Desalination and Advance Water Treatment Economics and Financing

Corrado Sommariva

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2 Foreword

With real excitement I read and reviewed Dr. Corrado Sommariva second book "Desalination and Advance Water Treatment Economics and Financing". First of all it is very timely in view of the dramatic growth of the desalination and advance water treatment industry. The second reason was the fact that we share many common ideas about the current technologies and the direction of the future developments with emphasis on integration of water energy and the environment.

I was very happy, when Corrado ask me to write a forward to this book. Dr. Corrado Sommariva is a personal and professional friend. He is recognized as one of the world's foremost experts on the subject of desalination and advance water reuse. He gained his experience not only by being a principal engineer and manager with major suppliers of desalination equipment and leading consulting houses but also as an active director of the International Desalination Association (IDA) and as a past President of the European Desalination Society (EDS). I had the pleasure of working with Corrado as a technical co-chairman of IDA World Desalination and Water Reuse Congress-Dubai 2009 when once again he contributed his exceptional knowledge to the great success of the event. Dr Sommariva is a lecturer and frequent speaker on subjects of technology, management, financing and economics of Desalination and Advanced Water Treatment.

We all agree that, the future of water demands a new generation of professionals interested in water and creative solutions to water scarcity and environmental challenges. This book provides a great opportunity for readers who are interested to learn desalination, advanced water treatment technology, development, construction and financing of projects.

Most of the readers of this book already know that Desalination has proven during the last 30 years its ability and reliability to deliver large quantities of fresh water from the sea, from brackish resources and through advance water reuse. The rapid growth of this market is challenged now by the increased fossil energy prices and the need to increase energy efficiency and to reduce environmental impact. Although the sea is the unlimited source from which we can create new fresh water through desalination it has to be done economically and with minimum carbon footprint.

This book has offered the opportunity to update the readers with the rapid developments of the technology in the last several years and to provide a deeper understanding of the desalination and water re use technology and apply these skills to contracting and project financing.

Dr Sommariva structures the book in three parts. The first part of the book is dedicated to the technology options with the respective construction and operating features, assessing advantages and disadvantages of each of the technologies. It includes description of thermal and membrane processes and analysis of simple and integrated hybridization. One of the important chapters of the book deals with the understanding of matching power and water demand and how the thermal/membrane desalination and power/fuel costs can be optimised. It covers the latest aspects and future potential developments of the desalination technologies.

It includes chapters on energy efficiency comparison, technology sensitivity but also indicates the different impact on the environmental and carbon emission sustainability. Corrado points out sustainability of desalination technology has also posed several important questions due to both the relatively high energy footprint that is required to develop desalination processes and the impact of the seawater discharge on the marine ecology. The book provides the answers to these critical questions.

The second part of the book is dedicated to the possible alternatives to finance desalination and water treatment projects and different contracting options with their relative risk allocation. This part expands into the basics of financial modelling in desalination and water treatment as well as in the tariff structure of private water projects. It contains few examples of concession agreements as have been applied to major Independent Water and Water and Power Projects (IWP/IWPP). It describes the reason for worldwide adaptation of privatization model but also describes in details the approach to turnkey and multi-contracts. It looks at sensitivity analysis on CAPEX and OPEX costs as well as allocations of risks.

The third and final part of the book is dedicated to cost of water, tariffs and budgeting. Dr. Corrado reviews the cost of water as it is determined by capital costs, energy costs, and operation and maintenance costs and many other factors like plant availability and environmental concerns. It describes concept of fixed and variable costs, impact of plant life on water tariff. The expected economical life of a desalination plant can be extended significantly today. The value of existing assets allows the rehabilitation and upgrading with new technologies to provide plants with increased capacity and efficiency.

In this part of the book we can appreciate the general philosophy of water capacity charges, as well as description of tariff and payment settlement mechanisms in private projects. Finally Dr. Sommariva is providing an answer to the second most frequently asked question in desalination "what is the cost of a desalination plant and the tariff per cubic meter of desalinated water". It develops budgets for new facilities based on recent trends and awards of real projects. It provides the reader with very good guidelines to assess and optimise costs and forecast their variability and sensitivity to market conditions.

It should be of major benefit to the reader to understand, what I consider the book covers extremely well, the critical integration of energy, power generation, and water production, with an environmentally sustainable approach.
Corrado Sommariva's book makes it one step closer to achieve his promise to better understand core issues of technology, financing of projects and cost of water.
In summary Dr. Corrado Sommariva's book is a valuable contribution to the desalination and advance water treatment industry and to all who want to have a deep understanding of the important challenges facing the industry. There's no doubt Dr. Corrado Sommariva is a dynamic writer who can deliver a convincing message with great integrity.
Dr. Corrado Sommariva's book will help a new generation of engineers and scientist, developers and planners to confront the water challenge and to create fresh water, the essential element of life for country's sustainable development and to the security of its communities.

