturers or sold as LPG, while the gaseous product streams are sold to users as sales gas.

It was observed that solutions used for moisture and acid gas removal have affinity for mercury (see case study 2), allowing for the mercury to be removed from the gas during these processes.

There are amine-based systems usually used to remove acid gases from the gas mainstream. Mercury absorption into the amine system may occur, and this mercury can be emitted to the environment during amine regeneration and end up in the carbon dioxide vent stream where applicable, in the recovered sulphur or in solids captured by filters.

The mercury removal process must be deployed upstream of the cryogenic distillation because mercury may deposit in the cryogenic equipment, causing embrittment of aluminum heat exchangers. This may increase the risk of a catastrophic failure.

This process is carried out by a mercury removal unit or MRU, that consists of beds typically filled with adsorbents. The most commonly used adsorbents used to remove mercury from natural gas and LPG are based on metal sulphides or sulphur impregnated carbon.

Once these adsorbents are exhausted (saturated with mercury) or contain high concentrations of mercury they must be removed, transported, treated and disposed of as hazardous waste by a specialized and authorized treater.

Adsorbents may need to be exchanged "earlier" in cases where: [81]

- there is a mercury breakthrough.
- pressure drop is increased by liquid carryover or hydrocarbon condensation inside the beds.
- the adsorbent is fouled by free water and causes either a loss of adsorption capacity or plugging of the column making a change out necessary before the full adsorption capacity can be achieved.
- the adsorbent material is changed during a vessel inspection.

When CO_2 removal is required, a membrane technology may be employed. This technology would also remove mercury from the gas. This mercury may be emitted to the atmosphere as part of a

[81] Information provided by BATREC and IPIECA during consultation.

continuous removal process and also when the membrane material is changed and replaced during maintenance

There are also some processes that remove mercury from crude oil and natural gas within refineries. Many refineries have removal technologies to strip out undesirable chemical components that may reduce the overall calorific value of the fuel, like CO_2 and/or H_2.

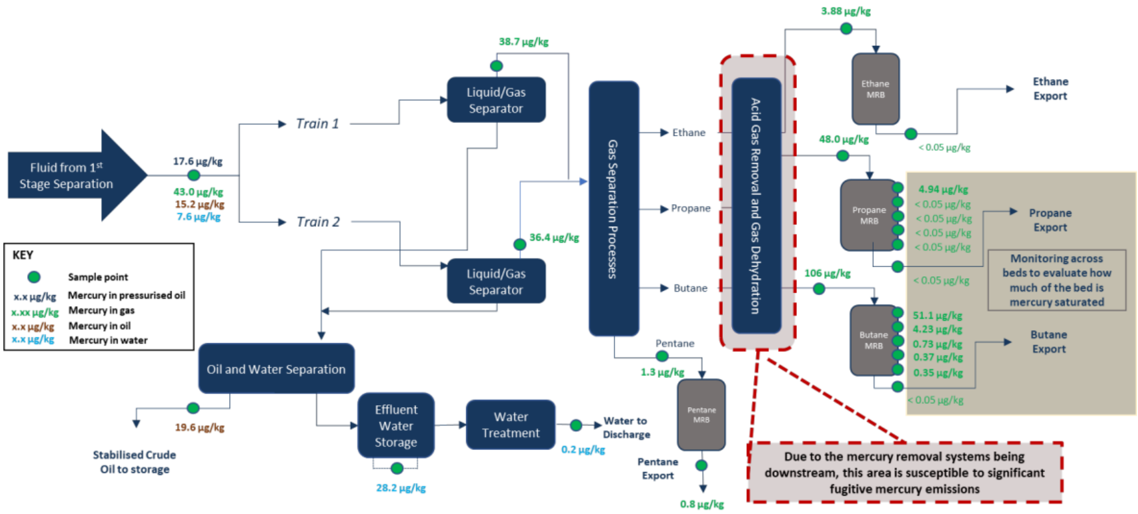
More recently, with the development of mercury removal media that is more tolerant to the presence of water, many companies are choosing to place mercury removal beds upstream in the process ahead of acid gas removal and dehydration.[82] This could avoid generating mercury containing waste streams during moisture and acid gas removal (case study 4).

Case study 4 by Qa3[83]:

Region: Europe.

