Conversion from Mercury to Alternative Technology in the Chlor-Alkali Industry

UNEP Global Mercury Partnership Chlor-Alkali Area

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INTRODUCTION

The mercury-cell process was widely used in the past for the production of chlorine and caustic soda, and approximately 100 facilities globally still use this process. Concerns about the environmental impact of using mercury, together with development of lower-cost alternative chlor-alkali production processes, have led to a reduction in the number of mercury-cell facilities throughout the world. Between 2005 and 2010, global mercury-cell chlorine capacity has decreased by about 30 percent.

The UNEP Global Mercury Partnership chlor-alkali area encourages the conversion of the approximately 100 remaining mercury-cell facilities to non-mercury technology. The World Chlorine Council (WCC), a global industry association that represents chlorine producers, has recognized that production should move away from mercury-based technology. This paper explores the issues associated with the conversion of mercury cell chlor-alkali production to alternative technology. Its aim is to inform facility managers, policymakers and other stakeholders about the technical and economic factors affecting conversions.

Many factors associated with economic conditions, regulations, customer product requirements and local aspects of specific plant operations should be considered when deciding whether to convert an existing mercury cell plant to another technology or to cease operation of the facility. While the primary replacement technology (membrane technology) has lower energy and operating cash costs, the conversion itself requires significant capital investment. Therefore, both the payback period and financial underpinning of the investment are major elements in the decision to convert.

This report describes the production technologies, the factors influencing conversion, and several economic scenarios to illustrate the financial components of conversion decisions and to calculate payback time of the investment using a cash flow model. The purpose of these scenarios is to estimate the magnitude of investment required for conversions, and the model in particular is used to show how conversion may affect cash flow at a facility. These scenarios are based on cases representing the best available information and knowledge but some of the data do not represent any specific conversions that have occurred. Instead, they use estimates for economic parameters supplied by the chlorine industry. Using this information, a cash flow model was applied to calculate a payback time for the investment. It should be emphasized that this is still a model calculation and therefore each case, due to its specific local conditions, will differ from this calculation.

Of course, every facility considering a conversion will have a different set of economic, financial, technical and regulatory conditions. Elements influencing the decision include the scope of the project, the market situation, the cost of electricity, the possibility of extending or reducing production capacity, financing mechanisms, technical specifications and regulatory constraints. End-of-life issues such as demolition, decommissioning and remediation of the mercury plant are not included in the operating cash cost estimate, but also should be considered when evaluating the project.

In addition to the analysis presented in this paper, which used data from a European industry study (Prochemics, 2008), additional information on chlor-alkali conversion economics in the U.S. and India is presented. In Appendix 2, the key parameters used in this analysis are compared with the United States Environmental Protection Agency's regulatory impact analysis for proposed amendments to the national emission standards for hazardous air pollutants for mercury emissions from mercury cell chlor-alkali plants. Appendix 3 presents insights from the Indian chlor-alkali industry's experience converting to membrane cell technology.

Note: except if otherwise mentioned, the product quantities are expressed in metric tonnes.

1. PRODUCTION TECHNOLOGIES AND TECHNOLOGICAL DEVELOPMENTS

The main production process for chlorine is electrolysis, i.e., passing an electric current through brine (salt water – mainly sodium chlorine or, to a lesser extent, potassium chloride, KCl). Essential co-products obtained in the process are caustic soda (sodium hydroxide) (or potassium hydroxide for KCl solution electrolysis) and hydrogen. These products are reactive and therefore technologies have been developed to separate them inside the electrochemical reactor. In addition to **mercury cell technology**, where mercury acts as a cathode and transports the sodium to a separate reactor for caustic and hydrogen production, two other technologies are available: diaphragm technology and membrane technology.

Diaphragm technology uses a porous fibre separator system and produces a diluted, less pure caustic soda (containing a high concentration of sodium chloride), which has limitations for certain applications. The diaphragm is usually made of asbestos but more recently non-asbestos diaphragms (using fluorocarbon polymeric fibres) have been introduced. The new materials extend the lifetime of cells.

The third technology, **membrane technology** results from advances in the polymer industry. While the ion-exchange membrane itself is very expensive and requires very high purity brine, the technology yields a high quality product. It needs less electricity than mercury technology, but the caustic produced usually needs to be concentrated to the 50% commercial grade by evaporation. For some applications, the chlorine gas produced needs to be processed for oxygen removal. Membrane cells occur in different structural configurations - monopolar (where anodes and cathodes are electrically connected in parallel) or bipolar (where anodes and cathodes are connected in series). Bipolar cells represent a more advanced technology with lower electricity consumption. In membrane technology, innovation is focusing mainly on electricity consumption reduction via improvements in membranes and cells design.

