MANAGING MERCURY IN LIBYAN OIL AND GAS FIELDS: CHALLENGES, RISKS, AND RECOVERY OPPORTUNITIES

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ABSTRACT

Mercury pollution from produced water from three main oilfields in Libya's Sirte Basin Zaltan, Al-Lahib, and Al-Jabal is estimated to be 194.5 tons per year. With a predicted 3% annual rise in generated water volumes, mercury discharge might reach 254 tons by 2034, highlighting the critical need for proactive field-level actions. Libya can extract and recover mercury from hydrocarbon streams by using modular mercury removal devices and modern treatment technology. Using new transmutation techniques, this mercury may be transformed into gold, changing a dangerous byproduct into a very valuable commodity. This strategy not only promotes environmental compliance and lowers operating liabilities, but it also creates a new revenue stream through the sale of converted gold.

Libya might reinvent itself as a regulated producer and exporter of mercury and gold generated from recovered mercury by adopting this invention and taking use of its advantageous location near European and Mediterranean markets. This change has the potential to transform an environmental issue into a strategic industrial opportunity by promoting economic diversification, drawing in foreign investment, and enhancing the nation's position in the world commodities market.

INTRODUCTION

Mercury contamination is turning into a serious issue in Libya's energy sector. Though naturally present within the crust of the earth, the heavy metal can pose significant issues when it is emitted during the production of oil and gas. In various Libyan oilfields particularly those within the Sirte Basin such as Al-Lahib, Zaltan, and Al-Jabal mercury within the produced water was found at disturbingly high levels. In various cases, mercury was up to 100 milligrams per liter as against the international safety standards (Aghow & Idris, 2025). It is not only an environmental threat it is also an increasing operating and commercial danger.

The occurrence of mercury in Libyan oilfields is similarly due to the natural geology of the country. Geological heat and pressure over time capture mercury in oil and gas formations. When hydrocarbons are recovered for production, the mercury is often recovered as well. In the gas phase, mercury will exist as a vapor; it will exist as dissolved or particulate mercury in crude oil and produced waters. Once on the surface, if not removed or treated, the mercury will enter storage tanks, lines, processing units, and export shipments as well. In Libya, aging facilities and lack of standardized treatment practices have exacerbated the issue.

Beyond equipment wear and tear, mercury contamination creates real headaches for exports. In early 2021, several shipments of Libyan crude from Abu Attifel and Zueitina were rejected by international buyers after tests showed high mercury levels (Gupte & Carr, 2021). These rejections don't just affect revenues they damage Libya's credibility as a reliable supplier. From a technical standpoint, mercury damages refining units, corrodes metal surfaces, and destroys catalysts. It also causes light-end products like naphtha and LPG to fall out of spec, creating downstream quality issues (Fontenot et al., 2013).

The environmental impacts are just as concerning. Mercury is highly toxic in minute quantities. Once it gets into the waters or grounds, it persists there for decades. In wetlands and rivers, it is converted to methylmercury, a substance that proceeds through the fish and wildlife into the human food supply. In the vicinity of oilfields, the pollution poses risks to nearby agriculture, groundwater, as well as regional ecosystems. Communities around the impacted sites are subject to long-term exposure risks if the remediation is set back or overlooked (UNEP, 2019). Mercury's biggest issue is its permanence—it doesn't degrade over time. It builds up in equipment, contaminates pipelines, and seeps into the environment, becoming a costly operational and environmental hazard. However, with proper strategies, mercury can be captured, treated, and reused. This paper highlights Libya's mercury challenge from source to export and shows how advanced technologies and better management can turn risk into resource recovery.

2. Origin and Occurrence of Mercury in Libyan Hydrocarbon Reservoirs

Mercury in petroleum systems typically originates from organic-rich sediments and source rock minerals. As hydrocarbons form under heat and pressure, mercury enters the fluid phase and moves with oil and gas, often bonding with sulfur compounds common in Libyan reservoirs. Over time, mercury can accumulate. For instance, mercury concentrations in produced water at Libya's Al-Lahib field have reached 100 mg/L, raising environmental and operational concerns (Aghow & Idris, 2025).

