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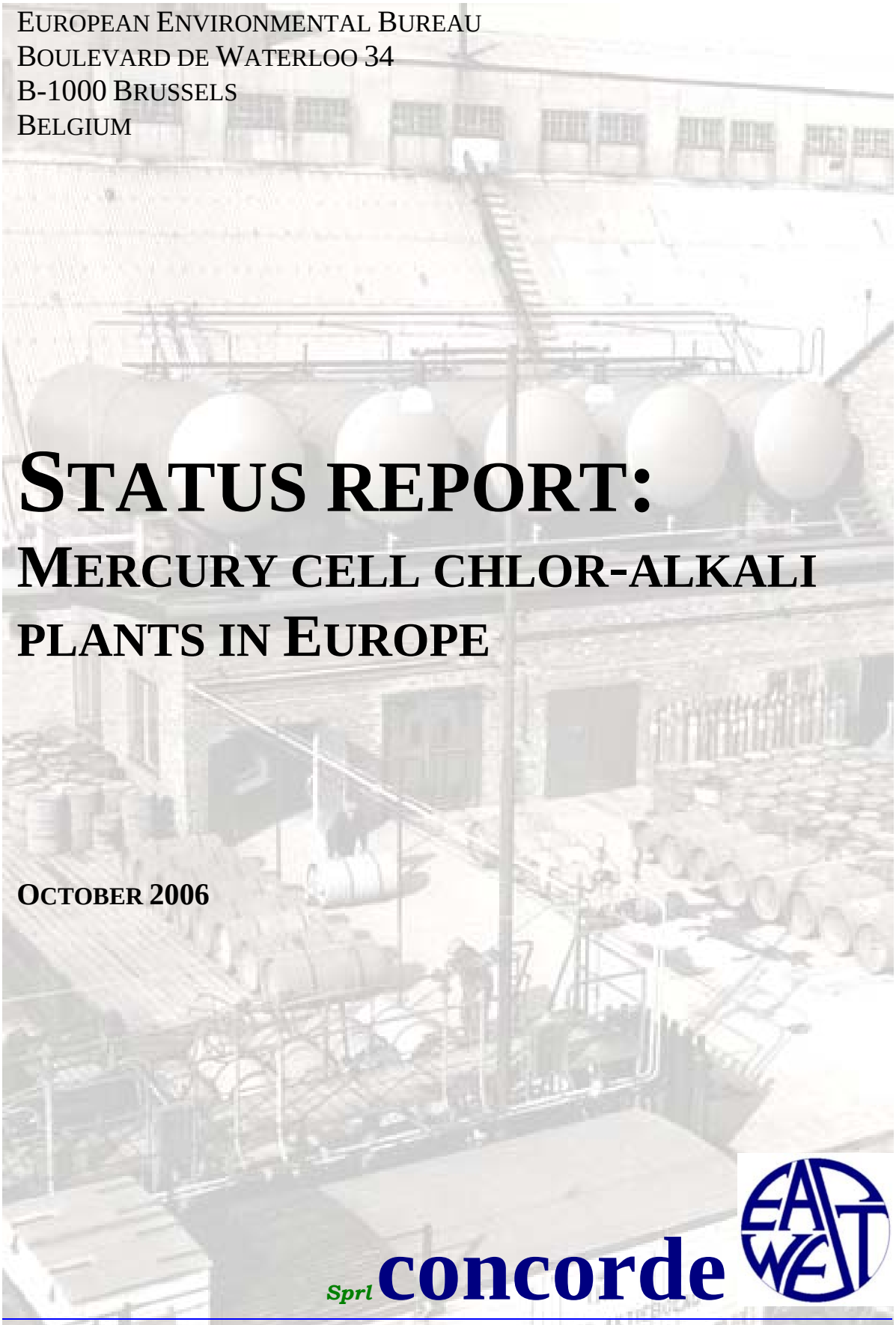

STATUS REPORT:
MERCURY CELL CHLOR-ALKALI PLANTS IN EUROPE

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Executive summary

The chlor-alkali industry is a major player in the European chemical industry. In 2005 it produced about 10.2 million tonnes (hereafter meaning “metric tonnes”) of chlorine and nearly 11.5 million tonnes of caustic soda in Europe, with a market value of some 7 billion (i.e., thousand million) euro. More impressive still, industry literature claims that European chlorine and caustic soda production “underpin” over 300 billion euro of the European chemical industry turnover. Meanwhile, in the European Union (EU) chlor-alkali industry prospects and profits appear to be as attractive as at any time during the last 20 years.

Mercury consumption

In the production of chlorine and caustic, the European chlor-alkali industry consumes 175-200 tonnes of mercury[†] every year – amounting to 40-50% of the total EU consumption of mercury – in mercury cell chlor-alkali plants (MCCAPs). Historically important in Europe, these plants use mercury in a highly energy-intensive electrolytic process that is more than 100 years old. Alternative technologies have been available for many years – especially the membrane process – that use no mercury, use far less energy, and are widely regarded to be superior, both economically and environmentally.

Regulation of mercury cell plants

While many of the MCCAPs in Europe (and elsewhere) have already been converted to mercury-free alternatives, just under 50 of these plants remained in operation in the EU at the beginning of 2005, responsible for nearly 6 million tonnes of chlorine production. Mercury consumption and releases have been greatly reduced from the 500-1,000 tonnes per year estimated in the 1970s. However, the average age of the EU plants is nearly 35 years, and further efforts to reduce mercury releases below present levels may challenge the technical limits of what is possible without converting to a mercury-free process.

Unacceptably high mercury emissions before and into the 1980s pressed the member countries of PARCOM (also known as the OSPAR countries) to recommend in 1990 that the mercury cell chlor-alkali process should be phased out by 2010. The European IPPC Bureau, in its 2001 BAT (best available techniques) Reference Document on the chlor-alkali industry, confirmed that the mercury cell process does not reflect BAT, and the IPPC Directive calls for non-BAT processes to be phased out by mid-2007.

[†] As in other sectors of mercury demand, this range includes some mercury that goes into the waste stream and is subsequently recovered.

The implementation of the 1990 PARCOM Decision, and the IPPC Directive as well, are ultimately the responsibility of each of the countries concerned; however, their uneven response to PARCOM, and the prospect of many countries taking a flexible interpretation of the 2007 IPPC deadline with regard to their MCCAPs, reflect the diverse and shifting political and economic priorities of different countries within the EU. In the larger EU countries, typically endowed with a larger number of MCCAPs, there is no general agreement that a phase-out of the mercury process is needed before 2020. The production costs of these old plants are low and, apart from the MCCAPs that have already been phased out for strategic and economic reasons, the remaining operators have not been eager to invest in converting to a mercury-free process.

Industry commitments

As a result of periodic discussions with industry, regulatory authorities of various EU countries have chosen to postpone or ignore phase-out deadlines in return for industry commitments of, e.g., further decreases in mercury emissions, and more detailed reporting. The assurance of continuing decreases in mercury emissions is the most crucial commitment, since it has supported the industry argument that the risks of MCCAP emissions to health and the environment are now negligible, and do not justify the proposed 2010 phase-out.

For example, the self-imposed industry target for 2007 is an EU average of one gram of mercury emitted per tonne of chlorine capacity. European representatives to the UN ECE Convention on Long-Range Transboundary Air Pollution (LRTAP) discussions have said they expect to be able to reach an EU industry average of 0.75 gram of mercury emitted per tonne of chlorine capacity by 2012, although some North American representatives to LRTAP consider such targets unrealistic. Meanwhile the best-performing EU MCCAPs are reported to already achieve emissions of 0.2-0.5 gram per tonne of chlorine capacity, and this lower range of emission limit values is reflected in the BAT Reference Document on chlor-alkali production.

Industry reporting

The only way to demonstrate such environmental performance is by accurately measuring emissions. However, one result of the massive amounts of electricity consumed by MCCAPs is that the cell rooms, where the process mercury is located, are very hot, and traditionally open-sided or otherwise extremely well ventilated. Combined with a process design that inherently provides many opportunities for mercury vapour leaks, which may not be readily detected, mercury emissions to the atmosphere have been particularly difficult to measure accurately. Likewise, it is quite difficult to know the amounts of mercury disposed of in diverse wastes. Over time, the industry has developed various methods and guidelines for measuring and/or estimating consumption and releases of mercury. New analytical devices and techniques have also become available to help in that effort, but their adoption has not been systematic.

The basic reporting approach is focused around a “mercury balance,” i.e., the generally sound assumption that all of the mercury put into a MCCAP process eventually comes out of that process – whether as emissions, as mercury in chlorine or other products, as mercury in wastes, etc. Nevertheless, as mentioned previously, even with the best intentions, estimates and extrapolations remain a fact of life in generating these reports.

Mercury emissions and other elements of the mercury balance are reported annually in the EU by each participating MCCAP operator using a standard form. Operating MCCAPs typically send their reports to government regulators and to Euro Chlor, the association of European chlorine producers. Euro Chlor, in turn, condenses and compiles the information for annual reports to OSPAR, for publishing on its website, etc. It must be mentioned that the published reports retain a certain number of questionable or meaningless data. Nevertheless, once published, the OSPAR reports are widely accepted as accurately representing industry performance. Largely because there has been no alternative source of viable data, the EU industry data have been generally accepted in IPPC-related discussions of best available techniques, they have been introduced into the LRTAP process (and viewed as overly optimistic by some participants), they have been used as the basis for a finding of negligible health and environmental effects of MCCAP emissions in France, etc.

During the last four years, the EU chlor-alkali industry has reported (mostly atmospheric) emissions to the environment of 6-8 tonnes of mercury, or roughly one gram of mercury per tonne of chlorine production capacity. It has also estimated the mercury disposed of in wastes at some 90-100 tonnes per year (after accounting for 30-40 tonnes that are recycled). Completing the mercury-in vs. mercury-out balance, however, the EU industry reports reveal another 40+ tonnes (annual average for 2002 to 2005) of mercury releases or losses that are unaccounted for, referred to by the industry as “difference-to-balance.” These are indicated in the summary table below.

Table ES-1 Mercury releases from chlor-alkali plants in the EU-25

EU-25 mercury releases from chlor-alkali plants, based on Euro Chlor reports (tonnes)					
	2002	**2003**	**2004**	**2005**	**Average 2002-5**
Reported emissions to products, air and water	8	8	6	6	7
Reported mercury disposed of in waste	102	108	86	86	96
Reported unaccounted for (“difference-to-balance”) mercury losses	12	20	78	53	41
Total mercury losses and disposal (may not be exact due to rounding)	**122**	**135**	**171**	**146**	**144**

In fact, industry has offered explanations of these “difference-to-balance” losses as annual variations in mercury inventories, uncertainties in the measuring techniques, accumulations of mercury in piping and equipment, etc. All of these explanations contain some elements of fact, but none has come close to explaining the large quantities of mercury that cannot be accounted for. In fact, faced with analogous industry losses of mercury in the US, the Natural Resources Defense Council, an environmental NGO, has brought legal action against the US Environmental Protection Agency because the agency accepted such mercury losses year after year without receiving adequate industry explanation of where the mercury was lost.

Analysis of industry reports and emissions

The “added value” of this paper is that it is the first analysis that builds on independent European and US research measuring MCCAP mercury emissions, that combines these research findings with industry reports of mercury releases, and that arrives at logical

conclusions about the final destination of much of this large category of “unaccounted for” mercury losses.

EU and US MCCAPs are, overall, similar in operation and management. The following table shows that the total mercury losses (normalised per unit of production capacity) reported by the EU and US chlor-alkali industries, while roughly comparable, on average, during the last four years, were extremely variable. The reported data are marked by abrupt variations, especially between 2003 and 2004, in the magnitude of “unaccounted for” mercury losses, increasing in the EU while decreasing in the US. During the last two years the data reported by the US show a remarkable reduction in “unaccounted for” mercury losses, especially relative to reported emissions.

Table ES-2 EU-25 vs. US MCCAP mercury losses (g Hg/metric tonne Cl_2 capacity)

Industry-wide mercury losses (g Hg/metric tonne Cl_2 capacity)	**2002**	**2003**	**2004**	**2005**	**Ave.**
European Union (EU-25)					
Reported mercury emissions to air & water	1.1	1.1	1.0	1.0	1.1
Reported “unaccounted for” mercury losses	1.9	3.3	13.3	9.1	6.9
Total water/air emissions + “unaccounted for” mercury losses	**3.1**	**4.4**	**14.3**	**10.0**	**8.0**
United States					
Reported mercury emissions to air & water	3.7	3.5	3.3	2.7	3.3
Reported “unaccounted for” mercury losses	20.7	22.2	5.1	2.5	12.6
Total water/air emissions + “unaccounted for” mercury losses	**24.3**	**25.7**	**8.4**	**5.1**	**15.9**
Note: Rounding may introduce small discrepancies in totals.					

These observations already question the integrity of industry estimates of MCCAP mercury emissions. However, a stronger challenge comes from independent scientific studies of mercury emissions at MCCAPs in both the EU and the US that have been published recently. Combined with other information in the public domain, the unavoidable conclusion from these research efforts is that MCCAP mercury emissions are evidently significantly greater than those that have been typically estimated and reported in the EU, and in the US as well.

More specifically, this paper relies on those research results to make the case that actual average EU MCCAP mercury emissions are likely within the range of 4-5 g mercury per tonne of chlorine produced, rather than the reported level of close to one gram. This revised level of emissions would unfortunately place the EU chlor-alkali industry in the same general category as large EU coal-fired power plants in terms of mercury emissions to the atmosphere.

While the apparent failings of EU MCCAP mercury consumption/emission reports demonstrate that mercury monitoring efforts have been inadequate, there is no evidence that individual MCCAP operators have intentionally misrepresented their emissions. On the contrary, MCCAP operators are perfectly willing to explain how they produced

mercury consumption and emissions data that meet EU industry targets. Furthermore, since many authorities have been willing to accept the data as presented, it may be understood that there has been no compelling reason for industry to invest more money and time to improve the data gathering process, or the accuracy of the data.

Benefits and costs of conversion

Based on the revised estimates of EU MCCAP mercury emissions as presented in this analysis, it follows that the health (and environmental) effects represent a much higher cost to the economy and society than previously assumed. Recent research studies on the costs and benefits of reducing mercury emissions from US coal combustion facilities were used to derive a conservatively estimated annual EU health benefit of some 25-30 euro per gram of MCCAP atmospheric mercury emissions eliminated. Environmental benefits may also be significant, but are not included here.

This paper then takes a closer look at the costs and "bottom-line" benefits (especially energy savings, reduced costs of mercury monitoring and waste disposal, etc.) to industry of converting a typical MCCAP to the membrane process. There are various cases of actual conversions that have generated an attractive two- to three-year return on investment. On average, however, it is calculated that an EU industry investment in conversion may not show an attractive bottom-line return until close to 10 years. This is not bad for a facility that may operate for 40-50 years, but it is still not sufficient, without a further strategic rationale or incentive, to convince many chemical manufacturers to make the investment independently.

However, if one combines the considerable "bottom-line" benefits of MCCAP conversion with even a conservative estimate of the public health benefits, the overall benefits, even when accumulated over only 5 years, are nearly twice the costs associated with the transition to a mercury-free chlor-alkali industry.

Table ES-3 Combined benefits & costs of converting European MCCAPs to membrane

Combined benefits and costs (billion euro of 2004)	***Estimated annual benefits & costs***	***During 5 yrs.***		***During 10 yrs.***	
		Discount rate 5%	Discount rate 10%	Discount rate 5%	Discount rate 10%
Present value – total conversion costs, including: Investment cost, cleanup, etc.	2.6 one-time	**2.6**	**2.6**	**2.6**	**2.6**
Present value total benefits, including:		**4.9**	**4.4**	**8.4**	**6.9**
Industry benefits	various	1.7	1.5	2.8	2.3
Health benefits*	0.7 annual	3.2	2.9	5.6	4.6
Environmental benefits	significant	not included	not included	not included	not included
Ratio of total benefits/costs		**1.9**	**1.7**	**3.2**	**2.7**

Assumptions for conversion of European MCCAPs to the membrane process:
- annual chlorine production capacity ≈ 6 million tonnes
- 10-15% of capacity will close rather than convert
- annual atmospheric mercury emissions ≈ 4-5 g Hg per tonne chlorine capacity ≈ 25-30 tonnes mercury total
- annual health benefits >25 euro per gram of mercury emissions eliminated
- annual environmental benefits may be similar to health benefits, but are not quantified here

Note:
* Health benefits are based only on estimates of neuro-developmental impacts – specifically loss of intelligence – of methylmercury exposure in the US due to fish consumption, although there is evidence of other health effects as well. The figure of 25 euro per gram of mercury emissions eliminated (multiplied by 25-30 tonnes of mercury emissions eliminated upon full conversion) is a conservative estimate based on two key sources: one assuming human methylmercury exposure from consumption of both marine and freshwater fish, and the other assuming exposure from consumption of freshwater fish only.

It may be concluded, therefore, that the conversion of MCCAPs should be a high priority for any government that considers the whole range of public health and other benefits associated with its industrial development strategy. It is for this primary reason that the European Investment Bank (EIB) and some EU governments have agreed to offer financial incentives to assist in the conversion of some MCCAPs. Likewise, the European Commission, which enforces regulations limiting State subsidies to industry, has approved such assistance on environmental grounds.

