Applying a Life-Cycle Assessment to the Ultra Pure Water Process of Semiconductor Manufacturing

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Abstract

A life-cycle assessment (LCA) is based on the attention given to the environmental protection and concerning the possible impact while producing, making, and consuming products. It includes all environmental concerns and the potential impact of a product's life cycle from raw material procurement, manufacturing, usage, and disposal (that is, from cradle to grave). This study assesses the environmental impact of the ultra pure water process of semiconductor manufacturing by a life-cycle assessment in order to point out the heavy environmental impact process for industry when attempting a balanced point between production and environmental protection. The main purpose of this research is studying the development and application of this technology by setting the ultra pure water of semiconductor manufacturing as a target. We evaluate the environmental impact of the Precoat filter process and the Cation/Anion (C/A) filter process of an ultra pure water manufacturing process. The difference is filter material used produces different water quality and waste material, and has a significant, different environmental influence. Finally, we calculate the cost by engineering economics so as to analyze deeply the minimized environmental impact and suitable process that can be accepted by industry. The structure of this study is mainly combined with a life-cycle assessment by implementing analysis software, using SimaPro as a tool. We clearly understand the environmental impact of ultra pure water of semiconductor used and provide a promotion alternative to the heavy environmental impact items by calculating the environmental impact during a life cycle. At the same time, we specify the cost of reducing the environmental impact by a life-cycle cost analysis.

Key Words: Life-cycle Assessment, Ultra Pure Water, Life-cycle Cost Analysis

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1. Introduction

In recent years global environmental protection problems have been brought to everyone's attention, such as climate changes, acid rain, and ozone layer depletion. The Organization for International Standards (ISO) has listed a life-cycle assessment through the ISO 14000 series of standards- ISO 14040- ever since 1993. It has also announced relevant successive standards since 1998, which can be used as an effective tool and method for assessing the environmental impact of a business evaluation or to improve a product's design, manufacturing, usage, or disposal. This offers a global enterprise a clear common rule to adjust to the growing environmental awareness. The semiconductor manufacturing industry is a hi-tech industry consisting of electrical machinery, physics, optics, material, and machinery and management science. The competitiveness of electronic industrial products is affected by the technical development of semiconductors. The semiconductor component process uses many kinds of sour and alkali solutions, organic solvents, and special gases. These original supplies not only may be dangerous to staffmembers, but may create a heavy pollution of wastewater, waste gas, and toxic materials. The pollution characteristics even become more and more complicated with the level of products. If a firm does not conduct pollution prevention work early on, then it will consume more money for disposal treatment and may cause a serious problem of environmental pollution in the future.

This research studies the technical aspects of life-cycle assessment and the impact of the prefilter plant process and the C/A filter process of ultra pure water of the semiconductor manufacturing process. We are concerned about the environmental perspectives and potential impacts of raw material procurment, manufacturing, usage, and disposal (from cradle to grave). We also focus on the effectiveness, cost, and environmental impact of a suitable manufacturing process and hope to provide valuable reference information for industry. The purpose of two draft projects in this research is as follows: (1) Study the overall environmental impact influence for energy consumption and the water production effectiveness of the prefilter plant process and the C/A filter process of ultra pure water of the semiconductor manufacturing process; (2) Study the cost and environmental impact of the ultra pure water process of semiconductor manufacturing to find a suitable process for industry as reference, relating to minimizing the environmental impact through integrated operations.

2. Literature Review

2.1 Life-Cycle Assessment

Ever since August 1990, the U.S. Society of Environmental Toxicology and Chemistry (SETAC) has offered a series of seminars and training courses on life-cycle assessment technology, which has contributed to the completion of its well-recognized framework of related technical tools. SETAC has thus become the worldwide authority of LCA application technical tools and methods. The ISO 14040 environmental management - life-cycle assessment - principles and framework (ISO/TC-207/SC5, 1997) was officially published in 1997, proposing an integrated and conceptual framework and direction of life-cycle assessment technology. The ISO 14041 environmental management - life-cycle assessment - goal and scope definition and inventory analysis (ISO/TC-207/SC5, 1998) was published in 1998, clearly stating that the goal and scope definition are the first essential job of life-cycle assessment. This means that we must first clarify the goals and reasons for a life-cycle assessment as well as the end user or target audience of the life-cycle assessment results. Such a way prevents aimless life-cycle assessments, and thus the type and the depth of data needed by an assessment can be determined correctly (Ding, 1997). Appraisers must acknowledge that life-cycle assessment research is an iterative process, meaning that as the data and information collected increase, the pre-determined research scope may change in order to satisfy the initial research objectives. One thing worth cautioning is that the life-cycle assessment is a highly data-intensive assessment approach. The various data collected during the course of research must be evaluated by a logical, formal, and repetitive method to ensure the reliability of research results (Xu, 1996a/1996b). Lu (1996a/1996b) pointed out that life-cycle inventory analysis can be divided into six stages: raw material procurement, manufacturing and assembly, distribution and transportation, use/reuse/maintenance, recycling, and disposal handling.