Type of Facility: Gas Separation and Fractionation Plant (methane already removed by upstream processing, remaining gas removed from oil and separated into individual products; ethane, propane, butane, pentane).

Mercury Issues: This case study shows a process with downstream MRB's and highlights the area in the process where there are often unconsidered emissions.



The disposal of the mercury collected by a mercury removal system (mercury waste) varies depending on the type of system used. As previously mentioned, the most commonly used MRU media are based on metal sulphides on inert support material (e.g., alumina), or sulphur impregnated carbon, these can be regarded as "non regenerative sorbents".. The spent adsorbent, depending on local regulations, may be classified as hazardous waste, which must be treated in an environmentally sound manner.

D. Lang in his publication "Mercury arising from oil and gas production in the UK and UK continental shelf", 2012, indicates that this waste is *"stored or combusted to release the mercury. If the waste is combusted then mercury must be condensed, captured and disposed of".*

Regenerative mercury adsorbents that utilize the high affinity of mercury for precious metals such as gold and silver are less used. The unit is regenerated by hot regeneration gas typically at temperatures around 290°C, with the cycle being repeated on a preset timeline depending on

[82] Qa3. Unconsidered Mercury Emissions from the Oil and Gas Industry. Published online 2021.
[83] Qa3. Unconsidered Mercury Emissions from the Oil and Gas Industry. Published online 2021.

capacities. The mercury is removed from the main process stream and is concentrated in the regeneration stream. This stream requires the mercury to be removed, which is typically achieved with a smaller non-regenerative MRU that may eventually need an appropriate treatment of the adsorbent.

7. FATE OF MERCURY GENERATED FROM OIL AND GAS ACTIVITIES

The oil and gas sector mobilize, emits and releases mercury at different stages of its activity. The international policy/legal framework that deals with and establishes measures for this “anthropogenic” mercury is the Minamata Convention, which was adopted in 2013 and entered into force in 2017. The Minamata Convention contains provisions that relate to the entire life cycle of mercury and addresses issues of mercury supply, trade, uses, emissions, releases, storage and disposal, providing the framework for countries to take coordinated actions to reduce the concentration of this toxic metal in the environment. Below is a brief description of some provisions of the Minamata convention that could be of potential relevance to mercury generated from the oil and gas sector.

Based on in house data generated from a number of studies and the total mass of mercury in natural gas and LPG for each region (Statistical Review of World Energy 2020, 69th edition), Qa3 have estimated that approximately 300 tonnes of mercury were produced as a byproduct by the oil and gas sector in 2020.[84]

For instance, under Article 3 on Mercury supply sources and trade, paragraph 5, each Party shall endeavour to identify, amongst others, the sources of mercury supply that generate stocks exceeding 10 metric tonnes per year that are located within its territory. This provision could potentially involve the oil and gas sector. Information that may be provided by Parties in the context of this provision could contribute to further enhancing the global knowledge on mercury generated by the sector.

While article 8 on “Emissions” establishes measures to control and where feasible reduce mercury emissions to the atmosphere from the point sources falling within the source categories listed in Annex D (which does not include the oil and gas sector), Article 9 on “Releases” focuses on measures to reduce mercury emissions to water and soil from the relevant point sources not addressed in other provisions of this Convention.

Article 11 of the Minamata Convention, which addresses "Mercury waste", calls for collaboration with the Basel Convention: in its paragraph 2 on the definition of relevant thresholds and in its paragraph 3 on measures to be adopted for the environmentally sound management of mercury waste, considering the guidelines developed under the Basel Convention[85] (last guidelines adopted in 2015 and currently under review).

Mercury in aqueous waste

The mercury present in wastewater is mostly in suspension (as insoluble mercury sulphide) or associated to suspended particles.

Refineries use conventional wastewater treatments that can capture this mercury. Refineries that run elevated mercury crudes may generate solid waste with a high mercury concentration that requires sound disposal.[6] Reinjection is a common disposal option for oil and gas liquid waste streams and some solid waste streams (including sludge) in several regions.