In Libyan oilfields, mercury exists in elemental, inorganic, and organic forms (mainly methylmercury). Elemental mercury, due to its volatility, is commonly found in gas and can condense in surface equipment. In crude oil and produced water, it may be dissolved or particle-bound. This variation complicates detection and removal, especially without proper filtration systems (Fontenot et al., 2013).

Mercury's movement from reservoir to surface is influenced by temperature, pressure, and reservoir chemistry. Pressure shifts during production can cause it to separate. In gas systems, mercury may form corrosive amalgams on metal; in oil and water systems, it tends to build up in tanks and pipelines (Dos Santos et al., 2014).

Aging infrastructure worsens the issue in Libya. Many facilities, particularly in eastern fields like Ras Lanuf and Zueitina, were not designed to manage mercury and have been further damaged by conflict and neglect (Gupte & Carr, 2021).

Mercury levels differ by geology, with Libya's high-sulfur and carbonate reservoirs posing greater risk (Harkness et al., 2015). Without detailed geochemical profiling, operators react instead of prevent. Libya must prioritize mercury monitoring, characterization, and mitigation to protect equipment, meet standards, and manage risks.

3. Impact on Upstream Operations

In Libya's upstream oil and gas sector, mercury contamination is a growing technical and environmental challenge. Although mercury occurs naturally in subsurface reservoirs, it becomes hazardous once it enters surface facilities, causing damage throughout production. Limited field-level mitigation, aging infrastructure, and poor awareness of mercury behavior have turned this into a silent operational threat.

- **Equipment Degradation**

Mercury bonds with metals like aluminum and copper, causing internal corrosion in separators and compressors. In cryogenic systems with aluminum exchangers, it can damage linings, leading to shutdowns and repairs (Fontenot et al., 2013). Older Libyan facilities are especially at risk due to outdated materials.

- **Catalyst Poisoning**

Even small amounts of mercury can deactivate catalysts in gas processing, disrupting reactions and lowering efficiency (Dos Santos et al., 2014). This increases flaring and costs. In fields like Abu Attifel and Zueitina, contamination has led to crude export rejections (Gupte & Carr, 2021).

- **Environmental Discharge**

Produced water is a major mercury release pathway. In fields like Al-Lahib and Zaltan, levels have reached 100 mg/L (Aghow & Idris, 2025). Often discharged untreated into open pits or dry wadis, mercury then migrates through soil and can reach groundwater, posing long-term environmental threats.

- **Operational Safety**

Mercury builds up in low-flow areas of tanks and pipelines, releasing harmful vapors during maintenance. Without proper safety measures, workers face serious health risks (Harkness et al., 2015). Most Libyan facilities lack real-time monitoring. To reduce these risks, Libya should adopt early detection, install adsorption units, and use corrosion-resistant materials essential steps for safety and environmental protection.

4. Mercury in Downstream and Export Logistics

Mercury contamination remains a concern even after oil and gas leave the production site. In downstream operations like refining, storage, and export it affects performance, damages infrastructure, and can lead to rejected shipments. Libya's lack of advanced mercury removal and monitoring systems makes the entire supply chain more vulnerable.

- Catalyst Damage

Even small amounts of mercury can deactivate catalysts in refineries, reducing output and causing costly shutdowns. In Libya, where catalyst supply is limited, this puts refining operations at risk (Olajire, 2020).

- Off-spec Shipments

Mercury tends to concentrate in lighter hydrocarbons like LPG and naphtha. If levels exceed strict global standards, buyers may reject or discount entire cargoes as seen with Libyan crude from Amna, Abu Attifel, and Zueitina (Gupte & Carr, 2021).

