# Hidden Costs

## Reduced IQ from Chlor-Alkali Plant Mercury Emissions Harms the Economy

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## Executive Summary

Mercury-cell technology has been used to produce the industrial chemicals chlorine and caustic soda since 1894 – even before Ford's Model-T was produced. While the automotive industry has advanced beyond Ford's original concept, four United States chlor-alkali facilities continue to rely on mercury-based technology to make their products even though a mercury-free alternative is readily available. Besides being terribly inefficient, mercury-based chlor-alkali technology is a major source of mercury pollution to our air and water. In 2006, the four remaining mercury-based chlor-alkali facilities released over 2,000 pounds of mercury into the air – earning these factories the distinction of being named the "Foul Four" by Oceana.

While the financial costs of mercury use to chlorine manufacturers have been quantified[1], the costs of mercury pollution to society from these plants have received far less attention. Each of the many effects of mercury exposure, including environmental harm to wildlife and heart disease and neurological damage in humans, has a cost that is borne by society - but rarely recognized and has never been comprehensively investigated. While this analysis presents only a small fraction of the total costs of mercury pollution, it takes a first step by quantifying the cost to society of reduced economic productivity, as measured by the reduction in the Intelligence Quotient (IQ) of United States citizens attributable to mercury releases from chlor-alkali plants in the United States.

This report builds on prior, peer reviewed studies that placed a dollar value on lost economic potential resulting from IQ loss related to neurological damage in young children due to mercury pollution. Here we apply similar methodology to conservatively estimate the costs to society from mercury-based chlor-alkali factories in the United States. These conservative estimates do not include other health related costs associated with mercury exposure, nor do they include other external costs due to local environmental degradation. Thus the true costs are higher than what is estimated here.

Some of the estimates in this report include:

- Total mercury emissions, from all sources, have lowered the IQ of over 400,000 children in the United States annually. Millions of dollars of economic productivity have been lost annually as a result of these lower IQs.
- Based on figures from the year 2000, the United States mercury-based chlor-alkali industry emitted over 12,000 pounds into the air, resulting in over $24 million in lost economic productivity that year.

- The Foul Four emitted over 2,000 pounds of mercury into the air in 2006, resulting in an estimated $3.9 million in lost economic productivity for that year.
- Olin's Tennessee plant alone has caused an estimated $24 million in lost productivity due to lowered IQs over the past ten years.
- Olin's Georgia plant has caused an estimated $17 million in lost productivity due to lowered IQs over the past ten years.
- PPG's West Virginia plant has caused an estimated $20 million in lost productivity due to lowered IQs over the past ten years.
- Ashta's Ohio plant has caused an estimated $23 million in lost productivity due to lowered IQs over the past ten years.

Even though these externalized costs due to mercury pollution from the chlor-alkali industry can never be fully recovered, they are preventable. Mercury-free and more energy efficient membrane technology has been available since the 1970s. Nearly 95 percent of the chlorine capacity in the United States already uses mercury-free technology and, as a result, does not contribute to the societal costs estimated here.

Switching to mercury-free technology is the economically and socially responsible decision, since the new membrane technology can increase energy efficiency and production capacity considerably. In fact, some facilities that have switched to mercury-free technology have reported that the new technology paid for itself in five years or less. Over the past several years, the Foul Four have collectively spent an estimated $150 million in mercury pollution control technology.[2] The Foul Four have also spent a cumulative $158 million on inefficient energy use over the past decade alone.[3] Their mercury-free competitors, on the other hand, have simply avoided those costs and profited from improved process efficiencies. Adding these internal costs of mercury use by the Foul Four to the external costs of mercury pollution to society demonstrates that the financial benefits of switching to mercury-free technology clearly outweigh the costs of conversion.

In light of these findings, Oceana recommends that:

- Mercury-based chlor-alkali facilities should immediately upgrade to mercury-free technology,
- Mercury-based chlorine production should be prohibited to ensure that the conversion to mercury-free technology happens in a timely manner,
- Hidden costs of mercury pollution from chlor-alkali facilities, including public health and environmental costs, must be addressed when considering the so-called economic "burden" of switching to mercury-free technology, and
- Additional studies on the harm associated with mercury pollution should consider health and environmental costs as well as costs resulting from inefficiencies of mercury use in the chlor-alkali sector.

## Introduction

Mercury-based chlor-alkali production uses outdated technology, is unnecessary and represents a significant source of preventable mercury pollution. In 2006, four mercury-based chlor-alkali factories - the "Foul Four" - together emitted over 2,000 pounds of mercury into the air, in addition to 60 pounds discharged directly to rivers and streams. Some of this mercury can contaminate local waterways, with the remaining airborne mercury entering the global mercury pool. This mercury is transported in the atmosphere across the globe and can eventually accumulate in seafood consumed by humans.

Until recently, the external economic costs of mercury pollution from industrial processes had not been fully evaluated, and as a result are still generally overlooked. External costs include environmental degradation and risks to public health that are not reflected in the price consumers pay for a product. These, then, are the costs that society bears. In 2005, scientists from the Mount Sinai Center for Children's Health and Environment published the first study to estimate one component of that cost – the cost to society of reduced intelligence (as measured by IQ) caused by neurological damage occurring from exposure to mercury in the United States.[4] The findings were staggering: mercury pollution from United States industrial activities cost the country an estimated $3.1 billion in lost economic productivity annually just from one measurable health outcome – lowered IQ.

This report adapts a model developed by Dr. Leonardo Trasande and colleagues[5] that allowed them to separate out the economic costs from mercury pollution from specific sources, such as coal-fired power plants in the United States. This report has adapted their useful model (with some modifications) to estimate the cost of economic productivity lost due to mercury emissions from the chlor-alkali sector. Because most model variables were estimated for the year 2000, we used mercury emissions from the twelve mercury-based chlor-alkali facilities operating in 2000 to estimate the fraction of costs attributable to the plants still in operation today. There are four remaining mercury-based chlor-alkali plants still using this outdated mercury technology in the United States. It is important to note that nearly 95 percent of chlor-alkali capacity in the United States today relies on mercury-free technology that does not contribute to the lost economic productivity estimated in this report.