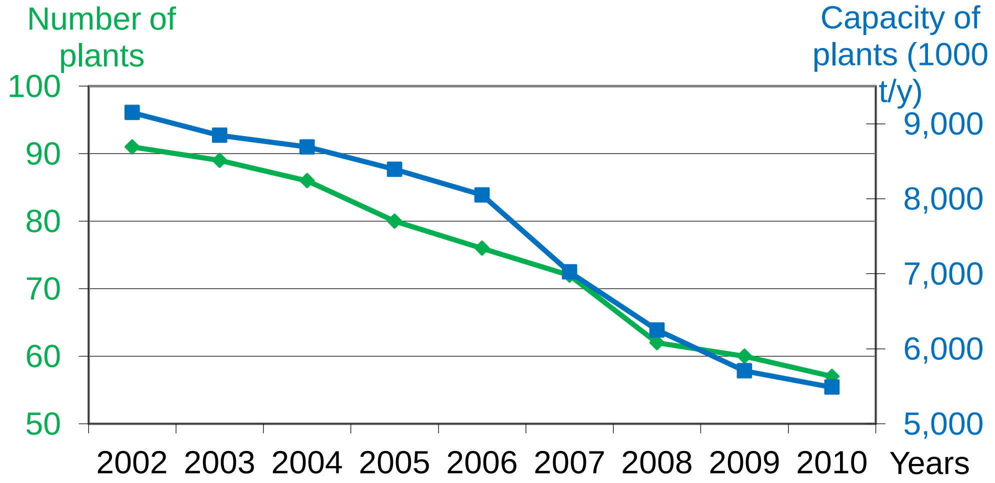
Chlor-alkali plants currently operating with mercury technology have mostly been built before the 1970's. Some companies have made efforts and investments to continuously modernize these units in order to have efficient production and ensure environmental and health protection. Innovation in mercury technology processes has focused particularly on reduction of electricity consumption, improvements around cell maintenance efficiency and the reduction of fugitive mercury emissions. Still, it is generally agreed that the mercury-cell process is no longer an economically or environmentally preferred technology for new chlor-alkali facilities or capacity additions, and that existing facilities should be phased out.

Emerging technologies are also under development, e.g. a modified membrane cell using oxygen depolarized cathodes. This technology allows for further energy savings as no hydrogen gas is produced but requires pure oxygen to be fed to the unit, leading to the production of water.

Voluntary commitments to ensure phase-out of mercury technology have already been put in place by industry in India (by end 2012) and in the European Union, Switzerland and Norway (by 2020 at the latest). The United States Environmental Protection Agency (US EPA) is considering, as one of two regulatory options in a proposed rule, regulations that would require mercury-cell chlor-alkali plants in the U.S. to close or convert within three years of the effective date of the final rule. A WCC assessment shows that the production capacity relying on mercury has decreased from 9.1 million tonnes to 5.5 million tonnes (-40%) between 2002 and 2010. This assessment covers North America and Mexico, Brazil, Argentina (one plant), Uruguay (one plant), European Union plus Switzerland and Norway, India and Russia.

In addition, many firms in the global chlor-alkali industry have been continuously reducing use and emissions of mercury. WCC's Leaflet 'Reduction of Mercury Emissions and Use from the Chlor-Alkali Sector Partnership - updated September 2011' – provides more information. The reduction in the number of chlor-alkali facilities in WCC member countries from 2002-2010 is illustrated in the following graph:

Global mercury-based production capacity 2002-2010 (in 1000 tonne chlorine per annum)



2. <u>FACTORS FOR CONVERSION</u>

<u>2.1 Description of a conversion scenario and elements of good practice</u>

Any production plant will have an end-of-life scenario at some point in time with specific requirements for handling its shutdown. Demolition and decommissioning of a mercury plant may have additional challenges when closing down or converting. The first part of this chapter will briefly describe a scenario for closure or conversion; the second part will summarize the key factors influencing a decision to convert a mercury plant or to shut down.

Demolition or decommissioning of a mercury plant would include plant shutdown, dismantling/demolition of equipment and circuits, handling of dismantled materials, and restoration and clean-up of the site so that the land can be re-used (depending on local authorities' decision on land use planning). Decontamination will represent a significant part of the work after options for re-use of the building, materials or equipment have been evaluated and agreed. When technically and economically feasible, distillation of mercury from solid waste can be done on site or with external support; water or chemical cleaning or a combination of these may be required. Special techniques can also be used, generally offered by specialised contractors.