A review published in 2019 provides an overview of methods used in the treatment and disposal of petroleum sludges from waste water treatment, amongst which incineration,

[84] Qa3, Unconsidered Mercury Emissions from the Oil and Gas Industry. 2020. https://www.qa3.co.uk/images/pdfs/Unconsidered_Mercury_Emissions_from_the_Oil_and_Gas_Industry_July_2021.pdf

[85] The Conference of the Parties to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal adopted at its twelfth meeting the “Technical guidelines for the environmentally sound management of wastes consisting of elemental mercury and wastes containing or contaminated with mercury” (Decision BC-12/4), which it decided at its fourteenth meeting to update (Decision BC-14/8)

stabilization/solidification, oxidation and biological treatment are included.[86] None of the techniques mentioned in this publication addresses the presence of mercury in the sludge nor the prevention of its release to the environment. The practices mentioned in the document are not the best available techniques for the treatment of mercury-containing waste.

Mercury in solid waste

Mercury Removal Units (MRUs) - used to capture mercury from natural gas or certain fractions in crude oil refineries - are based on adsorbent materials that are saturated with mercury after some months or years of use.

Some MRUs are designed to last for the whole life cycle of the processing plant, while for others there is a need to replace the adsorbent material every few months or years. The adsorbent material contains 1–15% mercury by weight at the time is replaced. Such waste contaminated with mercury, according to the Technical Guidelines on the Environmentally Sound Management of Waste Consisting of, Containing or Contaminated with Mercury or Mercury Compounds of the Basel Convention (Table 3) requires environmentally sound treatment and disposal.[87]

There is very little information available in scientific databases and reports from the industry about the fate of the solid waste with a high mercury content, which comprises saturated wastewater filters, sludge from maintenance and cleaning operations and saturated adsorbent from MRUs.

This hazardous waste should be managed by specialized and certified operators as indicated by IPIECA in its guideline (Mercury management in petroleum refining). Providers of MRUs and adsorbent materials may also offer a service which includes the sound disposal of the adsorbent material at the end of their useful life as hazardous waste. [88]

The “Catalogue of Technologies and Services on Mercury Waste Management” developed by the UNEP Global Mercury Partnership Area on Mercury Waste Management lists some of these waste management operators that treat waste from the oil and gas sector and are members of the Partnership[89].

The Swiss company BATREC indicated (interview organized during the development of this report) that in their facility, 1,000 to 2,000 tonnes/year of material can be treated per furnace (3 furnaces in operation) originating from gas processing facilities, mostly as saturated adsorbent from MRU, and that they typically receive approximately 500 tonnes of material per year[90]. In the process developed by the company, mercury recovered from the treatment of the solid waste is stabilized as mercury sulphide and sent to salt mines for final storage.

In order for mercury from oil and gas extraction and processing to enter the formal or informal market, it should first be extracted from solid waste. As it has been discussed previously, a large fraction of the mercury mobilized is captured by MRUs and other techniques generating mercury-containing solid waste. Unfortunately, it is not possible to provide an accurate estimate for the quantities of mercury captured by the oil and gas sector. Consequently, it is difficult to assess how much of this mercury may be entering the market after being captured, if any, as facilities that treat waste from oil and gas also treat mercury waste from other sources.

According to BATREC, only a fraction of mercury containing solid waste is treated in specialized facilities. In addition, the complexity of the process and the required (expensive) equipment

[86] O. A. Johnson, and A. C. Affam. Environ. Eng. Res. 2019, 24(2), 191-201.
[87] Technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with mercury or mercury compounds. UNEP/CHW.12/5/Add.8/Rev.1
[88] Johnson Matthey. Handling mercury in gas processing plants. 2017
[89] https://wedocs.unep.org/bitstream/handle/20.500.11822/27819/WMA_catalog.pdf?sequence=1&isAllowed=y
[90] The treatment consists in the roasting / thermal treatment (700 - 850 °C) of the material with the aim of vaporizing the mercury contamination and obtaining elemental mercury in a subsequent condensation step. The recovered mercury is then stabilized to form mercury sulphide, which is subsequently packed for transport and permanent storage in salt mines in Germany.

makes it difficult to address such waste locally. However, Econ industries reported their experience with an on-site mercury waste treatment technology in Australia.

Mercury in oil and gas products

Unlike for the products used by chemical and pharmaceutical companies, there is less incentive to remove mercury from oil and gas products that will be used for combustion, as this use can tolerate higher levels of trace contaminants.

The mercury present in the different fuels will be released to the atmosphere as elemental mercury after its combustion in vehicles and heaters.