### *Most Mercury Contamination is Caused by Human Activity*

In 1997, the United States Environmental Protection Agency published its eight-volume Mercury Study Report to Congress – the first major attempt to account for all mercury emissions from anthropogenic and natural sources within the United States.[6] Recent estimates for annual global mercury emissions range from 6,060 tons to 6,411 tons including natural and anthropogenic sources.[7] At the same time, approximately 67 percent of mercury currently in the environment that is available to bioaccumulate has come from anthropogenic, or human originated sources like coal burning and chlor-alkali manufacturing. Within EPA's 1997 Mercury Study Report, the Agency identified mercury-based chlor-alkali facilities as "a well-known source of mercury release," and "[t]he chlor-alkali industry is the largest user of mercury...." Ten additional years of Toxics Release Inventory data on mercury emissions from the chlor-alkali industry, show that chlor-alkali facilities clearly continue to be a significant source of preventable mercury pollution.[8]

When emitted, mercury can end up in aquatic ecosystems where it is transformed by small microorganisms to a more toxic form, methylmercury, which accumulates and concentrates in food webs. Methylmercury is absorbed by small plants at the base of the food web and as these mercury-contaminated organisms are consumed, the mercury accumulates and concentrates further in animals at each step higher on the food chain. Eventually animals at the top of foodwebs, such as humans and predatory wildlife, which eat contaminated fish and other seafood, become contaminated with mercury themselves. Fish consumption is the primary way Americans are exposed to mercury.[9]

### *Mercury is Dangerous*

In the year 2000, it was estimated that nearly 1 out of 6 women of child-bearing age carried enough mercury in her blood to pose neurological risk to her developing baby.[10] That number is closer to 1 in 10 today, still almost 7 million women, due to decreases in mercury levels in women of childbearing age in the past few years.[11] "Neurological risk" includes a large range of health implications in children, including reduction of IQ, memory loss and delay of motor skill development, among others.[12] Aside from neurological problems, excessive mercury exposure in adults has been linked to increased risk of heart disease and death by heart attack, and is suspected to cause harm to reproductive and immune systems.[13] Methylmercury is also considered a "possible carcinogen" by the United States Environmental Protection Agency.[14]

### *Mercury Pollution Harms Our Economy*

A person with a higher IQ is expected to earn more than if that person had a lower IQ. Excessive mercury exposure, especially in utero, can reduce a person's IQ and therefore, reduce lifetime earnings. When assessed at the population level, mercury pollution can cause significant damage to a country's economy because of reduced IQ levels across its citizenry. Annual cost estimates for this report are based on the loss in earnings over an entire lifetime for the whole birth cohort affected by mercury in that year.

To determine the costs to the United States economy from mercury releases from all anthropogenic sources and from the chlor-alkali sector in particular, we used three approaches to produce low, mid-range and high estimates. The different assumptions in each estimate are explained in detail in the Methods section. On a per-pound basis, we estimate United States anthropogenic mercury sources reduce the United States' economic productivity by $1,900 per pound of mercury emitted (range: $740/pound - $8,900/pound; see Table 5).

We estimate that the annual cost of lost economic productivity in the United States, attributable to United States mercury emissions is $640 million (range: $250 million - $3.1 billion) based on year 2000 figures (See Table 1). The entire United States chlor-alkali industry caused an estimated $24 million in lost economic productivity due to mercury pollution in 2000 (range: $9.3 - $110 million).

There are a number of degrees of conservatism built into these estimates. For example, these figures are only based on societal costs of mercury as a result of lost productivity due to reduction of IQ points. IQ is an integrative measure of several cognitive functions, but does not cover all neurological endpoints, such as motor skills and attention/behavior effects affected by mercury.[15] Since these cost estimates do not include the costs of all neurological and other mercury health effects, such as heart disease, they represent a conservative estimate.

***[Table 1]*** Annual cost of lost U.S. productivity from anthropogenic mercury (Hg) pollution

| | **High Est.** | **Mid Est.** | **Low Est.** |
|---|---|---|---|
| Total Cost from Anthropogenic Hg | $8.7 billion | $3.2 billion | $1.2 billion |
| U.S. Anthropogenic Hg cost contribution | $3.1 billion | $640 million | $250 million |
| U.S. Chlor-alkali cost contribution | $113 million | $24 million | $9.3 million |
| Price per pound of Hg | $8,900 | $1,900 | $740 |

*Costs are in U.S. $ for the year 2000. See Methods section for derivation of cost estimates.*

Other costs not included in the health-based estimates above include those from environmental damage caused by mercury contamination from these outdated chlor-alkali plants. This damage extends to impaired waterways, grossly contaminated sites, injury to wildlife, fish consumption advisories, and cultural and recreational losses. In addition, nearly all operational and former mercury-based chlor-alkali facilities are either using taxpayer dollars to assist in clean up activities or are required to continuously manage mercury contamination under federal law.[16]

Recently, the United Nations has attempted to estimate the total economic benefit to human health, the environment and society from reducing mercury pollution. According to the United Nations estimate, mercury pollution results in $5,700 in lost economic productivity per pound of mercury emitted ($12,500 per kilogram Hg).[17] Given that the chlor-alkali industry is the third largest mercury user worldwide, the overall global economic benefits of switching to mercury-free technology would be tremendous.[18] Compared to the economic loss estimated in this report, which is based on an estimated $1,900 per pound of mercury attributable from a single health indicator (decrement in IQ points), the United Nations estimate provides a global reference point for our nation-specific estimates.

### *The Cost Contribution from Chlor-Alkali Facilities*

In 2000, there were twelve mercury-based chlor-alkali facilities in the United States which reported a total of 12,648 pounds of mercury air emissions that year (Table 2). Collectively, these factories caused an estimated $24 million in lost economic productivity due to mercury pollution in 2000.