The ISO 14042 environmental management - life-cycle assessment - life-cycle impact assessment (ISO/TC-207/SC5, 2000a) and the ISO 14043 environmental management - life-cycle assessment - life-cycle interpretation (ISO/TC-207/SC5, 2000b) were published in 2000. The goal of the life-cycle impact assessment stage is to assess the significance of potential environmental impacts with inventory analysis results. The process includes correlating inventory data to specific environmental impacts and trying to understand the degree of these impacts, the detail level of which depends on the selection of impact assessment items, the approach adopted, as well as the operational goal and scope.

Based on the above, the cause-effect relations, logic processes, and functional applications of life-cycle assessment technology are summarized in Figure 1. To date, many research organizations and experts and scholars have given somewhat different definitions to life-cycle assessment. The U.S. SETAC (Society of Environmental Toxicology, 1991/1993) believes that life-cycle assessment is a tool that can be used to measure the environmental burdens resulting from manufacturing or human activities. Vigon *et al.* (1993) defined life-cycle assessment as an evaluation of the environmental impact incurred during the entire course from cradle to grave, meaning from the starting point of raw material procurement to the ending point of disposal to the earth for products. Lai (1997), the domestic life-cycle assessment expert, stated that a life-cycle assessment in essence uses scientific methods to investigate activities, products, and services systematically, assess and quantify the energies and resources used and the various emissions and pollutions produced during their life cycle (that is, from cradle to grave) so as to derive an environmental impact and arrive at conclusions that can be used as reference points for future improvement opportunities and items. According to Yang (1997), the concept of a product life cycle integrates the environmental impact at different stages of raw material exploration, manufacturing, product use and disposal, etc. from up-stream to downstream and assesses the degree of impact that a product life cycle has on the environment.

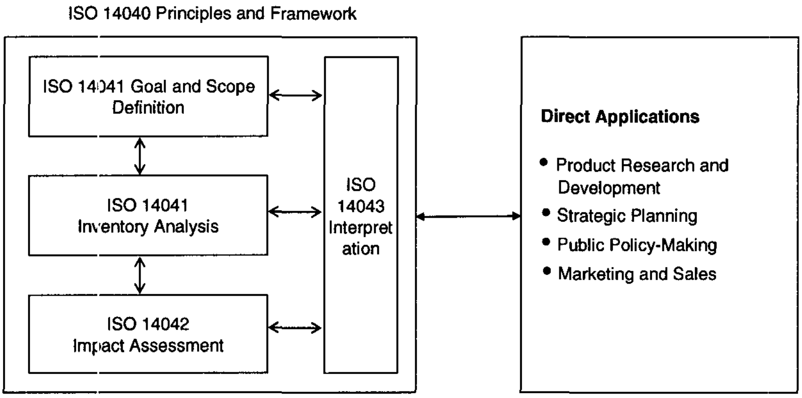

Figure 1. Life-Cycle Assessment Phases and Applications

More and more countries in the world are adopting environmental protection-oriented technical trade barriers. The ISO 14000 series of standards have rapidly created a trend. Since life-cycle assessment is the basis for products' environmental protection conditions and quantified data computation and research, it should become the tool for enterprises to use to assess products' "green conditions" and for governments to set limits and control over products that are unfriendly to the environment. The attention given to life-cycle assessment and the applications of life-cycle assessment has increased exponentially (Cheng *et al.*, 2000). The Industrial Technology Research Institute (ITRI) is delegated by the Department of Technology, Ministry of Economy to devote efforts into studying and advocating life-cycle assessment technology. The first research, "Life Cycle Assessment Case Study- Most Appropriate Domestic Waste Paper Percentage of Industrial Paper", has been completed by Lai *et al.* (1995). This case study concludes that in the life cycle of industrial paper, the manufacturing phase- including foreign pulp preparation to domestic paper formation – has the largest environmental impact. To date, many existing domestic cases focus on how to apply life-cycle assessment technology to evaluate the environmental impact at various life stages of products or manufacturing processes. "Applying ISO 14040 Life-Cycle Assessment to Illumination Product" was completed by Hsieh (2001). The research results show that the electricity consumption of incandescent lamps at the service stage imposes the most significant impact on that environment - that is, it is most unfriendly to the environment. In particular, the "heavy metal" dimension is most influential to the human living environment. However, no case study has been done on the ultra pure water process of semiconductor industry. Therefore, this research employs Life-Cycle Assessment technology to study the ultra pure water process' environmental impact.

2.2 Life-Cycle Cost Analysis

The life-cycle cost analysis (LCCA) is an economic technology to determine the total operating (or using) facility expense during a period (Tim *et al.*, 1999). The National Institute of Standards and Technology define LCCA as a total discount cost of operating (or using), maintaining, construction (or facility) handling, and construction (or facility) owning. LCCA is a very important design method to control the initial and future cost of construction owning. There are three variables in the LCC equation: holding related cost, happening cost during a period, and using a discount rate discounting the future cost to current cost (Tim *et al.*, 1999).