Conclusions

In the absence of sufficiently critical oversight of the chlor-alkali industry at the EU level, and lacking unambiguous guidelines for the application of the IPPC Directive, many regulators at the national level have been left with insufficient means to adequately monitor this industry's environmental performance. As a result, the chlor-alkali industry has been regulated unevenly at the national level, which, over time, has resulted in virtual self-regulation in a number of EU countries.

This is not to deny that the chlor-alkali industry has made significant progress in reducing mercury releases. The industry association, Euro Chlor, has made a series of commitments on behalf of its industry members, most notably since 1990, to meet ever more strict mercury emission targets in return for an effective Europe-wide license to continue operating. These efforts have certainly been helpful. Despite the passage of many years, however, this analysis demonstrates that industry has apparently not been able to come as close to its own emission targets as generally reported. The resulting costs to European health and the environment have probably been large, and remain so.

It is time to carefully examine the results of the mostly hands-off approach with which a number of European countries have dealt with the chlor-alkali industry, and the (voluntary) mercury cell phase-out date of 2020 that has emerged by default. It is time to carefully re-examine the individual performance of the many MCCAPs that remain in operation in Europe, and to objectively assess their phase-out and conversion plans in light of the IPPC Directive. Meanwhile, it should be kept firmly in mind that the total costs of converting all European MCCAPs to a mercury-free process, including the costs of facility decommissioning and cleanup, appear to be far outweighed by the combined economic and human health benefits of doing so.

Status report: Mercury cell chlor-alkali plants in Europe

1 Background

Mercury releases from chlor-alkali plants have always been difficult to measure. In light of increasing concern since the early 1990s about mercury in the environment, European producers, among others, have undertaken to measure these releases more accurately. The intent of this paper is to briefly review recent scientific assessments that help to shed light on mercury releases from Europe's chlor-alkali industry, and to consider such scientific evidence within the broader socio-economic perspective of the phase-out of the mercury cell process in Europe.[2] The scope of this analysis does not permit an exhaustive treatment of the chlor-alkali industry or mercury cell technology, nor does it permit a comprehensive discussion of all relevant literature. Nevertheless, it strives to present a fair and balanced picture of developments in the industry, and provides ample evidence to support any conclusions drawn.

According to Euro Chlor information, there remained at the beginning of 2005 over 50 MCCAPs in Europe (49 of them in the 25 member countries of the European Union, commonly referred to as the EU-25) that continue to use the mercury process to produce chlorine (see Attachment 1). The production of chlorine takes place typically in combination with production of caustic soda (sodium hydroxide, NaOH), and more rarely in combination with production of potassium hydroxide (KOH, also known as caustic potash).

The use of mercury as a cathode in electrolytic cells to produce chlorine from brine is an industrial process that is over 100 years old. Up to the mid-1970s Europe generally preferred this technology because of the availability on the continent of two key raw materials – rock salt and mercury. However, there are two primary alternative processes – membrane and diaphragm – that have long been available, are less costly, and are less damaging to the environment, as confirmed by the EIPPCB report on best available techniques in the industry – the chlor-alkali BREF.[3] The United States (US) initially relied mostly on the diaphragm process because asbestos and brine were more accessible on the North American continent. The membrane technology was not demonstrated in a full-scale plant until 1983. However, since the early 1990s virtually all conversions and new plants are using this process.

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[2] Europe, as defined in this paper, includes the 25 present EU Member States (often referred to as the EU-25), the two Accession Countries (Bulgaria and Romania), plus Switzerland, Norway, Macedonia, Croatia, Bosnia and Serbia/Montenegro. Euro Chlor, on the other hand, presently considers the "Europe" of its member countries to comprise the EU-25 plus Norway and Switzerland. References to industry data will generally focus on the data available for Euro Chlor's "Europe."

[3] *IPPC Reference Document on Best Available Techniques in the Chlor-Alkali Manufacturing Industry*, European IPPC Bureau, Institute for Prospective Technological Studies, European Commission Joint Research Centre, Seville, December 2001.

In light of the evident risks related to mercury releases in the OSPAR region of Europe,[4] the parties to PARCOM agreed in 1990:

> *"that existing mercury based chlor-alkali plants shall be required to meet by 31 December 1996 a standard of 2g Hg/t Cl_2 capacity for emissions to the atmosphere, unless there is a firm commitment that the plant will be converted to mercury-free technology by the year 2000."*[5]

PARCOM Decision 90/3 also recommended that use of the mercury cell chlor-alkali process in the OSPAR region should eventually be phased out. The target date of 2010 was selected by the group in order to give adequate time to all parties to plan for and implement the necessary phase-out.[6] However, the implementation of PARCOM Decision 90/3 is ultimately the responsibility of each of the individual OSPAR member countries, and their uneven implementation of the Decision reflects their shifting – and changing, in certain cases – political and economic priorities.

2 Review of PARCOM Decision 90/3

A brief review of some discussion surrounding the implementation of PARCOM 90/3 is useful to provide the context for further developments cited in this paper.

During the late 1990s, aware that the OSPAR member countries (and their MCCAP industry operators) were not uniformly committed to a 2010 phase-out of mercury cell technology, Euro Chlor proposed that the Decision should be revisited in order to establish the "most practicable timetable and modalities for the timely and sustainable implementation of the recommendation in PARCOM 90/3."[7]

In 1999, in "Euro Chlor's Plan for the Implementation of PARCOM Decision 90/3 for Mercury Cells in the Chlor-Alkali Industry,"[8] Euro Chlor presented the following key arguments for pushing back the 2010 phase-out date to 2025:[9]

1. "Euro Chlor has carried out a science-based evaluation of the risk to humans and the environment created by mercury emissions from chlor-alkali production. The study … showed that … there is no risk of harm to humans or the environment from current plant operations."[10]
2. "A forced phase-out of mercury cell technology by the year 2010 would imply substantial cost increases (30%) … for a large part of the European chlor-

[4] Comprising all European river basins emptying into the North Atlantic, i.e., much of Western Europe.

[5] PARCOM Decision 90/3 of 14 June 1990 of the Commission for the Protection of the Marine Environment of the North-East Atlantic (PARCOM2). Publications can be found at http://www.ospar.org.

[6] As agreed, PARCOM Decision 90/3 "recommends that existing mercury cell chlor-alkali plants should be phased out as soon as practicable. The objective is that they should be phased out completely by 2010."

[7] As presented in "The mercury cell technology in Western Europe," collection of documents presented by Euro Chlor at the OSPAR Workshop on the Chlor-Alkali Industry, 27-29 September 1999.

[8] See footnote 7.

[9] Some years later the proposed phase-out date was changed to 2020 – with exceptions, as discussed below.

[10] "Risk Assessment for the Marine Environment – Mercury," OSPARCOM Region – North Sea, prepared by Euro Chlor, Brussels, August 1999 (undoubtedly updated since that date).

alkali industry." There would also be negative effects on "production capacity and also on employment, trade balance and capital requirement." "…these very serious social and economic consequences are not balanced by any measurable environmental improvement."[11,12]

3. "As a result of significant investment made by the industry, today's emissions are quite different from those at the time of adoption of PARCOM Decision 90/3. They are significantly below the level set in paragraph 1 of that Decision."
4. "The importance of accurate, complete and consistent data for the compilation of the annual mercury balance cannot be overstated. The document "Guidelines for Making a Mercury Balance in a Chlorine Plant"[13] represents the currently available know-how…. All Euro Chlor member companies have committed themselves to follow these best practice guidelines."
5. "In 1998, the independent consultant SRIC (Stanford Research Institute Consulting) studied the "natural" phase-out of the mercury-based chlor-alkali facilities in Western Europe.[14] … After carefully considering this SRIC study, Euro Chlor has concluded that it could support the conclusion indicating that it is likely that all remaining mercury capacity in the OSPAR area should be converted or closed down by 2025."
6. "For the future, industry will continue to seek further substantial emission reductions beyond the standard set by PARCOM Decision 90/3."
7. "We conclude that … the scenario based on a combination of closures, conversions and emissions reductions will result in a lower cumulative environmental burden of mercury" during the period 1998-2025, "and thus be the more favourable approach for the implementation of PARCOM 90/3," than other scenarios for the "forced phase-out by 2010…."
8. "…the companies will regard as the most favourable disposal option, the return of all pure mercury not required within the industry to an established mercury producer – on condition that this displaces new production of the equivalent quantity of virgin mercury."

The scope of this paper does not permit a detailed analysis of each of the above points. However, in response to Euro Chlor's initiative, the OSPAR member countries did review PARCOM Decision 90/3 during the course of 1999-2001, and voted to keep the Decision without any changes.

Not entirely by chance, PARCOM Decision 90/3 was generally consistent with the economic realities of closing or converting many of the old mercury cell chlor-alkali plants (MCCAPs), and despite uneven implementation, it has surely contributed to the gradual transition toward mercury-free chlor-alkali production. By 2005, nearly half of the 100+ MCCAPs operating in Europe in 1990 had been closed or converted to a mercury-free process. Most of these plants were located in the OSPAR region, but some were in

[11] "Competitive Situation of the Western European Chlor-Alkali Industry in a Global Context," SRI Consulting, report prepared under contract to Euro Chlor, April 1997.

[12] A. Lindley, *An Economic and Environmental Analysis of the Chlor-Alkali Production Process*, author seconded by ICI Chemicals and Polymers to DG III (Enterprise), Brussels, 30 June 1997.

[13] "Guidelines for Making a Mercury Balance in a Chlorine Plant," Env Prot 12 2nd Edition, Euro Chlor, Brussels, July 1998.

[14] "Assessment of the Western European Closures of Mercury-Cell Based Chlor-Alkali Capacities 1998-2020 and Beyond," SRI Consulting, report prepared under contract to Euro Chlor, October 1998.

other parts of Europe (see Annex 1), including Hungary, Italy, Greece, etc. Nevertheless, at the beginning of 2005 close to 50 percent of over 12 million tonnes[15] of total European chlorine production capacity were still equipped with the mercury cell process.[16,17,18] These plants contained an estimated 11,000 tonnes of mercury in the electrolytic cells, not to mention additional mercury accumulated in equipment and structures, other accumulations on-site from historic leakage, waste disposal, etc.

The chlor-alkali industry throughout the EU-25 is also covered by the IPPC Directive,[19] which requires chlor-alkali installations to have permits based on best available techniques (BAT). According to the chlor-alkali BREF document,[20] the mercury-cell process is not considered to be BAT for the chlor-alkali sector. Further, the IPPC Directive states in Article 5 that "existing installations," i.e., installations in operation before 30 October 1999, should operate in accordance with the requirements of the Directive (i.e., based on BAT) by 30 October 2007. Some EU countries have adopted a more flexible interpretation of the IPPC Directive, and consider that if their mercury cell chlor-alkali plants will be decommissioned and/or converted to mercury-free technology by 2010, this may also be acceptable under the Directive.

In spite of the intentions of the 1990 PARCOM Decision, the IPPC Directive and the chlor-alkali BREF document, the author estimates that after 2010 there will remain in the EU-25 some 30-35 MCCAPs still operating, and containing 7-8,000 tonnes of mercury in the electrolytic cells. This estimate is based on studies carried out for Euro Chlor, conversions and closures already planned[21] or announced in the press, etc. MCCAPs that continue to operate after 2010 will include some of the plants in Poland, the Czech Republic and Slovakia, as well as various sites in the former EU-15 that gained a reputation over the years for particularly high mercury releases and extensive site contamination.

At different times, the following arguments have been advanced by the operating companies to justify the continued use of the mercury process after 2007, and after 2010 as well:

- that investments in conversion to mercury-free technology will hurt European competitiveness, reportedly because the investment cost is too great, and therefore the payback period is too long;
- that many plants will be obliged to close rather than convert, and workers will lose jobs;
- that there is virtually no risk from MCCAPs to human health or the environment;

[15] In this text the word "tonne" always denotes "metric ton."

[16] Linak E, S Schlag and K Yokose, "Chlorine/Sodium Hydroxide," CEH Marketing Research Report, Chemical Economics Handbook, SRI Consulting, August 2005.

[17] Euro Chlor report to OSPAR published as, "Mercury Losses from the Chlor-Alkali Industry in 2003," OSPAR Commission, ISBN 1-904426-61-1, Publication Number: 2005/225, 2005.

[18] Chlorine Industry Review 2004-2005, Euro Chlor, Brussels, August 2005. Note also that the text generally refers to chlorine (or caustic) production capacity, and less frequently to actual chlorine (or caustic) production, which is currently about 15% less than production capacity for Europe as a whole.

[19] Integrated Pollution Prevention and Control Directive (Council Directive 96/61/EC).

[20] See footnote 3.

[21] See "Overview Assessment of Implementation of PARCOM Decision 90/3 on Reducing Atmospheric Emissions from Existing Chlor-Alkali Plants," which can be found at the OSPAR website under "hazardous substances/implementation reports and implementation reporting formats" (www.ospar.org).

- that, in any case, most European MCCAP operators have committed to make their best effort to voluntarily phase out the mercury process no later than 2020, except in "cases where mercury cells are indispensable for the production of some speciality chemicals".[22]

The first three of these points will be discussed in further detail in Section 4 and Section 6 of this paper. The last point also deserves further attention, since the voluntary commitment by industry has been interpreted by some observers as a complete and final phase-out of the mercury process by 2020, at which point the average age of the European plants will be nearly 50 years. In fact, it is not clear how many plants may consider they should be excluded from the voluntary 2020 phase-out, nor is it clear on what basis such a determination might be made. The plants that produce potassium hydroxide,[23] for example, may argue for continued use of mercury after 2020, and perhaps other plants as well, although viable mercury-free alternatives exist.

Table 1 Mercury cell plants producing potassium hydroxide in the EU-25

COUNTRY	COMPANY	SITE	Cl_2 CAPACITY (000 TONNES)
BELGIUM	Tessenderlo Chemie	Tessenderlo	250
FRANCE	Albemarle	Thann	72
GERMANY	BASF	Ludwigshafen	160
	Degussa	Lülsdorf	136
ITALY	*Syndial*	*Priolo (closed in 2005)*	*204*
SPAIN	EIASA (Aragonesas)	Sabiñánigo	25
SWEDEN	*Akzo Nobel*	*Bohus (closed in 2005)*	*100*
UK	Ineos Chlor	Runcorn	738
Totals		**6 plants** (not incl. Bohus and Priolo)	**1381** (not incl. Bohus and Priolo)

In order to avoid further confusion in this sector, to avoid misinterpretation of the IPPC Directive, and to limit unfair competition between those EU chlorine producers that give up the mercury process by end October 2007, and those that may continue using it until 2010 or later, the appropriate authorities of the EU member states (or the European Commission, by default) should formally confirm and publish the phase-out dates that are relevant to each operator's circumstances. Furthermore, they should determine which plants, if any, may continue to operate after the phase-out date, and under what conditions. Otherwise the EU risks another "OSPAR deadline" that some member states may interpret differently from others, or a situation where certain companies may wait until 2009 (or 2019) to announce that, in their opinion, the 2010 (or 2020) phase-out date does not apply to them.

[22] This voluntary commitment was proposed by Euro Chlor several years ago. Therefore, it is not clear why this wording (used in the Euro Chlor presentation at the EEB Conference - "EU Mercury surplus management and mercury-use restrictions in measuring and control equipment," 19 June 2006, Brussels, Belgium) is different from previous wording: "…an exception being made for the coproduction of chlorine with certain speciality chemicals where no other technologies exist." The latter wording was earlier submitted in "Euro Chlor's contribution to the European Commission's consultation document on the development of an EU Mercury Strategy," Euro Chlor, 11 May 2004.

[23] The chlor-alkali BREF (see footnote 3) mentioned that some plants in Japan, which largely phased out the industrial use of mercury following the Minamata incident, were permitted to continue to use mercury cells to produce potassium hydroxide for many years after other uses were discontinued. Even for this use, however, the remaining Japanese plants had all been converted to mercury-free processes by 2002.

3 Chlor-alkali industry mercury releases

The main difficulty in establishing emission limits for the chlor-alkali industry is that there has never been broad agreement with regard to actual emissions and releases of mercury from the industry. Industry consumption of mercury is high, but reported emissions are relatively low. Monitoring of emissions, while improving, is highly variable from one site to another, and even more challenging in cell rooms with open walls or no roof. Practically speaking, all emissions reports are based on estimates and extrapolations. Euro Chlor has argued that risks from emissions are negligible. Yet the Natural Resources Defense Council (NRDC), a US environmental advocacy organization, initiated legal proceedings against weak USEPA regulation of US chlor-alkali plants based on their concern about the possible health and environmental impacts of these operations. The legal document noted, "Based on … recently available study results, fugitive emissions from the "cell rooms" of these plants are very significant and need to be addressed with aggressive action."[24] Clearly, further scrutiny of mercury releases is necessary in order to better assess the threat these facilities may pose to health and the environment. The following discussion is intended to take a significant step in that direction.