Only four of these facilities continue to rely on mercury and refuse to upgrade to mercury-free technology. In 2006[19] the Foul Four emitted over 2,000 pounds of mercury into the air. Mercury emissions from the Foul Four are estimated to have caused nearly $3.9 million in lost economic productivity in 2006.[20]

***[Table 2]*** Mercury-based chlorine production cost the United States $24 million in 2000

| **Facility (*Foul Four in italics*)** | **Mercury Air Emissions 2000 (lbs.)** | **Attributable Lost Economic Productivity ($Millions)** |
|---|---|---|
| ***Olin Corp. - Charleston, TN*** | 1,414 | $2.7 |
| ***Ashta Chemicals - Ashtabula, OH*** | 1,390 | $2.6 |
| ***PPG Ind. - Natrium, WV*** | 1,227 | $2.3 |
| PPG Ind. - Lake Charles, LA | 1,224 | $2.3 |
| Olin Corp. - St. Gabriel, LA | 1,204 | $2.3 |
| ERCO Worldwide - Port Edwards, WI | 1,111 | $2.1 |
| OxyVinyls - Deer Park, TX | 1,106 | $2.1 |
| Westlake Chemicals - Calvert City, KY | 1,100 | $2.1 |
| OxyChem - New Castle, DE | 1,076 | $2.0 |
| OxyChem - Muscle Shoals, AL | 1,075 | $2.0 |
| ***Olin Corp. - Augusta, GA*** | 719 | $1.4 |
| Georgia-Pacific – Bellingham, WA | 3 | $0.006 |
| **Total** | **12,648** | **$24 million*** |

*Source: Mercury Emissions compiled from the United States Environmental Protection Agency's Toxics Release Inventory (see Tables 1; 5 and Methods). *Costs do not add due to rounding*

In addition to the health related costs associated with mercury emissions from chlor-alkali factories, environmental costs also contribute to this industry's economic burden. One study estimated costs to remediate mercury-contaminated sites in Sweden and Japan at over $1,000-$500,000 per pound of mercury contamination.[21] These costs, which are in addition to those derived here for health-based injury from the United States' chlor-alkali industry ($740-$8,900 per pound of mercury emitted) (Table 1), show that the true costs to society have not yet been fully considered. Since mercury-free technology is readily available for chlorine production, these factories are operating at the expense of public health.

## The Foul Four

The last mercury-based chlor-alkali facilities in the United States that continue to use mercury, the Foul Four, are major mercury emitters. For the decade between 1997 (when EPA published its Mercury Study Report to Congress and identified chlor-alkali facilities as major sources of mercury emissions) and 2006 (the most recent year in which public mercury emission data for this sector were available), the Foul Four emitted over 44,000 pounds of mercury into the air. These emissions cost the United States economy an estimated $84.5 million (range: $32.8 million - $395.6 million) based on per-pound estimates from the year 2000.[22] These costs do not include all public health concerns associated with mercury pollution, like heart disease, nor do they account for the full environmental costs. Fortunately, mercury-free technology is readily available. Modern membrane technology, for example, neither uses nor releases mercury, and this technology has been in use for over 30 years. Simply switching to membrane technology would eliminate mercury pollution from the Foul Four. The economic costs already borne by the public due to the mercury emissions of the Foul Four, not to mention the threat to economic productivity, are an unnecessary financial burden.

## *Olin Corporation – Charleston, Tennessee*

The Olin Corporation's Tennessee facility is the largest of the four remaining mercury-based chlorine factories in the United States. Built in 1962, this facility has consistently been the single largest source of mercury air pollution in the entire state of Tennessee. Based on estimates for the year 2000, for every pound of mercury that is emitted into the air $1,900 will be lost in economic productivity in the United States (See Methods for complete analysis). Mercury emissions from Olin's Charleston Tennessee plant over the past decade are conservatively estimated to have resulted in nearly $24.2 million in lost economic productivity (range: $9.4 million - $113.5 million). These are hidden costs that society pays for the mercury pollution from Olin's Tennessee plant.

Mercury use at Olin in Tennessee has cost society millions of dollars (1997-2006)

| | |
|---|---|
| Mercury Air Emissions (1) | 12,752 lbs. |
| Attributable Lost Economic Productivity *(Range)* (2) | $24.2 million *($9.4 million - $113.5 million)* |

*Sources: 1) Environmental Protection Agency Toxics Release Inventory; and 2) This report, see Methods for further detail.*

In addition to the costs of the public health effects described above, mercury from Olin's facility has harmed the local environment. Olin's Tennessee facility discharged over 400 pounds of mercury directly to the Hiwassee River since public data reporting began in 1988.[23] As a result, toxic levels of mercury have accumulated in the sediment near and downstream of the plant.[24] The segment of the scenic Hiwassee River, near Olin, is now listed as impaired due to mercury contamination of fish, and the state has issued a fish consumption advisory that warns women of childbearing age and children to not eat certain fish from this segment of the river due to high mercury content. If Olin's facility were not discharging mercury into the river, it is unlikely that this consumption advisory would have been necessary.[25] As a result of the contamination, the health of anglers and the families that consume their catch may be at risk. These are additional localized economic losses that are not quantified in this report, thus adding to the conservative nature of our estimate.

In addition to these external and previously uncounted costs to society and the local economy, the Olin plant endures its own internal costs of continued mercury use, such as production inefficiencies and environmental liabilities that the company pays. For example, Olin's plant manager has estimated that the company has spent $54 million over the years to install pollution controls[26] – costs that Olin's mercury-free competitors have simply avoided. Additionally, Olin Corporation pays mercury-related waste treatment, storage and disposal costs that add up from year to year.

Oceana estimates that a one-time investment of about $117.8 million would allow the facility to switch to a mercury-free process.[27] Switching to a mercury-free process makes sense for the public health and environmental benefits, but also because of the benefits to Olin. Increased energy efficiency and capacity, in addition to savings from costs avoided (due to handling requirements of mercury), can help recover most of the conversion costs. Some factories have recouped their modernization costs in less than five years because of increased efficiency, capacity and costs avoided.

Considering all of these costs and not even taking into account those that can not be quantified as discussed previously, it is clear that a switch to mercury-free technology would benefit not only Olin, but also society as a whole. The $24.2 million dollar figure represents not only a loss to the economy but also the loss to the quality of life of those who have suffered from these health and environmental costs. As a result, the arguments for switching to mercury-free technology are both economically and morally justifiable. The switch will benefit individuals, society and even the company itself. For these reasons, the Olin Corporation should switch to mercury-free technology at its Tennessee factory immediately.

### *Olin Corporation – Augusta, Georgia*

The Olin Corporation's Georgia facility is the second largest remaining mercury-based chlorine factory in the United States. Built in 1965, this facility has consistently been the third largest source of mercury air pollution in the entire state of Georgia for several years. Based on estimates for the year 2000, for every pound of mercury that is emitted into the air $1,900 will be lost in economic productivity in the United States (See Methods for complete analysis). Mercury emissions from Olin's Augusta Georgia plant over the past decade are conservatively estimated to have resulted in nearly $17 million lost economic productivity, (range: $6.6 million to $79.9 million). These are hidden costs that society pays for the mercury pollution from Olin's Georgia plant.