- Contaminated Terminal

Without proper controls, mercury accumulates in tanks and pumps, endangering workers and contaminating crude. Outdated terminals like Ras Lanuf and Zueitina are most at risk. Libya must improve mercury removal and monitoring to protect exports and reputation (Veil et al., 2004).

5. Environmental and Health Implications

In Libya's oil regions, untreated produced water often releases mercury into the environment, posing major risks to public health and ecosystems. Mercury can persist for decades, building up in soil, seeping into groundwater, and entering the food chain impacting areas far beyond the oilfields.

- Persistent Environmental Threat

Mercury is a toxic element that doesn't break down over time. In Libya's oil regions, untreated produced water often discharged into open pits allows mercury to contaminate soil, groundwater, and the wider ecosystem.

- Soil and Groundwater Contamination

In fields like Al-Lahib and Zaltan, produced water with mercury levels up to 100 mg/L is released without treatment (Aghow & Idris, 2025). Mercury binds to soil and slowly seeps into aquifers. Contaminated water used in agriculture can transfer mercury into crops and the food supply.

- Human Health Risks

Mercury exposure even at low levels can harm the brain, kidneys, and heart. Methylmercury is especially dangerous for pregnant women and developing fetuses (UNEP, 2019). Field workers may inhale vapor during maintenance tasks, with symptoms like memory loss and fatigue often going unnoticed until it's too late.

- Airborne Exposure from Dust

In Libya's arid climate, evaporation leaves mercury residues in pit sediments. Winds can carry this toxic dust into nearby communities, increasing inhalation risks especially for children and field personnel (Fontenot et al., 2013).

- Lack of Long-Term Monitoring

Mercury cycles through air, water, and soil for decades. Libya currently has no national framework for long-term monitoring posing a continued threat beyond oil production.

6. Case Study: Elevated concentrations of heavy metals (mercury) in produced water discharged from Zaltan, Al-Lahib, and Al-Jabal oil fields in the Sirte Basin, Libya

Libya's Sirte Basin hosts major oil fields where produced water from extraction contains dissolved mercury (Hg) a toxic element harmful to marine life and human health. This case study examines three key fields: Zaltan, Al-Lahib, and Al-Jabal, analyzing their water output, mercury levels, and annual discharge to assess environmental impacts, see Table 1. All three fields are operated by Sirt Oil Company and located in sirt basin, see Figure 1.

Table 1: Field profiles including PW, Hg concentration, annual Hg discharge, and field type.

Field	PW Volume (bbl/day)	Hg Conc. (mg/L)	Annual Hg Discharge (t/year)	Field Type
Zaltan	190 000	7.0	77.2	Oil field
Al-Lahib	14 000	100.0	81.3	Oil field
Al-Jabal	13 800	45.0	36.0	Oil field

Fig. 1. The location of the three fields in Libya

6.1. Mercury Contamination Overview

- Concentrations
  Al-Lahib exhibits the highest mercury level at 100.0 mg/L, over 14 times Zaltan's 7.0 mg/L and more than double Al-Jabal's 45.0 mg/L .
- Produced-Water Volumes
  These concentrations multiply into vast Hg loads when combined with daily PW flows:
  - Zaltan: 190 000 bbl/day
  - Al-Lahib: 14 000 bbl/day
  - Al-Jabal: 13 800 bbl/day
- AnnualDischarge
  From our calculations:
  - Zaltan → 77.2 t Hg/year
  - Al-Lahib → 81.3 t Hg/year
  - Al-Jabal → 36.0 t Hg/year
  - Total ≈ 194.5 t Hg/year
- Ecotoxicity
  These discharge rates vastly exceed typical freshwater Hg limits (≤ 0.002 mg/L) and, when released untreated, pose acute neurotoxic threats to soil, groundwater, and biological receptors near each field.

