MANAGEMENT OF MERCURY IN LIGHTING PRODUCTS

Kevin Begley
Environmental Consultant
Sweden

Torbjörn Linderson
Stockholm University
Sweden

Abstract

Mercury pollution is a serious environmental problem in industrialized countries. One source of this pollution is discarded lighting products which contain mercury. In a world trying to cleanse itself from mercury excess, questions have been raised concerning the environmental impact of the increasing use of these lamps.

Due to technical improvements, the mercury content within each lamp has been reduced by over 50% during the last 20 years in Western Europe. Extended lamp life has provided a further reduction in mercury per lumen-hour. This trend should continue with the application of developed technology in commercially available lamps, as well as probable further technological breakthroughs.

As with nearly any sort of waste problem, pollution prevention needs to be the keystones of any program to deal with mercury from lighting products. Enacting lamp policies to limit mercury content, encourage further reductions, classifying the mercury in lighting products as the hazardous waste it is, and requiring proper recycling of this mercury would all be positive actions in a program for reducing the impact of mercury on the environment. Furthermore, using creative solutions concerning lighting systems can reduce electricity usage and the number of lamps needed. Although lighting products are a minor source of mercury emission sources, they need to be seriously addressed in order to avoiding aggravating already serious mercury accumulation problems.

In regions using fossil fuels or uranium to generate electricity, there is a clear incentive to invest in energy efficient lighting with low mercury content. For example, if conserved electricity results in a reduction of coal use, there would be a net decrease in mercury emissions, even with release of the mercury contained in these lamps. Obviously, a reduction in coal combustion would provide many other environmental benefits as well.

Although the article is international in scope, the main country of reference is Sweden due in part to the relatively large quantities of mercury being recycled from lamps.

MERCURY

Living organisms are adversely effected upon relatively small exposure to heavy metals[1]. Therefore, it is disturbing that human activity has been responsible for emission quantities far greater than environmentally normal background levels[2]. Heavy metals are toxic, bioaccummulate, and they remain persistent in the environment. They constitute a definite hazard[3].

Mercury has been classified as the most dangerous heavy metal[4]. Not only is mercury toxic, but most compounds containing mercury are toxic as well[5]. Methyl mercury is the most important of these compounds from an environmental perspective, as it is efficiently absorbed by organisms. Both organic and inorganic forms of mercury can be transformed into methyl mercury, especially in water sediment where the presence of microorganisms intensifies this process. Both mercury and methyl mercury accumulate as they pass through the food chain[6]. Their toxicity can cause grave and permanent damage to the central nervous system and cause serious genetic injuries, especially to the developing fetus. Mercury and its compounds can upset the chemical balance of the body, and damage a number of organs, most specifically the kidneys with ingestion[7,8]

Mercury vapor forms rapidly from exposed mercury, even at ambient temperatures. It transfers into the blood and the brain much more readily than ingested mercury. About 80% of the mercury inhaled is absorbed[9]. Absorption through the skin probably only occurs in minute amounts. Metallic mercury is disposed through the urine, and organic mercury (including methyl mercury) is discharged through the feces[10]

Mercury is a basic element, it can't be broken down or destroyed through chemical reactions. Therefore, it remains a potential hazard in the environment until it becomes permanently settled into a geologically stabile condition.

Background Case - Mercury in Sweden

Mercury accumulation in Sweden has already reached hazardous levels in many parts of the country. The Swedish Environmental Protection Agency (Statens Naturvårdsverk) estimates that approximately 10,000 of the 83,000 Swedish lakes are so polluted that the fish should not be consumed[11]. Mercury levels in topsoil are close to values which effect microbiological activity. During the 20th century concentrations have risen dramatically[12,13]. Considering Sweden's comparatively low density of industrial activity, this should serve as a warning sign to industrialized countries with a greater density of activity.

Efforts made during the last decade have led to a drastic reduction of mercury emissions in Sweden. However, concentrations in both lakes and soil are still increasing and the leaching of the mercury accumulated in soils, lakes, and waste will cause substantial mercury releases for hundreds of years. This situation is made more severe by the effects of acid precipitation in a environment with few natural alkaline buffers[14]. Critical load estimates calculate that an 80% reduction in mercury emissions is necessary in order to prevent harmful effects to the ecological system[15]. Furthermore, areas of dense mercury accumulation, such as in landfills, must be well sealed, otherwise the situation in such areas will move from acute to chronic. The challenge of staying below critical loads requires that all potential releases of mercury in the environment be addressed.

Discharge lamps are among only a few remaining consumer products sold in Sweden that still contain mercury[16]. The total mercury content in lamps has declined steadily from an estimated 520 kg/year sold in 1987 to an estimated 250 kg/year in 1990[17]. This decrease stems from improvements in lighting technology. Today's lamps last longer and contain less mercury per unit than their predecessors. Currently, lighting products contain about 20% of the mercury in products sold in Sweden and is about 5% of the mercury waste stream[18] Both of these percentages are increasing due to the rapid decline of other sources.

MERCURY IN LIGHTING PRODUCTS

A common mistake made when discussing mercury in lighting products is to focus solely on the lamps. Lamps function in a system (lamp, ballast, luminaire, lighting controls, and lighting layout). The efficiency of this system can have a direct impact on the total mercury used in lamps, as well as power plant emissions. These combined emissions need to form the basis of any discussion on the impact of lighting products.

Note. Mg of mercury/unit and unit lifetime are calculated together as mercury/lumen-hour.

Lamps that contain mercury are all discharge lamps. There are a number of discharge lights which contain mercury:

* Fluorescent tubes (including Compact Fluorescents - CFLs)
* Mercury lamps
* Metal halide lamps
* High pressure sodium lamps
* Mixed light lamps

In 1980, it was estimated that 30 tons of mercury were used globally in various lamps. Of this, 25 tons were used in the 1.2 billion fluorescent lamps produced that year. By comparison, 7000 T/y of mercury are released by nature (volcanos, etc), 6000 T/y are used intentionally, and 3000 T/y are emitted through the burning of fossil fuels. If the mercury contained in a years production of lamps were directly released into the open environment it would still represent less than 0.2% of global annual releases (anthropogenic and natural)[19]. From a global perspective the mercury contained in lamps is not a major source of emissions.