2.3 Integrated Life-cycle Assessment and Life-cycle Cost Analysis

Traditional life-cycle environmental assessment focuses on decision-making, important related issues of avoiding any influence for the evaluator's benefit, and making the product design between economic effectiveness and life-cycle environmental assessment. In spite of this, there are some alternatives that are combined with cost accounting, life-cycle cost analysis, based-economic-risk model, and life-cycle assessment by correctness and logicality. A life-cycle cost analysis is mixed with economic, environment, and all related transaction items on product (process) decision-making (Gregory, 2001). Developing the scope of life-cycle assessment is not according to internal and external economic perspectives. Therefore, life-cycle cost analysis is combined with an economic analysis by a life-cycle assessment, and not according to the ISO 14040 series standards. There are some differences in using these methods between life-cycle assessment and life-cycle cost analysis as Table 1 shows. The flow scope is the biggest difference between these two methods. LCCA only includes a cost item that is described as before, and it must notice that it may not be proportional on some cost flow. While LCA ignores flow timing, LCCA must list cost flows carefully. LCCA might include some cost risks, such as a design change or preventing some investment choice in the function of the product or process. LCA does consider pollutions and resource flows of process models.

Table 1. Difference in Purpose and Method between LCA and LCCA (Norris, 2001)

Tools/Methods	LCA	LCCA
Purpose	Complete related environmental factors comparison by the same functional unit product system.	Compare the effectiveness of investments or commercial decision alternatives through the view of the economic decision maker (manufacturer or consumer).
Be part of life-cycle activities	All related processes connect to the product life cycle including all material supply chain processes, usages, and supply of manufacturing using the product.	Direct cost or benefit of decision-maker's investments that come out during the economic life cycle.
Considered flow	Pollution, resources, and used materials and energy during production.	Direct impact from the finance flow of cost and benefit.
Unit	The main units are gravity, energy, volume, and other physical units.	Financial units (such as USD, EUR)
Timing and scope	There is no consideration for the timing of flow handling and usage by tradition. The value of impact assessment may be evaluated by fix timing. Generally, the future impact cannot be assessed by a discount rate.	Timing is a very important factor. Cost and benefit will be discounted as the prevent value by a discount rate, but they will be ignored as they are out of the scope of a specific time, cost, and benefit.

3. Methodology

3.1 Quality Analysis of Inventory Data

The Precoat filter process is a traditional process of the ultra pure water manufacturing process. The production flow chart is shown as Figure 2. The functional unit is raw water volume which can be calculated by producing 10,000 wafers. One needs 3.3m^3 of raw water to produce a wafer. We can calculate the total raw water needed as 44,840.71m^3 when producing a functional unit by calculating the reverse process.

3.1.1 Precoat Filter Process

The components of the sand filter process include $FeCl_3$, NaOH, a raw water pump which transits raw water to the sand filter, a dosing pump which transits $FeCl_3$ and NaOH to the sand filter, an agitator pump which is the tank stirrer of mixing $FeCl_3$, and sand which filters raw water in the tank of the sand filter where the diameter is 0.4~0.8mm. The chemical reaction equation is shown as follows:

$$2\ FeCl_3 + 3\ Ca\ (HCO_3)_2 \rightarrow 2\ Fe\ (OH)_3 + 3CaCl_2 + 6\ CO_2$$
$$2\ NaOH + 6\ CO_2 \rightarrow 6\ NaHCO_3$$

We calculate the total demand of ultra pure water as 33,000m^3 by a functional unit which sets 10,000 wafers. Producing one wafer needs 3.3m^3 of water. If the machine can provide 141 tons of ultra pure water per hour, then it needs 234 hours to manufacture raw water into ultra pure water. We find that the 95% production rate of an ultra filter unit to calculate the demand of raw water input for the ultrafiltration plant unit is 34,736.8m^3 (33,000/95%), while producing 5% of water reversal to the permeate tank takes up 1,736.8m^3. If there is no waste during the processes of the up tank, UV-185 nm, Polish filter, UV-254 nm, and Vacuum degasifier, then one just uses only trace water in testing the water quality for which we will ignore it.