The fact that automobiles emit mercury at ground level where people get direct exposure should be considered as an important factor.[91] [92] In 1997, the US Environmental Protection Agency estimated the amount of mercury that was emitted to the atmosphere from combustion of Distillable Fuel Oil (DFO) and Residual Fuel Oil (RFO) in domestic and industrial boilers in this country. It concluded that in that year, 11 tonnes of mercury were emitted as a result of the combustion of RFO and DFO. [93]

Table 8: *Estimation of mercury emissions by combustion of fuel*

Boiler	Btu/year (10^{17})	Fuel type	Fuel Oil Amount (10^{10} L/year)	Emission Factor (kg/10^{13} Btu)	Hg (kg/year)	THg in fuel (ppb)
Utility	840	RFO	2.4	0.24	200	10
Industrial	2,178	RFO/DFO	6.2	3.09/3.27	7,000	100
Residential	890	RFO/DFO	2.5	3.09/3.27	2,900	100
Total					**10,100**	

Other sources of mercury: Decommissioning of facilities and pipelines

The replacement of pipelines that may have accumulated mercury and the decommissioning of entire facilities and tankers generate mercury-containing waste that must be correctly disposed of, otherwise this mercury will be released to the environment. It is estimated that 20 % of mercury present in Oil and Gas is accumulated in the processing facilities.[26]

Mercury can be removed from pipelines and equipment by cleaning them (scrubbing and scrapping) at the location of the facility. This process generates sludge with high content in mercury that must be treated by specialized companies. According to Qa3, there are three end of life options for pipelines used in off-shore natural gas extraction: leaving them in situ on seabed, leaving them in situ on seabed after cleaning or sending them to smelting for recycling. [94]

[91] J. H. Won, J. Y. Park, T. G. Lee. Atmospheric Environment, 2007, 41, 7547–7552.
[92] M. S. Landis, C. W. Lewis, R. K. Stevens, G. J. Keeler, J. T. Dvonch, R. T. Tremblay. Atmospheric Environment. 2007. 41. 8711–8724.
[93] U.S. EPA, 1997. Mercury Study Report to Congress, EPA/452/R-97/003 (NTIS PB98-124738), Office of Air Quality Planning and Standards,
[94] Qa3. Unconsidered Mercury Emissions from the Oil and Gas Industry. Published online 2021.

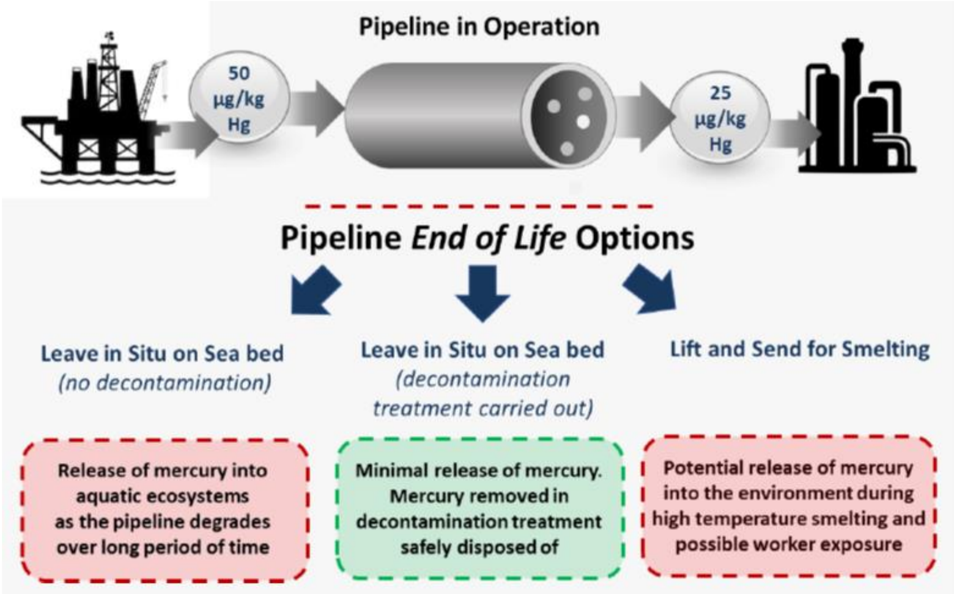


Figure 6: *Fate of pipelines used in off-shore natural gas extraction. Image provided by Qa3.*

8. INITIAL IDEAS FOR FURTHER RESEARCH AND COOPERATION

Mercury present in crude oil and natural gas, due its nature and the processes involved (during extraction, refining, transport and decommissioning of infrastructures) may be released and emitted in different proportions and stages of the industrial operations, depending on the control measures in place.