Furthermore, if all discharge lamps where replaced by incandescent lamps of equivalent light output (1980 global lumen-hour levels), then an additional 2,000 TWh/y would be needed globally. This would require 600 MT of coal or its equivalent, emitting an estimated 300 T of mercury, or about 10 times the mercury content of the replaced lamps[20].

Although lighting is not the largest contributor to global mercury emissions it is an important contributor to mercury accumulation. It is an extremely toxic metal which requires only small quantities to pollute large areas, it accumulates, and is very persistent in nature. Furthermore, the mercury in lamps is often disposed of in or near cities, in pin-point locations where the total quantities can cause problems.

Technological improvements have continually reduced the quantity of mercury in lighting, especially in CFLs and fluorescent tubes. More precise dosing, reduced tube diameter, and better phosphor coatings have all contributed to this reduction. The switch from magnetic ballasts to electronic ballasts has also caused a significant reduction in mercury per lumen-hour. Electronic ballasts can extend tube lifetime by over 50%[21]. Any extension of lamp lifetime leads to a mercury/lumen-hour reduction, so long as the mg mercury/unit remains the same.

An example of a recent dramatic improvement can be seen with mercury lamps, which are mainly used for street lighting and in industry. A typical 125 W (135-140 system watts) mercury lamp has an economic lifetime of 16,000 hours, contain 30 mg/unit of mercury, and has an output of 47 lumens/system watt. Philips recently presented a lamp called QL, an 85 W (system watts) low pressure mercury lamp with a economic lifetime of 60,000 hours, a mercury content of 5.5 mg/unit, and an output of 65 lumens/system watt. That's a 95% reduction in mercury/lumen-hours[22]. The QL is expensive and thus is a "special use" lamp, but if prices decrease, it could well replace many standard mercury lamps.

ELECTRICITY GENERATION IMPACTS

Lighting requires electricity, which requires a generating source. All methods of electricity generation have an environmental burden, even when based upon "renewable" energy sources[23] . However certain fuels, such as fossil fuels and uranium, clearly have a greater burden than others. Thus, it is important to examine the varying impacts different lighting products have on emission quantities from these fuels.

According to a study done by Warren Leibold and Lindsay Audin, "The overriding source of pollution from any lighting source is not the lamp or ballast, but the solid, liquid and gaseous wastes produced at the power plants which generate the electricity for the lamp or fixture[24]." Tables 1, 2, and 3 show pollution impact comparisons from various incandescent lamps and CFLs. Pollutant emissions are weighted proportional to the distribution of electricity production from "non-renewable" fuels in the US[25]. According to Leibolds and Audins scenario (Table 1), mercury emissions, as well as emissions of many other pollutants, are more severe using an incandescent lamps, than they are with a CFL[26]. In fact, total mercury emissions were actually decreased by using a CFL lamp (contains mercury) instead of an incandescent lamp (mercury free). This is because there is mercury resident in fossil fuels, especially coal, which is released upon combustion. Incandescent lamps are very inefficient (75 W lamp = 14 lm/system W) and require the combustion of more fuel than a CFL (15 W = 60 lm/system W)[27] There is also a distinction in potential mercury emissions. The mercury in lamps can be recycled. The mercury in power plant ash (and incinerator ash) can't be[28]. In addition, the mercury in a lamps isn't spread high into the atmosphere unless it's incinerated.

Many countries do use fossil fuels to generate electricity - with disastrous effects upon the environment. In these countries (and their neighbors) a reduction in fossil fuel combustion would be a welcome change for the better. For countries heavily dependent on coal for electricity generation, like China and Poland, there are great environmental benefits to be reaped by using energy efficient lighting. Not only would it mean an overall reduction of mercury emissions, but in the emissions of a host of other pollutants as well. This assumes, of course, that electricity supplies are reduced to meet lowered demands.

Table 1: Pollution from lighting operation (gm. per 30,000 hours of operation, unless otherwise noted) for compact fluorescent, "ecolight" incandescent, and standrad incandescent.

Pollutant	Compact Fluorescent	"Ecolight" Incandescent	Standard Incandescent
Mercury	0.059	0.100	0.114
Arsenic	2.72	7.18	7.98
Lead	6.73	17.81	19.79
Sulfur Dioxide	370.1	979.7	1088.6
Nitrogen Oxide (kg)	2.00	5.35	5.94
Carbon Dioxide (kg)	657.3	1740.2	1933.6
Radioactive Gases (microcuries)	533	1410	1570
Radwaste (Ci)	0.21	0.55	0.61
Solid Waste[a] (kg)	145.5	384.9	427.7

[a] This includes ashes, scrubber sludge, "low level" radioactive wastes, etc.

However, it is not only countries who use fossil fuels to generate electricity who benefit from switching from incandescent lamps to CFLs. Table 2 focuses solely on the radioactivity burden created by the use of these lamps. Again, the CFL clearly creates the smallest burden, about 1/3 that of the standard incandescent.

In Table 3, the contribution of direct solid waste is compared. Here one can note how lamp lifetime and ballast type effect solid waste quantities.

Table 2: Total radioisotope burden (microcuries over 30,000 hours of operation) for compact fluorescent, "ecolight" incandescent, and standard incandescent.

	Compact Fluorescent	"Ecolight" Incandescent	Standard Incandescent
Lamp Radioactivity[a]	0/1.2	0	0
Radioactive Gases[b]	533	1410	1570
High-level Radwaste[c]	210,000	550,000	610,000
Uranium In Coal[d]	0.11	0.28	0.31

[a] Electronic ballast CFLs contain no radioactivity. Some magnetic ballast CFLs contain Pm-147 (half-life = 2.6 years) or Kr-85 (half-life = 10.8 years). The curie level listed exists at the time of manufacturing, but drops significantly by the time the lamp is discarded.