3.1 Euro Chlor reports to OSPAR

Part of the Euro Chlor commitment to the OSPAR process is to provide annual reports of mercury emissions and mercury flows (inventory changes, waste generation, treatment and disposal, etc.) for all MCCAPs operated by Euro Chlor member companies.[25] Euro Chlor has expanded its umbrella over the years so that by 2005 all operators of MCCAPs in the EU-25 were Euro Chlor members except for one in Poland and one in Italy. As Euro Chlor members, all MCCAP operators are obliged to submit annually the same forms on mercury emissions and flows as those submitted for the OSPAR region.

Based on detailed mercury consumption and release estimates provided to Euro Chlor by industry operators, the following summary results emerge for 2002-2005. In this table, mercury "releases" are the sum of emissions (to products, air and water), plus mercury sent for disposal in wastes, plus other losses of mercury whose destination cannot be adequately accounted for.

[24] "Petition [before the Administrator, United States Environmental Protection Agency,] for reconsideration of the National Emission Standard for Hazardous Air Pollutants (NESHAP): Mercury Emissions from Mercury Cell Chlor-Alkali Plants," 17 February 2004.

[25] As in footnote 17, these Euro Chlor reports are entitled, "Mercury Losses from the Chlor-Alkali Industry in [Year]," and eventually find their way onto the OSPAR Commission website at www.ospar.org.

Table 2 Mercury releases from chlor-alkali plants in the EU-25

EU-25 mercury releases from chlor-alkali plants, based on Euro Chlor reports (tonnes)					
	2002	**2003**	**2004**	**2005**	**Average 2002-5**
Reported emissions to products, air and water	8	8	6	6	7
Reported mercury disposed of in waste	102	108	86	86	96
Reported "unaccounted for" ("difference-to-balance") mercury losses	12	20	78	53	41
Total mercury losses and disposal (may not be exact due to rounding)	**122**	**135**	**171**	**146**	**144**

* Including minor adjustments of the most obvious data errors, and estimates of releases from two plants whose operators are not Euro Chlor members.

** Operator estimates of the mercury content of waste sent to disposal.

As seen in this table, the industry reported total mercury emissions to products (chlorine, caustic, hydrogen, etc.) and the environment (air and water) averaging about 7 tonnes per year during the period 2002-2005. Apart from recycling of some wastes, the disposal of mercury in chlor-alkali industry wastes was another 90-100 tonnes per year, and "unaccounted for" mercury losses (reported as "difference-to-balance" in the OSPAR reports) averaged over 40 tonnes per year during the same period. In other words, of the total 48 (average) tonnes of mercury losses (i.e., not counting the mercury disposed of in waste) from EU MCCAPs each year, only about 15% are reported as emissions. The reported air and water emissions (losses to products are a relatively small percentage) may be summarised as in the following table, showing in recent years a "normalised" industry average of about 1.0 gram of reported mercury emissions per tonne of chlorine production capacity.

Table 3 Reported EU-25 MCCAP mercury emissions to air and water

	2002*	**2003***	**2004**	**2005**
Reported air & water emissions (tonnes mercury)**	7.1	7.0	5.9	5.7
Plant production capacity ('000 tonnes Cl_2)	6272	6088	5890	5887
Reported air & water emissions (g Hg/metric tonne Cl_2 capacity)**	1.1	1.1	1.0	1.0

* Estimates based on EU-15 data, as EU-25 information was less readily available in 2002 and 2003.

** Not including mercury losses in products.

Source: Euro Chlor data (via industry reports) as summarised by the author.

Industry representatives have explained that some or all of the "lost" 41 tonnes per year (average 2002-5) are accumulations of mercury in various parts of the plant and equipment, which may be recovered or disposed of during eventual decommissioning of the plants. These losses – and the industry explanation – are discussed further in Section 3.8 below.

Despite the apparent precision of the data reported by the EU-25 chlor-alkali industry, the measurement of mercury emissions specifically, and mercury losses in general, from the industry are subject to a great range of uncertainties. All of the following factors are

relevant, as well as others described in the chlor-alkali BREF,[26] the NRDC legal proceedings[27] and various technical reports cited later in this paper:

- There are a great variety of management approaches, operating procedures, waste treatment/storage/disposal methods, etc., among EU-25 MCCAP operators.
- Despite Euro Chlor guidelines for monitoring emissions, in practice the monitoring methodologies are highly variable across the industry.
- Despite Euro Chlor guidelines for calculating and reporting inventories, emissions, etc., the operators of MCCAPs use a range of techniques, methodologies and estimates to compile the necessary data.[28]
- Due to uncertainties, even the most carefully collected data concerning plant mercury inventories must be compared over a number of years in order to confirm trends.
- The periodic closure and conversion of MCCAPs, and the increasing number of operators who report to Euro Chlor, not to mention the occasional expansion of the EU itself, means that the list of specific plants in the Euro Chlor database changes frequently.
- Some mercury emissions are relatively easy to assess, provided they do not vary too much over time. These tend to be "choke-points," such as the discharge of wastewater through a pipe, or flue gases through a stack.
- Other mercury losses in a chlor-alkali plant are more difficult to assess. Mercury amalgamates or binds with other metals. When failed parts are removed, some mercury is removed with them. When mercury accumulates in tanks, sumps and drains, the mass is not evident until it is removed and analyzed. Depending on plant monitoring, mercury vapour leaking from decomposers and pumps, for example, may be detected rather quickly, or may not be detected for some time.
- In order to better ventilate a hot working environment, most MCCAPs have many openings in walls and ceilings – in some cases completely open to the outside air. It may therefore be quite difficult to accurately monitor the (non-stack) exit air.
- Chlor-alkali production, even more than in many industries, includes periodic maintenance, and is subject to occasional leaks or malfunctions. Invasive maintenance or system upsets can be sources of major releases of mercury vapour, sometimes only detectable through a well-designed system of continuous monitoring of mercury in the air.

For all of these reasons and more, the mercury emissions that are measured and/or reported at EU operating plants, under present circumstances, may hardly be assumed to accurately reflect actual emissions. Meanwhile, other findings raise similar questions. For example, a 2005 Euro Chlor observation that MCCAP occupational exposures are higher than expected may also be interpreted to suggest that actual emissions are higher than those reported:

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[26] See footnote 3.

[27] See footnote 24.

[28] As in any industry, there may also sometimes be a disconnect between administrative guidelines and actual practice "on the ground," due to the perceived importance of meeting targets, the difficulty of collecting data as suggested, insufficient time, equipment or budget, etc.

> *"Since 1991, Euro Chlor has been collecting data on mercury levels in workers' urine from member companies operating mercury-based chlorine plants. This shows that exposure levels have not been decreasing at the same rate as the [reported] mercury emissions…."*[29]

In response, while operators take steps to better understand and measure mercury releases and losses, researchers have also been making efforts to do the same. Most emission-related research activities have been carried out in the EU and the US, and a number of recent efforts (especially partnerships through UNEP, chlorine industry associations, etc.) have been made to share information about research findings and "best practice" with operators in other countries as well. Later sections discuss the most important recent scientific findings with regard to mercury releases.

Before going into the details of recent research, however, it is necessary to mention that there are unresolved questions about the relative performance of MCCAPs in the EU vs. the US. Since the data collection and reporting processes in each region are somewhat different, an across-the-board comparison is not possible. However, focusing on the areas where reporting is comparable, and after reviewing mercury consumption and emissions data submitted annually by US companies to the TRI database,[30] and by the US Chlorine Institute to the US EPA,[31] it is clear that reported emissions by MCCAPs in the US are significantly higher than those in the EU. As can be seen in the table below (when compared with the previous table for the EU), even after considerable improvements in US MCCAP mercury management in recent years, the normalised (g Hg/metric tonne Cl_2 capacity) US mercury emissions reported are typically at least three times higher than the average EU-25 emissions shown above in Table 3. These are numbers that receive the full attention of MCCAP operators, and may be assumed to be at the lowest levels the operators believe they can justify.

Table 4 Reported US MCCAP mercury emissions to air and water

	2002	2003	2004	2005
Reported air & water emissions (US tons mercury)*	5.0	4.8	4.5	3.3
Plant production capacity ('000 US ton Cl_2)	1355	1353	1363	1221
Reported air & water emissions (g Hg/metric tonne Cl_2 capacity)*	3.7	3.5	3.3	2.7
* Not including mercury emissions to products				

Source: US EPA Toxics Release Inventory (TRI) reports, and Chlorine Institute annual reports to the US EPA.

In search of some explanation for this anomaly, one could include other aspects of EU vs. US operating performance by comparing total reported MCCAP mercury releases (excluding mercury in wastes sent to disposal). In light of the similarities in plant designs, and the considerable amount of shared information between the EU and US as regards limiting and monitoring mercury emissions, and other environmental and safety

[29] See footnote 18.

[30] Industry reports to the US EPA Toxics Release Inventory database are available at http://www.epa.gov/enviro/html/tris/

[31] US Chlorine Institute annual reports are available at http://www.epa.gov/region5/air/mercury/reducing.html#regulation

concerns, it would be reasonable to conclude that the average performance of the US plants should be roughly comparable to the average in the EU. The following table shows that the total normalised mercury losses (to air & water + miscellaneous losses, and excluding mercury in wastes) reported by the EU and US chlor-alkali industries while roughly comparable on average during the last four years, were extremely variable. The reported data are marked by abrupt variations, especially between 2003 and 2004, in the magnitude of "unaccounted for" mercury losses, increasing in the EU while decreasing in the US.

Table 5 EU-25 vs. US MCCAP mercury losses (g Hg/metric tonne Cl_2 capacity)

Industry-wide mercury losses (g Hg/metric tonne Cl_2 capacity)	**2002**	**2003**	**2004**	**2005**	**Ave.**
European Union (EU-25)					
Reported mercury emissions to air & water	1.1	1.1	1.0	1.0	1.1
Reported "unaccounted for" mercury losses	1.9	3.3	13.3	9.1	6.9
Water/air emissions + "unaccounted for" mercury losses	**3.1**	**4.4**	**14.3**	**10.0**	**8.0**
United States					
Reported mercury emissions to air & water	3.7	3.5	3.3	2.7	3.3
Reported "unaccounted for" mercury losses	20.7	22.2	5.1	2.5	12.6
Water/air emissions + "unaccounted for" mercury losses	**24.3**	**25.7**	**8.4**	**5.1**	**15.9**
Note: Rounding may introduce small discrepancies in totals.					

Nevertheless, considering that EU and US MCCAPs are quite similar not only in their design, but also in their operators' ability to control mercury releases, one is obliged to ask why the ratio between reported air+water emissions and "unaccounted for" losses in the EU is so different from that in the US? Specifically, the ratio for the EU is about 1:6 over the last four years, and around 1:10 during the last two years. The ratio for the US is nearly 1:5 over the last four years, but closer to 1:1 during the last two years.

Further clarification is sought in the research findings presented below.

3.2 Southworth et al. *findings*

Certainly the most comprehensive effort to assess actual emissions at a specific chlor-alkali site was undertaken in 2000 in the US. According to the researchers, no previous on-site/off-site combined studies had been as thorough, including continuous monitoring over an extended time period, and no previous independent research had correlated emission measurements directly with plant operating and maintenance events. As

written in one of a series of papers (most of them published in 2004)[32] by the principal researcher, G.R. Southworth, and/or colleagues:

> *It has long been recognized that the mercury cell process for producing chlorine and caustic soda on an industrial scale is an important source of atmospheric mercury (e.g. Caban and Chapman, 1972; Hogstrom and Enger, 1979). Many mercury cell sites also contain extensive areas of mercury-contaminated soils from local fallout and former waste landfills (e.g. Rule and Iwashchenko, 1998), suggesting that even closed, as well as active factories can be air emission sources (e.g. Lindberg and Turner, 1977). It has been noted that much of the mercury consumed by this process cannot be accounted for (Ayers, 1997). While this report was based on US factories, the design features of these factories are very similar to ones in other countries, and the global implications are significant.*[33]

Evidence gathered by this research team in collaboration with a well-managed and otherwise rather typical MCCAP (Olin Corp. – Augusta, Georgia) in the southeastern United States showed elevated mercury contamination around the plant, in soil, vegetation and air, that clearly demonstrated that there have been, and continue to be, significant mercury releases into the environment from this plant. More specifically, levels of mercury in the air upwind of the cell building (three sides of the basement and cellroom floor were open to the atmosphere) were typically in the range of 5-10 ng/m^3, while the "plume" of mercury downwind and within 100m of the cell building ranged from 2000-3500 ng/m^3, decreasing to 1000 ng/m^3 over a relatively large area up to 500 m downwind from the cell building, and generally less than 100 ng/m^3 over most of the rest of the site, including areas more than 500 m downwind of the cell building. These readings should be understood relative to the background mercury level, which was typically 1.5-2 ng/m^3.

Further away, the researchers found levels of mercury in soils downwind of the plant that were fifteen times higher than background levels, with mercury concentrations increasing with proximity to the cell building. Mercury levels in tall and ground-level vegetation were also elevated, exceeding background levels typically by two orders of magnitude – up to 8 km from the cell building. The mercury in foliage was found to exceed the mercury in the underlying soils in 75 percent of the samples, which

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[32] Southworth GR, SE Lindberg, H Zhang, FR Anscombe, Fugitive mercury emissions from a chlor-alkali factory: sources and fluxes to the atmosphere, *Atmospheric Environment* 38 (2004) 597–611.

Landis MS, GJ Keeler, KI Al-Wali, RK Stevens, Divalent inorganic reactive gaseous mercury emissions from a mercury cell chlor-alkali plant and its impact on near-field atmospheric dry deposition, *Atmospheric Environment 38* (2004) 613–622, Elsevier.

Kinsey JS, J Swift and J Bursey. Characterization of fugitive mercury emissions from the cell building at a US chlor-alkali plant. *Atmospheric Environment 38* (2004) 623-631.

Kinsey JS, FR Anscombe, SE Lindberg, GR Southworth, Characterization of the fugitive mercury emissions at a chlor-alkali plant: overall study design, *Atmospheric Environment 38* (2004) 633–641, Elsevier.

Kinsey JS, Characterization of Mercury Emissions at a Chlor-Alkali Plant - VOLUME I, Report and Appendices A-E, NRMRL-RTP-236a, U.S. Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory, Research Triangle Park, North Carolina, January 2002.

[33] Southworth GR, SE Lindberg, H Zhang, FR Anscombe, Fugitive mercury emissions from a chlor-alkali factory: sources and fluxes to the atmosphere, *Atmospheric Environment* 38 (2004) 597–611. See this source for details of other references cited.

suggested that the source of the mercury in foliage was atmospheric rather than root uptake of mercury from the soil. Moreover, since most foliage is renewed annually, its contamination with mercury must logically have resulted from recent months of exposure and deposition, rather than previous years of accumulation.[34]

Within the cell building of this Olin plant, the researchers reported that during their first preliminary (effectively unannounced) survey at the plant, they were surprised at the levels of mercury vapour coming from the decomposers. In fact, twelve of the twenty-five monitoring locations had such high mercury levels that they exceeded the limit of the monitor, which was capable of registering mercury levels up to about 1,200 µg/m^3. By chance, these measurements were taken shortly after intensive maintenance activities, while later pre-scheduled measurements were taken under calmer conditions.[35] When the researchers later asked the operator to open a decomposer and to carry out a typical maintenance activity in order to ascertain its direct impact on emissions, the operator declined to do so.

However, during the subsequent continuous nine-day test, there was one overnight "upset" (i.e., unscheduled and unanticipated) that led to a six-fold spike in mercury concentrations over a three-hour period.[36] Both of these observations are evidence of episodic, if not routine, releases of substantial quantities of mercury from the cell room – releases that would not be measured during many "normal" monitoring activities. Based on such observations, the authors confirmed that periods of invasive maintenance, not to mention upset conditions, result in significant spikes in fugitive mercury emissions.[37]

Resulting from the extensive measurements carried out in 2000 at the Olin MCCAP (rated output of 309 tonnes/day, or about 100,000t annual chlorine capacity), the researchers estimated that the plant's total annual atmospheric emissions of mercury (typically comprising at least 90% of a well-managed MCCAP's mercury emissions to the environment) were between a best-case 300 kg and a worst-case 3,000 kg, or between about 3 g and 30 g per tonne of annual chlorine capacity. Southworth *et al.* clearly noted that their investigation did not have the opportunity to observe and record a "full and representative range of maintenance activities typically conducted at a chlor-alkali factory." For this and other reasons, they considered their own "best-case" air emissions estimate of 300 kg mercury to represent an optimal and virtually unachievable lower limit. Based on their observations and experience, the researchers did not believe that even the best operator could achieve, let alone to go below, this lower limit.[38]

Further, the Olin Augusta plant is considered to be one of the better performers (with regard to mercury emissions) in the US, as implied by the findings in Section 3.6 below. This leads to the combined observation that the Olin Augusta plant is probably unable to achieve air emissions of 3 g Hg per tonne of chlorine capacity; nevertheless, it probably

[34] See footnote 33.

[35] However, it was not possible to definitively link the high readings to the previous maintenance activities. As noted by Southworth *et al.* (footnote 33), "None of the maintenance operations we observed [later] produced localized mercury concentrations in air as high as those we observed around hot, actively running decomposers/pumps with vapor leaks."