The following would contribute to better understanding and assessing mercury emissions and releases from crude oil and natural gas:

- Monitor in a systematic, standardized, comparable and multicentric way the whole process: from production to refined products.
- Complete mercury mass balances of every oil and gas process in the most accurate way.
- Promote information exchange on mercury determination and sampling methods where mercury is known to be emitted and released to the environment from gas processing plants and oil refineries.
- Facilitate the access to information on the production and fate of mercury waste and mercury containing waste flow, especially in crude oil and natural gas deposits and/or regions where mercury concentrations are known to be higher (fate of the saturated adsorbent from mercury removal systems as well as from filters, pipeline pigging activities and others).

The following would support the implementation of measures to reduce or eliminate mercury emissions and releases from the sector:

- Identify, monitor and assess mercury waste and mercury containing waste volumes generated by the sector.
- Understand and track the fate of such waste.
- Disseminate information on best available practices as well as best environmental technologies.[95]
- Improve the capacities of the concerned facilities to process mercury and mercury containing waste and safely dispose of it off.
- Strengthen human and technical capacities, and collaboration needed to facilitate the identification and evaluation of mercury emissions and releases from oil and gas all along its value chain.

It is important to highlight that there is also a need for dissemination of guidelines to support the implementation of best available technologies and best environmental practices for the removal of mercury from oil and gas at the different stages of the process.

In relation to worker's protection, while several guidelines aim to prevent chemical toxic exposure and codes of practice for the control of occupational exposure to mercury, none appear to focus specifically on workers exposure to mercury in the petrochemical industry.

From the present study, these objectives remain far from being achieved. To carry out this task in a coordinated and transparent manner, enhanced cooperation amongst relevant players would contribute to the further development and dissemination of BAT/BEP on mercury in the oil and gas industry as well as enhanced understanding of the topic.

The Global Mercury Partnership and its Partnership areas, including on “mercury air transport and fate research”, “mercury supply and storage” and “mercury waste management” may offer a multi-stakeholder and multisectoral platform for dialogue and cooperation. It may contribute

[95] Guidance on Best Available Techniques and Best Environmental Practices, Secretariat of the Minamata Convention on Mercury. September 2017
https://wedocs.unep.org/bitstream/handle/20.500.11822/33122/BAT_BEP.pdf?sequence=1&isAllowed=y

supporting an enhanced overview of mercury along the different stages of the oil and gas value chains, including its fate and transport, measurement techniques and the species of mercury found; as well as facilitating information and experience sharing on the topic of mercury from oil and gas and best practices for its environmentally sound management.