Careful recovery of mercury is important in this respect as, when emptying the equipment, considerable amounts of high quality liquid mercury become available, which can be either re-used or disposed of, depending on the regional regulations in place or best environmental practices. These practices for handling surplus mercury, or any mercury recovered during decommissioning, are key elements for ensuring minimisation of exposure and emission. Guidelines have been prepared by industry applicable to emptying of the cells, containers description, loading, transport, unloading and temporary or permanent storage facilities. Working under confinement and choosing dedicated sealed and clearly labelled steel containers are part of the recommendations.

Recovered metallic mercury should always be stored in dedicated areas. The storage area should fulfil all local and regional requirements and, at a minimum, remain accessible for a sufficient period of time, be secured, dry and geologically stable. Floors should be able to bear the loads of mercury containers, be impervious and slope towards collection sumps. The area should be monitored and emergency plans in place to cover potential spills. Health and safety aspects are key to consider in advance of decommissioning, as the exposure risk is higher than under usual operations.

Remediation of contaminated sites should be subject to risk assessment that evaluates soil, air and water compartments. Risk over time will be controlled by changes in the bioavailability and mobility (leaching) of mercury. Monitoring should be part of such evaluation to track status and progress. Treatment or containment techniques can be used depending on the potential risk of exposure.

2.2. Factors influencing conversion decisions

The investment costs of conversion from mercury to membrane technology vary considerably due to many influencing factors, which were identified through conversations with WCC member companies that have converted or are considering converting mercury-cell facilities to alternate technologies.

To illustrate these elements, we describe below some key factors influencing conversion, according to a study realised on behalf of Euro Chlor by an external consultant (Prochemics, 2008) and other data provided by stakeholders.

- Energy prices and efficiency

    As chlor-alkali production relies on energy intensive electrochemical technology, the price of electricity, representing roughly 40% of the operating cash costs, has a strong influence in the decision making process. Membrane technology requires less electrical energy and will lower operating cash costs by an average of about 6 %. It must be noted that the caustic produced by membrane technology usually requires subsequent concentration, consuming additional energy (steam), which should be taken into account in the overall energy savings calculation.

- Production capacity

  If the market demand for the products is increasing, the need for increased production of either chlorine or alkalis could support additional capacity investment, which may favour conversion at the same time.

- Access to finance

  Appropriate access to finances and availability of fiscal measures and investment grants could favour conversion. Conversions are typically financed by bank loans, but may also be paid for by reinvestment of profits.

- Technical constraints

  Technical specificities, like the link between two different technologies in the same production unit, can add severe complications in changing the current installation structure (e.g. shifting from a combined diaphragm and mercury plant to a diaphragm and membrane plant).

- Scale of the conversion / Condition of equipment

  A key factor to consider is the possible re-use of a significant part of the mercury plant. Depending on the age of the plant, it may or may not be technically feasible and convenient to continue using some existing parts of the facility. Even if it is technically feasible, the re-use of parts of the former installation may not be an option from an overall business perspective, e.g. if the resulting shutdown period for conversion creates an unacceptable business interruption for the customers.

- Feedstock and product quality

  As stated before, a membrane plant requires higher brine purity than a mercury plant. Furthermore the chlorine gas from a membrane plant is of lower quality than that from a mercury plant, because chlorine from membrane plants usually has higher oxygen content. Both aspects can trigger a need for additional treatment units for a new membrane plant. An alkali concentration unit is often needed to concentrate the caustic soda or potassium hydroxide from the membrane cells to commercial grade products (usually 50%). This new unit will consume steam, which can represent an additional investment in the utilities unit. In some cases a chlorine liquefaction / vaporisation unit is required to reduce the oxygen content of the gas.

- Financial consequences of selection of the current density

  The selection of the current density derives from a balance between the operating cash costs and the investment costs. A lower current density will result in a lower electricity consumption per tonne of chlorine produced (i.e. lower operating cash costs), but requires more electrolysers (i.e. higher investment cost) to produce the same amount of chlorine and alkali.

- Market conditions

  Various market-related factors highly influence the potential for conversion

  - the highly variable prices of construction materials like nickel, titanium and others
  - the relative parity value of currencies
  - the economic situation in the countries such as a mature or growing market
  - the costs for the equipment and membranes and the highly variable construction and engineering costs.
  - the particular needs of the downstream customer for the chlorine and caustic soda. Food or pharmaceutical customers, for example, might demand a feedstock with extremely low mercury content.
- Regulatory compliance and elimination of costs related to the environmentally sound management and use of mercury at the facility. These may include cost savings from eliminating the need for mercury monitoring and some pollution control equipment, and decreased legal liability.