[36] If the research team had not picked up extraordinary emissions on their measuring instruments, a significant amount of time might have passed before this "upset" would otherwise have been noticed.

[37] See footnote 33.

[38] See footnote 33.

generates mercury emissions that are among the lowest of the MCCAPs operating in the US. These findings suggest that the (2004-5) reported US MCCAP average (air and water) emission estimate of 3 g Hg per tonne of chlorine capacity, being precisely at the lower and "unachievable" end of the emissions range suggested by the researchers, almost certainly underestimates actual emissions.

The immediate questions that arise are:

1. If the reported (air and water) mercury emissions (3 g/tonne chlorine capacity) may be unrealistic, based on Southworth *et al.*, what might be a more reasonable estimate of average emissions in the US?
2. Is it conceivable that EU MCCAP emissions could be three or more times (or more) lower than US emissions?
3. If not, what might be a more reasonable estimate of mercury emissions for EU MCCAPs?

Southworth *et al.* offered only a partial explanation of what would cause Olin to underestimate its reported emissions – an explanation possibly applicable to other US plants as well as to those in Europe. They explained, in reference to their Olin research, how mercury concentrations in the air were measured at regular intervals, under generally optimal operating conditions, with a view mostly to monitoring for occupational exposures:

> *The routine industrial hygiene program at the plant involved daily (once per 8-h shift) measurements of elemental mercury concentrations in air at face-level on the cell-room floor using Jerome instruments. Readings were taken at 15 points spaced along the walkway around the perimeter of the cells where workers might be exposed to Hg vapor. These measurements were made in a fashion similar to those we made above the decomposers, but were taken ~2m laterally away from the nearest equipment, and thus outside their mercury vapor envelope.*

In light of the Olin research findings, one might conclude, at least as an initial hypothesis, that actual average MCCAP (mostly atmospheric) mercury emissions in the US during 2004-5 were almost certainly above 5 g/tonne chlorine production capacity, but probably not as high as 10 g/tonne. However, even though the Olin studies were comprehensive, they nevertheless observed closely only one well-managed MCCAP. It is therefore advisable to consider other recent scientific evidence that may shed further light on those findings.

3.3 Wisconsin DNR findings

In 2002 the Wisconsin Department of Natural Resources monitored ambient mercury levels at the Vulcan MCCAP site (on the grounds, but external to any buildings) using a stationary Tekran monitor. The average daily reading during April and May was 44.0 ng/m^3 (range from 4.3 to 394.6 ng/m^3). For the period of August and September, the daily average was 61.0 ng/m^3 (range from 7.8 to 277.8 ng/m^3), probably reflecting the warmer ambient temperature. Some hourly and five-minute readings exceeded 2,000

ng/m^3. For comparison, the average background mercury concentration measured in remote locations was 1.5 ng/m^3.[39]

The elevated readings, while not necessarily suggesting local environmental or health effects, do support the observation by researchers at Olin that elevated mercury levels in grasses and foliage in the vicinity of an MCCAP are due mostly to emissions from the plant. Furthermore, there is additional evidence that upset conditions or other sporadic releases manifest themselves directly as spikes in atmospheric mercury emissions.

3.4 Grönlund et al. *and EMECAP findings*

To date, the most definitive independent scientific study of European MCCAP atmospheric mercury emissions was carried out by a group of researchers from Sweden's Lund Institute of Technology in 2002 and 2003, as part of the European Union funded project known as “European Mercury Emissions from Chlor-Alkali Plants” (EMECAP).[40] This research relied on measurements provided by the LIDAR technique.

The LIDAR device emits laser light, which is refracted back from fine particles present in the atmosphere. LIDAR can measure elemental mercury vapour up to a certain distance, and within this range it can generate an image of elemental mercury vapour distribution. LIDAR can detect elemental mercury vapour that could arise from flue gas stacks or fugitive (non-stack) origins, as long as there is line-of-site visibility between the LIDAR and the target (atmosphere). In order to create an image of the mercury vapour plume above an MCCAP, during this research the LIDAR was located outside the mercury cell building, but still on the plant site and not far from production areas.

Some of these researchers have long experience with LIDAR. Since 1989, members of this research group have published a variety of papers in which they reported using LIDAR to measure mercury vapour from several chlor-alkali plants in Europe during specific observation periods. The Grönlund *et al.* research paper referred to here[41] compared emissions from three different MCCAPs in three different countries (Sweden, Italy, and Poland).

Data was acquired over four weeks (two weeks during winter and two weeks during summer) at each of the plants in Sweden and Italy, and only during the summer at the plant in Poland. The data showed that emissions were typically about two times greater during summer readings than they were during winter. The authors suggested that there appeared to be a clear relation between the measured mercury flux and the ambient temperature, i.e., warmer weather seemed to be associated with higher emissions.

The Grönlund *et al.* Figure 1 below offers a summary of some of the findings. The LIDAR device does not permit a [ng/m^3] determination of atmospheric mercury concentration, but rather it determines the quantity of mercury released to the

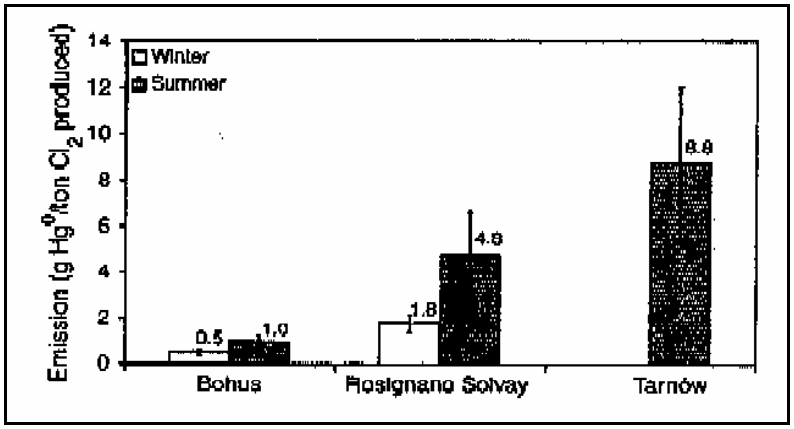
[39] Memo from David Grande & Mark Allen, Wisconsin Department of Natural Resources (Feb. 18, 2003), as cited in Petition for reconsideration of the National Emission Standard for Hazardous Air Pollutants (see footnote 24).

[40] European Commission, DG Research, contract number QLK4-CT-2000-00489.

[41] Grönlund R, M Sjöholm, P Weibring, H Edner and S Svanberg. "Elemental mercury emissions from chlor-alkali plants measured by LIDAR techniques." *Atmospheric Environment* 39 (2005) 7474-7480. Elsevier.

atmosphere from an MCCAP over time, which has been “normalized” in Figure 1 on the basis of the amount of chlorine produced by each plant.

Figure 1 Measured atmospheric mercury emissions from three European MCCAPs



Average mercury flux from the different sites, normalized to the chlorine production during the different campaigns.

Source: R Grönlund, M Sjöholm, P Weibring, H Edner, and S Svanberg. "Elemental mercury emissions from chlor-alkali plants measured by LIDAR techniques." *Atmospheric Environment* 39 (2005) 7474-7480. Elsevier.

The Grönlund *et al.* Figure 1 shows considerable variability among the three MCCAPs, after normalisation to account for different production levels, which enables a reasonable comparison of how well the different plants controlled their mercury emissions. For the LIDAR-measured mercury emissions from these three MCCAPs, Bohus (in operation since 1924) emitted a yearly summer/winter average of about 0.75 gram of atmospheric mercury emissions per tonne of chlorine produced, Rosignano (operating since 1920) was responsible for about 3.3 grams per tonne of chlorine produced, and Tarnow (operating since about 1935) an estimated 6 grams per tonne of chlorine produced.

Since Bohus was known to have BAT or near-BAT equipment and procedures, as well as operators particularly sensitised to mercury management, it is reasonable to assume that Bohus typically had quite low emissions compared to most other MCCAPs. This is confirmed by the emissions officially reported to Euro Chlor. Rosignano also officially reported air emissions significantly below the average of MCCAPs in Italy, and in fact well below the average for the EU-25. There is little comparable information on Tarnow, since it has chosen not to become a member of Euro Chlor, nor to report its emissions publicly. On the basis of Grönlund *et al.,* the atmospheric mercury emissions of Tarnow appear to be about twice those of Rosignano.

Table 6 compares the reported emissions of Bohus and Rosignano with the emissions measured by the researchers. For these two plants, the measured emissions are 3 to 6 times those values reported by industry, and there is good reason to believe that even the measured values are lower than the real average. This is because both sites were notified well in advance, and gave permission to the research team to take measurements on site. It is logical that these two sites would have carried out maintenance activities in advance of the arrival of the research team, or at least would have taken other reasonable precautions to keep emissions as low as possible during the measurement periods.

Table 6 MCCAP reported mercury emissions vs. Grönlund *et al.* measurements

Bohus (Akzo Nobel)	**2001**	**2002**	**2003**	**2004**	
Reported mercury emissions to atmosphere	0.27	0.23	0.20	0.23	
Average (2001-4) reported (to Euro Chlor) mercury emissions to atmosphere (g/tonne Cl_2)					**0.23**
Average (four weeks during 2002-3) measured (by Grönlund et al.) mercury emissions to atmosphere (g/tonne Cl_2), under probably optimal operating conditions					**0.75**
Rosignano (Solvay)					
Reported mercury emissions to atmosphere	0.81	0.67	0.41	0.38	
Average (2001-4) reported (to Euro Chlor) mercury emissions to atmosphere (g/tonne Cl_2)					**0.57**
Average (four weeks during 2002-3) measured (by Grönlund et al.) mercury emissions to atmosphere (g/tonne Cl_2), under probably optimal operating conditions					**3.3**
Tarnow					
Reported mercury emissions to atmosphere	Not publicly reported				
Average (2001-4) reported (to Euro Chlor) mercury emissions to atmosphere (g/tonne Cl_2)					Not available
Average (based on two weeks during summer of 2003) measured (by Grönlund et al.) mercury emissions to atmosphere (g/tonne Cl_2), under probably optimal operating conditions					est. 6.0

Sources: Euro Chlor reports (see footnote 25), Grönlund et al. (see footnote 41)

Of necessity, this sort of detailed research can deal with only a small sample of MCCAPs at one time. However, the general conclusion drawn from this research – that actual MCCAP mercury emissions across the EU may be at least 3-6 times greater than the officially reported emissions – agrees rather well with the Olin research findings that suggest that average mercury emissions from US (and similar EU) MCCAPs are probably at least 5 grams per tonne of chlorine capacity.

Although mercury emissions to water were not a specific focus of the EMECAP research effort, an assessment was carried out at Rosignano:

> *Another contribution to the mercury pollution by the plant is the mercury discharged into the sea water: through a discharge ditch we estimated a release of mercury in the coastal seawater of about 400-800 kg/y*.[42]

It is disturbing to note that this research assessment is 100-200 times the average annual mercury emissions to water reported by the operator of Rosignano during the period 2000-2005.

The EMECAP project also carried out basic health assessments of chlor-alkali workers and others living close to operating MCCAPs. These showed relatively clear health effects on some of the workers, but no evident effects on the general population. This was attributed to the fact that "most of the mercury emitted is dispersed and transported

[42] EMECAP Project Progress Summary and Final Report, European Mercury Emissions from Chlor-Alkali Plants, carried out with the assistance of European Community research funds, DG Research, European Commission, 2006.

away." As this mercury contributes significantly to the global pool, the EMECAP research team also concluded that "it is crucial to replace the mercury cell [technology] as soon as possible."[43]

3.5 Implications of revised MCCAP emissions

Considering EU mercury cell capacity of about 6 million tonnes chlorine, the research findings described above would imply that actual annual mercury emissions from MCCAPs could be some 25-30 tonnes rather than the approximate 6 tonnes reported. This magnitude of emissions would readily explain a large part of the EU chlor-alkali industry's "unaccounted for" mercury losses of 40+ tonnes per year. However, such a level of emissions will probably not be accepted by the industry, as it contradicts years of reporting, and it would place the EU chlor-alkali industry roughly on a par with large EU coal-fired power plants as a primary source of atmospheric mercury emissions – and deserving of immediate and close scrutiny.

It must be stressed once again that the above research findings are based on measurements taken at a small number of plants; however, they demonstrate a compelling consistency, and fit a larger pattern of mercury emissions and "unaccounted for" losses too closely to be easily dismissed. Moreover, the implications of these findings are rather unsettling – that the reliability of years of EU (and US) emissions data might be open to question. Furthermore, whatever their reliability, it must be pointed out that the MCCAP emissions reports were submitted by European operators to their national authorities and to Euro Chlor, and emissions data were forwarded by Euro Chlor to OSPAR, after which they were routinely published by OSPAR and widely accepted as scientific fact.[44] In comments to the European Commission with regard to the EU Mercury Strategy, Euro Chlor remarked that national governments have generally come to accept the self-regulation of the chlor-alkali industry:

> *The European chlor-alkali industry has an established voluntary monitoring programme in place to measure the individual performance of all plants. In fact this monitoring has been fully recognised by OSPAR. Since 2000 Euro Chlor has replaced national governments in being the provider of data for the annual Mercury Emissions report published by OSPAR. The methodology has been subject to verification and endorsement by the German TÜV standard.*[45]

Moreover, it cannot be ignored that Euro Chlor has made concerted efforts over many years to improve the credibility of the industry, to demonstrate its responsibility and transparency, and to stimulate MCCAP operators in various regions of the world to reduce losses and to improve the efficiency of their use of mercury. Without these efforts, the industry would be under much greater pressure to convert to mercury-free operations. Especially in light of the real progress that has been made, it would be very

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[43] See footnote 42.

[44] These possible discrepancies take on added importance as Euro Chlor is contributing to an evaluation of emission limit values for existing mercury-based chlorine plants under the UN Economic Commission for Europe (UN-ECE) Heavy Metals Protocol.

[45] "Euro Chlor's contribution to the European Commission's consultation document on the development of an EU Mercury Strategy," Euro Chlor, 11 May 2004. While the methodology was reportedly endorsed by TÜV, the implementation of the methodology at plant level remains very uneven.

damaging at this point if Euro Chlor commitments and industry reports dealing with mercury use and emissions are confirmed to have been misleading or inaccurate.

3.6 NRDC research findings

In July and August 2005, without advance notification of industry operators, researchers from the Natural Resources Defense Council (NRDC) sampled atmospheric mercury concentrations around six of the seven US chlor-alkali production facilities. As published in the resulting report, at all six locations mercury concentrations in the air outside the site boundaries greatly exceeded "background" concentrations, in some cases by as much as 50 times.[46]

The NRDC researchers recorded off-site atmospheric mercury levels at several chlor-alkali facilities that also significantly exceeded federally determined "safe levels" for long-term exposure, suggesting that plant employees and residents of nearby communities may be at risk. Even so, the NRDC sampling probably missed episodic releases of airborne mercury.[47] The table below summarises the maximum atmospheric mercury concentrations recorded in the vicinity of these US MCCAPs – in all cases off-site.

With reference to the Southworth *et al.* research, it may be noted in this table that measurements taken around the Olin plant in Augusta were found to be lower than around most others, suggesting, at least on the basis of this brief period of measurement, relatively good mercury management at Olin Augusta.

Table 7 Airborne mercury concentrations around MCCAPs in the US

Above or below the EPA "safe level" for chronic exposure (300 ng/m³)?	Location	Chlor-alkali facility	Maximum level of mercury present (ng/m³)
Above	St. Gabriel, Louisiana	Pioneer Americas	2,629
Above	Charleston, Tennessee	Olin Corporation	1,788
Above	New Castle, Delaware	Occidental Chemical	618*
Above	Lake Charles, Louisiana	PPG Industries	371
Below	Augusta, Georgia	Olin Corporation	252
Below	Muscle Shoals, Alabama	Occidental Chemical	103

* Indicates that this result was captured using a 10-second average. All other samples taken with instantaneous (one-second) readings.
Note: For a complete description of NRDC's sampling methods and results, see page 11 and Table 3.

Source: NRDC report (see footnote 46).

The fact that the Olin Augusta plant appears to have generally lower emissions than most other MCCAPs in the US is further supported by the US EPA Toxics Release Inventory data (reported by industry) shown in the following table.[48] Therefore, once again referring to the findings of the Southworth *et al.* research carried out at Olin Augusta, considering that the researchers estimated Olin emissions at 3-30 g Hg per

[46] Quirindongo M, J Devine, A Leiter and L Greer, *Lost and Found: Missing mercury from chemical plants pollutes air and water*, NRDC Issue Paper, Natural Resources Defense Council, Washington DC, April 2006.

[47] See footnote 46.

[48] As compiled and presented by Winalski D, S Mayson and J Savitz, *Poison Plants: Chlorine factories are a major global source of mercury*, OCEANA, Washington DC, January 2005.

tonne of chlorine capacity, and considering that Olin emissions appear to be generally below the US average, it would be reasonable to conclude that average mercury emissions for MCCAPs in the US are at least 5 g per tonne chlorine capacity.

Table 8 2002 mercury releases reported by MCCAPs in the US (one lb. = 454 g.)