9. BIBLIOGRAPHY

1. Determination of Mercury in Crude Oil Is Covered in New ASTM Petroleum Standards: https://www.envirotech-online.com/news/environmental-laboratory/7/astm-international/determination-of-mercury-in-crude-oil-is-covered-in-new-astm-petroleum-standards/12208
2. Oil - global production 1998-2019. Published by M. Garside, Sep 30, 2020. https://www.statista.com/statistics/265203/global-oil-production-since-in-barrels-per-day/
3. Expert consultations on "Mercury from oil and gas" under the UNEP Global Mercury Partnership - Kick-off meeting (23 April 2020)- Summary of main discussion points https://wedocs.unep.org/bitstream/handle/20.500.11822/32793/GMPOiG.pdf?sequence=1&isAllowed=y
4. Maytiya Muadchim et al. Case study of occupational mercury exposure during decontamination of turnaround in refinery plant. Published online 2018 Jan 15. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6060844/
5. Fabian G. Lombardi, AXION ENERGY SA, Procesamiento de crudos con mercurio, Petrotecnia.5, 2018.
6. http://www.petrotecnia.com.ar/518/Procesamiento.pdf
7. Wilhelm et al., Mercury in crude oil processed in the United States, 2004.
8. Mercury management in petroleum refining, An IPIECA Good Practice Guide, 2014.
9. D Lang. et al., Mercury arising from oil and gas production in the United Kingdom and UK continental shelf. IMKIP Oxford. 2012.
10. Office of Air Quality Planning and Standards (EPA). Research and Development. Mercury in petroleum and natural gas: estimation of emissions from production, processing and combustion. 2001.
11. Chalkidis et al. Mercury in natural gas streams: A review of materials and processes for abatement and remediation, Centre for Advanced Materials & Industrial Chemistry (CAMIC), School of Science, RMIT University, GPO Box 2476, Melbourne, VIC, 3001, Australia, b. CSIRO Energy, Private Bag 10, Clayton South, VIC, 3169, Australia. 2019.
12. OSPAR. Background Document concerning Techniques for the Management of Produced Water from Offshore Installations. 2013.
13. Yuyun Ismawati. "Mercury from oil and gas production". Expert consultations under the UNEP Global Mercury Partnership. Kick-off webinar. 2020.
14. S. K. Pandey, K-H. Kim, U.-H. Yim, M-C. Jung, C-H. Kang. Journal of Hazardous Materials. 2009, 164, 380–384
15. A.H.M. Mojammal, S-K. Back, Y-C. Seo, J-H. Kim, Atmospheric Pollution Research. 2019, 10 (1), 145 - 151
16. UNEP. Global Mercury Assessment. 2018.
17. https://www.unenvironment.org/resources/publication/global-mercury-assessment-2018
18. IPIECA. Mercury management in petroleum refining An IPIECA Good Practice Guide. 2015.
19. X. Lan, R. Talbot, P. Laine, A. Torres, B. Lefer, and J. Flynn. Environ. Sci. Technol. 2015, 49, 10692−10700
20. J. H. Won, J. Y. Park, T. G. Lee. Atmospheric Environment, 2007
21. J. Grant, A. K. Lutz, A. D. Kulig and M. R. Stanton. Ecotoxicology. 2016.
22. S. J. Maguire-Boylea and A. R. Barron. Environ. Sci.: Processes Impacts, 2014
23. Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe. AEA/R/ED57281 Issue Number 11 Date 28/05/2012.
24. N. Abualfaraj, P. L. Gurian, and M. S. Olson. Environmental Engineering Science. 2014.
25. J. Grant, A. B. Weimer, N. K. Marks, E. S. Perow, J. M. Oster, K. M. Brubaker, R. V. Trexler, C. M. Solomon 5 and R. Lamendella. Journal of Environmental Science and Health, Part A. 2015.
26. SPE International. Mercury monitoring and removal at gas processing facilities. 2007.