3 ECONOMIC ASPECTS OF CONVERTING CHLOR-ALKALI PLANTS FROM MERCURY TO MEMBRANE TECHNOLOGY

3.1 Introduction

The conversion of a mercury-based chlor-alkali plant to membrane technology is a capital intensive investment and every conversion of an existing mercury cell plant is a different case. Membrane cell plants have lower operating cash costs compared to mercury cell plants, but from a business point of view, it is necessary to evaluate if it is economically/financially attractive and/or feasible to invest in the conversion.

In this chapter of the report, the economic implications of the investment cost of conversion for a model plant are evaluated using an illustrative example of calculating conversion costs.

For this calculation, economic criteria generally used by industry to evaluate any capital investment will be used. Inevitably, such a calculation can only be done by making assumptions on possible variations of the economic parameters. Nevertheless, although the results obtained will be different in each case, it is believed that the values indicated in this document represent a realistic order of magnitude. The key criterion for decision making considered here is the payback period.

3.2 Methodology

The data used in the model calculation presented here are taken from a study performed in 2007 by the consultant company Prochemics for Euro Chlor (Prochemics, 2008). Although this study is mainly based on European information, it provides useful insights into the economics of the chlor-alkali industry globally. Even though this evaluation is based on typical and realistic assumptions, it should be clear that each case will differ from this model calculation due to its specific local conditions. To cover this variability, a sensitivity analysis has been performed for the major factors influencing the economics of the conversion.

The industry input to the study showed a range of investment costs depending on factors such as reuse of existing equipment and extent of dismantling.

The approach followed for this economic assessment of conversion is using estimates based on best available data to calculate the investment required to convert to membrane technology. The evaluation is done for a plant producing 100,000 tonnes chlorine per year. The revenue is based on a representative average income from 1 ton of chlorine and 1.1 ton of caustic soda, including the marginal valorisation of hydrogen as fuel (i.e. one electrochemical unit: ECU; represents the sum of chlorine, caustic and hydrogen produced simultaneously).

3.3 Cost structure of chlor-alkali production – Mercury vs Membrane technology

The operating cash costs of chlorine /caustic can be segmented as follows:

- Variable costs, which include raw materials, chemicals and utilities (process steam, electricity, natural gas as fuel, process water, cooling water and inert gas).
- Plant fixed costs which include plant operating and maintenance costs.
- Indirect plant costs, including plant overhead personnel, local taxes and insurance.
- Corporate sales, general and administrative costs.

Electricity cost is by far the most important cost factor and both the electricity consumption per ton of chlorine produced and the unit price of electricity have a direct impact on the cost of conversion and the competitive position in the markets. Electricity prices vary considerably within and across regions and over time, but for this model calculation a representative energy price of **$63 US/MWh** was used (45 EUR/MWh = current average value in the Prochemics (2008) study). There are of course differences depending on the country and specific supply contract conditions.

The variable costs of a mercury cell plant are higher than those of a membrane plant of the same capacity. This is mainly due to the higher electricity requirement of a mercury plant. The average electricity consumption reduction resulting from the conversion varies between 20 and 30% based on industry data (Prochemics (2008) uses an average of 25%). A part of these energy savings is offset, mainly by the steam consumption increase due to the requirement to concentrate the caustic from 32% solution to the commercial grade of 50%, and also by the higher cost for chemicals required to operate a membrane cell plant.

A reduction in the fixed costs can be realised in reduced manpower to operate the converted plant. Typically a membrane plant may require about 15% fewer personnel than a mercury cell plant. Also manpower for maintenance, and costs of materials and spare parts for a membrane cell plant will normally be lower.

Taking all variations in variable and fixed costs together, the operating cash costs of a membrane plant are about 6% lower (Prochemics, 2008) than the operating cash costs of a mercury cell plant in this scenario. This is relevant for the European situation, but will differ in other regions depending on local conditions. It should be emphasized that the above only covers operating cash costs which will be the basis for the calculation of the economic attractiveness of the conversion from mercury to membrane technology. The costs for dismantling of the mercury unit, treatment/elimination of the related waste, restoration and clean up of the site are not included.

For the economic evaluation of the conversion of mercury to membrane technology that follows hereafter, depreciation of the investment cost is not included in the operating cost since there is no cash flow involved. Only cash operating cost items are accounted for as shown in Appendix 1.

3.4 Conversion of an existing mercury cell plant

In order to convert an existing chlor-alkali plant from mercury to membrane, at a minimum, the following modifications have to be made:

- Replace the mercury cells with membrane electrolysis cells and adapt the building
- Replace or adapt electricity transformers/rectifiers
- Add secondary brine purification and filtration units since membrane technology requires higher purity brine
- Add a caustic soda concentration unit since the caustic concentration from membrane cells needs to be increased to the commercial standard of 50% in most of the cases.