Mercury use at Olin in Georgia has cost society millions of dollars (1997-2006)

| | |
|---|---|
| Mercury Air Emissions (1) | 8,973 lbs. |
| Attributable Lost Economic Productivity *(Range)* (2) | $17 million *($6.6 million - $79.9 million)* |

*Sources: 1) Environmental Protection Agency Toxics Release Inventory; and 2) This report, see Methods for further detail.*

In addition to the public health costs described above, mercury from Olin's facility has negatively affected the local environment. Olin's Georgia facility discharged 179 pounds of mercury directly to the Savannah River since public data reporting began in 1988.[28] Due to mercury contamination, both Georgia and South Carolina have advised residents to limit their consumption of certain fish from the section of the Savannah River in front of the plant. In 2006, sediment tests from the Olin Corporation's canal, which leads to the Savannah River, revealed mercury levels about 1,000 times higher than areas upstream of the factory.[29] The canal sediment was toxic enough to kill sediment-dwelling worms exposed to it for just 3 days. While it is difficult to predict the magnitude of ecological harm caused by these toxic sediments, their connection to the river's fish and wildlife suggest that there are additional localized economic losses that are not quantified in this report, further adding to the conservative nature of our estimate.

In addition to these externalized and largely unaccounted for costs to society and the local economy, the Olin plant endures its own internal costs of continued mercury use, such as production inefficiencies and environmental liabilities that the company pays. It is estimated that it will cost about $3 million to place a cap on Olin's contaminated canal to try to prevent mercury from escaping into the river.[30] Excavating the sediments, a more permanent solution, would cost even more. Additionally, Olin's technology director estimated that the company has spent $48 million over the years to install additional pollution controls[31] – costs that Olin's mercury-free competitors have simply avoided. Additionally, Olin Corporation pays mercury-related waste treatment, storage and disposal costs that add up from year to year.

Oceana estimates that a one-time investment of about $90 million would allow the facility to switch to a mercury-free process.[32] Switching to a mercury-free process makes sense for the public health and environmental benefits, but also because of the benefits to Olin. Increased energy efficiency and capacity, in addition to savings from costs avoided (due to handling requirements of mercury), can help recover most of the conversion costs. Some factories have recouped their modernization costs in less than five years because of increased efficiency, capacity and costs avoided.

Considering all of these costs, not accounting those that can not be quantified as discussed previously, it is clear that a switch to mercury-free technology would benefit not only Olin, but also society as a whole. The $17 million dollar figure represents not only a loss to the economy but also the loss to the quality of life of those who have suffered from these health and environmental costs. The switch will benefit individuals, society and even the company itself. For these reasons, the Olin Corporation should switch to mercury-free technology at its Georgia factory immediately.

## *PPG Industries - Natrium, West Virginia*

The PPG Industries facility in West Virginia operates in part as a mercury-free facility, but about 33 percent of its capacity relies on mercury-based technology.[33] Built in 1957, this facility is the oldest mercury-based chlorine factory in the country and it is the largest mercury discharger to the Ohio River from West Virginia. Based on estimates for the year 2000, for every pound of mercury that is emitted into the air $1,900 will be lost in economic productivity in the United States (See Methods for complete analysis). Mercury emissions from PPG's Natrium West Virginia plant over the past decade are conservatively estimated to have resulted in nearly $20.1 million of lost economic productivity, (range: $7.8 million - $94.1 million). These are hidden costs that society pays for the mercury pollution from PPG's West Virginia plant.

Mercury use at PPG in West Virginia has cost society millions of dollars (1997-2006)

| | |
|---|---|
| Mercury Air Emissions (1) | 10,575 lbs. |
| Attributable Lost Economic Productivity *(Range)* (2) | $20.1 million *($7.8 million - $94.1 million)* |

*Sources: 1) Environmental Protection Agency Toxics Release Inventory; and 2) This report, see Methods for further detail.*

In addition to the costs of the public health effects described above, mercury from PPG's facility has contaminated the local environment. PPG's facility has discharged almost 1,400 pounds of mercury directly to the Ohio River since public data reporting began in 1988.[34] The factory's excessive mercury discharges to the river have not gone unnoticed. PPG has been taken to court multiple times for exceeding the legally allowable amount of mercury that the factory discharges.[35] PPG has been given additional time to comply with its permit, but the company has acknowledged that the factory cannot meet such a low mercury discharge level.[36] In March 2009, Oceana and West Virginia Rivers Coalition announced its intent to PPG Industries over its violations of the Clean Water Act (CWA). PPG's own discharge permitting reports show that it has discharged far more mercury into the Ohio River than its permit allows, including four mercury violations in December 2008. The groups will formally file the case in May. Environmental harm caused by PPG's discharges into the river is not quantified in this report, thus adding to the conservative nature of our estimate.

On top of these external and previously unaccounted for costs to society and the local economy, the PPG plant endures its own internal costs of continued mercury use, such as production inefficiencies and environmental liabilities that the company pays. For example, it is estimated that PPG's facility has spent $13.8 million over the years to install additional pollution controls[37] not to mention the legal costs associated with the permitting process. Meanwhile, PPG's mercury-free competitors have simply avoided costs associated the use of mercury. Additionally, PPG pays mercury-related waste treatment, storage and disposal costs that add up from year to year.

Oceana estimates that a one-time investment of about $71.2 million would allow the facility to convert its mercury-cells to a mercury-free process.[38] Switching to a mercury-free process makes sense for public health and environmental reasons, but also because of the benefits to PPG. Increased energy efficiency and capacity, in addition to savings from costs avoided (due to handling requirements of mercury), can help recover most of the conversion costs. Some factories have recouped their modernization costs in less than five years because of increased efficiency, capacity and costs avoided.

Considering all of these costs, not even taking to account those that can not be quantified as discussed previously, it is clear that a switch to mercury-free technology would benefit not only PPG, but also society as a whole. The $20.1 million dollar figure represents not only a loss to the economy but also the loss to the quality of life of those who have suffered from these health and environmental costs. The switch will benefit individuals, society and even the company itself. For these reasons, PPG Industries should switch to mercury-free technology at its West Virginia factory immediately.