27. A.A. El-Fekya, W. El-Azaba, M.A. Ebiada, M. B. Masoda, and S. Faramawya. Journal of Natural Gas Science and Engineering. 2018.
    a. A. Johnson, and A. C. Affam. Environ. Eng. Res. 2019.
28. M. S. Landis, C. W. Lewis, R. K. Stevens, G. J. Keeler, J. T. Dvonch, R. T. Tremblay. Atmospheric Environment. 2007.
29. European Commission. Best Available Techniques Guidance Document on upstream hydrocarbon exploration and production. Final Guidance Document - Contract No. 070201/2015/706065/SER/ENV.F.1
30. https://ec.europa.eu/environment/integration/energy/pdf/hydrocarbons_guidance_doc.pdf
31. Pam Boschee. Advancements in the Removal of Mercury From Crude Oil. Oil and Gas Facilities Editor. 2013.
32. Minamata Convention on Mercury: http://www.mercuryconvention.org/Portals/11/documents/conventionText/Minamata%20Convention%20on%20Mercury_e.pdf
33. Basel Convention:
34. http://www.basel.int/theconvention/overview/textoftheconvention/tabid/1275/default.aspx
35. Khairi, N.A.S.; Yusof, N.A.; Abdullah, A.H.; Mohammad, F. Removal of Toxic Mercury from Petroleum Oil by Newly Synthesized Molecularly-Imprinted Polymer. Int. J. Mol. Sci. 2015, 16, 10562-10577.https://www.mdpi.com/1422-0067/16/5/10562
36. Ernesto López Anadón. El Abece de los Hidrocarburos en Reservorios No Convencionales 4a ed. revisada - Ciudad Autónoma de Buenos Aires: Instituto Argentino del Petróleo y del Gas, 2015.
37. Wood Environment & Infrastructure Solutions UK Limited. Best Available Techniques Guidance Document on upstream hydrocarbon exploration and production. - European Commission. 2019.
38. Liu Q Y. Mercury concentration in natural gas and its distribution in the Tarim Basin. Science China: Earth Sciences, 2013, 56: 1371–1379
39. S. Mark Wilhelm. Estimate of Mercury Emissions to the Atmosphere from Petroleum. Environmental science & technology / VOL. 35, NO. 24, 2001.
40. L. Liang et al. A novel analytical method for determination of pictogram levels of total mercury in gasoline and other petroleum-based products. The Science of the Total Environment I87, 1996.
41. Anastasios Chalkidis et al. CeO2-Decorated α-MnO2 Nanotubes: A Highly Efficient and Regenerable Sorbent for Elemental Mercury Removal from Natural Gas. Langmuir 2019.
42. Dingyuan Zhang et al.Turning fulvic acid into silver loaded carbon nanosheet as a regenerable sorbent for complete Hg0 removal in H2S containing natural gas. Chemical Engineering Journal, Volume 379. 2020.
43. S.M. Wilhelm, N. Bloom. Mercury in petroleum. Fuel Processing Technology 63, 2000.
44. Wilhelm et al. Identification and Properties of Mercury Species in Crude Oil. Energy & Fuels 20, 2006.
45. J.L. Kirk et al. Atmospheric Deposition of Mercury and Methylmercury to Landscapes and Waterbodies of the Athabasca Oil Sands Region. Environ. Sci. Technol. 48. 2014.
46. UNEP Global Mercury Partnership. Waste Management Area Catalogue of Technologies and Services on Mercury Waste Management. 2020.
47. OSPAR. Convention for the Protection of the Marine Environment of the North-East Atlantic. Meeting of the Offshore Industry Committee (OIC) - 2009 and 2010.
48. Gallup, Darrell & Strong, James. Removal of Mercury and Arsenic from Produced Water. Chevron Corporation. 2007.
49. UNEP 2019. Global Mercury Assessment 2018 UNEP Chemicals and Health Branch. Geneva, Switzerland.
50. UNEP, 2017. Global mercury supply, trade and demand. UNEP, Chemicals and Health Branch. Geneva, Switzerland.

51. G. Corvini et al. Mercury removal from natural gas and liquid streams. UOP LLC Houston, Texas, USA.
52. Chelsea E. Willis et al. Tailings ponds of the Athabasca Oil Sands Region, Alberta, Canada, are likely not significant sources of total mercury and methylmercury to nearby ground and surface waters. Science of The Total Environment, Vol. 647, 2019.
53. Chelsea E. Willis et al. Sources of Methylmercury to Snowpacks of the Alberta Oil Sands Region: A Study of In Situ Methylation and Particulates. Environmental Science & Technology. 2018.
54. Saeid Mokhatab et. al., Handling mercury in gas processing plants, Digital Refining, May 2017.
55. Qa3. Unconsidered Mercury Emissions from the Oil and Gas Industry. ANNUAL BUYERS GUIDE 2016.
56. Qa3. Unconsidered Mercury Emissions from the Oil and Gas Industry. Published online 2021.
57. Gasmet, Emissions Monitoring Handbook.
58. https://info.gasmet.com/hubfs/Gasmet_EMISSIONS_MONITORING_HANDBOOK.pdf?hsCtaTracking=336fe4c3-7aec-45e9-a306-152bc816e811%7C2b436ded-8906-47b0-90db-29a12e620082
59. WHO. Elemental mercury and inorganic mercury compounds: Human health aspects. Geneva 2003. https://www.who.int/ipcs/publications/cicad/en/cicad50.pdf
60. Subirachs Sanchez, Mercury in extraction and refining process of crude oil and natural gas, University of Aberdeen, 2013.
61. Johnson Matthey. Handling mercury in gas processing plants. 2017
62. B. Doll et al. (IPIECA) Industry Input to the UN Global Mercury Treaty Negotiations Focus on Oil and Gas. SPE/APPEA International Conference on health, Safety and Environment. 2012.