Experience shows that the time to convert a plant is 1.5-2.5 years depending on the administrative procedures and the scope of the conversion. Once the permit has been granted, the delivery time for the cells, transformers and rectifiers is usually the most critical activity.

The costs of converting a mercury cell plant with this scope of modifications are in many cases in the range of $500-700 US per metric ton of chlorine capacity (Prochemics, 2008). This means that the conversion cost of an existing plant requires an investment of 40-50% of that for a new membrane plant.

Additional changes to the installation can be necessary, depending on local plant requirements, and there will also be costs for pre-commissioning, start-up, etc. The supplementary costs for removal of mercury, demolition of buildings and equipment, disposal of waste materials and site clean-up should be considered in the overall project. The supplementary cost savings of conversion should also be considered. These may include decreased costs of environmental compliance and lower expenses associated with storing process mercury.

For the model case of this economic evaluation, the investment cost for an annual capacity of 100,000 tonnes chlorine is calculated at $60 million US (i.e. 50 million EUR in Prochemics, 2008, taking into account the additional costs as mentioned above The corresponding depreciation costs would amount to $60 US per ton ECU (based on 10 years), however, these costs have not been included in the model, which only uses cash costs.).

3.5 Revenue from products - chlorine and caustic soda

The two key products manufactured by electrolysis technology are chlorine and alkali. Hydrogen produced as a by-product has been credited as fuel in this evaluation analysis. In some cases, high quality hydrogen can also be sold as a product if it is economically preferably to fuel use. Except in some regions like India, very little chlorine is sold in the open market (especially in Europe) and it is mainly used by the same company to make a range of derivatives. Therefore the value of chlorine depends on the value of the end products manufactured out of the derivatives. The largest outlet for chlorine is polyvinyl chloride (PVC) which is a large volume, low value commodity. PVC sales prices vary significantly over time depending on demand and the general economic status. On the other hand, chlorine can also have a higher value when contained in a high value specialty product, e.g. a crop protection product. Markets for large volume commodity chemicals such as PVC and caustic soda are globally open and very competitive cyclic markets, but transportation costs should of course be accounted for.

Prices of soda and other bulk chlorine derivatives are well covered in reports published on the chlor-alkali industry. Based on these reports, the average ECU (1 ton chlorine + 1.1 ton caustic) revenue to the chlor-alkali producer used for this model is $530 US/ECU on a delivered basis (210 EUR/t NaOH and 150 EUR/t Cl_2 in Prochemics, 2008).

It should be noted that in some cases, e.g. with high electricity costs, the model calculations may result in a negative income before taxes. For calculation purposes only, where needed, the sales assumptions were increased to avoid this calculation problem. This has no effect on the calculated payback time as the increase was applied for both mercury and membrane.

3.6 Economic evaluation

Based on the considered data on investments, total operating cash costs and revenue from products, the payback period and return on investment for the conversion of an existing mercury cell plant to membrane technology is calculated. This calculation can be considered as a *basic* calculation of payback period without including special financial support measures or other potentially beneficial circumstances, such as environmental benefits, which are more difficult to quantify. The payback period is defined as the time required to recover the initial investment based on the cash flow after tax impact.

In this calculation of the cash flow after income tax, it is assumed that:

- the annual depreciation of the investment cost for conversion generates a positive cash flow equal to the depreciation amount x corporate income tax rate.
- the lower operating cash costs from the to-membrane-converted plant will result in an equally higher net income which is taxed at the corporate tax rate.

The corporate tax situation will vary from country to country and also due to the company's financial situation. A representative corporate tax rate of 30% has been used for this model calculation. Linear depreciation over 10 years is used to calculate the tax impact.

The economic attractiveness of the conversion of an existing mercury cell plant is determined by comparing the cash flow of the converted plant versus the cash flow of the existing mercury cell plant. It is the difference between both "after taxes" cash flows that determines the profitability of the capital investment for the conversion.

The assumptions and results for this model calculation (conversion of a 100,000 tonnes per year chlorine plant), with an assumed electricity price of $63 US/MWh, are given in Appendix 1 and show that the after tax cash flow between the converted plant and an existing (non-converted) mercury plant amounts to $5.1 -0.8=4.4 million US. The corresponding payback period of the $60 million US investment cost is thus 14.7 years.