RANK BY TOTAL MERCURY RELEASES	FACILITY	CITY	STATE	EMISSIONS TO AIR (lbs)			TOTAL EMISSIONS (lbs) (TO AIR, WATER, AND OFF-SITE)
				fugitive	stack	total air	
1	Olin	Charleston	TN	1045	85	1130	2512
2	Occidental Chemicals	New Castle	DE	1046	28	1074	2238
3	PPG	New Martinsville	WV	1045	188	1233	2167
4	Occidental Chemicals	Muscle Shoals	AL	1067	20	1087	1771
5	ASHTA	Ashtabula	OH	1046	349	1395	1568
6	Vulcan	Port Edwards	WI	1054	28	1082	1462
7	PPG	Lake Charles	LA	1045	177	1222	1460
8	Pioneer	St. Gabriel	LA	862	48	910	1184
9	Olin	Augusta	GA	585	154	739	1028

Source: TRI data, as cited by Oceana (see footnote 48).

Because the off-site air concentrations of mercury measured by NRDC were already significant, and their analysis suggested that a complete assessment could reveal still higher concentrations, the report concluded that off-site mercury levels were sufficiently high to warrant immediate, comprehensive monitoring at all US MCCAPs, as well as more aggressive Federal and State regulation of the industry.[49]

Meanwhile, a few MCCAPs in the US are considering equipment for continuous monitoring of cell-room air, reflecting an obvious desire to better understand and measure their mercury emissions. However, there is as yet no legal obligation for continuous monitoring.

3.7 French industry-sponsored research

In 2003 the Association of Halogens and Derivatives (Syndicat des Halogènes et Dérivés), in cooperation with the French Ministry of Environment and Sustainable Development, convened government officials, industry representatives, journalists, unions, consumer groups and European Commission officials[50] to present the results of an assessment that concluded that none of the French MCCAPs have any significant impact on health or the environment. According to a 2004 Euro Chlor paper submitted to the European Commission:

[49] See footnote 46.

[50] "Day of information sharing regarding the health and environment impact analyses for the MCCAP production sites in France," organised jointly by the Ministry of Environment and Sustainable Development, and the Association of Halogens and Derivatives, 2 December 2003; in a speech by Thierry Trouve, Director of Pollution and Risk Prevention, French Ministry of Environment and Sustainable Development, he stated, "Pour chacun des sites concernés, l'évaluation des impacts demandée par la circulaire ministérielle en date du 7 mars 2000 a été réalisée et conclut globalement à l'absence d'impact significatif du fait des rejets de mercure des unités en fonctionnement en France."

> *The conclusion reported by the representative of the French Ministry of Environment and Sustainable Development [Ms Casimir, MEDD] was that "None of the French mercury plants have any significant impact on health or the environment. We will pursue continuing reductions in emissions."*
>
> *Euro Chlor is confident that the conclusions on the impact of the French plants are equally valid for plants in other countries.*[51]

Based upon presentations given at the French "Day of Information Sharing" and now available (as slides) on the internet,[52] it appears that the health and environmental assessment was sponsored by the French chlorine industry. It is not the role of this author to question the validity of the results of such an assessment, but it appears to have been less independent, lacking in peer review, and less open to external scrutiny during the preparation and execution of the research than the public is generally willing to accept. Since the results of the assessment were announced, the findings have been cited by the French chlor-alkali industry as justification for not needing to comply with the 2010 phase-out date of PARCOM 90/3. Possibly more damaging, however, is that in the absence of detailed independent research that should have been carried out at other MCCAP sites in the EU, the French findings have been represented by Euro Chlor (see quotation above) to be equally valid for all MCCAPs in the EU.

Consequently, despite the fact that French MCCAPs are basically similar to others in the EU, and the research cited in Section 3 strongly suggests that average MCCAP emissions in the EU significantly exceed those that are being reported, the French government has adopted the official position that there is no justification for phasing out the mercury cell process.

3.8 "Unaccounted for" mercury losses

The problem of "unaccounted for" mercury losses, referred to previously, has long beset the chlor-alkali industry:

> *"EPA needs to take more seriously the pollution from the mercury cell chlor-alkali sector, which regularly loses as much or more mercury from its manufacturing process than power plants emit to the air."*[53]

For some years, industry has promoted the theory that most of the mercury that goes missing in fact accumulates in the piping and equipment of the plant. While it is impossible to know for sure how much mercury has gone missing from a typical MCCAP during the previous 30 to 50 years of operation, some conservative estimates have been made, and several European and Canadian efforts,[54] and at least one American team (HoltraChem)[55] have tried to account for this lost mercury. Specifically, they have tried to recover all mercury from MCCAP piping, equipment, structures, etc. at

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[51] See reference cited in footnote 45.

[52] See http://www.ecologie.gouv.fr.

[53] See footnote 24.

[54] F. Verberne and P. Maxson, *Mercury concerns in decommissioning chlor-alkali facilities in Western Europe*, ERM and Concorde East/West Sprl for the Netherlands Ministry of Environment VROM, The Hague, September 2000.

[55] See footnote 24.

decommissioning, including, in some cases, recovering large pools of mercury from the soil underneath the plant – mercury that had apparently leaked through the foundation of the cell building over many years.

While significant accumulation of mercury at MCCAP sites has certainly been demonstrated, the quantities of mercury recovered during these decommissioning activities were not close to the estimates of what had disappeared during the long years of plant operation. Such observations invite only one rational conclusion:

> *"…neither EPA nor the chlor-alkali industry can account for the environmental fate of dozens to hundreds of tons of mercury purchased and/or added to the cells each year. In light of what we know about the mercury cell process, it is reasonable to conclude that significant quantities of these unaccounted for tons are escaping to the air. This is especially true because the industry – which is in a position to provide information debunking such claims and supporting its own belief that mercury is not lost but instead accumulates in plant equipment, such that it may be recovered when plants are decommissioned at the end of their operating lives – refuses or is unable to provide any such data about mercury accumulation."*[56]

While this author agrees with the basic thrust of the above statement, he cannot agree that industry has been uniformly uncooperative. During one particularly comprehensive effort to account for mercury at a closed MCCAP in the US, which would not have been possible without industry cooperation, less than half of the mercury estimated (very conservatively) to have been accumulated was recovered.[57]

3.9 On-site and local contamination

Contamination of MCCAP sites with mercury (and other pollutants) is briefly raised here to ensure that the costs, which may be considerable, are not ignored. At many MCCAP sites, soil and groundwater contamination are due not only to local deposition of mercury, but also to the historical[58] disposal of mercury sludges and wastes on and around the plant sites.[59] In addition, researchers have also detected dioxin contamination resulting from the dumping of sludges from historical use of graphite electrodes.[60,61] Since most MCCAPs in the EU are at least 30 years old, and some far

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[56] See footnote 24.

[57] See footnote 24.

[58] "Historical" here refers to activities no longer practiced in the EU and US, to the author's best knowledge.

[59] See footnote 3.

[60] Kjeller LO, SE Kulp, C de Wit, K Lexen, I Hasselsten, E Rappe, P Jonsson and B Jansson. Sediment, soil and water contamination by polychlorinated dibenzodioxins and dibenzofurans (PCDD/Fs) from sludge from graphite electrodes used in chlorine production. Paper presented at Dioxin '91, 23-27September 1991, Research Triangle Park, N. Carolina, USA.

Rappe C, LO Kjeller, SE Kulp, C de Wit, I Hasselsten and O Palm (1991). Levels, profile and pattern of PCDDs and PCDFs in samples related to the production and use of chlorine. *Chemosphere 23*(11 12): 1629-1636.

[61] The chlor-alkali BREF (footnote 3) mentions the continued use of graphite as a catalyst in some decomposers, though it is not mentioned whether this may also give rise to PCDD/PCDF-contaminated wastes.

older, contamination of the production site and the surrounding area is a common problem.[62]

With regard to local deposition of mercury, atmospheric mercury emissions from MCCAPs, primarily in the elemental form, have a long residence time and broad dispersion characteristics. Hence, emissions to the atmosphere greatly exceed local deposition. Nevertheless, over time, there is also extensive local deposition of mercury from chlor-alkali plants. European studies have confirmed pronounced deposition near MCCAPs and lower, yet still elevated, levels much farther away.[63] Similar findings have been reported for MCCAPs in the US by Southworth *et al.* and others.[64]

With regard to MCCAP waste disposal practices, it is natural to assume that mercury wastes are now being handled responsibly. On the other hand, there are persistent incidents of mislabelled waste shipments within the EU. And to take only one country – Italy – as an example, it is difficult to overlook recent scandals with regard to the transport and disposal of mercury and other hazardous wastes, which should be cause for serious concern, as well as increased scrutiny.[65]

In the EU there is considerable documentation on MCCAP decommissioning and site cleanup.[66] As concerns the US, many former MCCAP sites have such extensive contamination, and the liable party or parties are impossible to identify, or lacking the necessary financial resources, etc., that site remediation has been assigned to the Superfund programme.[67]

If not already dealt with, historical waste disposal sites used by MCCAPs must ideally be cleaned up, capped or otherwise carefully managed in order to adequately deal with emissions. Most operating MCCAPs have taken measures to limit emissions from historical waste disposal areas on-site. The hazards of inadequate attention to waste disposal areas are demonstrated by an old study of former wastewater ponds on a single MCCAP site, which reported nearly 37 kg of annual mercury emissions to the air – and that was after plant operations had been terminated.[68]

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[62] "Most of the mercury cells in the EU were installed up to the mid-1970s and economic plant lifetimes can be in the range of 40-60 years." See Lindley AA, ICI Chemicals & Polymers (UK), "An Economic and Environmental Analysis of the Chlor-Alkali Production Process," report prepared for the European Commission during a secondment from ICI to DG III C-4, 1997 (as cited in the *IPPC Reference Document* on chlor-alkali – see footnote 3).

[63] Wängberg I, L Barregard, G Sällsten, M Haeger-Eugensson, J Munthe and J Sommar. Emissions, dispersion and human exposure of mercury from a Swedish Chlor-Alkali plant. *Atmospheric Environment 39* (2005).

Pacyna JM, J Munthe, K Larjava and EG Pacyna (2005) Mercury emissions from anthropogenic sources: estimates and measurements in Europe. In: *Dynamics of Mercury Pollution on Regional and Global Scales. Atmospheric Processes and Human Exposures Around the World*. N Pirrone and KR Mahaffey (eds), Springer, N.Y. 51-64.

[64] See footnote 32; also Makholm M and J Bennett. *Water, Air, & Soil Pollution* **102**: 427-436 (1998); etc.

[65] See *La chimera delle bonifiche*, Legambiente, 2005; and *Rapporto Ecomafia 2005*, Legambiente, Italy, 2005.

[66] For example, see "Gamla klor-alkalifabriken i Skoghall, Hammarö kommun – Saneringen av fabriksområdet – Miljökonsekvensbeskrivning," Envipro Miljöteknik AB report for Akzo Nobel Base Chemicals AB, Skoghall, 22 October 2001. See also the chlor-alkali BREF (footnote 3). See also Verberne and Maxson (footnote 54).

[67] To take one example, the EPA Record of Decision for Alcoa (Point Comfort)/Lavaca Bay Site, December 2001, can be viewed at: http:www.epa.gov/region6/6sf/pdffiles/alcoa_lavaca_final_rod.pdf.

[68] Lindberg SE and RR Turner. *Nature* **268**, 133-136 (1977).

The Olin MCCAP (previously described) in Augusta, Georgia, appears to be an example of good planning and management of an historic waste disposal site. This is a large area (~400 hectares) of land surrounding the facility, that was once used for wastewater settling basins and for disposal of mercury-contaminated wastes. The size of this waste area is such that even small fluxes of gaseous mercury per unit area could produce significant emissions. However, the contaminated basins and soils appear to have been adequately capped, and the measured flux from these historic mercury waste areas appeared to be negligible (probably less than 0.5%) relative to overall atmospheric mercury emissions from the operating MCCAP .[69]

Optimally, clean-up of a chlor-alkali waste site must be done according to a methodical and thorough procedure. At the beginning, typically, it is not known in detail how contaminated the site is, or what types of contaminants may be present. An initial study that covers a large portion of the site should be followed by more detailed studies of smaller areas where contamination is found. This could mean that a clean-up or containment project might need to be planned and carried out over a year or more.[70] Even in the best case, as noted by SRI Consulting, "The cleanup costs of closing down a mercury cell plant are significant…."[71]

4 EU health risk from MCCAP mercury emissions

4.1 Mercury Strategy impact assessment

The European Commission, in the Extended Impact Assessment that accompanied its Mercury Strategy, wrote that most EU residents in coastal areas of Mediterranean countries, as well as less than 5% of the remaining EU population, are likely exposed at a level close to the USEPA health reference dose for methylmercury. Roughly estimated, that assessment thus applies to some 100-150 million persons. Moreover, large numbers of the Arctic population and Mediterranean fishing communities are known to suffer significantly higher exposure levels – specifically, levels at which it is accepted that there may be clear neurological effects.[72] These exposures are mostly related to fish or marine mammals in the human diet. The European Commission discussed – in an annex to the Extended Impact Assessment – the benefits that would accrue to a reduction of mercury emissions, but declined to put a number to such benefits on the basis that the number of studies available at that time was too limited.

4.2 Recent research studies

It has been demonstrated that micro-organisms and natural processes generate the most common organic mercury compound, methylmercury, from other forms of mercury.

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[69] See footnote 33.

[70] See footnote 3.

[71] See footnote 16.

[72] European Commission. SEC(2005)101 Communication from the Commission to the Council and the European Parliament on Community Strategy Concerning Mercury, *Extended Impact Assessment* {COM(2005)20 final}28.1.2005. The document cited one study of fish consumption in which experts estimated that almost half (44%) of young children in France could have methylmercury exposure levels that would put them at risk of health effects. Document available at:
http://www.europa.eu.int/comm/environment/chemicals/mercury/pdf/extended_impact_assessment.pdf

Thus, while MCCAPs do not directly emit methylmercury, the US EPA and various researchers have pointed to the links between elemental mercury emissions, e.g. from coal-fired power plants, followed by long-range diffusion in the atmosphere and deposition on (salt and fresh) water bodies, and from there to the uptake and conversion of mercury to methylmercury by micro-organisms and natural processes, some of which is then accumulated in the food chain (especially via certain fish) and eventually returns to humans in their diet.[73] The quantities of mercury and methylmercury that follow this route for any given emission source may not be large, but the health implications and related costs may be considerable. Using this methodology and others, there have been a number of recent efforts in the US to model and quantify the health and related economic benefits of reducing atmospheric mercury emissions and/or human exposures, including:

EPRI. 2003. A Framework for Assessing the Cost-Effectiveness of Electric Power Sector Mercury Control Policies, Technical Report 1005224, Electric Policy Research Institute, Palo Alto, CA, May 2003.

Gayer, T. and R.W. Hahn. 2005. "Designing environmental policy: Lessons from the regulation of mercury." Regulatory Analysis 05-01, AEI-Brookings Joint Center for Regulatory Studies. http://www.aei-brookings.org/admin/authorpdfs/page.php?id=1126

Hagen, D. A., J. W. Vincent and P. G. Welle. 1999. Economic Benefits of Reducing Mercury Deposition in Minnesota. Minnesota Pollution Control Agency. http://www.pca.state.mn.us/publications/reports/mercury-economicbenefits.pdf

Jakus, P. M., M. McGuinness, and A. Krupnick. 2002. "The Benefits and Costs of Fish Consumption Advisories for Mercury in the Chesapeake Bay." Resources for the Future Discussion Paper 02-55, October. http://www.rff.org/Documents/RFF-DP-02-55.pdf

Lutter, R., E. Mader, and N. Knuffman. 2001. "Regulating mercury: What do we know about benefits and costs." Regulatory Analysis 01-03, AEI-Brookings Joint Center for Regulatory Studies. http://aei-brookings.org/admin/authorpdfs/page.php?id=143

Palmer, K., D. Burtraw, and J-S. Shih. 2005. "Reducing emissions from the electricity sector: the costs and benefits nationwide and in the Empire State." Resources for the Future Discussion Paper 05-23. http://www.rff.org/documents/RFF-DP-05-23.pdf

Rae, D. and L. Graham. 2004. "Benefits of reducing mercury in saltwater ecosystems." Report for Office of Wetlands, Oceans, and Watersheds, US EPA. http://www.cleanairnow.org/pdfs/officewatermerc.pdf

Rice, G. and J.K. Hammitt. 2005. "Economic valuation of human health benefits of controlling mercury emissions from U.S. coal-fired power plants." Report for NESCAUM, Northeast States for Coordinated Air Use Management. http://bronze.nescaum.org/airtopics/mercury/rpt050315mercuryhealth.pdf

Trasande, L., Landrigan, P.J., and Schechter, C. 2005. Public health and economic consequences of methyl mercury toxicity to the developing brain. Environmental Health Perspectives 113:590-596.