## *Ashta Chemicals - Ashtabula, Ohio*

The Ashta Chemicals facility is the smallest remaining mercury-based chlorine factory in the United States. Built in 1963, this facility had consistently been a large source of mercury air pollution according to the Environmental Protection Agency's Toxics Release Inventory. While recent reports have shown a reduction in reported emissions, readily available air monitoring data surrounding the plants has yet to confirm those reports. Based on estimates for the year 2000, for every pound of mercury that is emitted into the air $1,900 will be lost in economic productivity in the United States (See Methods for complete analysis). Mercury emissions from this facility over the past decade are conservatively estimated to have resulted in nearly $23.1million lost economic productivity, (range: $9 million - $108.1 million). These are hidden costs that society pays for the mercury pollution from Ashta Chemicals' Ohio plant.

Mercury use at Ashta Chemicals in Ohio has cost society millions of dollars (1997-2006)

| | |
|---|---|
| Mercury Air Emissions (1) | 12,151 lbs. |
| Attributable Lost Economic Productivity *(Range)* (2) | $23.1 million *($9 million - $108.1 million)* |

*Sources: 1) Environmental Protection Agency Toxics Release Inventory; and 2) This report, see Methods for further detail.*

In addition to the costs of the public health effects described above, the historic mercury pollution from Ashta Chemicals and its former owners including Linden Chemical Products,[39] have contributed to the degradation of the local environment and Lake Erie. In 1985 the portion of the Ashtabula River that receives Ashta's effluent was designated a Great Lakes Area of Concern due to severe pollution problems from contaminants such as mercury. The Ashtabula River was deemed impaired due to restrictions on fish and wildlife consumption, degradation of fish, wildlife and benthic populations, fish tumors and deformities, and loss of habitat. In 2005 a public partnership agreed to fund a $50 million clean-up of the river to one day hopefully restore these beneficial uses.[40] These are additional localized economic losses that are not quantified in this report, thus adding to the conservative nature of our estimate.

In addition to these external and previously unaccounted for costs to society and the local economy, the Ashta plant endures its own internal costs of continued mercury use, such as production inefficiencies and environmental liabilities that the company pays. For example, it has been estimated that Ashta Chemicals has spent $29.7 million over the years to install additional pollution controls[41] – costs that Ashta's mercury-free competitors have simply avoided. Additionally, Ashta Chemicals pays mercury-related waste treatment, storage and disposal costs that add up from year to year.

Oceana estimates that a one-time investment of about $30.6 million would allow the facility to switch to a mercury-free process.[42] Switching to a mercury-free process makes sense for public health and environmental reasons, but also because of the benefits to Ashta Chemicals. Increased energy efficiency and capacity, in addition to savings from costs avoided (due to handling requirements of mercury), can help recover most of the conversion costs. Some factories have recouped their modernization costs in less than five years because of increased efficiency, capacity and costs avoided.

Adding all of these costs, not even taking to account those that can not be quantified as discussed previously, it is clear that a switch to mercury-free technology would benefit not only Ashta, but also society as a whole. The $23.1 million dollar figure represents not only a loss to the economy but also the loss to the quality of life of those who have suffered from these health and environmental costs. As a result, the arguments for switching to mercury-free technology are both economically and morally justifiable. The switch will benefit individuals, society and even the company itself. For these reasons, Ashta Chemicals should switch to mercury-free technology at its Ohio factory immediately.

## Conclusions

Mercury-based chlor-alkali production reduces the economic productivity of the United States and the world as a whole. Based on this analysis, the four remaining mercury-based chlor-alkali facilities that have refused to upgrade have cost the United States nearly $84 million in lost productivity over the past ten years, solely due to the costs of a single health effect. This public health cost estimate is conservative and does not take into account the majority of the true costs of environmental and social harm, which remain hidden and difficult to measure. While health-based costs identified here cannot be recovered, the costs of conversion to mercury-free technology can be largely recovered in just a short period.

Every year that these companies delay the conversion to mercury-free production, the costs to society, including the lost productivity due to cognitive impairment in children, multiply. This loss in productivity is completely unnecessary; given that mercury-free technology is so broadly available. Of all the industries that still use mercury and aim to eliminate its use, the chlor-alkali sector is at a distinct advantage in having a readily available, economically efficient alternative. In fact, 95 percent of the chlorine capacity in the United States already uses mercury-free technology. The economic, social and environmental benefits of switching to mercury-free technology vastly outweigh the costs.

Recommendations:

- Mercury-based chlor-alkali facilities should immediately upgrade to mercury-free technology.
- Mercury-based chlorine production should be prohibited to ensure that the conversion to mercury-free technology happens in a timely manner.
- Hidden costs of mercury pollution from chlor-alkali facilities, including public health and environmental costs must be addressed when considering the economic "burden" of switching to mercury-free technology.
- Additional studies on the harm associated with mercury pollution should consider health and environmental costs as well as costs resulting from inefficiencies of mercury use in the chlor-alkali sector.

## Methods

The general model used in this study to estimate societal costs of mercury pollution due to the chlor-alkali industry was developed by the Institute of Medicine (IOM)[43] and used by Trasande and colleagues[44] to calculate the costs of lost productivity resulting from IQ decrements associated with mercury exposure from specific anthropogenic sources. It is an "environmentally attributable fraction" (EAF) model which attributes the fraction of costs of specific environmental hazards to a portion of a disease rate.

The model is described by the following equation:

Costs = EAF x Population Size x Disease Rate x Cost per Case

Where, in this study:

> **EAF** = the percentage of IQ decrements from mercury exposure that is due to controllable mercury sources.
> **Population Size** = size of the population at risk from mercury exposure from all sources
> **Disease Rate** = incidence of disease in the population; specifically, IQ points lost in an individual per increase in maternal blood mercury concentration. (units in "IQ points")
> **Cost per Case** = loss of lifetime earnings due to disease (decrease in IQ points), including costs due to losses in productivity, health care and rehabilitation. (units in "$/ IQ point")

This study follows many of the assumptions and calculations that were used by Trasande and colleagues to separate out the societal costs of mercury both from all human sources and from United States coal-fired power plants separately.[45] As with all models, there are a number of assumptions and parameters chosen to estimate each variable. Some of the assumptions and choices used by Trasande et al. in their model were updated or changed in our primary model and are described below. We have, however, retained the original Trasande model to estimate the upper bound in societal costs due to mercury from chlor-alkali plants.

### *EAF:*

Since people are exposed to mercury primarily through fish consumption, the EAF components take into account the sources of mercury in fish, where that mercury originates, as well as both the total amount and the proportion of domestic and imported fish that people consume.