[b] These include regulated operating emmisions from nuclear power plants in the US. Kr-85 (half-life = 10.8 years) and Xe-133 (half-life = 5.3 days).

[c] This consists of fission products and transuranic elements with a variety of half-life's (up to millions of years).

[d] This consists of U-235 (half life = 710 million years) and U-238 (half-life = 4.5 billion years).

Table 3: Direct solid waste production (kg over 30,000 hours of operation). for three varieties of compact fluorescents and two varieties of incandescents.

Lamp Type	Units Discarded	Kg of Solid Waste
QUAD CFL (modular)	4 lamps, 1 ballast	0.63
QUAD CFL (integral)	4 lamps, 4 ballasts	0.78
Globe CFL (intergral)	4 lamps, 4 ballasts	1.80
"Ecolight" Incandescent	12 bulbs	0.34
Standard Incandescent	30 bulbs	1.34

A study conducted by the Ministry of Housing, Physical Planning and the Environment in the Netherlands examined the emissions and solid waste released in each stage of the life chain of the eight most important lamp types in the Netherlands. The results are shown in tables 4 and 5[29]

Table 4: Solid waste emissions from lamp operation (milligrams per million lumen hours) for various specified lamp types.

Lamp Type	Mercury	Lead	Copper
Incandescent	2.11	870	1080
Halogen	1.14	74	8000
CFL (bulb)	2.71	81	12840
CFL (QUAD)	2.76	64	2740
Tubular Fluorescent	1.28	23	1360
High Pressure Mercury	1.18	42	770
High Pressure Sodium	0.71	30	665
Low Pressure Sodium	0.18	19	606

Table 5: Air emissions from lamp operation (milligrams per million lumen hours) for various specified lamp types.

Lamp Type	Mercury	Lead	Copper	NOx	SOx
Incandescent	46.8	2.66	0.54	17100	8800
Halogen	25.3	1.44	0.29	9200	4700
CFL (bulb)	14.2	0.69	0.12	4100	2000
CFL (QUAD)	17.2	0.69	0.14	4500	2300
Tubular Fluorescent	10.0	0.45	0.09	2900	1500
High Pressure Mercury	11.5	0.66	0.13	4200	2200
High Pressure Sodium	6.4	0.36	0.07	2300	1200
Low Pressure Sodium	4.0	0.23	0.05	1500	670

CONSERVATION = LESS POLLUTION

The cheapest and easiest way to reduce the flow of mercury in lighting products is to practice energy conservation. Unnecessary electricity use occurs in many ways:

* Unoccupied rooms with lights on
* Overlighting
* Inefficient lamps, ballasts, and luminaries
* Poor design in placing lights

This over-consumption of electricity contributes to a lot of unnecessary mercury emissions, as well as emissions of other harmful pollutants, which are then spread and accumulated into the environment. A little effort to save would go a long way in keeping this planet clean from harmful pollutants. (Not exactly a new concept, but unfortunately it is often ignored and forgotten.)
By combining lighting efficiency strategies lamp use can be optimized to achieve even greater conservation. Here are some of the methods we can use to reduce the quantity of mercury from lighting related sources by either increasing lamp life and/or decreasing the mercury per lamp:

* Lighting design that requires fewer tubes per square meter of illuminated area, while still maintaining lighting quality
* Placing reflective material behind the lamp to increase illumination (a specular reflector)
* Occupancy sensors
* Daylight sensors, and daylighting strategies
* Light timers
* Dimming Controls
* Magnetic ballasts Electronic ballasts
* Higher frequency electronic ballasts
* Long tubes CFLs
* Mercury Vapor Sodium Vapor[30]
* Large diameter Small diameter fluorescent tubes
* Timing group relamping as close to lamp lifetimes as possible Using removed but not-yet-exhausted lamps as interim spot replacement lamps until the next group relamping

Of course, other requirements need to be considered as well. For example, lighting quantity and quality and problems with glare. But, there are many methods to achieve the optimal combination of light quality and energy use, a balance which does not have to be mutually exclusive. It is possible to reduce electricity consumption for lighting, and also maintain or actually improve the lighting environment[31] Creativity can find the answers.

Making the above changes are investments which may have payback periods of several years. Producing and marketing new and improved technology is more costly than with established technology. This means that it is necessary for consumers to reprioritize their system of accounting to reflect the long term economic savings gained by reduced energy costs and lowered labor costs in connection with lamp replacement (where applicable). And, then there are the environmental benefits...

Note To benefit from efficiency improvements requires efficiency transfer - reducing electricity production, or at least avoiding the increase of total electricity consumption (please, no more supply-side energy policies).

LAMP, BALLAST AND LUMINAIRE STANDARDS AND MERCURY LIMITS

The benefits of electricity conservation are clear. The next step is standards and limits.

Standards for decreasing mercury emissions from lighting products:

* Maximum of x mg mercury/unit
* Minimum unit lifetime of y hours
* Minimum unit efficiency of z lm/w

In the US, national and state efficiency standards have been enacted for many appliances (e.g. water heaters, furnaces and boilers, heat pumps, room and central air conditioners, clothes washers and dryers, freezers, refrigerators, dishwashers, and most fluorescent ballasts). These standards have removed inefficient products from the market, saved energy, and saved money for consumers who otherwise would have purchased low-efficiency products which were not comparatively cost-effective. Estimates are that these efficiency standards will have saved consumers $4.3 billion by the year 2000, and will conserve approximately 72,000 GWH/year and 28,000 peak MW/year of electricity. This corresponds to nearly 4% of current installed US electricity generating capacity. When revised standards take effect during the remainder of the 1990's, then the savings will be even greater[32].