USEPA. March 2005. Regulatory Impact Analysis of the Clean Air Mercury Rule. EPA-452/R-05-003. 566 pp. http://www.epa.gov/ttn/atw/utility/ria_final.pdf

USEPA. October 2005. Technical Support Document. Revision of December 2000 Regulatory Finding on the Emissions of Hazardous Air Pollutants from Electric Utility Steam Generating Units. http://www.epa.gov/ttn/atw/utility/TSD-112-final.pdf

These studies represent a range of scenarios for reduction of mercury emissions and exposures – most of them focusing on the costs and benefits of reducing coal combustion emissions, which have been the subject of intensive debate in the US. The health or other endpoints of these studies include, variously, decreases in intelligence

[73] "Observations on EPA's Cost-Benefit Analysis of Its Mercury Control Options," GAO-05-252 Clean Air Act, Report to Congressional Requesters, US Government Accountability Office (GAO), Washington DC, February 2005.

quotient (IQ) or increases in general neurological deficiency, increases in acute myocardial infarction (AMI) or all-cause mortality (ACM), impacts on recreational fishing, etc. The benefits are calculated, depending on the study, on the basis of lost earnings, willingness to pay, cost of illness, value of a statistical life, etc., and the uncertainties associated with different benefits vary considerably.

4.3 Observations concerning health benefits of reduced emissions

Due to the methodological differences among these studies, any comparison must be made with great caution. However, if one were to identify a simple but useful metric that could be drawn from these studies, it would be a quantified benefit per tonne (or gram) of mercury emissions eliminated. On this basis (and when a range was presented, accepting the "most likely" benefits suggested by the researchers), the annual benefits (in euro of 2004) calculated by these studies ranged from a low of about €5 (the parental willingness to pay for IQ increases through chelation therapy) per gram of atmospheric mercury emissions eliminated, to a high of about €185 (costs associated with decreased IQ, and increases in non-fatal AMI, hypertension and ACM) per gram of atmospheric mercury emissions eliminated.

In an attempt to further narrow this range, it was logical to focus especially on the economic analyses that concentrated on benefits of reduced mercury emissions from coal combustion (especially the exposure route via fish), the methodologies for which are most readily transferable to chlor-alkali emissions.[74] Even for this basic exposure route, there were several critical decisions that had to be made by each research team using this model:

1. what assumptions to make regarding changes in mercury deposition to water bodies);
2. what assumptions to make concerning changes in fish methylmercury levels in response to changes in deposition;
3. what assumptions to make concerning changes in human methylmercury levels in response to changes in fish methylmercury levels; and
4. what health benefits to include, and what assumptions to make concerning changes in those health benefits in response to changes in human methylmercury levels.

Unsurprisingly, the decisions and assumptions made with regard to these four points had a great impact on the range of benefits and uncertainties calculated. Therefore, with regard to narrowing the benefit range for the purposes of this analysis, it was logical to disregard the more extreme high and low values, to focus on the methodologies with

[74] Based on the fact that the contribution of elemental mercury to MCCAP emissions (well over 90% elemental mercury) is not much different from the contribution of elemental mercury to coal emissions (around 80% elemental mercury). The research carried out around Olin Augusta confirmed that, at most, one percent of emissions from active MCCAPs is reactive gaseous mercury (RGM), which would typically deposit locally. This leaves 99 percent of the emissions as elemental mercury Hg(0), mostly emitted no more than 30-40m above the ground. Despite this "stack" height that is significantly lower than most utility boiler stacks, most models would suggest that the majority of such Hg(0) emissions are transported at least hundreds, and possibly thousands of kilometres from the site, depending on the atmospheric oxidation rate and other meteorological conditions. As mentioned previously, there are elevated concentrations of mercury around MCCAPs due to local deposition, but that only means that deposition to soils and plants around an MCCAP is elevated above ambient levels. It does not mean that most of the mercury is deposited locally. At Olin Augusta the mercury plume was tracked at ground level over 15 km from the site, simply by measuring air concentrations with a Lumex device (see footnote 32).

lower levels of uncertainty, to consider researcher reputation and independence, to recognise special methodological rigour and, again in the interest of reducing uncertainties, to generally favour more conservative assumptions. These criteria ultimately led to a focus, in particular, on two of the research efforts listed above – the peer-reviewed paper by Trasande *et al*., and the October 2005 report published by the US EPA.

Trasande *et al.* limited their analysis to the neuro-developmental impacts of methylmercury exposure[75] – specifically loss of intelligence – in the US. The authors chose not to include mortality benefits, but assumed that a small percentage of mercury deposition to the ocean is probably implicated in human health effects. The Cost-of-Illness (COI) impact was calculated, assuming that a reduced mental capacity is directly related to diminished economic productivity that persists over the lifetime of the individual exposed. The authors concluded that approximately $US1.3 billion (range: $US0.1–6.5 billion, in dollars of 2000) each year in diminished productivity in the US is attributable to the (49 US tons of) mercury emissions from American power plants.[76] Very simply, one could calculate – for this single health effect, and only for the US population – annual benefits of about €26 (euro of 2004) per g of mercury emissions eliminated.[77]

In the October 2005 US EPA study the authors, like Trasande *et al.*, limited their analysis to the COI measurement of reduced US neuro-developmental capacity due to methylmercury exposure, and did not include mortality benefits. However, contrary to Trasande *et al.*, these authors ignored the effects of mercury deposition to seawater (despite the preponderance of marine species in the typical American diet), focusing instead on the recreational and subsistence freshwater fish pathway of mercury exposure, under the assumption that the freshwater pathway "leads to the greatest individual exposure due to utility-attributable mercury emissions." The US EPA analysis concluded that the implementation of the Clean Air Interstate Rule (CAIR), which is expected to eliminate well under 10 US tons of annual mercury emissions, would confer what was described as a "dramatic overestimate" of $168 million (dollars of 2004) per year in US health benefits.[78] This would imply – for this single health effect, and only for the US population – annual benefits of about €19 (euro of 2004) per g of mercury emissions eliminated.[79]

This level of benefits is remarkably consistent with an earlier analysis prepared by the US Environmental Protection Agency with specific regard to basic emission controls for

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[75] This health effect is related to a level of exposure for which there is evidence of human neurotoxicity based on several epidemiological studies (e.g., in the Faro Islands and New Zealand). Other well regarded studies carried out in the Seychelles, on the other hand, have not shown an increase in neurotoxicity associated with increased *in utero* methylmercury exposures.

[76] Trasande L, PJ Landrigan and C Schechter, "Public Health and Economic Consequences of Methyl Mercury Toxicity to the Developing Brain," *Environ Health Perspect 113*:590–596 (2005).

[77] Since only a small percentage of US coal combustion mercury emissions are assumed to enter the food chain and cause health effects in the US population, this should be considered a highly conservative estimate. An estimate of the global benefits of US mercury reductions would have to assume an additional percentage of those coal emissions enters the food chain of populations outside the US.

[78] USEPA. October 2005. Technical Support Document. Revision of December 2000 Regulatory Finding on the Emissions of Hazardous Air Pollutants from Electric Utility Steam Generating Units. http://www.epa.gov/ttn/atw/utility/TSD-112-final.pdf.

[79] The comment in footnote 77 applies to this calculation as well.

MCCAPs. In this calculation, the EPA determined that more stringent mercury controls are "cost-effective and warranted" if the incremental annual cost is up to $9,000 (in 2001-2) per additional pound of mercury eliminated.[80] Converting these figures to euro per gram, one arrives at an annual benefit due to MCCAP mercury emission controls of just under €19 (euro of 2004) per gram of atmospheric mercury emissions eliminated.

Finally, these calculations also reflect rather closely the results of the earlier and well regarded study by Staring and Vennemo, based on a wide range of other studies, which estimated the health cost to society of atmospheric mercury emissions at about $17 (dollars of 1996) per gram,[81] which would be equivalent to well over €25 (euro of 2004) of EU health benefits per g of mercury emissions eliminated, especially if one considers that the $17/g cost estimated by Staring and Vennemo represented a weighting of health costs in both richer and poorer countries.

4.4 Socioeconomic benefits of reduced emissions

It is useful to keep in mind that the benefits calculated by the Trasande *et al.* and US EPA studies are due only to mitigation of the most widely accepted health (neurotoxic) effects of consuming fish contaminated indirectly by elemental mercury emissions to the atmosphere, and are not a comprehensive total of potential health benefits that could accrue from reduced mercury emissions from coal combustion (or MCCAPs). Other potential health effects (i.e., fatal and non-fatal acute myocardial infarction, all-cause mortality, etc.) mentioned above would obviously increase the benefits estimated by these studies. In addition, it has been previously noted that atmospheric concentrations recently measured outside a number of MCCAPs exceed government-determined "safe" levels for long-term exposure.[82] Any health effects due to the general public's long-term exposure to elevated levels of atmospheric mercury would be over and above the health effects associated with fish consumption.

4.4.1 Health benefits

Therefore, based on the balance of the scientific evidence as presented in the studies cited, and the straightforward analysis presented above, this author proposes a conservative estimate of annual EU health benefits in the range of €25-30 per gram of atmospheric mercury emissions eliminated. This would imply that phasing out the estimated 25-30 tonnes (see Section 3.4) of annual EU MCCAP mercury emissions would confer annual health benefits of at least 750 million euro, and more likely even exceeding one billion[83] euro if less conservative estimates had been used.

Despite repeated efforts in the preceding analysis to reduce uncertainties and to rely on the most widely accepted science, the main references cited do point out that uncertainties remain. For example, there is a very small probability that the neurotoxic

[80] Federal Register, Part II, [US] Environmental Protection Agency, 40 CFR Part 63, National Emission Standards for Hazardous Air Pollutants: Mercury Emissions From Mercury Cell Chlor-Alkali Plants; Proposed Rules, Vol. 67, No. 128, at p.44,683, Wednesday, 3 July 2002.

[81] Staring K and H Vennemo (1997). "Pricing hazardous substance emissions." ECON - Centre for Economic Analysis for the Norwegian Research Council – NFR. ECON-report no. 63/97, Project no. 10228. ISSN: 0803-5113, ISBN: 82-7645-216-7. Oslo, Norway.

[82] See footnote 46.

[83] "Billion" as used in this text means "thousand million."

effects cited above may not exist at these levels of exposure,[84] and that simultaneously there may be no ACM or AMI risks. In such an unlikely case, the level of health benefits calculated here could be a significant overestimate. On the other hand, there is a far greater probability that the neurotoxic effects cited are not only real, but may be even greater than assumed here,[85] and that there are, at least, some additional ACM and/or AMI effects.[86] In such a likely case, the level of health benefits calculated above would clearly be a significant underestimate.

4.4.2 Environmental benefits

The human health impacts of mercury and methylmercury exposures have received considerably more research attention than have the environmental impacts. However, a recent European Commission sponsored study by DHI[87] of the impact of proposed REACH[88] legislation suggested that the annual environmental benefits of reducing chemical emissions in the European Union likely approximate the direct health benefits. While the DHI study does not address environmental benefits specifically for the case of mercury, and while this paper does not assume the DHI findings can be directly transferable to the case of mercury, it nevertheless provides an intriguing basis for the hypothesis that the environmental benefits due to reducing mercury emissions may be of the same order of magnitude as the health benefits estimated above.

However, for the purpose of this analysis, another conservative – though illogical – assumption has been made. That is, the environmental benefits for the European Union of reduced elemental mercury emissions will not be considered in this paper, simply because they are difficult (or have not been a sufficiently high research priority) to quantify in a manner useful to this analysis. It is hoped that additional research efforts will soon be devoted to better costing the environmental impacts of mercury emissions. Meanwhile, one may confidently assume that the benefits of reduced mercury emissions calculated below are probably significant underestimates.

5 Economics of MCCAP conversion to BAT

5.1 Key issues

Considering the magnitude of the potential health benefits to be gained by conversion of EU MCCAPs to a mercury-free process, it is logical to ask what the direct economic costs and benefits of conversion are. While the cost is one of the reasons commonly given by industry for delaying conversion, the fact that there have already been many conversions from the mercury process to membrane since the early 1990s, especially in the US and Europe, significantly reduces the force of that argument.

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[84] While they firmly support the findings of decreased cognitive development by Trasande *et al.* and others, for example, the possibility of no decrease in IQ is acknowledged by Cohen JT, DC Bellinger, BA Shaywitz. 2005. A quantitative analysis of prenatal methyl mercury exposure and cognitive development. *Am J Prev Med 29*(4): 353–365.

[85] Trasande L, C Schechter, KA Haynes, PJ Landrigan. 2006. Mental retardation and prenatal methylmercury toxicity. *Am J Ind Med 49*:153–158.

[86] There is credible, though not conclusive, evidence that exposure to methyl mercury through fish consumption leads to higher rates of adverse cardiovascular events.

[87] "The impact of REACH on the environment and human health," revised final report, DHI Water & Environment for the European Commission (DG Environment), contract ENV.C.3/SER/2004/0042r, September 2005.

[88] REACH (Registration, Evaluation and Authorisation of CHemicals) is the acronym for a draft EU law on chemicals.

It is generally agreed that the membrane process is the most economically and environmentally attractive mercury-free process for the production of chlorine and caustic. According to SRI Consulting, an influential source of information to the chemical industry, “Currently, there is no justification for not using membrane cell technology in any new chlor-alkali plant or revamp of an existing plant.”[89] The membrane process has been in use for many years and is well proven. Despite the fact that no two MCCAPs are identical, most are quite similar, and this has permitted a considerable body of experience to have been accumulated with regard to decommissioning and converting MCCAPs, including planning and managing the conversion process, the costs of conversion, the nature and costs of site contamination, the recovery of residual mercury from equipment, structural materials and soils, etc.[90]

In a number of cases, MCCAPs have been closed rather than converted. As in the case of MCCAP conversions, these closures have generally been motivated by economic concerns, often carried out as part of a redesign of an integrated chemical production process, although environmental and safety considerations have often further reinforced the economic rationale. For example, during the early 1990s various MCCAPs in the Nordic countries closed due to the disappearance of the regional market for bleaching wood pulp. At the same time, there were increasing concerns about mercury emissions, as well as concerns about the safety of transporting chlorine over longer distances.

Likewise, the industry has seen a great deal of consolidation, during which a number of smaller MCCAPs have been closed, while more integrated complexes have expanded chlor-alkali output to supply increasing markets for such products as isocyanates, PVC and polycarbonates.

Any review of MCCAP conversion costs is complicated by the fact that there are always mercury, and sometimes other contamination, issues to deal with at the same time. Apart from other contaminants, mercury cleanup can be complicated and expensive. Whether an MCCAP is closed or converted, there is typically a significant site decommissioning and cleanup cost, although it varies widely depending on local regulations, the intended use of the site, previous clean-up efforts, etc. Because of the range of environmental and other concerns associated with MCCAP conversion, it is suggested that all MCCAPs, even those that may not be planning conversions in the near future, should be required to have an independent site contamination assessment, as well as an independent estimate of clean-up costs, so that government authorities and others may better understand potential liabilities, draft more appropriate operating permits, and have a better basis for assessing eventual conversion plans and investment programmes.

While an MCCAP continues operating, it can defer many of the costs of eventual site remediation, as long as it can demonstrate compliance with relevant regulations and meet any other requirements of its operating permit. Therefore, there are multiple incentives for an MCCAP to stay in operation as long as possible: investment costs amortised long ago, experienced operating staff, low production costs, deferral of eventual investment in conversion, no conversion-related downtime or uncertainties,

[89] See footnote 16.

[90] See footnote 54.

deferral of various site remediation costs, etc. From industry's point of view, if there is a market or process justification for continued production of chlorine or caustic, the economic rationale for keeping an old MCCAP in operation is clear.

5.2 Conversion and cleanup costs

Section 4.2.2 of the chlor-alkali BREF provides a good overview of the costs involved in MCCAP conversion and cleanup. The chlor-alkali BREF explains that, when carrying out a conversion to a mercury-free process, depending on the original process configuration, one of the key objectives is to limit downtime and production losses. With this objective in mind, most operators have either built an entirely new "green-field'' plant, or they have expanded production capacity with a new plant alongside their existing mercury facilities. Mercury-free conversion is technically applicable at all mercury cell chlor-alkali plants, but the specific challenges of conversion may differ considerably from one site to another. Many operators have completely converted their existing mercury-based plant, but there are also examples of partial conversion – again, frequently for the purpose of limiting production downtime, but sometimes also to test new technologies and/or innovative designs – where some of the mercury cells are shut down and converted while the remaining mercury cells continue in operation.[91]

Various parts of the manufacturing process must be modified during conversion, of which the cell building and equipment are the main focus. Existing cell room buildings can be reused to accommodate membrane electrolysers. The saving of space makes it theoretically possible, with membrane technology, to install up to 400% more capacity in an existing building. However, a clean room is needed for the membrane cells. Therefore, the decision to reuse an existing building will depend on:

- the condition of the building;
- whether space for a separate (new) membrane cell room is available; and
- the length of time production may have to be halted.[92]

There is a wealth of experience to support a rough estimate of the cost of cellroom conversion. Inevitably, however, for reasons such as those mentioned above, the costs may vary significantly from plant to plant, even on a capacity-adjusted basis. Because the scope of work may vary greatly, any "average" cost estimate invites the classic debate over which costs should be included and which should not. The cost of conversion of a mercury cellroom typically includes not only the decommissioning and removal of mercury from the cells, and the cost of the new electrolysers, but also, as a minimum, the costs associated with caustic recycle, caustic evaporation and brine secondary purification and dechlorination. In many cases there are further costs for additional gas cooling, new rectiformers (and possibly new electrical supply and switchgear equipment), changes to the supply of utilities and gaseous hydrogen chloride (HCl), new building structures, and decontamination and/or disposal of previous structures and equipment – not to mention any remediation of surrounding soils, downstream sediments, etc. (see discussion in Section 3.9). The chlor-alkali BREF document reported conversion costs, based on actual projects, ranging from 194 to 700 euro per tonne of chlorine capacity, as shown in the table below.[93]

[91] See footnote 3.