6.2. Comparative Analysis of Mercury Loads

- Absolute Load & Share
  - Al-Lahib: 81.3 t (41.8 % of total)
  - Zaltan: 77.2 t (39.7 %)
  - Al-Jabal: 36.0 t (18.5 %)
- Concentration vs. Volume Dynamics
  Though Zaltan's PW flow is around13 times that of Al-Lahib, its low Hg concentration yields a similar annual load illustrating that both high-volume/low-conc and low-volume/high-conc sources can be equally burdensome.

- Impact Patterns
  - Al-Lahib (Hotspot Risk): High-conc PW creates localized "toxic plumes," rapidly bioaccumulating in soils and food webs.
  - Zaltan (Diffuse Risk): Moderate-conc PW spread over vast desert areas threatens broad-scale soil salinization and groundwater contamination.
  - Al-Jabal (Intermediate): Presents a mixed profile requiring both point-source and regional controls.
- Mitigation Priorities
  - Al-Lahib: On-site Hg removal prior to any discharge.
  - Zaltan: Volume reduction or centralized treatment to limit diffuse Hg release.
  - Al-Jabal: Hybrid approach combining targeted metal removal with salinity management.

Focusing interventions on both concentration-driven hotspots and volume-driven diffuse contamination will be essential to curb Libya's projected 194.5 t Hg/year discharge.

7. Predictive Modeling of Mercury Concentrations in Produced Water Across Zaltan, Al-Lahib, and Al-Jabal Using Machine Learning

Mercury released in produced water from Libya's oil and gas fields poses a serious environmental and health risk. This analysis combines both current measurements and future projections to illuminate where attention is most urgently needed:

7.1 Present Annual Mercury Discharge by Field (2025)

- Zaltan: 190 000 bbl/day PW @ 7 mg/L Hg → 77.2 t Hg/year
- Al-Lahib: 14 000 bbl/day PW @ 100 mg/L Hg → 81.3 t Hg/year
- Al-Jabal: 13 800 bbl/day PW @ 45 mg/L Hg → 36.0 t Hg/year
- Total Present Annual Discharge ≈ 194.5 t Hg/year

Below is a chart pinpoint which fields dominate today's mercury output and reveal how future production trends could dramatically amplify pollution unless mitigated, see Figure 2.