Recently, several states in the US have begun to apply efficiency standards to lamps and lighting fixtures[33]. If the standards adopted in the state of Massachusetts were adopted nationally, then the estimated conservation of electricity would be 72,000 GWh/year and 27,000 peak MW/year (approximately equivalent to the combined total of all other appliances with standards)[34] They will also indirectly lower the quantity of mercury/lumen-hour[35] Furthermore, the commission responsible for establishing the lamp standards in Massachusetts estimated that the savings from the standards will be 3-4 times greater than the costs (a benefit/cost ratio of 3-4)[36].

Efficiency standards are the single most effective way to assure that consumers buy medium or high efficiency lighting systems[37]. A side benefit would be that lamps with relatively high mercury/lumen-hour would also be removed from the market. Nonetheless, limits which progressively decrease over time should also be established for mg mercury/lamp in order to assure reductions.

Mercury reductions in alkaline and brown stone batteries sold in Sweden are a dramatic example of what establishing limits can achieve. In 1987 these batteries contained more than 2500 kg of mercury, today heavy metal free alkaline batteries (something the industry once said was impossible) are widely available[38]. As of Winter 1992, all brown stone and alkaline batteries sold in Sweden will be heavy metal free[39] Limits set by environmental groups and the governments of Sweden and Switzerland were the catalyst to this decision[40].
Properly established limits would lower total mercury emissions from lighting products and stimulate research for new solutions. Other incentives, such as comparative environmental labels, requiring manufactures to list mercury/lumen-hour specifications, mercury reduction contests[41], and education and promotion campaigns can also be used to encourage improvements. While there is currently no effective substitute for mercury in low-energy lighting, current "best available technology" can be improved. And who knows, perhaps a mercury free, low energy, long life lamp is waiting to be invented with the right encouragement.

Perhaps certain products should be removed from the market altogether. For instance, magnetic ballasts for fluorescent long tubes and CFLs could be phased out, and those magnetic ballasts that contain radioisotopes should definitely be banned[42]. This can be justified by the fact that the semiconductor based electronic ballasts have much longer lifetimes which means they use much less mercury/lumen-hour, and they contain no radioactive substances whatsoever.

Such actions are not unprecedented. The Swedish government has decided that mercury thermometers will no longer be sold after January 1, 1992. This decision was based on the fact that electronic thermometers are available which provided a much better alternative for the environment.

The same argument can be applied concerning removal of standard incandescent lamps from the market. Clearly, their inefficiency is a major cause of pollution and environmental strain, especially when the source of electricity generation is from either fossil fuels or nuclear power. By replacing incandescent with CFLs, there will be less overall stress upon the environment.

A phase-out of incandescent lamps might go in stages. Removal of standard incandescent (operation ratings worse than "ecolight" incandescent) could be followed by stricter standards later on. It is important that efficiency standards have a system of renewal, so that they continue to be as effective as possible. If a new lamp is developed that is an improvement over current lamps, then standards should be strengthened to help establish the distribution of this technology. For example, if a new low energy lamp without any heavy metal content is invented, then CFLs could be phased-out.

Note: Independent tests have shown that manufacture listed specifications do not always correspond to actual performance[43]. For standards to be applied properly results need to be reliable and comparable. For these reasons independent tests and testing procedures need to be established and standardized.

Controversy Whenever the discussion of standards, limits, and removal of a product is brought up, there are always those who yell, "Wait! That's a trade hindrance!" We don't agree. It's called protection of the environment and public health. Free trade is great, and we hope there will be lot's of competition in the energy efficient lighting market, but free-trade shouldn't mean the right to produce excessive pollution. That's irresponsible. From an environmental stand-point hazardous waste and inefficient electrical appliances should definitely be removed from the market. But, whether environmental sustainablity in the 21st century is given more value than "free-market" ideals from the 18th century remains to be seen.

PRODUCTION OF LIGHTING WITH MERCURY

Most manufactures of discharge lighting use a drop or spray method to apply the mercury into the tube. This method has several drawbacks. Emission problems are created in the manufacturing plant which leads to over exposure for workers, and potentially leads to releases outside the plant as well[44].

Another problem with the drop or spray method is the inaccuracy of the mercury dosing to the lamps. They can vary by several mg. This methods leads to continual overdosing, even with careful application.

So, an important aspect of containing the environmental impacts from lighting products is assuring low emissions during the production process. Designing production equipment and facilities using strategies to prevent emissions can assure minimal emissions during the production process. "Zero emissions" technology already exists in lighting production.

For example, an excellent example of applied pollution prevention strategies are the production techniques used by Philips concerning the use and application of mercury. The entire system functions in "closed loops". That is, these are sealed systems which don't allow for mercury emissions.

Capsules containing specific dosing of mercury (± 0.1 mg) are inserted into each lamp before the lamp is sealed. Once sealed, and the mercury in the capsules is released using ultrasound to burst the capsules. These capsules are mechanical produced and filled in a sealed production system. In cases of lamp defects, Philips uses an in-plant end-cutting machine (Kusters) to recycle most of the elements of the lamp, including reusing the ends of the lamps. Unburst capsules are reused, and the mercury from burst capsules, now intermixed with the phosphor powder, is sifted out and stored for later recycling or disposal[45]..

The capsule method described above allows for rather exact dosing that dramatically helps avoid any unnecessary over-dosing which could potentially leak into the environment, or any underdosing that would cause a premature shortening of lamp lifetime.

Osram also uses an automated and sealed system steered by computers. An amalgam pill (mercury integrated into a little piece of iron) which is inserted into the lamp before it is sealed. The mercury is released from the iron the first time the lamp is lit (ignited). Osram utilizes this technique with their production of high pressure sodium lamps, among others[46]..

MERCURY IN THE WASTE STREAM

Mercury in lamps has been classified as a hazardous waste by the European Community. Many observers in Sweden are concerned about uncontrolled mercury releases that occur when fluorescent lamps are disposed of as common refuse[47] This is a legitimate concern.