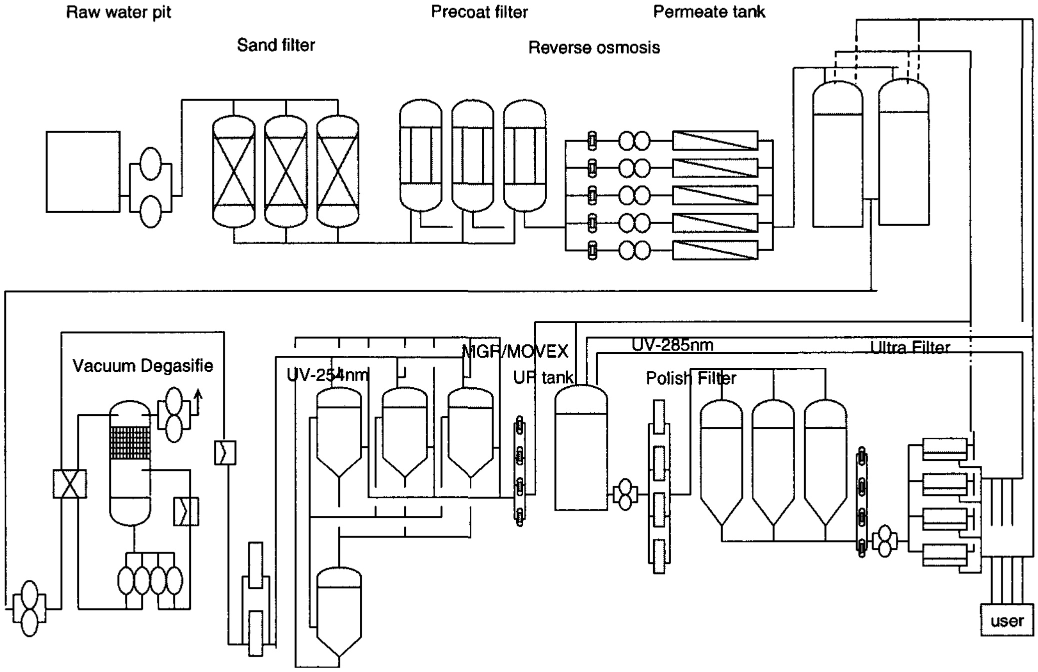

Figure 2. Precoat Filter Process Flow Chart

The process of MGR/MOVEX is operated by the recycle process. We calculate a recycle rate of 120 hours and the demand water for it is 42.6m^3. Producing 10,000 wafers takes up 234 hours; therefore, it needs is 85.3m^3 (2x42.6m^3) of water by twice recycling. The total input water of the MGR/MOVEX process is 34,822.1m^3 (34,736.8m^3+85.3m^3). To keep continuously calculating the water volume, we find out that the remaining water is 14m^3/hr in the tank, collected by using the FAB; and it needs 3,276m^3 (234Hx14m^3/hr) of water. At the same time, it also needs 1,736.8m^3 of water for the UF process (5% emission). The total water of the reverse osmosis (R.O.) process is 29,809.3m^3 (34,822.1m^3 – 3,276m^3 – 1,736.8m^3).

There is a 70% water creation rate in the reverse osmosis (R.O.) of the Precoat filter process. We need 6 R.O. machines operating at the same time [29,809.3m^3 / (234hrsx22m^3/hr)]. This needs 4.5m^3 of water and 20 minutes for reverse cleaning every 12 hours. Therefore, we need 20 times (234hrs/12hrs). The total input water to R.O. is 43,124.71m^3 [(29,809.3/ 70%)+(6x20x4.5)]. In the Precoat filter process the normal production rate is 164m^3/hr. It needs 2 reverse cleannings every 7 days (234hrs/168hrs) and 6m^3 of water each time. The total consumption of water for the Precoat filter process is 43,160.71m^3 [43,124.71+(2x3x 6m^3)]. The sand filter process needs reverse cleaning every 12 hours and 20 times (234hrs/ 12hrs), at 28m^3 of water in 3 sets. Total raw water consumption is 44,840.71m^3 [43,160.71+ (20x28m^{3}x3)]. The energy consumption is described as follows:

(1) Raw water pump: it is designed to use three pumps, but there are only two of them operating. The energy consumption is 14,040kw-h (30kwx2x234h).
(2) Agitator pump: it consumes 42.12kw-h (0.18kwx1x234h) for mixing $FeCl_3$.
(3) Dosing pump: it consumes 16.848kw-h (0.012kwx6x234h) for pouring NaOH to piping and 60.372kw-h (0.043kwx6x234h) for pouring $FeCl_3$ to piping.
(4) Air blower: it uses 100Nm^3/hr of air pressure for reverse cleaning. In the sand filter process, the air backwash needs four cycles and six minutes for each one. The volume of air is 120Nm^3 [100Nm^3/Hx(6x4x3/60)] at 20Hp, which can provide 116 CMH. Therefore, the energy consumption is 15.4344kw-h [20Hpx0.746kw/Hp x (120Nm^3/116 CMH)]; and the total energy consumption is 14,174.7744kw-h.

The output of backwash is 31,590Kg - combined by 5,981.04Kg for NaOH and 25,608.96 Kg for $FeCl_3$. The consumptive materials' description and change frequency of the Precoat filter process are shown in Table 2 for the material life cycle.