While the sources of mercury are numerous (including natural as well as anthropogenic sources), the EAF may be calculated to separate out the fraction of harm attributable to specific pollution sources, in this case chlor-alkali facilities. The variables used to calculate the EAF in our primary model for this study are listed in Table 3 and discussed in more detail below. For a full listing of differences in assumptions and variables used to calculate the upper, mid (primary model) and lower cost estimates, see Table 4.

***[Table 3]*** Variables used to calculate the EAF in our primary (mid-range) model

| **Variables used to derive EAF due to mercury (Tons or %)** | **Equation** | **Variable** | **Reference[46]** |
|---|---|---|---|
| a. Global emissions (tons) | | 6411 | Seigneur et al. 2004 |
| b. Anthropogenic emissions (tons) | 67% *a | 4277 | Seigneur et al. 2004 |
| c. U.S. Anthropogenic emissions (tons) | | 151.9 | Seigneur et al. 2004 |
| d. U.S. emissions transported globally (tons) | 67%*c | 101.8 | EPA 1997 |
| e. U.S. emissions remain in U.S. (tons) | 33%*c | 50.1 | EPA 1997 |
| f. U.S. mercury deposition (tons) | e + 35 | 85.1 | Seigneur et al. 2004; EPA 1997 |
| h. % Domestic deposition from global sources | 1-i | 41 | EPA 1997 |
| i. % Deposition from domestic sources | e/f | 59 | EPA 1997 |
| j. % Imported seafood consumed in U.S. | | 68 | NMFS 2000 |
| k. % Domestic seafood consumed in U.S. | | 32 | NMFS 2000 |
| l. % Domestic Hg sources in imported fish | (c-e)/(a-f) | 1.61 | |
| m. % Domestic Hg sources in domestic fish | e/f | 59 | EPA 1997 |
| | | | |
| EAF all anthropogenic Hg sources | b/a | 67 | |
| Fraction from all U.S. Hg sources | (k*m) + (j*l) | 20 | |
| Fraction of U.S. Hg sources from Chlor-alkali plants* | 5.7/c | 3.8 | |

** 5.7 tons of mercury were emitted by the U.S. chlor-alkali sector in 2000. See Table 2. All tons are in metric tons unless otherwise noted.*

**[Table 4]** Summary of model parameter differences for each cost estimate

| Model parameters chosen for EAF due to mercury (Tons or %) | High[a] | Mid (primary model, this study)[*] | Low[b] |
|---|---|---|---|
| For EAF due to mercury (Tons or %)<br>a. Global emissions | 5500 | 6411 | 6411 |
| b. Anthropogenic emissions | 70% | 67% | 67% |
| c. U.S. Anthropogenic emissions | 158 | 151.9 | 151.9 |
| d. %U.S. emissions transported globally | 67% | 67% | 67% |
| e. %U.S. emissions remain in U.S. | 33% | 33% | 33% |
| f. U.S. Deposition[c] | 87 | 85 | 85 |
| h. %Domestic deposits from global sources | 40% | 41% | 41% |
| i. %Domestic deposits from domestic sources | 60% | 59% | 59% |
| j. % Imported seafood consumed in U.S. | 42% | 68% | 68% |
| k. % Domestic seafood consumed in U.S. | 58% | 32% | 32% |
| l. %Domestic Hg sources in imported fish | 2% | 1.61% | 1.61% |
| m. %Domestic Hg sources in domestic fish | 60% | 59% | 59% |
| EAF all anthropogenic Hg sources | 70% | 67% | 67% |
| Fraction from all U.S. Hg sources | **36%** | **20%** | **20%** |
| Fraction of U.S. Hg sources from Chlor -alkali plants | 3.8% | 3.8% | 3.8% |
| Population size (year 2000) | 405881 | 405881 | 405881 |
| Disease rate (loss of IQ points / 1-ug/L increase in Hg in maternal blood) | -0.093[e] | -0.093 | -0.036[d] |
| *dose response curve* | logarithmic | linear | linear |
| Cost per case<br>*Life time earnings (male/female) for 2000[f]* | $1,032,002/ $763,468 | $1,032,002/ $763,468 | $1,032,002/ $763,468 |
| *% loss earnings due to IQ decrement (male/ female)[g]* | 1.93/3.23 | 1.93/3.23 | 1.93/3.23 |

*[a]From base case estimate in Trasande et al. 2005, unless otherwise noted. [b]Uses the same parameters as the mid range estimate except for the disease rate. [c]Based on percent of domestic emissions that remain in the United States (e*c) + 35 tons deposited in the United States from global sources (U.S. EPA 1996). [d]From Axelrad et al. 2007 and using conversion ratio of mercury in hair to blood from Budtz-Jorgensen et al. 2004. [e]Corrected negative decrement in IQ due to mercury from Trasande et al. 2006. [f]From Max et al. 2002. [g]From Salkever 1995. [*]Conservative assumptions from lines b,c, and j account for the lower "Fraction from all U.S. sources" in the mid range model. This fraction and the linear dose response curve primarily account for the lower costs estimates compared with the High estimate.*

*Anthropogenic and Natural Mercury Sources*

Although several studies have attempted to quantify the amount of mercury in the environment, the proportion of mercury emissions from natural and anthropogenic sources still remains difficult to accurately measure. Nonetheless, estimates were chosen based on up-to-date studies focusing on mercury emissions in the year 2000 in order to attribute a portion of health consequences to natural and anthropogenic mercury emissions in this study.

Natural mercury emission estimates are highly variable between studies. Estimates for natural mercury emissions from recent studies range from 1,600 tons to 2,134 tons of mercury emitted annually.[47] Trasande et al. (2005) relied on total mercury emissions as estimated by the United Nations Environmental Program in a 2002 report for the year 1995,[48] whereas this study relied on Seigneur et al.'s (2004) estimated level of natural mercury emissions (2,134 tons) out of a total 6,411 tons emitted annually for the year 2000.[49] Seigneur et al.'s more recent estimate of the percentage of total emissions that are from natural sources (33% of 6,411 tons) is considerably higher than the estimate that Trasande et al. used (30% of 5,500 short tons). Choosing a higher estimate of mercury coming from natural sources and the corresponding lower ratio of natural-to-anthropogenic emissions (67% as compared to 70%), adds a conservative component to our mid-range estimate as it will ultimately reduce the magnitude of damage attributable to mercury from chlor-alkali facilities, and thus lower the estimated cost to society attributable to these plants.