For example, the modern incineration techniques used in Sweden, manage to filter out about 95% of the mercury emissions from smoke stack emissions. The remaining 5% that is emitted into the air attaches itself to small micro particles upon cooling down. These particles constitute a health problem[48] as well as cause long term accumulation problems downstream[49] Most of the removed 95% is in the fly ash. Unfortunately, Sweden has yet to classify fly ash as the hazardous waste it is[50]. Instead, it is placed into common landfills. Due to the concentration of the fly ash, there is little to bind the mercury into more stable compounds[51]. Instead, there exists an increasingly larger leachate problem, of high concentration, at a specific point[52] For these and other reasons, it is extremely important that mercury is not incinerated.

Mercury contained in municipal solid waste that is landfilled (without incineration) has a greater chance of binding itself to other substances and thereby possibly remaining in a stable condition within the landfill. However, this does not prevent the well documented leachate problems associated with landfills (even modern ones). The leachate is less concentrated and thereby dispersed more slowly than with landfilled incineration fly (and bottom) ash, but the environmental and health problems still exist[53]. Furthermore, laser analysis has shown that gaseous mercury is emitted from landfills as well[54]. Therefore, it is important that mercury is removed altogether from municipal solid waste.

RECYCLING

Recycling reduces a degree of the potential emissions. It helps to decrease the quantity of mercury being disposed of, and decrease the quantity being extracted as a raw material, even if the total quantities circulating in products remains the same. Recycling mercury in lamps is an essential temporary solution until mercury free low energy lamps are developed.

Recycling involves effective collection and delivery of lamps, effective extraction and separation of the mercury in these lamps, proper disposal of the remainder of the lamps, and reuse of the extracted mercury. During each of these stages, it is important that the mercury is contained in a safe manner so as to assure that mercury emission releases do not occur, thus avoiding the endangerment to public health (especially among workers) and the environment.

Unfortunately, the sale of recycled mercury only covers a small part of the recycling costs. These costs must be covered by consumers, producers, or some other sponsor, perhaps by communities or national governments.

RECYCLING IN SWEDEN

Most countries are just beginning to recycle mercury in lighting products in significant quantities. However, Sweden has been doing so for over a decade. Currently, an estimated 30% of the discarded mercury in lamps is being recycled. All these lamps are sent to Kvicksilver Återvinning AB (Mercury Recycling Inc), a facility in the city of Karlskrona[55].

Presently, the operation recycles mercury from all types of lamps. These lamps are collected locally, crushed into sealed packages, and then transported to Karlskrona. The material is sifted into various fractions - metal, glass, and the phosphor powder, which contains the majority of the mercury. This powder is heated in a vacuum chamber, and most of the mercury is then condensed in cooling traps, with the remainder absorbed by a charcoal screen. The metal fraction is sent to a metal recycling company, the glass is sent to a landfill, and the remains of the fraction powder are sent to the national facility for handling of hazardous waste (SAKAB)[56, 57].

There has been one reported case of over-exposure, which was apparently due to employee error. Airborne emissions from the plant have been less than 1% (>1 kg) of the total flow of mercury processed at the plant[58]. Airborne emissions for all the recycling activity has been cautiously estimated at 3% of the processed mercury[59]. Recycling costs, including transport, are approximately 5.5 SEK ($0.89) per lamp[60]. Energy use, including transport, is approximately 0,02 percent of the lifecycle energy consumption of fluorescent tubes[61].

MRT manufactures all the equipment used in the recycling facility. They also manufacture a machine that cuts the ends off of long tubes allowing the phosphorus (containing phosphorous and mercury) to be blown out of the tubes. The mercury is then processed as described above. Osram manufactures a similar end-cutting machine.

Integral CFLs (a single unit combining both ballast and lamp) present a special problem. Integral CFLs are expensive to recycle because the ballast section is difficult to separate from the lamp, and can cause damage to the recycling equipment. Modular CFLs (separate ballast and lamp) simplify recycling operations, reducing costs[62] By allowing only modular CFLs recycling problems are limited to a manageable little lamp whose bottom can easily be cut off, rather than the snarl of electronics or mechanics the current one-piece CFLs cause in the recycling process. Consumers can reuse the longer lasting ballast section by merely snapping in a new lamp. A more cost-effective option and a double gain in terms of the environment.

SOURCE SEPARATION AND COLLECTION

The very cornerstone of effective recycling is source separation. Source separation means keeping different types of waste separate so that they can be collected and recycled in the easiest and most effective manner possible. Unseperating mixed waste has never achieved golden results, and is just plain counter intuitive. Why mix it up in the first place?

It is also important to assure that these users are provided with the information and the opportunity to deposit their old lamps. Even more important, is to conceive a system that assures that lamps are not broken during deposit, storage, and collection.

Residential Sources

This would include small locations, such as local shops, and businesses, which at most replace a few lamps a year.

Residential and small business use of fluorescent lighting is widely scattered. Due to the long life of the lamps, replacement is a seldom and sporadic occurrence. Like other types of residential hazardous waste, lamps with mercury have a much slower turn over time than they do in industry and business. This limits the volume of quantities for collection. For example, if a small apartment complex where to deposit 25 lamps a year, these lamps could fit into an 8 liter container[63] Because the quantities are relatively small, residential lamps are largely not collected in Sweden, except from large complexes which perform group relamping. However, more attention has recently been placed upon residential lights, and several small pilot tests involving strategically located containers are being conducted.

To assure that large quantities can be successfully collected requires a clearly defined system which can be safely applied. Users need to be provided with the information and the opportunity to deposit there old lamps, and a system(s) needs to be designed that assures that lamps are not broken during deposit, storage, and collection.

Below we list a variety of possible solutions. We feel a system of deposit and return with recollection occurring at retail shops to be the best solution. However, a combination of all the solutions listed below might provide the flexibility to cover almost ever area in a society.

It is important that wide reaching campaigns are run in order for people to be aware that they should recycle their discharged lamps. This should include labels on packaging, advertisements in the media, and notices sent to their residency and place of business.