Table 2. Consumptive Materials of the Precoat Filter Process

No.	Material	Description	Frequency
1	Sand filter	Filter check/resupply	Every year
2	Precoat filter	Renew filter	Every three years
3	R.O.	Wash	1. WCF decrease < 60% 2. Pressure difference increase >15%
		Change	1. After wash, WCF < 60% 2. After wash, cannot recover.
4	R.O. Prefilter	Renew	Every month

We assume that the material consumption is 50% in the sand filter, and then the functional unit consumption is 0.108m^3 {8.1m^{3}x50%x[234hrs/(365daysx24hrs)]}. To sum up all of the above, we show the sand filter manufacturing subsystem in Table 3, the Precoat filter manufacturing subsystem in Table 4, and the R.O. filter manufacturing subsystem in Table 5.

Table 3. Sand Filter Manufacturing Subsystem

Inventory Item	Volume	Inventory Item	Volume
Total raw water (Ton)	44,840.71	Total electricity (kw-h)	14,174.77
Total output water (Ton)	43,160.71	Wastewater after chemical reaction (Kg)	31,590
Wastewater (Ton)	1,680	Physical waste (Ton)	0.108
Output item	Ablate plankton and sludge in the water		

Table 4. Precoat Filter Manufacturing Subsystem

Inventory Item	Volume	Inventory Item		Volume
Total raw water (Ton)	43,160.71	Total electricity (kw-h)		11,105.49
Total output water (Ton)	43,124.71	Wastewater after chemical reaction (Kg)		7,272.72
Wastewater (Ton)	36	Physical solid waste (Ton)		0.156
Disposal material (Kg)	0.768	Output item	Ablate impurities in the water	

Table 5. R.O. Filter Manufacturing Subsystem

Inventory Item	Volume	Inventory Item		Volume
Total raw water (Ton)	43,160.71	Total electricity (kw-h)		42,340
Total output water (Ton)	42,584.71	Wastewater after chemical reaction (Kg)		5,981.04
Waste water (Ton)	540	Recovery compressed water (Ton)		12,775.41
Waste filter (Kg)	25.92	Output item	R.O. process water	

3.1.2 C/A Filter Process

The manufacturing flow chart of the C/A filter process is shown as Figure 3. This is the popular application in the current semiconductor industry. The water by this process can promote the effectiveness and the life cycle - for example, WCF of the R.O. process can go to 90% and above. It is better than the Precoat filter process which is 75%. The change frequency of the R.O. membrane can be for three years, longer than the two years generally provided by the Precoat filter process (see Table 6).

The consumption water of the permeate tank of the C/A filter process is the same as the R.O. water creation volume of the Precoat filter process which has to be 29,809.3m^3. The WCF of R.O. is 90% and each one can produce 33m^3/hr water. It thus has to start four R.O. equipment machines [29,809.3m^3/(234H×33m^3/H)] that operate at the same time to accomplish this demand and every 12 hours need 6.5m^3 of water to backwash for 25 minutes. Therefore, the input water to the R.O. process is 33,641.44m^3 {(29,809.3/90%)+[4×(234hr/

12hr) ×6.5]}. There are two sets of equipment for the C/A filter process to operate and one set standing standby. Generally, they have to backwash every day under normal water quality and produce waste liquid in the amount of 2,060m^3 [(234H/24H×2)×10m^3]. However, the industry recovers the wastewater of the final step (25.83m^3) which is cleaner for water saving. The total water consumption of the C/A filter is 35,184.84m^3 [33,641.44+2060-(20×25.83m^3)]. The process of the MM filter has to backwash and consume 68.79m^3 every 12 hours. The steps, time, and output of the backwash of the three pieces of equipment are shown as Table 7. The total water consumption is 39,312.24m^3 {35,184.84+[(234hrs/12hrs)×68.79m^3×3sets)]}.