[92] See footnote 3.

[93] See footnote 3.

Table 9 Cost of cleanup and conversion of MCCAPs to mercury-free process

Source Plant/base (year of conversion)	Annual plant capacity [tonne Cl_2]	Investment in original currency	Investment in euros (currency date)	euros/tonne Cl_2	Comments
[Lindley, 1997] European union, OSPARCOM impact	Calculation for 1 tonne of Chlorine	EURO 560–610	560–610	560-610	worst case assumptions; non-conversion costs included
[Lindley, 1997] European union, OSPARCOM impact	Calculation for 1 tonne of Chlorine	EURO 360	360	360	"ideal case": no changes in power supply and buildings
[SRI Consulting, 1997] average Western European chlorine plant	157000	USD 111 M	92.5 M (April 1997)	590	worst case assumptions; non-conversion costs (chlorine drying, liquefaction, bleach unit etc.) and disposal costs included
[Schindler], [UBA (A), 1998] Donau Chemie, Brückl, Austria (1999)	60000	ATS 200 M	14.5 M (fixed EMU conversion rate)	242	power supply and cell-room building reused; non-conversion costs included such as down-stream modifications and increased capacity of HCl and bleach; site clean-up not included
		ATS 160 M	11.6 M (fixed EMU conversion rate)	194	pure conversion cost; estimated waste disposal costs included
[Schubert], [Chemie Prod., Mai 2000] Bayer, Dormagen, Germany (1999)	300000	DEM 240 M	122.7 M (fixed EMU conversion rate)	409	total cost including engineering and construction (new equipment: DEM 170 M); cell-room building, brine filtration, H_2 and Cl_2 gas treatment facilities and compressors reused; dismantling of most Hg-cells not included;
[de Flon, 1998] Borregaard, Sarpsborg, Norway (1997)	40000	NOK 210 M	26.6 M (October 1997)	665	rectifiers reused; new cell room; new brine circuit; construction and building of a landfill; non-conversion costs included
[Lott, 1995] Associated Octel, Ellesmere Port, UK (1992)	40000	GBP 11.6 M	14.5 M (January 1995)	362.5	"old" costs (no previous practical experience); includes the clean-up and disposal of the contaminated parts of the plant (excluding soil)
[García Ara] Aragonesas, Vilaseca, Spain, (new capacity together with a mercury plant 1992/1998)	40000	ESP 4660 M	28 M (fixed EMU conversion rate)	700	cell equipment (approx. 150-170 euros/ t Cl_2), brine supply (rock salt), rectifiers, new building, training and start-up included; not included are caustic soda conc., liquefaction and evaporation unit for oxygen elimination
Akzo Nobel, Skoghall, Sweden, 2000 Akzo Nobel, Skoghall, Sweden (conversion of one membrane cell design to another 1999)	75000	SEK 250 M	29 M (December 1999)	387	new cell room, rectifiers, cells and caustic evaporation included
OxyTech Systems, Inc. 1998 adapted calculation of an actual conversion project	122500	USD 56.2 M	51 M (April 1998)	416	net cost: no changes in power supply and no reconstruction, some overhauling of existing equipment included
[SEPA, 1997] Akzo Nobel, Bohus, Sweden (estimated 1997)	100000	SEK 250 M	29 M (October 1997)	290	rectifiers, site clean-up and waste disposal costs not included
UHDE Gmbh, 1998 average conversion costs	Calculation for 1 tonne of Chlorine	DEM 500	255 (December 1998)	255	average conversion costs excluding disposal
Asahi glass Co., 1998 average conversion costs	166000	JPY 5000 M	35.4 M (December 1998)	213	average conversion: including rectifiers, excluding disposal

Source: *IPPC Reference Document on Best Available Techniques in the Chlor-Alkali Manufacturing Industry*, European IPPC Bureau, Institute for Prospective Technological Studies, European Commission Joint Research Centre, Seville, December 2001.

According to the chlor-alkali BREF, conversion costs of more than 600 euro/tonne chlorine (Cl_2) capacity typically include costs not directly related to the conversion, such as landfill construction, site clean-up, training of personnel, capacity increases, start-up costs, etc. Costs of 400-600 euro generally include a new cell room, power supply, waste disposal, down-stream modifications, etc. Lower conversion costs between 200 and 400 euro per tonne of chlorine capacity are typically associated with less extensive modifications, but still include costs for clean-up and/or disposal of wastes, contaminated structures and equipment, etc.[94]

Generally assuming that the mid-range of these conversion costs may be used as an industry average, one might also consider some of the most recent estimates, e.g., two Italian conversions announced for 2007:

- The Altair Chimica plant in Saline di Volterra has a chlorine production capacity of 27,000t/yr. (holding an estimated 50 tonnes of mercury in the electrolytic cells), and has planned an investment of €13.5 million. Noting that some of the projected investment is for clean-up and various other costs, this represents an overall unit conversion cost of €500/tonne of chlorine production capacity.
- The Solvay plant in Rosignano has a chlorine production capacity of 127,000t/yr (holding an estimated 220 tonnes of mercury in the electrolytic cells). The estimated total conversion cost of €48 million implies a unit cost of €378/tonne of chlorine production capacity.[95]

While further details of these proposed conversions have not been made public, one could safely assume, based on the above information, that average total investment costs for MCCAP conversion currently do not exceed €500/t chlorine capacity, and are often significantly lower.

As shown in Annex 1, the EU-based MCCAPs operating in 2005 (not including the one in Switzerland, which is not a member of the EU) had a production capacity of just under 6 million tonnes of chlorine. Converting all of this capacity to mercury-free at an average cost of less than €500 per tonne of chlorine capacity would require a capital investment of less than €3 billion.

However, as mentioned previously, a certain number of these MCCAPs will choose to close rather than convert. In a study carried out for Euro Chlor in 2002,[96] a consulting firm (Prochemics Ltd.) used various criteria to determine which MCCAPs would almost surely convert, which were less sure (i.e., some would convert while others would close), and which would almost certainly close. As noted by the consultant, anticipated closures were related to the "age of plants and lack of economic attractiveness," rather than any specific environmental pressures. Based on the Prochemics analysis, it is evident that

[94] See footnote 3.

[95] "State aid: Commission endorses €18.5 million of aid to reduce mercury emissions in Italy," European Commission press release IP/05/303, Brussels, 16 March 2005.

[96] "Projection of the Phase-Out of Mercury Cell Plants in the Western European Chlor-Alkali Industry," Prochemics Ltd., project no. 2-04-722, prepared for Euro Chlor (Brussels), June 2002.

some 10-15% of remaining EU chlorine capacity will likely close rather than convert.[97] Such closures would reduce slightly the overall investment required for conversion to a mercury-free chlor-alkali industry in Europe[98] – from the maximum €3 billion mentioned above, to an investment no greater than €2.5-2.7 billion.

5.3 Direct "industry" benefits of conversion

The estimated health and environmental benefits of converting to a mercury-free chlor-alkali process in the EU have been discussed previously. These socioeconomic benefits do not typically enter into the corporate decision-making process since most corporate decision-makers focus on the "bottom line" of corporate profit or loss.[99] However, there is a range of operating benefits – referred to here as "industry" benefits – associated with conversion to the membrane process that have a direct impact on the corporate bottom line.

Conversion to membrane technology has the advantage, *inter alia*, of greatly reducing energy use, which is a high priority for most industries and virtually all governments. Because energy costs comprise well over 50% of MCCAP production costs, this is an enormous opportunity to reduce production costs. The precise energy savings depend on the operating characteristics before and after any conversion.

At the Borregaard plant in Sarpsborg (Norway), membrane cells resulted in electrical energy savings of 30% (per tonne of 100% sodium hydroxide (NaOH) produced), compared to the mercury process.[100] Elsewhere, the US EPA reported some years ago that 17% energy savings were a useful guide.[101] SRI Consulting has provided the most current estimate, suggesting that electricity consumption is reduced from the range of 3.2-3.6 MWh/tonne of MCCAP production, to the range of 2.2-2.6 MWh/tonne (including energy required to raise caustic concentration from around 30% up to 50%) at a membrane plant.[102] This is a savings of about one MWh/tonne of chlorine produced, with a value that varies from country to country (depending on the energy sources), but was typically in 2005 valued at €40-50/t chlorine produced in the EU. The cost of energy is certainly higher in 2006, and has led to chlor-alkali industry demands for preferential energy pricing or subsidies from the energy companies. But preferential energy pricing and subsidies serve only to prolong the excessive energy consumption of MCCAPs, and distort the economic rationale for conversion to the membrane process.

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[97] This 10-15% Prochemics estimate is a reduction from the 33% industry estimate advanced in 1997 when questioned about the impact of a forced phase-out of mercury technology by 2010. See "Competitive Situation of the Western European Chlor-Alkali Industry in a Global Context: An independent assessment," SRI Consulting, prepared for Euro Chlor, April 1997 (as cited in EIPPCB "Reference Document on Best Available Techniques in the Chlor-Alkali Manufacturing Industry").

[98] In addition, the Prochemics report leaves the door open for the several plants that may keep using the mercury cell process, referring to the "virtually total disappearance of all mercury cell based capacity. Only plants requiring amalgam as raw material for downstream processes (specialties) will likely continue operations."

[99] For a fuller discussion of how such health and environmental benefits, while given little attention by many corporations, may significantly influence the bottom line, see Heemskerk B, P Pistorio and M Scicluna, *Sustainable Development Reporting: Striking the balance*, ISBN 2-940240-45-0, World Business Council for Sustainable Development WBCSD, Geneva, December 2002.

[100] See footnote 3.

[101] United States Environmental Protection Agency, "Mercury Cell Emission Control Practices and Techniques Guidelines," May 1998.

[102] See footnote 16.

Other benefits of conversion, in approximate order of economic significance, include:

- avoiding costs of recycling, retorting, transporting, inventorying and/or disposing of mercury wastes.
- elimination of the mercury wastewater treatment facility.
- reduced labour costs due to reduced need for maintenance.
- reduced labour costs due to reduced need for monitoring mercury emissions and occupational exposures, health testing, reporting and abatement measures.
- sale of residual mercury; it must be noted that this is not advocated by all MCCAP operators (on environmental grounds), but it is legally permitted until the EU mercury export ban and storage legislation comes into force.
- alternatively, the avoided cost of long-term storage of residual mercury, if conversion takes place before the trade ban comes into force.
- elimination of mercury monitoring equipment, as well as equipment for cleaning mercury from product streams, flue exhausts, etc.
- miscellaneous benefits not easily quantified (but possibly at least 5% of the total benefits listed above), such as improved community relations, decreased legal liability, improved public/investor image of the company, improved attractiveness of the company as a place to work (employee satisfaction), reduced energy demand during a time of raised energy consciousness, reduced CO_2 emissions related to energy demand, etc.

All of these industry benefits except those listed in the last bullet point are included in the summary Table 10 below.

Table 10 European industry benefits of converting MCCAPs to mercury-free

Assumptions for converting a generic European MCCAP to the membrane process:

- *Annual chlorine production capacity = 100,000 tonnes*
- *Mercury contained in electrolytic cells = 180 tonnes*
- *Annual atmospheric mercury emissions ≈ 4-5 g Hg per tonne chlorine capacity ≈0.4-0.5 tonne Hg total*
- *Annual mercury emissions to water = 10 kg*
- *Annual mercury wastes produced = 50 tonnes containing >2 tonnes mercury*
- *Conversion cost = max. €50 million (euro of 2004)*

Industry benefits (million euro of 2004)	**Estimated annual benefits**	**Benefits during 5 yrs.**		**Benefits during 10 yrs.**	
		Discount rate 5%	Discount rate 10%	Discount rate 5%	Discount rate 10%
	*Discount factor→**	*x 0.90**	*x 0.82**	*x 0.80**	*x 0.65**
Energy cost savings (€40-50 per tonne capacity)	4.5 annual	20.3	18.5	36.0	29.3
Avoiding costs of recycling, retorting, transporting, storing and/or disposing of mercury wastes (average €5-10 per kg of waste)	0.3-0.5 annual	1.8	1.6	3.2	2.6
Elimination of the mercury wastewater treatment facility (€2-3 per tonne capacity)	0.2-0.3 annual	1.1	1.0	2.0	1.6
Reduced labour costs due to reduced need for maintenance	0.2 annual	1.0	0.8	1.8	1.4
Reduced labour costs due to reduced need for monitoring mercury emissions, reporting, abatement measures and monitoring of occupational exposures	0.1 annual	0.5	0.4	0.8	0.7
Sale of residual mercury – noted for this analysis, but not relevant after the EU mercury export ban/storage requirement takes effect (30-50% of market price, i.e., MAYASA agreement)	1.1-1.8 one-time	1.5	1.5	1.5	1.5
Avoided cost of long-term storage of residual mercury, if conversion before the trade ban comes into force (min. ~2%, and potentially up to 8% of MCCAP conversion cost, depending on whether mercury is stored above ground or sent for long-term disposal)	>1.0 one time (equivalent)	1.0	1.0	1.0	1.0
Elimination of mercury safety monitoring equipment, as well as equipment for cleaning mercury from product streams, flue exhausts, etc.	<0.1 annual	0.4	0.3	0.6	0.5
Total economic benefits for converting a typical MCCAP of 100,000 tonnes Cl_2 capacity		**27.6**	**25.1**	**46.9**	**38.6**
Total economic benefits for phasing out European MCCAPs of 6 million tonnes Cl_2 capacity		1,700	1,500	2,800	2,300

Note:

* The discounted benefit equals the annual benefit multiplied by the number of years assumed for calculating return on investment, multiplied again by the "discount factor," which merely reflects the fact that the value of each subsequent year of benefits is discounted by the assumed discount rate, or "opportunity cost of capital," i.e., the assumed return on investment available through alternative business opportunities.

Sources:

Euro Chlor report to OSPAR published as, "Mercury Losses from the Chlor-Alkali Industry in 2003," OSPAR Commission, ISBN 1-904426-61-1, Publication Number: 2005/225, 2005;

IPPC Reference Document on Best Available Techniques in the Chlor-Alkali Manufacturing Industry, European IPPC Bureau, Institute for Prospective Technological Studies, European Commission Joint Research Centre, Seville, December 2001;

European Commission, SEC(2005)101 Communication from the Commission to the Council and the European Parliament on Community Strategy Concerning Mercury, *Extended Impact Assessment* {COM(2005)20 final}28.1.2005, p.31;

Maxson P, *Mercury flows in Europe and the world: The impact of decommissioned chlor-alkali plants*, report by Concorde East/West Sprl for DG Environment of the European Commission, 2004; and consultant estimates.

Table 10 shows that by far the most important benefit of conversion has to do with energy savings. The non-energy industry benefits add typically 30-40% to the energy-related benefits. This means that as energy costs rise, the bottom-line benefits of conversion will rise especially fast. Variations in the other benefits will have less impact on the total.

Moreover, Table 10 shows the importance of the time frame assumed for the return on an investment in conversion to mercury-free. An industry that takes a 10-year perspective and calculates a 10-year return-on-investment will typically view the present-value benefits of that investment as being at least 50% more attractive than an industry taking a five-year perspective on its investment.

Nevertheless, based only on the numbers in Table 10, and in the absence of strategic or other justification, most operators would not consider conversion an attractive investment since the return approaches the actual investment only within a time-frame of 10 years, and at a relatively low discount rate. Even if one includes the value to industry of various investment tax credits, this will not much change these results.

At the same time, it should not be ignored that in various cases the payback may be much faster. For example, a plant converted in Norway during 1997 reported sufficient savings on energy and other costs to achieve a five-year return on investment, notwithstanding the expenditure of 26.6 million Euros to build the new facility and conduct cleanup operations at the site.[103]

In any case, despite these initial observations, the benefit-cost analysis must be pursued further since the “industry” benefits are only a part of the larger collection of benefits that should be considered.

5.4 Combined benefits and costs of conversion

Table 11 groups together the main benefits and costs related to phasing out all 6 million tonnes of European mercury cell capacity. It combines the industry benefits summarized in Table 10 with the socioeconomic benefits discussed earlier in the text. Further, in order to avoid any possible criticism of the latter, the annual value of the health benefits is taken as €25 per gram of mercury emissions eliminated (the lower end of the conservative range established for health benefits in Section 4.4.1); the value of environmental benefits, which could also be significant, is not included.

[103] IPPC Reference Document on BAT in the Chlor-Alkali Manufacturing Industry, European Commission, December 2001, Table 4.7.