Deposit System with Recollection in Retail Shops

Results with beverage containers in Sweden have shown that having a deposit system increases collection percentages. Customers pay a deposit upon purchasing a lamp, which is then refunded upon returning the lamp to a store which sells lamps. Such a system might also increase the possibilities of replacing the old energy efficient lamps with new ones. Furthermore, in this way it might be possible to require that companies be responsible for recycling efforts (see below - Alternative Concept).

Collection Stations

Collection stations are becoming common everywhere. Located in squares, outside super markets, in parking lots, they often consist of various containers for people to deposit their glass, cans, and other items to be recycled. A special container could be placed here for collection of lamps containing mercury. However, due to the potential toxic health problem, it must be assured that absolutely no mercury emissions occur, which can easily occur if the lamps are broken.

Specially Located Hazardous Waste Collections Stations

Collection stations for hazardous waste are located in strategic areas, where people can drop off their household hazardous wastes. In Sweden, these are often located at gas stations. A possible solution for low density areas. As we mentioned above, toxic health problems must be avoided.

Intermittent "household" collection

A spin-off on the "curbside" collection concept which has been so popular in the US. With this system, a special vehicle designed to handle hazardous wastes goes to different residential and small business areas and sets up a temporary collection center (one to several days). Announcements are sent out before the vehicle arrives and is set-up. The problem here is penetration. How many people are willing to hold onto their lamps several months before they can drop them off to a truck? And, how many will have the opportunity during the specified time to make a deposit of their lamps and other hazardous waste? Because this system is not very convenient we feel it would not be very successful.

Industrial Quantities

Included in this definition would be any large scale facility, such as schools, government buildings, the military, etc. which replace large or medium quantities of lamps every year. These can include any type of lamp containing mercury, but most common are the long fluorescent tubes.

A common feature of these lighting sources is that they perform "group relamping". That is, all the lamps are replaced at the same time according to a time schedule based upon the manufacture specified lamp lifetime. Spot lamp replacement occurs for lamps that either break or have an early death. In Sweden, these large quantities are placed into one or several containers where upon either the municipal waste company or a private waste transport company pick up these containers, crushes the lamps, and send them to the Karlskrona facility.

Any lamps that are not collected in large groups can be dealt with as part of what we have called the residential lamp collection program.

Alternate Recycling Concept: Making Producers responsible for the discarded product

Having producers and suppliers be responsible for their product refuse can be looked at as a system of deposit (the product) and return (with the refuse) for business. It establishes a logical recycling link for both material (raw material product raw material) and product (producer customer producer). The customer pays for the product and its recycling, the producer is made responsible for what they produce. This helps avoid excessive government involvement while requiring business to administer the system with free-market efficiency in order to keep product prices low.
Such a system could be applied at retail stores, as well as in industrial and other locations.

As an example, the beverage industry in Sweden was required to develop and administer their own deposit and collection system for discarded containers. For aluminum cans, they have placed machines at the entrance of stores which accept cans in return for a receipt to be cashed by the store. The system is privately run and funded. 85% of all aluminum cans are collected and recycled. A similar system exists for glass beverage bottles (98% are collected), as well as a newly established system for PET beverage bottles[64]. Both of these bottles are washed and refilled.

CONCLUSION

Lighting policies should be designed to bring forth the most environmentally friendly lighting products possible. Such decisions should be consistent with reliable statistics of complete lifetime lighting impacts. Based upon what is currently known, using efficient lighting systems can decrease environmentally dangerous emissions from electricity generation facilities, as well as avoid other environmental degradation. For this reason, we recommend that efforts be intensified to extend the usage of energy efficient lamps as much as possible.

Nonetheless, mercury is a serious toxin that creates long-term environmental problems which don't disappear when emissions stop. Accumulation is the key word. Mercury pollution has been spread across the surface of the planet, dumped into its waterways, and accumulated by its species. Therefore, every effort should be made to reduce and eliminate mercury emissions, including the mercury in lamps. Mercury quantities in lamps should be decreased and be more exact, lighting systems be made more efficient, and lamp lifetimes be extended. This has been the trend during the last decades, and hopefully it will continue at an accelerated rate. Furthermore, lamps need to be collected and recycled in order to minimize the release of mercury in the environment. Finally, research should be encouraged and stimulated for the development of a longlife, energy efficient lamp that uses no mercury or other acute toxin, and has good color spectrum rendering.

Governments and other agencies can pursue creative policies to achieve reductions of mercury in lighting products, such as: standards and limits, contests, and comparative labeling with mercury/lumen-hour ratings.

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REFERENCES AND NOTES

[1] Bjarni Jensson, et al, *Insamling och Återvinning av Kvicksilveravfall - Huvudstudie* (Collection and Recycling of Mercury Waste - Main Study), 1990, Stiftelsen REFORSK, Malmö, Sweden, Report #49 (in Swedish).

[2] *Kvicksilver - Problem, Miljömål, Åtgärder* (Mercury - Problems, Environmental Goals, Measures), 1990, Naturvårdsverket, Solna, Sweden, Report #3764 (in Swedish).

[3] A large number of international agreements have recognized this; among others the Paris and Helsinki agreement.

[4] *Mercury in the Environment - Problems and Remedial Measures In Sweden*, 1991, Naturvårdsverket, Solna, Sweden.

[5] Bjarni Jensson, et al, op cit, Ref 1.

[6] *Kvicksilver - Problem, Miljömål, Åtgärder* (Mercury - Problems, Environmental Goals, Measures), op cit, Ref 1.

[7] One reason mercury is so dangerous is that it binds tightly together with sulfur atoms, which are in most of the bodies proteins. Sulfur has the important function of maintaining the proteins proper form. Mercury deforms protein so that it stops functioning. Mercury can be passed to infatns through breast milk. Both sperm and kidney production are possible effected. Organs such as the lungs and liver can be injured depending on the types and methods of absorption. Mercury is also an allergenic.

[8] Bjarni Jensson, et al, op cit, Ref 1.