This payback period depends on assumptions of the calculations of which the investment cost per tonne capacity and the energy price are the most relevant ones. Chapters 3.7.1 and 3.7.2 demonstrate the effect of variation of these assumptions on payback time (±2 and ±3 years, respectively). If an electricity cost of $100 US/MWh would be used instead of the $63 used in

Appendix 1, the payback time would decrease to around 10 (9.6) years. This is similar to what a report by Concorde East/West for the European Environmental Bureau (EEB), a federation of environmental citizens' organisations in Europe, estimated. (EEB 2006)

In summary the payback time of 14.7 (+/- range calculated in section 3.7.4) years seems a reasonable *basic* approach for the European and US situation, while a higher electricity cost such as in India could lower the payback period to around 10 years or less. Other local or regional specific factors which have not been included in this basic calculation may provide further incentives for conversion and/or further lower the payback periods. Such factors might include increase of capacity, logistical advantages, requirements for environmental performance improvement, tax incentives or other financial support, etc. A combination of additional conditions may have a significant positive effect on actual payback time which effectively applied to several of the conversions realised in the recent past in different regions of the world. A study by Toxics Link suggested that payback periods for facilities in India due to a specific combination of conditions may reach 5-7 years (Toxics Link 2012).

Note that while environmental, health, and social costs and benefits of conversion are important considerations for policy makers, the economic analysis in this report does not attempt to factor them in to calculations. The tables on pages 35 and 37 of the 2006 Concorde E/W /EEB report provide more information on the quantification of various costs and benefits of conversion.

3.7 Impact of Ranges for Key Parameters

The key factors that determine the economic return of capital investment for conversion are:

- the conversion investment cost
- the total energy savings of electricity + steam and associated costs

For the calculations presented in chapter 3.6, values for the conversion costs, operating cost items and also sales prices of the products were chosen based on best available information and practical experience. Although they represent realistic assumptions, these cost items may vary depending on individual plant situation, differences at country or regional level, etc. There are many different plant conditions, each with their own specific production economics and revenues from the same chlorine and caustic products. A good example of this is the electricity unit price which can vary considerably across global markets. Other cost variations include environmental compliance costs related to air, water and waste.

In order to investigate the impact of different values of the major cost items, this chapter explores the effect of some realistic ranges using the economic evaluation methodology as presented in chapter 3.6. This methodology which calculates the difference between cash flows-in (revenue) and cash flows- out (operating cash costs plus taxes) is used to assess in how many years the initial conversion investment costs will be recovered through the higher cash flow-in generated by the converted plant. It should be noted that the depreciation cost is not included as a production cost item in this methodology, but the annual depreciation cost generates a cash flow-in as a result of the reduction of corporate income taxes. This means that a shorter plant depreciation time could make the conversion project more financially attractive.

3.7.1 Investment Cost of Conversion

A study published by the US EPA (US EPA, 2010) provides a range of capital investment costs in Europe, US and Asia (2007 values). They range from US$267-$941 per short ton (US ton) of chlorine with an average of $535. The average capital investment cost of recent US conversions was $596/ton of chlorine (which equals $657/metric tonne). The conversion cost used in the calculations of chapter 3.6 was $600 per metric tonne of chlorine, which is also comparable with data from European producers (expressed in Euro: €500, 2008 values).

Therefore as a reasonable range for the conversion cost around the average of $600 per tonne used in the calculation in Appendix 1, which has a pay-back time of 14.7 years, we assumed a range of 25% plus or minus or $150 per tonne. Applying this range, the following results are obtained:

- for an investment cost of $450/mt the payback period would be 12 years
- for an investment cost of $750/mt the payback period would be 16.6 years

3.7.2. Energy savings and associated costs

The net energy cost savings in electricity and steam used in the economic analysis of this document is based on a reduction (25%) in the electricity consumption for the membrane technology, partially offset by additional steam consumption for the evaporation of caustic of 32% to the commercial grade of 50%.

The effect of different electricity prices on the payback time was investigated by assuming that the unit price of energy ($/MWh electricity and $/tonne steam) would be 30% lower (both for electricity and steam) or 30% higher than the costs used for the calculation in Appendix 1 based on a $600/mt investment cost. Applying this range of ±30%, the following results are obtained:

- for an electricity price of 30% lower the payback time would be 20.4 years
- for an electricity price of 30% higher the payback time would be 11.6 years

Note: in the calculation from Prochemics (2008), the gain in electricity consumption by converting from mercury to membrane technology is assumed to be 25%. If we consider instead a hypothetical saving of 30%, the payback time becomes 12.5 instead of 14.7 years.

3.7.3. Revenue from products

Revenues from the products (chlorine and alkalis) depend on the general economic and specific market conditions and vary over time. However, any assumption on the increase of sales prices will change both cash flows in a similar way and will therefore not affect the payback period. Any expected decrease of sales prices will generally not favour decisions to convert.