*U.S. Anthropogenic Mercury Emissions*

In 1997, the EPA published a comprehensive report for Congress on anthropogenic mercury emissions from the United States. The report estimated emissions for 1995, and concluded that the United States emitted approximately 158 short tons of mercury – or about 3 percent of the global total (5,500 short tons), including natural sources.[50] Seigneur et al. (2004) report that total United States anthropogenic mercury emissions were 151.9 tons in 2000. Using Seigneur et al.'s estimate of total global mercury emissions (6,411 tons annually) and the United States anthropogenic mercury emissions (151.9 tons) we estimated that United States anthropogenic mercury sources accounted for 1.61 percent of the total global mercury emissions. Again, this approach uses conservative assumptions.

In 2000, there were twelve mercury-cell chlor-alkali facilities in the United States that reported mercury air emissions to the United States Environmental Protection Agency Toxics Release Inventory program. These twelve facilities accounted for 12,648 pounds (5.7 tons) of mercury air emissions in 2000 from the United States,[51] or about 4 percent of the U.S. total anthropogenic emissions. It is likely that, in fact, these facilities emitted a much larger amount of mercury due to "lost" mercury that many believe to have been emitted to the air or released to water surrounding the plants. Some estimates suggest that up to 80 percent of the plants' emissions were not reported to the Environmental Protection Agency's Toxic Release Inventory due to this "lost" mercury.[52] Again, since only reported mercury emissions were considered in this analysis, our cost estimate is conservative.

*Global and Domestic Mercury Deposition*

The percentages of mercury from global and domestic sources are used in the EAF calculation to estimate the fraction of United States fish consumption affected by these mercury sources (see Table 3, lines l & m). The ratios used in this paper for domestic and global mercury depositions in the United States are similar to those used in Trasande et al. (2005) (Table 4). Trasande et al. used the most recent estimate available at the time for deposition of mercury in the United States from domestic and global sources.[53] Accordingly, 33 percent of mercury emissions from the United States (33% *151.9 = 50.1 tons) fall domestically, and 67 percent of mercury emissions leave the country and are transferred globally.[54] In addition to this domestic mercury deposition from domestic sources (50.1 tons), the United States Environmental Protection Agency reported that an additional 35 tons of mercury is also deposited in the United States from the global reservoir for a total of 85 tons. Thus, 59% of mercury deposited in the United States is from domestic sources (50/85= 59%) and 41 percent of the anthropogenic mercury that is deposited in the United States is from international sources.[55] These figures are consistent with the more recent estimates of mercury deposition in the United States from domestic sources (9-81%) cited in Seigneur et al. (2004), and Driscoll et al. (2007).[56]

*United States Seafood Consumption*

Seafood is the primary source of mercury exposure for most Americans. Using 2002 landing data from the National Marines Fisheries Service, Trasande et al. (2005) estimated that 42% of edible fish are imported.[57] However, based on seafood consumption data for the year 2000 from the National Marines Fisheries Service, we have estimated that imported seafood accounted for 68 percent of seafood consumption in the United States, and therefore we have used these percentages in our model calculation.[58] Because only a small faction of the mercury in imported fish is estimated to come from U.S. domestic sources (Table 4, line l and see Table 3, line l for the calculation), using a higher percentage of imported fish consumption in our mid-range model serves to reduce the estimated mercury exposure, and costs associated with this exposure, in the U.S. from domestic sources (See Table 4).

*The Environmentally Attributable Fraction of Anthropogenic Mercury and Percentage from U.S. Chlor-Alkali Mercury Emissions*

In 2000, an estimated 67 percent of global mercury emissions were directly attributable to human activities. This is the EAF due to mercury exposure from anthropogenic sources. Of the total mercury emitted globally, roughly 2 percent were of anthropogenic origin from the United States and 3.8 percent of those anthropogenic emissions from the United States were from chlor-alkali factories (Tables 3 and 4). A fraction of mercury emissions from chlor-alkali factories is deposited near the plant and the remainder enters the global mercury pool.[59] Thus, mercury emissions from these factories contribute to contamination of both the domestic (local) and imported fish.

Of the mercury found in imported seafood, an estimated 1.6 percent of this mercury is from United States anthropogenic sources. Of the 151.9 tons of mercury emitted annually from the United States, 50.1 tons are deposited domestically (i.e. 33%*151.9 tons); thus, 101.8 tons (i.e. 151.9 tons - 50.1 tons) of domestic mercury emissions contribute to the global mercury pool of 6,411 tons. However, the 85.1 tons of mercury that is deposited in the United States is removed from the global mercury pool available to contaminate imported fish. Thus, out of the remaining 6325.9 tons (i.e. 6411 tons – 85.1 tons) of mercury available to contaminate imported seafood, 1.61 percent of these are of domestic origin (i.e. 101.8 tons /6325.9 tons) (Table 3).

Most seafood consumed in the United States in 2000 (68%) is from international sources and 1.61 percent of mercury contamination found in imported seafood is attributable to domestic sources. Domestic seafood represents 32 percent of American consumption and 59 percent of mercury contamination found in domestic seafood is attributable to sources from the United States (50.1 tons of United States emissions deposited domestically/85.1 tons total United States deposition, see Table 2). When taken together, an estimated 20 percent of anthropogenic mercury exposure (EAF) is due to domestic anthropogenic sources. This results from adding the product of the percent of domestic mercury sources in domestic fish consumed in the United States and the product of the domestic mercury sources in imported fish consumed in the United States (i.e 0.68*1.61% + 0.32*59%) (Table 3). We multiplied the 20 percent of the EAF attributable to United States domestic sources by 3.8 percent to account for mercury emissions from chlor-alkali facilities alone in the United States (i.e. 5.7 tons emitted from chlor-alkali plants in 2000 / 151.9 tons total United States anthropogenic emissions; Table 3).

### *Population Size:*

The size of the population affected by elevated mercury exposure in the year 2000 was estimated to be 405,881 in Trasande et al.'s (2005) original model. This is the total number of children who were born to women with mercury blood levels above 4.84 µg/L. Using this estimate, Trasande et al. assume no ill effects to those children who had mercury blood levels below 3.41 µg/L, taking into account the ratio of mercury in cord blood to maternal blood (1.7:1).[60] We have used the same assumptions and estimates in our primary model. Percentiles of this population (representing four different exposure levels) are analyzed separately in the model below and then summed to determine total costs (Table 5).