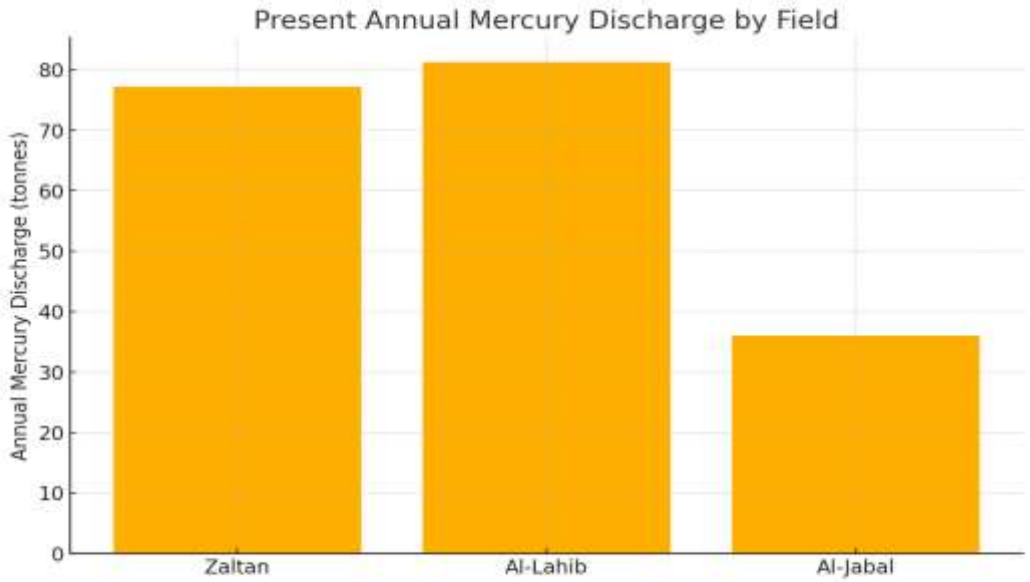

Fig. 2. Showing which fields dominate today's mercury output in tonnes

7.2 Present Annual Mercury Discharge by Field (2025 – 2034)

By assuming produced-water volumes rise 3 % /yr (Hg conc. constant), boosting total Hg to ~254 t by 2034. These charts illustrate that even modest growth in water production can significantly amplify mercury release unless treatment or discharge controls are improved.

- Field Contribution (Pie Chart)

Al-Lahib, despite a modest water volume, leads in mercury load (41.8 %), followed by Zaltan (39.7 %) and Al-Jabal (18.5 %) in 2025, see **Figure 3**. This highlights how high Hg concentration can outweigh sheer volume.

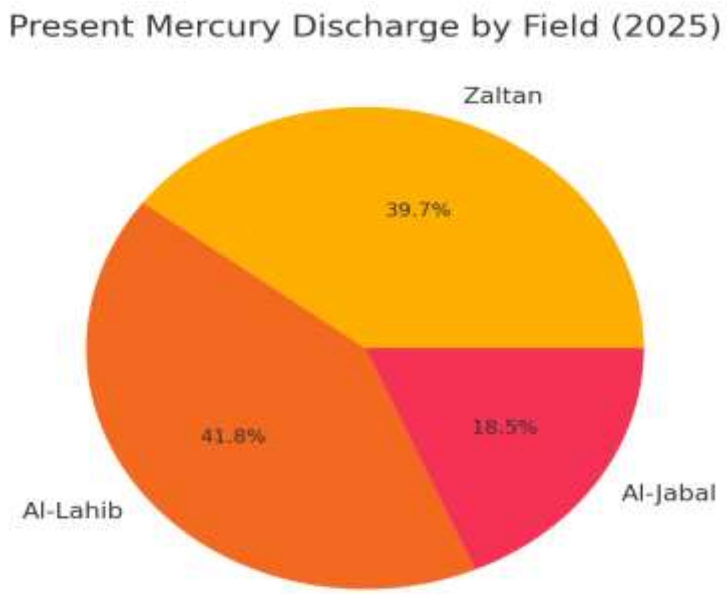

Fig. 3. Showing present mercury output by fields in percentages

- Volume vs. Concentration (Scatter Plot)

Zaltan has the highest flow but lowest Hg concentration; Al-Lahib the reverse; Al-Jabal sits mid–low on both axes, see Figure 4. There's no simple linear trend, underscoring the need to target both high-volume and high-concentration sources.