3.8 Conclusion

This chapter has assessed the economic factors of investing in the conversion of a mercury cell plant to the membrane technology taking into account the reduced operating cash costs of the latter. It is shown that the payback period for the investment cost to replace an existing mercury cell plant by a new membrane technology plant is in the range of 14.7 years if no particular incentive is considered. From the analyses of different scenarios under reasonable ranges of key parameters, it can be concluded that the payback period of conversion costs, as compared to the

14.7 years based on the original assumptions, ranges from 12 to 16.6 years for different investment cost assumptions and from 11.6 to 20.4 for different electricity costs. In addition it was shown that the high electricity costs in India (of $100/MWh) could lower the payback time to 9.6 years. Other examples suggest that taking into account additional specific circumstances, some cases may result in payback periods as rapid as 5 years. These additional justifications may be linked to the particular local company or country situation, such as increased production capacity required for chlorine or caustic soda, level of integration of a chemical plant, local circumstances yielding higher revenues, organisation of the company, fiscal measures or investment grants , etc. Indeed, given the number of recent conversions it is apparent that there are other economic as well as environmental/health and social factors in favour of conversion that are affecting these decisions. A more detailed overview of critical factors was given in chapter 2.2.

Companies that currently operate mercury cells will need access to adequate financial capacities in order to invest in conversion. Lack of such capacity will most likely result in the shutdown of the local chlor-alkali production.

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Appendix 1

Summary of assumptions and calculation results for the model calculation of conversion economics

Cash cost of chlorine production

(USD/ECU for 100 000 t Cl2/year)

Items	Mercury	Membrane
Raw materials	74.5	97.6
Utilities	229.7	188.2
of which electricity (63 USD/MWh)	*214.2*	*160.7*
of which steam	*5.2*	*18.6*
Variable costs	**304.2**	**285.8**
Operation and maintenance	160.7	135.9
Plant overheads	7.0	6.0
Taxes and insurances	13.4	25.2
Corporate costs	33.6	33.6
Cash cost	**518.9**	**486.5**

Difference related to membrane	6%

Economic evaluation of conversion

(Millions USD for a 100 000 t Cl2/yr plant)

Items	Mercury	Membrane
Sales (530 USD/ECU)	53.0	53.0
Cash costs	51.9	48.7
Income before taxes	1.1	4.4
Corporate income taxes (30%)	0.3	1.3
Net income	0.8	3.0
Depreciation (10 years linear)	0.0	6.0
Tax credit on depreciation (30% tax rate)	0.0	2.1
After tax cash flow	**0.8**	**5.1**

Cash flow difference	4.1
Capital investment	**60.0**

Payback period (years)	**14.7**

Appendix 2

Comparison of this analysis with the United States Environmental Protection Agency regulatory impact analysis for the mercury-cell chlor-alkali sector

The U.S. Environmental Protection Agency (EPA) is proposing amendments to the national emission standards for hazardous air pollutants (NESHAP) for mercury emissions from mercury cell chlor-alkali plants. As part of the regulatory process of preparing these amendments, EPA is required to develop a regulatory impact analysis (RIA)[1]. Note that this analysis was conducted to support a proposed rulemaking and that the analysis may change for the final rulemaking. The EPA RIA presents data on the costs of converting an existing mercury-cell plant to membrane technology. Because of the different types of costs estimated and the different methodologies, it is difficult to directly compare the results of the EPA RIA with this one. However, capital costs of conversion and energy costs, two key parameters, can be compared. In addition, the EPA analysis did take into account several additional costs, such as compliance costs and mercury storage costs that were not explicitly addressed in the above analysis but were included in the estimates of operating costs for a mercury-cell facility.

Capital Costs

EPA developed capital cost factors for conversion to membrane cell technology in units of dollars per ton ($/ton) of chlorine ($Cl_2$) production using data from conversions anywhere in the world that took place after 1995. The cost factors ranged from $294 to $1035/ metric tonne Cl_2 produced and averaged $589/ metric tonne Cl_2. The average of the cost factors from only the most recent US conversions (since 2000) was $657/ metric tonne Cl_2. This compares with the cost factor of $700/ metric tonne Cl_2 used in the Appendix 1 analysis.

Electricity/Energy Costs

Electricity costs used were higher in this analysis than the EPA analysis. This difference could be due to the different regions that were used to derive the electricity cost estimates. The EPA analysis used actual electricity costs for the areas in which the four remaining mercury-cell plants were located. There were also slight differences in the amount of electricity required per tonne of Cl_2 produced. The table below summarizes the different electricity costs.