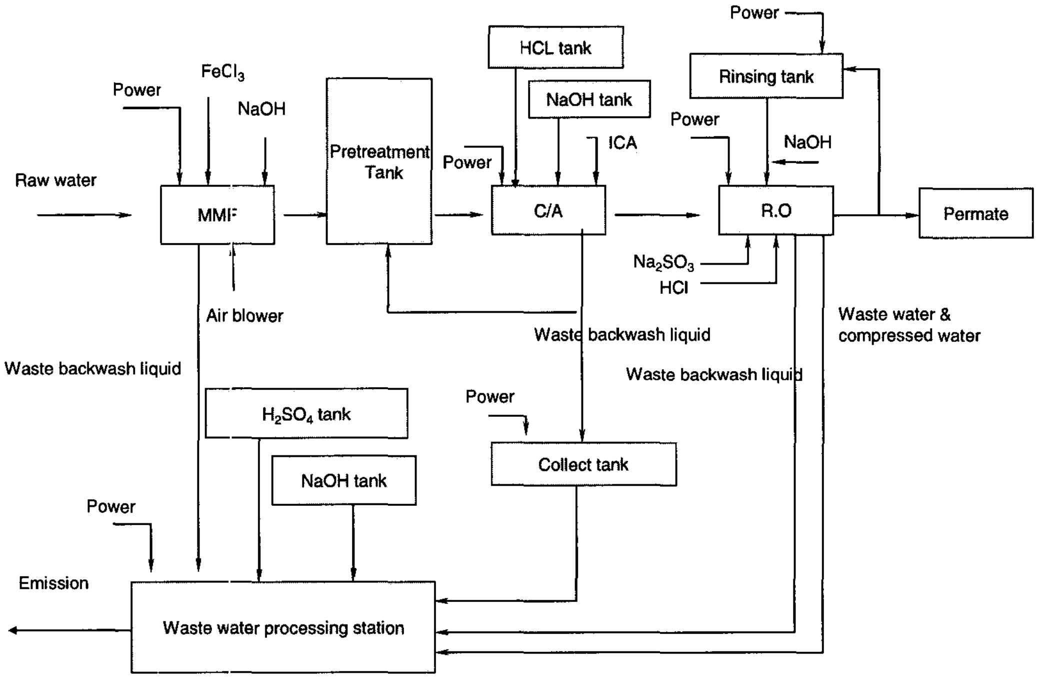

Figure 3. Inventory Analysis Flow Chart of the C/A filter Process

Table 6. Consumptive Materials of the C/A Filter Process

No.	Material	Description	Frequency
1	MM filter	Filter check/resupply	Every year
2	Active carbon filter	Renew filter	Every three years
3	C/A filter	Resin check/respply	Every year
		Renew resin	Four years
4	R.O.	Renew	Three years
5	R.O. prefilter	Renew	Half year

Table 7. Backwash Process of the MM Filter

Step	Time (Sec.)	Output (m^3/H)
Lowering	300	200
Backwashing with air	300	270
Baskwashing with water low	300	27
Baskwashing with water low	540	135
Refilling	150	27
Prefiltration	1,200	18

The energy consumption includes the following:

(1) Raw water pump: there are two pumps operating and one at standby. The energy consumption is 10,296kw-h (22kwx2x234h).

(2) Backwash pump: as Table 7 shows, the total time of it is 1,140 seconds for 418 kw-h [22kwx20x3setsx(1140/3600)].

(3) Dosing pump: it consumes 40.248kw-h (0.043kwx4x234h) for pouring NaOH to piping and 40.248kw-h (0.043kwx4x234h) for pouring $FeCl_3$ to piping.

(4) Air blower: the major function of it is to filter in the multilevel filter tower for the backwash while the pressure difference becomes greater. This is done to smooth out emission impurity. The energy consumption is 171kw-h [9kwx20x3setsx(1,140/3,600)].

(5) Mixing pump: it consumes energy of 351kw-h (1.5kwx1x234h) for mixing $FeCl_3$.

The output of the backwash is 21,060Kg, combined by 3,987.36Kg for NaOH and 17,072.64Kg for $FeCl_3$. The consumptive materials' description and change frequency of the C/A filter process are shown in Table 6 for the material life cycle. We assume that the material consumption is 50% in the MM filter, and then the functional unit consumption of anthracite is $0.0475m^3$ {$3.56m^3$x50%x[234hrs/(365daysx24hrs)]}, sand is $0.036m^3$ {$2.7m^3$x50% x [234hrs/(365daysx24hrs)]}, and gravel is $0.015m^3$ {$1.12m^3$x50%x[234hrs / (365daysx24 hrs)]}. To sum up all of it above, we show the MM filter manufacturing subsystem in Table 8, the C/A filter manufacturing subsystem in Table 9, and the R.O. filter manufacturing subsystem in Table 10.

Table 8. MM Filter Manufacturing Subsystem

Inventory Item	Volume	Inventory Item	Volume
Total raw water (Ton)	39,312.24	Total electricity (kw-h)	11,316.496
Total output water (Ton)	35,184.84	Wastewater after chemical reaction (Kg)	21,060
Wastewater (Ton)	4,127.4	Physical waste (Ton)	0.0985
Output item	Ablate plankton and sludge in the water		

Table 9. C/A Filter Manufacturing Subsystem

Inventory Item	Volume	Inventory Item		Volume
Total raw water (Ton)	35,184.84	Total electricity (kw-h)		15,562.404
Total output water (Ton)	33,641.44	Wastewater after chemical reaction (Kg)		6,608.16
Wastewater (Ton)	1,443.6	Waste liquid after waste C/A (Ton)		35,918.4
Waste resin (Ton)	54.09	Output item	Ablate ion in the water	

Table 10. R.O. Filter Manufacturing Subsystem

Inventory Item	Volume	Inventory Item		Volume
Total raw water (Ton)	33,641.44	Total electricity (kw-h)		41,368.19
Total output water (Ton)	29,809.3	Wastewater after chemical reaction (Kg)		3,987.36
Wastewater (Ton)	520	Recovery compressed water (Ton)		3,312.14
Waste filter (Kg)	5.8	Output item	R.O. process water	