[9] Elin Eriksson, *Kvicksilverbalans Över Sverige - En Materialströmsanalys* (The Mercury Balance in Sweden - A Flow Analysis), 1988, Institute for Water Supply and Sewage Treatment, Chalmers Technical University, Göteborg, Sweden (in Swedish).

[10] Bjarni Jensson, et al, op cit, Ref 1.

[11] The national limit for mercury content in food is 1 mg/kg, a level roughly double many other industrialized contries.

[12] Mercury concentrations have increased by a factor of 4-7 in southern and central parts of the country and 2-3 in the north.

[13] *Mercury in the Environment - Problems and Remedial Measures In Sweden*, op cit, Ref 4.

[14] *Kvicksilver - Problem, Miljömål, Åtgärder* (Mercury - Problems, Environmental Goals, Measures), op cit, Ref 2.

[15] *Mercury in the Environment - Problems and Remedial Measures In Sweden*, op cit, Ref 4.

[16] The others are batteries, and household thermometers. However, as of 1/1/92, neither thermometers, nor alkaline and brownstone batteries will be sold in Sweden.

[17] Based on calculations received in personal communications from Börje Beronius, OSRAM Light Consulting, Sweden on 16/10/91 and Leif Bergren, Philips Lighting, Sweden on 15/10/91.

[18] Revised calculations based on information from Bjarni Jensen, et al., op cit, Ref 1, and discussions with Anders Kjellund at Naturvårdsverket (The Swedish Environmental Protection Agency).

[19] *COMPETITEK*, 1988, Rocky Mountain Institute, Snowmass, Colorado, USA.

[20] *COMPETITEK*, op cit, Ref 19.

[21] Börje Borenius, op cit, Ref 17.

[22] Based on manufacture specifications from Philips Lighting Corporation. This calculation does not include Hg reductions incurred from lowered consumption of electricity in coal or oil fired generation units.

[23] These are related to construction impacts and habitat loss. For example, loss of a wild river, the allocation of land to solar and wind power. With energy crops there are also machinery and transport impacts. Finally, there are the substantial economic costs of establishing any type of power generating facility and its accompanying accessories.

[24] Warren C. Leibold and Lindsay Audin, *Compact Fluorescents, Radioisotopes and Solid Waste*, 1991, Draft Version. Contact Warren Leibold at Goldman Copeland Associates, New York, and Lindsay Austin at the Dept of Energy Conservation, Columbia University, New York.

[25] In 1990, the mixture of electricity production by non-renewable fuels in the US was coal 43.2%, nuclear 20.3%, oil 4.3%, and natural gas 8.6%. Again, pollutants are weighted according to their proportional distribution of US electricity from fuels which are "non-renewable". Other sources of electricity generation where not considered for these calculations. The calculations were based upon 30,000 operating hours. An Incandescent was assumed to have a lifetime of 1,000 hours and draw 100 watts, an "ecolight" incandescent 2500 hours and 90 watts, and a CFL 7,500 hours and 25 watts (a conservative estimate because they may last up to 10,000). Warren Liebold and Lindsay Audin, op cit, Ref 24.

[26] The "ecolight" emits about 15% less pollution than a standard incandescent, but it is still far inferior to the CFL.

[27] Allan Ottosson, *Developments In Energy-Efficient Lighting Technology*, 1991, 1st European Conference on Energy-Efficient Lighting, Stockholm, Sweden.

[28] We are aware of no such possibility in any case. It might be technical feasible, but the costs would be exorbitant.

[29] *Environmental Aspects of Lighting: A Product Oriented Approach - Final Report*, 1990, Ministry of Housing, Physical Planning and the Environment, Rotterdam, Netherlands. Pollutant emissions from electricity consumption were weighted proportional to the distribution of electricity production from "non-renewable" fuels in the Netherlands. In 1986, the mixture of electricity production by non-

renewable fuels in the Netherlands was natural gas 62.3%, coal 27.3%, nuclear 8.4%, and oil 2.0%. The calculations were based upon one million lumen hours. Lamp values were based upon "representative" lamps (for details please see their report). Transportation and production impacts are also included.

[30] Both high pressure sodium and low pressure sodium, depending on the application.

[31] Example: Vattenfall, the largest generator of electricity in Sweden, retrofitted their main office from a 1960's lighting system to a modern 1990's lighting system. By orienting the lighting to workplaces, installing adjustable placement lighting, using electric ballasts, and replacing incandescent lights with CFL's, they were able to reduce power consumption for lighting by 60%. These changes, in conjunction with increased product lifetime, resulted in a 60% reduction of mercury in the lighting system. Furthermore, employees felt the lighting environment was improved. Source: Vattenfall brochures and personal communications with Thomas Sundén at Vattenfall and Per Åke Alm at Philips, Sweden.

[32] Steven Nadel, *Efficiency Standards for Lamps, Motors, ad Lighting Fixtures,* American Council for an Energy Efficient Economy, Washington DC, USA.

[33] Massachusetts, New York, and California.

[34] This is impressive considering tht these standards would only remove the worst technogies from the market, but come nowhere near the conservation potential using "state of the art" technology.

[35] Steven Nadel, op cit, Ref 32.

[36] Steven Nadel, Howard Geller, Fred Davis, and David Goldstein, *Minimum Efficiency Standards for Fluorescent and Incandescent Lamps*, Amercian Council for an Energy Efficient Economy.

[37] Other solutions are building codes (also a standard), rebate programs and education programs. However, building codes only apply to construction and renovation activity, rebate programs are utilized by a relative small percentage of those eligible, and education efforts are often less effective than rebates. Nonetheless, these efforts are important compliments to standards.

[38] *Kvicksilver - Problem, Miljömål, Åtgärder* (Mercury - Problems, Environmental Goals, Measures), op cit, Ref 2.

[39] Personal communication, Stig Petersson, Tudor Batteries, Stockholm, Sweden, 17/10/91, and Anders Kjellund, Statens Naturvårdsverket (The Swedish Environmental Protection Agency), 13/10/91.