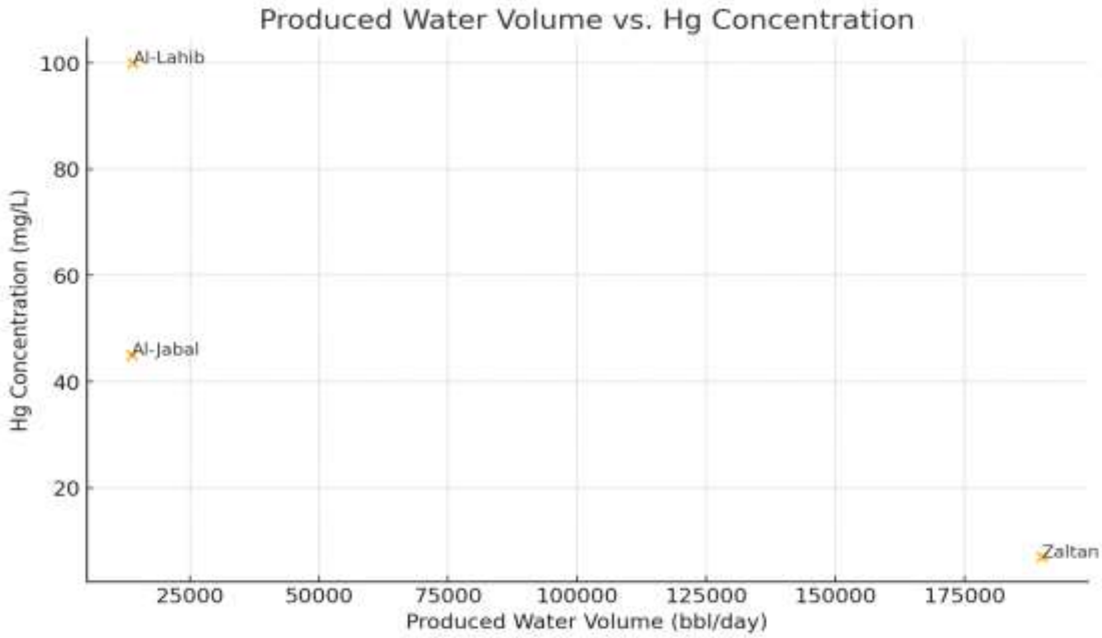

Fig. 4. Showing the produced water volume by field verses mercury concentration

- Multi-Scenario Projections

Total annual discharge for the three fields through 2034 under 0 %, 1 %, 3 %, and 5 % water-production growth, see Figure 5. Even a 1 % uptick adds ~20 t Hg/yr by 2034; at 5 %, it surges over 300 t/yr, more than 50 % above today.

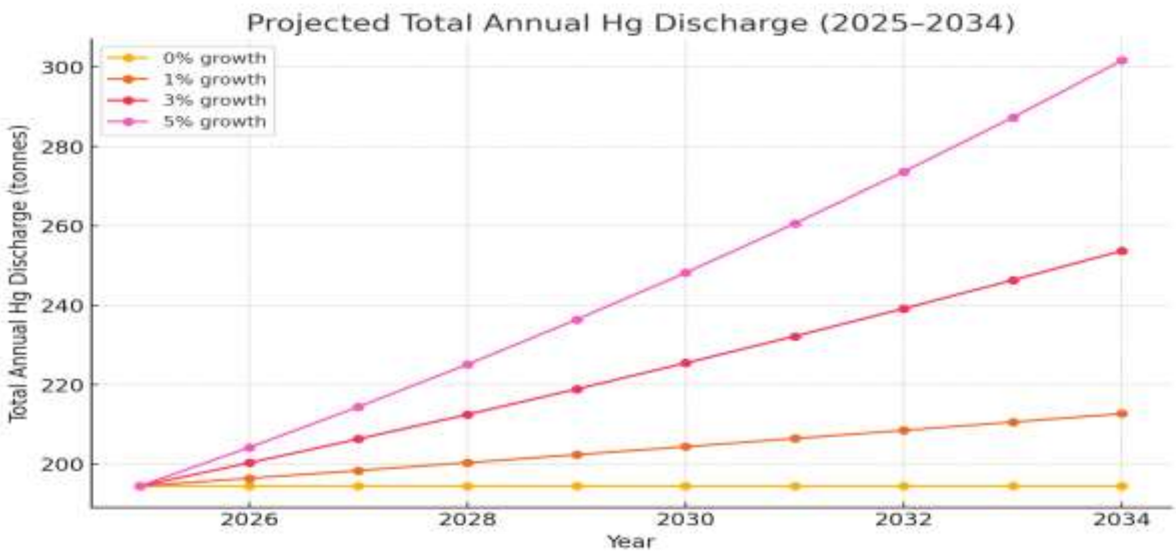

Fig. 5. Showing the projected total annual mercury output for the three fields through 2034.

- Cumulative Discharge

Shows the aggregated burden for the three fields over 2025–2034. With 3 % growth, you'd see ~2 200 t Hg discharged in a decade emphasizing that small annual rate changes compound dramatically, see Figure 6.