	US EPA		Appendix 1 Study	
Electricity Cost (USD/MWh)	39.00-57.70 (average = 51.08)		63.00	
	Mercury-Cell	Membrane	Mercury-Cell	Membrane
Electricity Intensity* (MWh/ton Cl_2)	3.23	2.5	3.315	2.715
Annual Electricity Costs for 100k tpy Plant (USD)	16,498,840	12,770,000	20,884,500	17,104,500

[1] http://www.epa.gov/ttnecas1/regdata/RIAs/mercurycell.pdf

Calculated for WCC by multiplying 45 €/MWh * Prochemics Net Utility Cost (€/metric ton) * 1.1 tons/metric ton

EPA estimated total energy cost savings from converting a mercury-cell facility to a membrane facility to be 22%, after steam costs were accounted for. This compares with a total utility cost savings of 18% calculated in the Appendix 1 study.

Other Costs

Compliance Costs

These costs deal primarily with the costs of storing mercury and complying with applicable environmental regulations. It is difficult to apply costs of environmental compliance between different nations with differing environmental compliance burdens. However, in the EPA analysis, two estimates for compliance costs were derived. The first value was obtained from the industry in the US ($7.15 USD/ton Cl_2) and the other was derived from literature review of mostly European facilities ($4.63 USD/tonne Cl_2).

For the example of a 100,000 tonne per year facility, the cost savings associated with conversion to a non-mercury technology could be between $463,000-715,000 USD per year.

Mercury Storage Costs

There are costs associated with the storage of unused mercury at chlor-alkali facilities. The analysis performed by the EPA did account for the costs savings produced by no longer having to store unused mercury on-site. A cost savings of $0.0561-0.134 USD per pound of mercury stored per year was estimated for facilities that convert. This saving amounted to an average of about $60,000 USD per year for the four US facilities included in the EPA analysis.

This study did not explicitly describe the costs associated with environmental compliance and mercury storage. However, these costs were included in the estimates of operating costs for a mercury-cell facility (see Appendix 1).

Appendix 3

Factors influencing the voluntary mercury-cell phase out by chlor-alkali facilities in India.

Present chlor-alkali capacity in India is 2.95 million tons chlorine per year, of which 95% is operating as membrane cell technology and only 5% capacity with 6 small scale units is operating with mercury cell technology. This 5% mercury cell capacity will be phased out by the year 2012, as per the CREP (Charter on Corporate Responsibility & Environmental Protection) voluntary commitment.

This change in technology was subsequent to introduction of CREP in the year 2003. This charter was signed by industry as a voluntary commitment and initiative for Responsible Care® to help build a partnership for pollution control with the Government of India and regulatory bodies. A CREP Task Force was constituted by the Ministry of Environment and Forests to monitor the progress of implementation of CREP recommendations. Continuous monitoring, rigorous follow up and cooperation from industry helped to achieve the set targets.

The chlor-alkali industry in India embarked on finalizing the program for conversion from mercury-cell to membrane-cell to complete the phase out by 2012. In 2003, mercury-cell capacity was 29% of total capacity. Within the last 8 years, the industry has achieved 83% conversion of mercury-cell facilities and today only 5% capacity is from mercury cells.

Environmental performance

One of the major reasons for the trend of conversions has been awareness about environmental regulations and the impact of mercury on human health and the environment. In several cases significant investments were needed to bring existing facilities to acceptable performance levels. In certain cases an additional requirement for higher purity product may have acted as a supplementary incentive.

Demand growth and market price – capacity expansions

Another reason is growing demand of caustic at a rate of 5% per year. After 1986, no mercury-cell units or expansions of existing mercury-cell units were allowed in India. Therefore, only membrane cell units were constructed to meet the growing demand for caustic. A favorable market price for chlor-alkali products from before the third quarter of 2009 and from late 2010 until the present has led the industry to switch over to membrane cell, expand and increase revenue, although it should be stated that higher caustic prices in itself does not result in lower payback time of conversion investments.

Energy savings

Converting to membrane cell technology yields net energy savings of 400 to 600 KWh/mt. The cost of electricity is very high in India (about $ 105/MWh compared to $63/MWh used in the Appendix 1 analysis), and energy savings was one of the major reasons to opt for conversion, reducing the cost of production and becoming more competitive in the market.

Summary of conversion incentives in India

In India a relatively rapid conversion away from the mercury cell technology has occurred over the past decade and is expected to result in a complete phase-out by the end of 2012. A combination of favourable factors supported the conversion in India:

- A need for significant investment to increase environmental performance of existing plants and perhaps some cases of additional product quality requirements. Such significant investments are preferably made using modern technology rather than in upgrading outdated technology
- Very high electricity costs compared to competitors in other parts of the world (see section 3.7.1)
- Significant market expansion opportunities in the form of increased caustic soda demand