[40] In Sweden, the Swedish environmental organization Naturskyddsföreningen established heavy metal limits for receiving special environmental labeling on batteries (which became important for marketing by the industry). The Swedish Government followed this up with allowable heavy metal limits for batteries. The Winter 1992 timeline was made by the industry as a preemptive strategy to avoid further governmental involvement. The effects of this decision will be felt throughout Europe.

[41] Contests which reward the manufacture who achieves the best overall rating of mg/lumen-hour. A similar contest sponsored by The Swedish Department of Energy (Statens Energiverk, 2/8/90) for energy efficient refrigerators with reduced atmospheric ozone impact was very successful.

[42] Certain magnetic ballast lamps contain either Promethium-147 (Pm-147) or Krypton-85 (Kr-85), which are used as part of the lamp starter circuit. Electronic ballast lamps contain no radioisotopes.

[43] Steven Nadel, op cit, Ref 32.

[44] Ansökan om tillstånd enligt miljöskyddslagen till verksamhet vid Lumalampan AB i Karlskrona (Application by Luma Lighting Inc, Karlskrona, for operating permission in accordance with the Law of Environmental Protection), till Länsstyrelsen i Blekinge Län (submitted to the government of Blekinge municipality), Sweden, on 9/28/89 (In swedish).

[45] *Environmental Aspects of Lighting - A Product Oriented Approach, Final Report,* 1990, Ministry of Housing, Physical Planning and the Environment. Personal communication with Goep Rümans, Philips, Netherlands, 9/10/91. Unfortunately, we have not been able to get any data concerning the in-plant mercury balance of this method.

[46] Personnel communication, Börje Beronius at Osram Sweden, 11/10/91.

[47] Mercury in lamps has still not been declared a hazardous waste in Sweden.

[48] Specifically, the cilia in the air channels leading to the lungs do not work against particle below 3 micrometers in size. Such particles are instead embedded into the lung tissue and can cause a variety of health problems. The paper and plastic burned in waste incinerators produces many particles below 2 micrometers in size, to which mercury readily binds itself to as the gaseous mercury cools down.

[49] Torleif Bramryd, *Environmental Effects In Connection To Waste Incineration,* 1990, Ecology Institution, Lunds University, Sweden.

[50] *An Environmental Review Of Incineration Technologies - A Technical Report,* Institute For Local Self Reliance, 1986, Washington DC, USA.

[51] The authors are aware of no methods to recycle the mercury in incinerator fly ash or bottom ash.

[52] Torleif Bramryd, "Leaching of Heavy Metals From Solid Waste Incineration Ashes" in *Energy Recovery Through Waste Combustion,* Elsevier Applied Science, London and New York.

[53] Joseph R. Visalli *The Similarity of Environmental Impacts From All Methods of Solid Waste Management,* 1989, New York State Energy Research and Development Authority, Division of Municipal Waste and Environmental Research, USA.

[54] Personal communication, Cindy Dewitt from Naturvårdsverket, March 1990.

[55] Anders Kjellund, op cit, Ref 39, and the operations chief at Kvicksilver Återvinning, Karlskrona, Sweden, 13/10/91. Kvicksilver Återvinning AB is a subsidiary of Sellsberg AB.

[56] The recovered mercury is sold to Degussa in Germany.

[57] Personal communication, Hans Månsson, MRT System, Karlskrona, Sweden. MRT System AB is a subsidiary of Luma Lighting AB.

[58] Ansökan om tillstånd enligt miljöskyddslagen till verksamhet vid Kvicksilver Återvinning AB i Karlskrona (Application by Mercury Recycling Inc, Karlskrona, for operating permission in accordance with the Law of Environmental Protection), till Länsstyrelsen i Blekinge Län (submitted to the government of Blekinge municipality), Sweden, on 11/29/90 (In swedish). According to officials, recently set allowable airborne emissions are now 0.5 kg/year based on plant emissions of 0.4 kg for the previous year of operation. The company also has permission to place up to 5 kg of mercury into the communities landfill (trace quantities on the separated glass), but we have been unaqble to find any estimates of how much mercury has actually been deposited there.

[59] Leif Eriksson, Sellsberg AB, Stockholm, Sweden 13/10/91, and Hans Månsson, op cit, Ref 57. Customers collect the lamps themselves and deposit them into the containers sent to the compactors. We contacted various municipal utility and waste officials in Sweden responsible for collecting lamps, and according to them, lamp breakage has not been a problem. However, customer collection containers appear to have few special safety features. The compactors use a charcoal filter which they send to Karlskrona to be recycled, emissions are 1.5% of total mercury. Compactor workers wear whole covering masks with special gas and mercury filters.

[60] Leif Eriksson, op cit, Ref 57. From Göteborg the costs are 4.95 SEK ($0.89); personal communication, Lars Mel, Göteborg Renhållningsverk (Gothenburg Municipal Waste Management), Sweden, 14/10/91. Kvicksilver Återvinning charges 3 SEK ($0.48) for the recycling; Kvicksilver Återvinning, op cit, Ref 53; Charges are based on 200 kg containers holding an estimated 1000 lamps, and an exchange rate of 6.25 SEK/$.

[61] Personal communication with Hans Månsson, op cit Ref 38, and SAAB SCANIA engine division. In the current process 1.23 Wh electricity is used per mg of recovered mercury. Assuming 50,000 lamps per truck, average transport distance of 500 km, using 250 liters of diesel fuel (2600 Kwh), and 20 mg of mercury/tube this calculates into 2.6 Wh/mg mercury for transport. Thus, the combined energy use for transport and processing is 3.85 Wh/mg mercury. Depreciation of equipment has not been considered in this calculation. Most other industrialized countries would have shorter transport distances.

[62] Hans Månsson, op cit, Ref 57.

[63] This assumes a volume of 0.3 dm^3/CFL.

[64] According to Ingrid Johnsson at Naturvårdsverket (The Swedish Environmental Protection Agency) these are the latest figures. Personal Communication, 10/18/91.