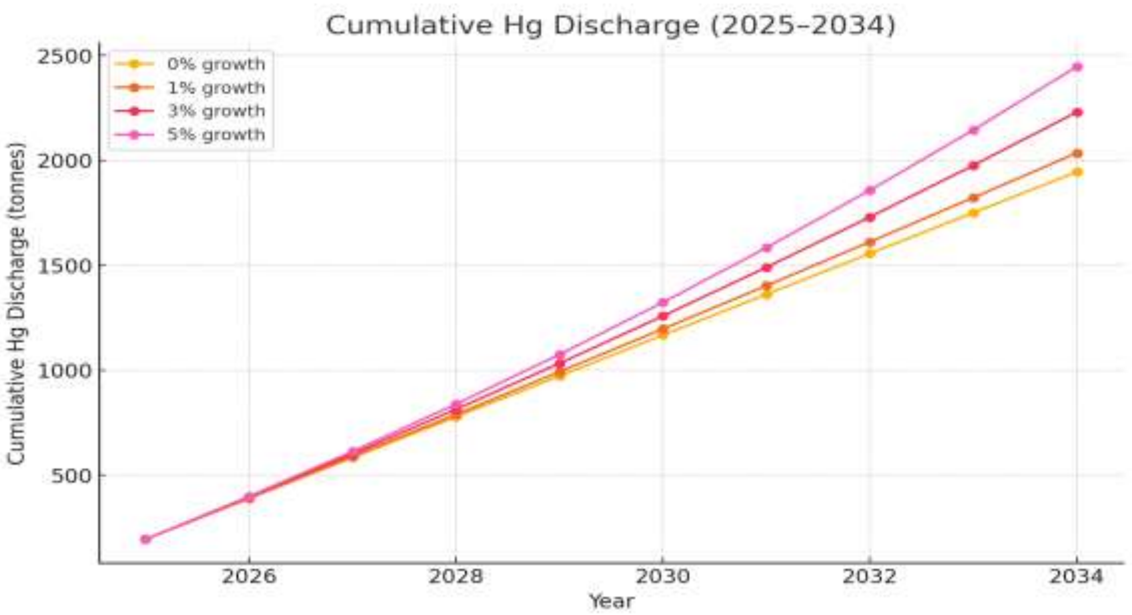

Fig. 6. Shows the cumulative mercury production of the three fields over 2025 – 2034.

8. Turning Mercury into a Useful Resource

Though mercury is often seen as a toxic hazard in oil and gas, it also holds potential value if safely captured and reused. In Libya where mercury contamination is a persistent issue this shift in perspective could transform an environmental challenge into a strategic economic opportunity.

- Industrial Demand

Mercury is still used in select industries such as lighting, batteries, instruments, and catalysts. Some countries even use it in artisanal gold mining (UNEP, 2019). While global demand has decreased, niche markets remain for safely recovered mercury, particularly where infrastructure allows for controlled handling.

- Economic Benefits

Libya currently pays for mercury through equipment damage, shipment rejections, and environmental cleanup. However, using proper technologies like activated carbon beds, sulfur-based adsorbents, or membrane systems, mercury can be safely removed and sold (Olajire, 2020). Examples from Malaysia and Australia show that recovery programs can be cost-effective when combined with regulated resale.

- Mercury-to-Gold via Fusion

Marathon Fusion's tokamak reactor can convert mercury-198 into gold-197 during fusion. Neutron bombardment triggers decay into gold, especially when using enriched mercury or a mercury-lithium alloy. The resulting gold is easily extracted. This process could yield up to five tonnes of gold per gigawatt of energy, turning toxic mercury into a valuable byproduct combining clean energy with profitable gold production (Marathon Fusion, 2025).

- Strategic Advantage

Libya's proximity to Europe positions it well to supply recovered mercury. Aligning with international frameworks like the Minamata Convention could unlock funding, support, and access to regulated markets (Minamata Convention, 2017).