4. Result and Analysis

4.1 The Result of Life-Cycle Impact Analysis

This study adopted SimaPro which is LCA software to provide several impact evaluation models such as: Ecopoints 1990 (CH), Ecopoints 1997 (CH), SimaPro 1.1 (CML), SimaPro 2.0 (CML), SimaPro 3, Eco-Indicator 95, SimaPro 4 Eco-Indicator 99 (C), SimaPro 4 Eco-Indicator 99 (H), SimaPro 4 Eco-Indicator 99 (I). The software analyzes the LCA of the ultra pure water manufacturing process by SimaPro 3 and Eco-Indicator 95 and can analyze Assembly perspective, Life-Cycle perspective, Disposal Scenario perspective, Disassembly perspective, and Reuse perspective. After establishing the inventory database, SimaPro analyzes the environmental impact by characterization, normalization, evaluation, and indicator to find out which is the worst one. The "Compare Function" then compares the environmental impact between the Precoat filter process and the C/A filter process. We first compare the environmental impact of the individual subsystem process for them before integrating a process comparison.

The environmental impact of the sand filter process (0.927 Pt) is worse than the MM filter process (0.635 Pt). For only on the "Carcinogen" item, the environmental impact of the MM filter process is worse than the sand filter process. All evaluation items of the environmental impact of the C/A filter process (18.9 Pt) is worse than the Precoat filter process (0.0235 Pt); and the difference between them is very big. The environmental impact of the R.O. filter process in the Precoat filter process (0.0922 Pt) is worse than in the C/A filter process (0.0777 Pt). In view of all ultra pure water manufacturing processes, the environmental impact of the C/A filter process is worse than the Precoat filter process, but only in the "Ozone" item. There is a very big difference in environmental impact between the Precoat filter process (1.02 Pt) and the C/A filter process (19.6 Pt).

4.2 The Result of Life-Cycle Cost Analysis

According to the implication of LCCA, we assume the the LCCA study period is five years and the discount rate is 5%. For the initial investment perspective, due to the process of the Precoat filter being too old at about a few decades ago, the information about it cannot achieve real data. We have no choice but to ignore it. For the operation cost perspective, we show the consumption per year for electricity, water, chemical, and wastewater processing fees in Table 11 and Table 12. For the maintaining cost perspective, there are resembling maintainence contents in these two processes. A Company lists NT$ 3,000,000 in budget for the Precoat filter process to be maintained and NT$ 2,000,000 in budget for the C/A filter process to be maintained, aside from the unexpected and accident costs which we ignore. From the renew cost perspective, it is the cost of upgrading equipment or renewing components and we show it in Table 13 and Table 14. From the residual perspective, due to assuming a five-year analysis period, we ignore this factor. Finally, we can see the integrated Life-Cycle Cost in Table 15.

Table 11. Operation Cost of the Precoat Filter Process

Item	Funtional Unit	One Year	Unit Cost (NT$)	Subtotal (NT$)
Electricity	67,620.26kw-h	2,531,425kw-h	$2	$5,062,850
Water	44,840.71m^3	1,678,652.22m^3	11.5	19,304,500
NaOH	11,962kg	447,808kg	3.7	1,656,890
HCl	3,341.52kg	125,092.8kg	3	375,278
$FeCl_3$	25,608.96kg	958,694.4kg	3.9	3,738,908
Na_2SO_3	3,931.2kg	147,168kg	26	3,826,368
Polymer	0.026kg	0.973kg	93	91
Total Cost NT$ 33,964,885				

Table 12. Operation Cost of the C/A Filter Process

Item	Funtional Unit	One Year	Unit Cost (NT$)	Subtotal (NT$)
Electricity	68,247.09kw-h	2,554,890kw-h	$2	$5,109,780
Water	39,312.24m^3	1,471,688.98m^3	11.5	16,924,423
NaOH	19,902kg	745,049kg	3.7	2,756,681
HCl	23,990.4kg	898,102kg	3	2,694,306
$FeCl_3$	17,072.64kg	639,129.6kg	3.9	2,492,605
Na_2SO_3	2,620.8kg	98,112kg	26	2,550,912
Total Cost NT$ 17,296,727				

Table 13. Renew Cost of the Precoat Filter Process

Item	Unit / Year	Cost / Unit (NT$)	Subtotal (NT$)
R.O. front filter	576	$560	$322,560
Renew R.O. module	51	30,000	1,530,000
Renew Precoat filter	68	6000	408,000
Renew active carbon	4667	35	163,333
Total Cost NT$ 2,423,893			

Table 14. Renew Cost of the C/A Filter Process

Item	Unit / Year	Cost / Unit (NT$)	Subtotal (NT$)
R.O. front filter	576	$680	$391,680
Renew R.O. module	34	50,000	1,680,000
Add resin of cation mixing	900	137	123,300
Add resin of anion mixing	720	57	41,040
Renew active carbon	14,000	35	490,000
Add resin of cation mixing	3,000	137	411,000
Add resin of poison mixing	2,400	57	136,800
Total Cost NT$ 3,273,820			