Table 11 Combined benefits & costs of converting European MCCAPs to mercury-free

Assumptions for conversion of all European MCCAPs to the membrane process:

- *annual chlorine production capacity ≈ 6 million tonnes*
- *10-15% of capacity will close rather than convert*
- *annual atmospheric mercury emissions ≈ 4-5 g Hg per tonne chlorine capacity ≈ 25-30 tonnes Hg total*
- *annual health benefits >25 euro per gram of mercury emissions eliminated*
- *annual environmental benefits may be similar to health benefits, but are not quantified here*

Combined benefits and costs (billion euro of 2004)	**Estimated annual benefits & costs**	**During 5 yrs.**		**During 10 yrs.**	
		Discount rate 5%	Discount rate 10%	Discount rate 5%	Discount rate 10%
	*Discount factor→**	*x 0.90**	*x 0.82**	*x 0.80**	*x 0.65**
Total conversion costs					
Initial investment cost, assuming €500/tonne chlorine capacity, not including plants that will close	2.6 one-time	**2.6**	**2.6**	**2.6**	**2.6**
Industry benefits					
Total industry benefits for phasing out MCCAPs of 6M tonnes capacity (from Table 10)		1.7	1.5	2.8	2.3
Socioeconomic benefits					
Health benefits** (€25 per gram x 25-30 t Hg emissions eliminated)	0.7 annual	3.2	2.9	5.6	4.6
Environmental benefits possibly similar to health benefits, but not included here	[0.7 annual]	not included	not included	not included	not included
Total benefits		**4.9**	**4.4**	**8.4**	**6.9**
Ratio of total benefits/costs		1.9	1.7	3.2	2.7

Notes:

* The discounted benefit or cost equals the annual benefit or cost multiplied by the number of years assumed for calculating return on investment, multiplied again by the "discount factor," which merely reflects the fact that the value of each subsequent year of benefit or cost is discounted by the assumed discount rate, or "opportunity cost of capital," i.e., the assumed return on investment available through alternative business opportunities.

** Health benefits, as explained in Section 4.3, are based on neuro-developmental impacts – specifically loss of intelligence – of methylmercury exposure in the US due to fish consumption. The figure of €25/g Hg emissions eliminated is a conservative estimate based on two key sources, one assuming human methylmercury exposure from both marine and freshwater fish, and the other assuming exposure only from consumption of freshwater fish.

As demonstrated in Table 11, even without including the value of any environmental benefits, as soon as the most modest human health benefits are considered in the calculation, the benefits of conversion over a brief 5-year period are nearly twice the investment, and even greater if the analysis considers a longer time period.

Table 11, therefore, illustrates the basic challenge of expecting industry to make this investment without any additional incentive. In the absence of other economic factors, such as changing markets, industry restructuring, aging plant, major renovations required, a lower-than-average conversion cost, etc., an investment in conversion may not be attractive to an industry that typically seeks an acceptable return on such an investment in as little as 5 years (despite an expected plant lifetime of over 40 years), and that does not take account of the social benefits of its investment.

It is for this reason that the European Investment Bank (EIB) and the Italian government decided in 2005, to cite only some recent cases, to subsidise the conversions of Tessenderlo in Belgium, and Rosignano and Saline di Volterra in Italy. Likewise, the European Commission, which enforces regulations limiting State subsidies to industry, approved the subsidies from the Italian government on environmental grounds.[104]

In contrast to the industry perspective, the investment in conversion to mercury-free is highly attractive to any government that considers (or should consider, in the public interest) the whole range of human health and other benefits associated with its industrial development strategy.

Furthermore, although the calculation is not presented here, the investment in conversion to mercury-free remains attractive, from the perspective of a benefit/cost analysis (still ignoring any environmental benefits), even if actual mercury emissions should be brought well below 2 g per tonne of chlorine capacity.

6 Health of the industry

Even without State aid, the timing could not be better for the European chlor-alkali industry to take a 10-year perspective, consider the age of most MCCAPs, assess the full socioeconomic benefits, and plan for the investment in converting to mercury-free sooner rather than later. The key reasons include:

1. The investment costs and benefits are well understood. There are no longer any significant surprises (either scheduling or financial) related to conversion to mercury-free chlor-alkali.
2. Corporate profits are high, while demand for both chlorine and caustic (sodium hydroxide) continues to rise. European capacity utilisation for chlorine is above 85% (2004), and higher than it has been since 2000. European production of, and demand for, both chlorine and caustic are higher than ever (2004), and are expected to grow steadily for at least the next five years. Market prices for caustic during the first quarter of 2005 were more than 50% above the highest quarterly market prices in 2004.[105]
3. The industry is more competitive than it has been in many years. In the past, energy prices, which comprise at least 50% of the cost of producing chlor-alkali, have generally been higher in Europe than in the US. With the recent major increases in fossil fuel prices, however, average US energy prices are now very similar to European prices, if not even higher. Furthermore, since most European chlorine is used close to where it is produced, transport is not a major competitive concern.[106]
4. European MCCAPs are aging and have long ago been fully depreciated. Meanwhile, operators are attempting to keep emissions low enough to respect

[104] "Environmental aid has an important role in encouraging companies to behave in a more environmentally-friendly way". State aid: Commission endorses €18.5 million of aid to reduce mercury emissions in Italy, Eur Commission Press release IP/05/303, Brussels, 16 March 2005.

[105] See footnote 16.

[106] See footnote 16.

mercury emission targets the industry has promised to meet. However, considering the evidence that past reporting of emissions may not have reflected actual practice, there will be increased scrutiny of the industry. Significant investments will be required in the near future to upgrade equipment and controls.

5. The Community Mercury Strategy is placing all uses, emissions and movements of mercury under increased scrutiny. Incidents such as the mismanagement of mercury wastes in Italy,[107] the 2002 flooding of mercury cells in the Czech Republic,[108] etc., reflect poorly on the chlor-alkali industry as a whole, and would not have made similar headlines if these plants had used mercury-free processes. National governments and society are increasingly asking themselves whether they need to be more vigilant as well with regard to industry activities in mercury waste retorting, recycling, storage and disposal operations.
6. As many MCCAPs have closed and converted, especially since 1990, large quantities of mercury have been sold on the world market, often with little attention to the final uses of that mercury. Euro Chlor addressed that concern in 2001 via its agreement with the Spanish mercury mining and trading company, MAYASA, confirming that the latter would purchase chlor-alkali mercury to replace mercury that would otherwise have been mined. MAYASA stopped mercury mining for good in 2003; however, chlor-alkali mercury is still sold to MAYASA for subsequent resale on the world market. While MAYASA now makes an effort to ensure that its mercury customers are responsible users, once the mercury changes hands, the potential for abuse remains. It is clear in the Community Mercury Strategy, and it has been one of the main concerns behind the EU mercury export ban/storage requirement, that any un-necessary supplies of mercury put into circulation are potentially problematic.

The chlor-alkali industry has occasionally pointed out that conversion of MCCAPs to a mercury-free process will cause plants to close and jobs to be lost. As listed in Annex 1 – Mercury cell chlor-alkali plants in Europe, dozens of European chlor-alkali plants have converted and closed, largely for economic and market reasons, since 1990. It is not the environmental preference for mercury-free chlor-alkali production that is closing most plants. The industry has also noted that at locations where industry has decided to stop producing chlor-alkali, while some jobs have been transferred, others have surely been lost. This is unwelcome, but it is a fact of life in every industry during periods of economic restructuring – and much more so in most other industries as manufacturing jobs are transferred overseas. Especially in the case of the chlor-alkali industry, there are compelling reasons to keep production facilities at home. Meanwhile, overall production and demand in Europe continue to rise, and this means that more new jobs are being created in this sector than are being lost.

The European chlor-alkali industry now holds out the date of 2020 as the date at which most MCCAPs (except those used in specialised production facilities) will have been voluntarily phased out – not for environmental reasons, but because they will have generally reached the end of their economic usefulness. As most of the MCCAPs now

[107] See footnote 65

[108] See H Kuncová, "Short Summary about Mercury in CZ," NGO Arnika, Prague, May 2004. <http://toxik.arnika.org>

operating will miss the 2010 phase-out date promoted by OSPAR in 1990, and even more will miss the 2007 date fixed by the IPPC Directive for implementation of Best Available Techniques,[109] it is possible that the voluntary 2020 date, as well, may not be taken seriously by national authorities or the general public.

7 Conclusions

In an industry where each mercury cell chlor-alkali production facility is slightly different from all others, it is impossible within the scope of this paper to address the specific circumstances of each operating MCCAP. Nevertheless, there are far more similarities than differences, and the following conclusions apply to all European MCCAPs, of which most operators are member companies of Euro Chlor.

1. The European chlor-alkali industry comprises a great range of companies and sites that, in turn, demonstrate a range of attitudes and activities with regard to those aspects of the business that are relevant to mercury releases, including process monitoring, plant management, maintenance, record-keeping, waste treatment, corporate responsibility, etc. Euro Chlor and its member companies should be commended for achieving great reductions in mercury use and releases, and for continuing to strive for ongoing improvements in all of the areas cited.

2. While acknowledging industry improvements, recent scientific research, including the most comprehensive measurements of emissions taken at any operating MCCAP in the world, provides compelling evidence that atmospheric emissions of mercury from European MCCAPs have probably been underestimated for many years.

3. Therefore, despite all industry efforts, the research cited, when analyzed together with mercury releases as reported by industry, appears to confirm that MCCAPs continue to pose unacceptable risks to public health and the environment. This was recognized by OSPAR in 1990, and reiterated in 2001 when the IPPC Reference Document on chlor-alkali declined to endorse the mercury cell process as BAT. Moreover, the actual atmospheric emissions from European MCCAPs appear to occur at levels that are likely associated with substantial human health costs, not to mention environmental costs.

4. While there is reason to believe that mercury monitoring efforts could be significantly improved, there is no evidence that individual MCCAP operators have intentionally misrepresented their emissions. In fact, Euro Chlor may be expected to counter the findings of this report with its own arguments and technical evidence in support of the emissions and performance as reported by industry. That is part of Euro Chlor's role. However, in light of the analysis presented here, the chlor-alkali industry will need to better understand and explain the "unaccounted for" mercury losses, and there will surely be strong pressure for industry to obtain independently verified, comprehensive, plant-by-plant assessments of actual atmospheric mercury emissions. Without more rigorous monitoring and reporting, the Euro Chlor assurances of yet further reductions in mercury emissions – as the main criterion for

[109] The unequivocal conclusion of the IPPC Reference Document on chlor-alkali (footnote 3) produced under the IPPC Directive (footnote 19) is that the mercury cell process is not BAT and should be phased out by 2007. Practically, it is the responsibility of Member States to determine precisely when MCCAPs on their territory must convert, but the basic point is that the mercury cell process is no longer desirable nor acceptable in a modern society.

gaining authorisation for continued operation of MCCAPs in Europe – will not be readily accepted by national and EU authorities.

5. Until such independent assessments yield credible results, the present system for industry reporting of mercury releases will remain under suspicion. The problem is compounded by the fact that OSPAR, EIPPCB, various national authorities and others, lacking continuous, comprehensive emissions data for each MCCAP as a closed system, have come to accept industry and Euro Chlor reports – however well-meaning – without closer scientific scrutiny.

6. In response to this analysis, industry may propose to carry out more rigorous assessments of mercury releases. It is likely that major investments would be necessary to reduce actual mercury releases to a level of one gram per tonne of chlorine capacity – if such a level is even technically possible. At the same time, other stakeholders may claim that industry has already had many years to adopt these measures, and has failed to achieve the promised reductions. In the latter case, there will be increased pressure to phase out the use of the mercury process within a much briefer period than European industry has proposed.

7. Contrary to some industry claims, the cost of converting an MCCAP to a mercury-free process is not a significant barrier. Even ignoring the public health benefits of conversion, the 10-year return-on-investment for a facility with a 40-year lifetime may be acceptable on its own merits, depending on the details of the investment, and the financial return improves rapidly as energy prices rise. If the anticipated return appears to be only marginal, the EIB and national governments have demonstrated their willingness to offer financial assistance. In any case, the chlor-alkali industry is healthy, and product prices are high. In 2004 Europe produced more chlorine and caustic than ever before, and industry has announced firm investment plans to continue expanding overall production during the coming years.

8. Contrary to occasional industry contentions, conversion to a mercury-free production process will not make European chlorine and caustic uncompetitive. Despite the fact that in Europe nearly all chlorine, and most caustic, is produced near the point of use for economic and safety reasons, the cost of production remains important. Chlorine and caustic are used in the production of many other products that are widely commercialised. A variety of factors play a role in chlor-alkali industry competitiveness – especially electricity costs, which have become quite comparable between Europe and the US, and industry consolidation. During the last decade the European chlor-alkali industry has become highly competitive and will remain so for the foreseeable future, whatever the extent of conversion to mercury-free production.

9. Contrary to certain industry concerns, the continued European transition to a mercury-free chlor-alkali industry will never be a key reason that workers may lose jobs. Dozens of chlor-alkali plants have closed or converted in Europe for economic and strategic reasons during the last 15 years, while the industry remains in expansion and continues to generate a net increase in jobs. Moreover, the structure and nature of the industry is such that transfer of production capacity to countries with lower labour costs is not a valid concern.

10. Consistent with all of the above conclusions, it has also been demonstrated in this report that the total costs of converting all European mercury-cell plants to a

mercury-free process, including the costs of facility decommissioning and cleanup, are far outweighed by the combined economic and human health benefits of doing so.

11. For most MCCAPs in Europe, the balance of the preceding analysis would seem to weigh rather heavily in favour of planning for relatively near-term decommissioning and conversion of mercury cell chlor-alkali operations.

Annex 1 – Mercury cell chlor-alkali plants in Europe

Mercury Cell Chlor-Alkali Plants in Europe as of January 2005
(Euro Chlor member companies, except as noted)

COUNTRY	COMPANY	SITE	Cl_2 CAPACITY (000 TONNES)	MCCAPs IN 1990
BELGIUM	SolVin	Antwerp (Lillo)	330	4
	Tessenderlo Chemie	Tessenderlo	250	
CZECH REPUBLIC	Spolana	Neratovice	135	2
	Spolchemie	Usti	61	
FINLAND	Akzo Nobel	Oulu	43	4
FRANCE	Albemarle	Thann	72	8
	Arkema	Jarrie	170	
	Arkema	Lavera	166	
	Arkema	Saint Auban	184	
	Prod. Chim. d'Harbonnières	Harbonnières	23	
	Solvay	Tavaux	241	
	Tessenderlo Chemie	Loos	18	
GERMANY	BASF	Ludwigshafen	160	17
	Bayer	Uerdingen	110	
	Vinnolit	Knapsack	120	
	Akzo Nobel	Ibbenbüren	125	
	Degussa	Lülsdorf	136	
	Ineos Chlor	Wilhelmshaven	149	
	LII Europe	Frankfurt	167	
	Vestolit	Marl	176	
	Vinnolit	Gendorf	82	
GREECE	Hellenic Petroleum	Thessaloniki	40	1
HUNGARY	BorsodChem	Kazincbarcika	137	3
ITALY	Altair Chimica	Volterra	27	13
	Solvay Ausimont	Bussi	87	
	Caffarro	Toreviscosa	68	
	Syndial	Porto Marghera	200	
	Syndial	Priolo	204	
	Eredi Zarelli (not Euro Chlor)	*Picinisco*	*6*	
	Solvay	Rosignano	125	
	Tessenderlo Chemie	Pieve Vergonte	42	
THE NETHERLANDS	Akzo Nobel	Hengelo	74	3
POLAND	Rokita	Brzeg Dolny	125	3
	Dwory	Oswiecim	39	
	Tarnow (not Euro Chlor)	*Tarnow*	*43*	
SLOVAK REPUBLIC	Novacke Chemicke	Novaky	76	2
SPAIN	EIASA (Aragonesas)	Huelva	101	10
	EIASA (Aragonesas)	Sabinanigo	25	
	EIASA (Aragonesas)	Villaseca	135	
	Elnosa	Lourizan	34	
	Ercros	Flix	150	
	Quimica del Cinca	Monzon	31	
	SolVin	Martorell	218	
	Solvay	Torrelavega	63	
SWEDEN	Akzo Nobel	Bohus	100	6
	Norsk Hydro	Stenungsund	120	
SWITZERLAND	SF-Chem	Pratteln	27	4
UK	Albion Chemicals	Sandbach	90	5
	Ineos Chlor	Runcorn	738	
	Rhodia	Staveley	29	
Totals		**50 plants**	**6072**	**85 plants**

Source: Chlorine Industry Review 2004-2005, Euro Chlor, Brussels, 2005.

Note: To complete the picture for Europe (as defined here), one should include the few companies are not members of Euro Chlor. According to information gleaned from Linak *et al.* (see footnote 16) and other sources, none of which is entirely complete or accurate, there are 2 MCCAPs in Romania of 186,000t and 5,000t capacity; 3 MCCAPs in Bosnia-Herzegovina of 17,000t, 35,000t and 39,000t capacity; 4 MCCAPs in Serbia-Montenegro of about 5,000t, 8,000t, 115,000t and 9,000t capacity, of which the latter 2 appear to be out of commission; 2 MCCAPs in Croatia of unknown capacity, possibly both out of commission; and 1 in Macedonia (Skopje) of 10,000t capacity, whose operational status is unclear.

To the column above for European MCCAPs operating in 1990 should be added: Austria 2, Ireland 1, Norway 1, Portugal 2, Romania 3 and (former) Yugoslavia 10.