- Innovation and Capacity Building

Valorization also opens opportunities for local research. Libyan universities and oil firms can develop new recovery methods, reducing reliance on foreign expertise and creating environmental sector jobs. With proper oversight, Libya could turn mercury from a liability into an environmental and economic asset.

9. Recommendations and Policy Directions

- To address the mercury problem effectively and turn it into a strategic opportunity, Libya should:
- Implement advanced mercury separation and treatment technologies in field operations to reduce environmental impact, ensure regulatory compliance, and enable safe, cost-effective recovery.
- Establish National Mercury Monitoring Standards: Routine testing at field and export terminals.
- Invest in Modular Treatment Units: Deploy scalable adsorption or membrane skids at gas plants and crude stabilization units.
- Enhance Terminal Protocols: Implement mercury removal steps before crude enters storage/export tanks.
- Engage in International Collaboration: Leverage support from the UN Global Mercury Partnership and regional centers.

10. Conclusion

Mercury in Libya's oil and gas sector is both a liability and an opportunity. The data from Sirte Basin fields confirm high concentrations of mercury in produced water and crude exports. Without mitigation, mercury threatens public health, export reliability, and environmental sustainability. However, with targeted investments in treatment, monitoring, and recovery, Libya can lead the region in addressing mercury pollution while creating economic value from what was once an overlooked hazard.

In conclusion, managing mercury in Libya's oil and gas sector is not just about solving a technical problem it's about protecting national assets, ensuring energy export reliability, and safeguarding the environment for future generations. With science-backed action, coordinated policy, and targeted investment, Libya can turn mercury from a liability into a symbol of responsible resource management.

References

1. Aghow, K., & Idris, S. (2025). Characterization and Environmental Impact of Produced Water from Oil Fields in the Sirte Basin, Libya. *Alqalam Journal of Medical and Applied Sciences*, 8(1), 67–72. https://doi.org/10.54361/ajmas.258111
2. Anonymous. (2021). *Mercury dumping in Abu Kammash's water, Libya*. Retrieved from https://ejatlas.org/conflict/abu-kammash-mercury-dumping-libya
3. Dos Santos, E. V., Aquino Neto, S., Botelho Junior, A. B., & Magriotis, Z. M. (2014). Decontamination of produced water containing petroleum hydrocarbons by electrochemical methods: A mini-review. *Environmental Science and Pollution Research*, 21(1), 8432–8441.
4. Fontenot, B. E., et al. (2013). Evaluation of water quality in private drinking wells near natural gas extraction. *Environmental Science & Technology*, 47(17), 10032–10040.
5. Gupte, E., & Carr, G. (2021). Buyers reject several Libyan crude cargoes due to high mercury content: sources. *S&P Global Platts*.
6. Harkness, J. S., Dwyer, G. S., Warner, N. R., Mitch, W. A., & Vengosh, A. (2015). Iodide, bromide, and ammonium in hydraulic fracturing and oil and gas wastewaters: Environmental implications. *Environmental Science & Technology*, 49(3), 1955–1963.
7. *Marathon Fusion*. "Turning Mercury into Gold: Fusion Technology's Golden Byproduct." Preprint, 2025.
8. Minamata Convention on Mercury. (2017). United Nations Treaty Collection. Retrieved from https://www.mercuryconvention.org
9. Olajire, A. A. (2020). Recent advances on treatment of oil and gas produced water. *Chemical Engineering Journal Advances*, 4, 100049.
10. Veil, J. A., Puder, M. G., Elcock, D., & Redweik, R. J. (2004). *A White Paper Describing Produced Water from Production of Crude Oil, Natural Gas, and Coal Bed Methane*. Argonne National Laboratory.
11. UNEP (United Nations Environment Programme). (2019). *Global Mercury Assessment 2018*. Geneva: UNEP Chemicals Branch.