Table 15. Life-Cycle Cost of the Precoat Filter Process and the C/A Filter Process

Item	Precoat filter process (NT$)	C/A filter process (NT$)
Initial investment cost	Ignore	Ignore
Operation cost	$147,050,177	$74,885,776
Maintaining cost	12,988,430	8,658,953
Renew cost	10,494,188	14,173,927
Residual	Ignore	Ignore
Total Life-Cycle Cost	$170,532,795	$97,718,656

5. Conclusion and Recommendation

This study focuses on understanding the environmental impact of resource procurement, manufacturing, usage, and disposal of the Precoat filter process and the C/A filter process of ultra pure water manufacturing by Life-Cycle Assessment. We also have studied the costs of these processes by Life-Cycle Cost Analysis.

5.1 The Implication of Life-Cycle Assessment

(1) According to the result of LCA, the environmental impact of the C/A filter process is

worse than the Precoat filter process. The reason is to use a lot of chemicals like HCl and NaOH to exchange the material while the C/A resin is reused frequently and discharges a large amount of waste liquid.

(2) We find that "Ozone" is the heaviest environmental impact of the sand filter process and the MM filter process. When we study the environmental impact of the whole process, "Acidification" is the heaviest environmental impact item.

(3) There is a big environmental impact difference between the Precoat filter process (0.0235 Pt) and the C/A filter process (18.9 Pt).

(4) The environemtnal impact of the R.O. filter process of the Precoat filter process (0.0922 Pt) is worse than that of the C/A filter process (0.0777 Pt). This is because the water quality filter is done by C/A rather than only by the R.O. membrane.

5.2 The Implication of Life-Cycle Cost Analysis

(1) There is a difference in maintaining costs between the Precoat filter process and the C/A filter process, because the established time is ten years old. A Company lists a NT$ 3 million budget for the Precoat filter process and a NT$ 2 million budget for the C/A filter process.

(2) From the operation cost perspective, the effectiveness of the C/A filter process is greater than the Precoat filter process; and the demand of the raw water from the C/A filter process is less than the Precoat filter process. The chemical consumption of HCl and NaOH of the C/A filter process is the only one much more than the Precoat filter process; and the operation cost of the C/A filter process is NT$ 16 million less than the Precoat filter process.

(3) From the renew cost perspective, the C/A filter process is an advance process. All equipment design of it is more serious than the Precoat filter process. To be effective, the consumptive material of the C/A filter process is more expensive by NT$850,000 than the Precoat filter process. After LCCA, it is more expensive by NT$ 3,067,000.

(4) After LCCA, the whole process of the Precoat filter process is more expensive than the C/A filter process by NT$ 72 million.

5.3 Recommendation of Implementation of the Life-Cycle Assessment

(1) Life-Cycle Assessment involves a very wide scope and everything in this scope is closely related. One should describe the purpose, scope, and hypothesis of the project as best as possible in detail when you imply the Life-Cycle Assessment in order to avoid the situation of "Garbage in Garbage out".

(2) When one collects inventory material information, some companies reserve business confidential processes, materials, and quantity. Some companies even do not know if

they discharge toxic material, and thus the real right data is need in order for analysis.

(3) There are two uncertainties in the LCA implementation, including data uncertainty and module uncertainty. From the data uncertainty perspective, an improvement is needed in high data-collection quality and data processing technology, but the project cost will also rise. Life-Cycle Assessment is a study that can reduce this problem and clarify environmental causal relationships for many years.

(4) The distance to target principle method has a weight of Eco-Indicator 95, which measures the environmental impact between current amount and a target. Although every country sets different weight values, they are not suited to be different in a country under LCA.

(5) In view of the chemical environmental impact assessment's lack of a local inventory database to analyze in this study, we hope to establish such a local inventory database to complete the fitted environmental impact analysis.

(6) There are many factors to influence the assessment of a suitable process selection such as risk degree, difficulty on personnel operations et al. After considering more factors to assess the environmental impact, the result of the assessment will be better trust.

Ultra pure water plays an important role in the semiconductor manufacturing process. In the nanometer process for producing more advanced components, the cleanliness of ultra pure water is more important. Therefore, we compare the Precoat filter process a decade ago and the C/A filter process recently. In the view of environmental protection, we suggest that the industry could adopt the Precoat filter process over the C/A filter process. However, in view of cost analysis, the cost of the Precoat filter process is much more than the C/A filter process. Therefore, the C/A filter process must be chosen by economics, effectiveness, and cleanliness of the water quality. There is a continuous pursuit of a balance point between advanced technology and eco-environmental protection. There are many chemicals used in the semiconductor manufacturing process. We just study only a few of them; but we hope it can be a basis of research and development for products which can involve the environmental protection ideal.

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