### *Disease Rate:*

The disease rates used in this study are based on the neurodevelopmental effects in young children (as expressed in IQ points lost) due to methylmercury exposure in the mother's womb. In their original study, Trasande and colleagues relied on methylmercury dose response slopes from the two large epidemiological studies in the Faroes and New Zealand as described by the National Research Council (NRC).[61] Trasande and colleagues chose for their primary model, the logarithmic dose response curve for the Faroes data set, which assumed that a doubling of mercury levels in-utero can result in losses of IQ in a range from 0.8 to 2.4 points in unborn children.[62] Trasande et al. also ran the same model using a linear dose response curve in a sensitivity analysis.[63] The linear dose response curve returns lesser effects at lower mercury exposures than does the logarithmic curve and thus reflects a more conservative cost estimate (See Table 4). This linear dose response curve with a slope of -0.093 IQ lost per 1 µg/L of cord blood is used in our primary (mid-range cost) model in this study (Table 4). The disease rate is calculated by multiplying the increase in maternal cord blood mercury level above the reference dose (µg/L) by the dose response slope (IQ points/ µg/L increase in cord blood level). The resulting unit is IQ points which cancels out in the cost per case ($/ IQ point) (See Table 5 and below).

A recent integrated analysis[64] of the three major epidemiological studies reviewed in the National Research Council study produced a linear dose response curve with a lower slope than that used in Trasande et al.'s original study. This analysis by Axelrad et al. (2007) found that for each increase of mercury levels in maternal hair by 1 µg/g (or 1 ppm) there was a decrease in IQ of 0.18 points in the child. This corresponds to a 0.036 decrement in IQ per 1 µg/L of cord blood[65] - less than Trasande et al.'s 0.093 IQ decrement in his linear model. Since all three published approaches apparently have standing in describing the epidemiological data, we have chosen to use Trasande et al.'s linear dose response slope in our primary mid cost estimate, while retaining his logarithmic model for our high cost estimate and using Axelrad et al.'s dose response slope for our low cost estimate (Table 4).

### *Cost Per Case:*

Trasande et al. uses published results from Max et al. (2002) for expected lifetime earnings for children. For males born in 2000, it was expected that these children would earn $1,032,002 over their lifetime while girls would earn $763,468.[66] Each loss of an IQ point results in a decrease in lifetime earnings of 1.931% for boys and 3.225% for girls as reported in Trasande et al. based on Salkever (1995).[67] Health effects are often translated into terms of IQ because methods to quantify the economic value of IQ are well established and frequently used in regulatory cost-benefit analyses to attach prices to and compare benefits gained or lost from proposed policy changes. As such, these methods allow calculation of the costs of any decrement in IQ level and are valid on a population, but not individual, basis.

Using all the above assumptions, our primary model used to derive mid-range cost estimates attributable to mercury exposure from specific sources is presented in Table 5.

The model calculations used in Table 5 (page 19) were run with the High and Low estimate models (Table 4) to set the ranges in costs to society from anthropogenic mercury pollution and the associated fractions from all United States sources and those from the chor-alkali sector (Table 1). These 2000 yearly cost estimates (utilizing the price per pound mercury) were used to estimate costs from the chlor-alkali sector and for each plant both forward and backward in time. We recognize that use of 2000 estimates could overestimate the chlor-alkali contribution to mercury-related costs for the years after 2000 due to lower mercury emissions in those years, but calculating the chlor-alkali contribution of years prior to 2000 based on that year's contributions could underestimate the contribution due to higher mercury emissions in those earlier years. Therefore, use of the year 2000 as a reference point provides a good mid-range balanced approach.

For plant-by-plant synopses, a 1997-2006 timeframe was evaluated because that was the decade for which the most recent publicly available data on mercury emissions were available during the drafting of this report. Toxics Release Inventory mercury emission data for the year 2007 are currently available; however, this data was not publicly available and finalized prior to drafting and peer-reviewing this publication.

***[Table 5]*** Primary mid-range model used to estimate costs of mercury induced IQ loss from anthropogenic mercury sources and associated fractions attributed to domestic and chlor-alkali sources

| **Variable** | **Percentile of population** 90-92.1 | 92.2-94.9 | 95-99.3 | ≥99.4 |
|---|---|---|---|---|
| A. Range of maternal total blood Hg concentration (µg/L) | 4.84-5.8 | 5.8-7.13 | 7.13-15.0 | >15.0 |
| B. Assumed total Hg concentration (maternal total Hg ) (µg/L) | 4.84 | 5.8 | 7.13 | 15 |
| C. No effect concentration (maternal total Hg ) (µg/L) | 3.41 | 3.41 | 3.41 | 3.41 |
| D. Change in concentration ((B-C) *1.7) (µg/L) | 2.431 | 4.063 | 6.324 | 19.703 |
| E. Dose-response slope linear (IQ points/µg/L) | 0.093 | 0.093 | 0.093 | 0.093 |
| F. Disease rate: IQ points lost at assumed concentration (D*E) (IQ points) | 0.23 | 0.38 | 0.59 | 1.83 |
| G. Loss of 1 IQ point = decrease in earning | | Earnings | | |
| H. Lifetime Earnings (male, 2000) | | $1,032,002 | | |
| I. Lifetime Earnings (female, 2000) | | $763,468 | | |
| J. %Lifetime earning loss due to 1 IQ decrement (male) | | 1.93% | | |
| K. %Lifetime earning loss due to 1 IQ decrement (female) | | 3.23% | | |
| L. Cohort (male) affected | 45693 | 58155 | 91387 | 12462 |
| M. Cohort (female) affected | 43601 | 55492 | 87201 | 11891 |
| Economic costs ($U.S. in 2000) N. Costs: Male = 67% (EAF)*L*F*H*J | $138 million | $293 million | $718 million | $305 million |
| O. Costs: Female = 67% (EAF)*M*F*I*K | $163 million | $346 million | $846 million | $359 million |
| Totals | $300 million | $639 million | $1.56 billion | $664 million |
| P. Total cost of anthropogenic mercury* | $3,170,000,000 | | | |
| Q. Cost due to U.S. anthropogenic mercury sources (P*20% ) | $642,000,000 | | | |
| R. Costs due to mercury from U.S. chlor-alkali sector (3.8% *Q) | $24,100,000 | | | |
| S. Costs per pound Hg emitted from chlor-alkali (R/total Hg emissions [lbs])[a] | $1,900/ lb Hg | | | |

[s]*See Table 2 for total Hg emissions (12,648 lbs)*

**Costs do not add due to rounding*

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