Leon Awerbuch

Chairman IDA Technical Programs

President, Leading Edge Technologies, Ltd

Winchester, MA, December, 2009

3 Introduction

Since the first issue of Desalination Management and Economics published in 2004, the water market has been constantly developing and new technological improvements have been continuously and successfully introduced in the desalination and water re-use market.

My first publication was aimed at bridging a gap between the purely technical literature on what was available in desalination and the financial, contractual and economical worlds.

The book was designed to be a very simple, and reader friendly access tool to those who were approaching the desalination market for the first time.

Like the first publication, the idea of writing a second book came during the short courses on Desalination Technology and Management that I normally conduct at the University of Genoa and L'Aquila.

There, I faced students coming from very different backgrounds but equally eager to develop a deeper understanding of the desalination and water re use technology and apply these skills to contracting and project financing.

The comforting experience of being asked questions during the course different topics such as : how contracts are structured, tariffs modelled and what are the main contract agreements, made me realise that there is a wealth of knowledge that would not be available to students and entrepreneurs unless they are effectively engaged in the negotiation of a project agreement. In addition this second publication has offered the opportunity to carry out several updating to my first publication that take into account the development of the technology in these four years..

Furthermore in these years the use of membrane technologies in advanced waste water treatment and re-use projects has gradually taken a more important role and now has a significant share of the desalination market for non domestic applications such as production of water for centralised cooling system irrigation and industrial water.

Many market players -both EPC contractors Plant operators and membrane manufacturers - are involved in membrane desalination and Membrane Bioreactor (MBR) or Ultra filtration (UF) projects, the contracting and costing structure for advance waste water is similar to membrane desalination plants. Therefore, I believed it was useful to extend a description of these technologies in the text of this book.

The question was then how to make this material available to the reader in simple and straight terminology.

Therefore compared to the previous publication, this book aims at providing a more detailed illustration of desalination and a deeper discussion on contracting, financial modelling and tariff structures. The aim is to provide hands on material going a little more in detail with respect to the previous book. The hope is that spreading knowledge and information will contribute to the development of desalination and water re-use and to a wider acceptance of these technologies in the community.

However the book remains only a guide. Hopefully the reader will be able to adapt the information provided to a constantly developing market environment and develop solutions that improve and optimise the current state of the art.

Over the years the desalination water costs has dropped dramatically whereas the conventional water treatment costs have increased due to depletion and pollution of natural water resources. In order to maintain sustainable development and minimize regional and international conflicts, desalination and water reuse can offer a solution.

4 Going through the book

The first part of the book is dedicated to the technology options available for desalination and advanced waste water treatment with the respective construction and operating features, advantages and disadvantages of the technology.

This includes a session on energy footprint, technology sensitivity but also indicates the different impact on the environmental and carbon emission sustainability.

The second part of the book is essentially dedicated to the available alternative to finance desalination project and different possible contracting options with their relative risk allocation. This session expand as well into the basics of financial modelling in desalination and water treatment as well as in the tariff structure of private water projects. The book contains few examples of concession agreements that have been applied to major IWP/IWPP but also some typical cases that are derived from minor projects and wastewater concessions.

The final part of the book is dedicated to costing and budgeting which aims at giving guidelines to assess and optimise costs and forecast their variability and sensitivity to market conditions.

A lot of material of this book, particularly on the private finance session, has been abstracted from executed contracts and elaborated in order to fit the educational purposes of this publication.

It is hoped that this will give the reader the possibility to access material that would be otherwise difficult to retrieve in the literature and allow to gain a more detailed understanding of desalination and water treatment technologies, and understand in more details the mechanism water tariffs are structured.

5 Desalination and waste water technologies and state of the art

5.1 The family of desalination processes

The diagram shown in Figure 5.1 illustrates the family of desalination technologies that are adopted for large-scale production of water.

Commercially proven technologies include

♦ Evaporative (distillation) processes
♦ Membrane (osmotic) processes

A combination of evaporative ad membrane processes is the so called

♦ Hybrid process

That will be discussed separately in the context of this book.

Both evaporative and membrane technologies require a driving force (or driving potential) necessary for the separation process hence they require the input of energy under various forms.

For evaporative processes the driving potential to achieve the separation of pure water from brine is the temperature difference between the hottest stage and the coolest stage while for membrane processes pressure is the driving force.

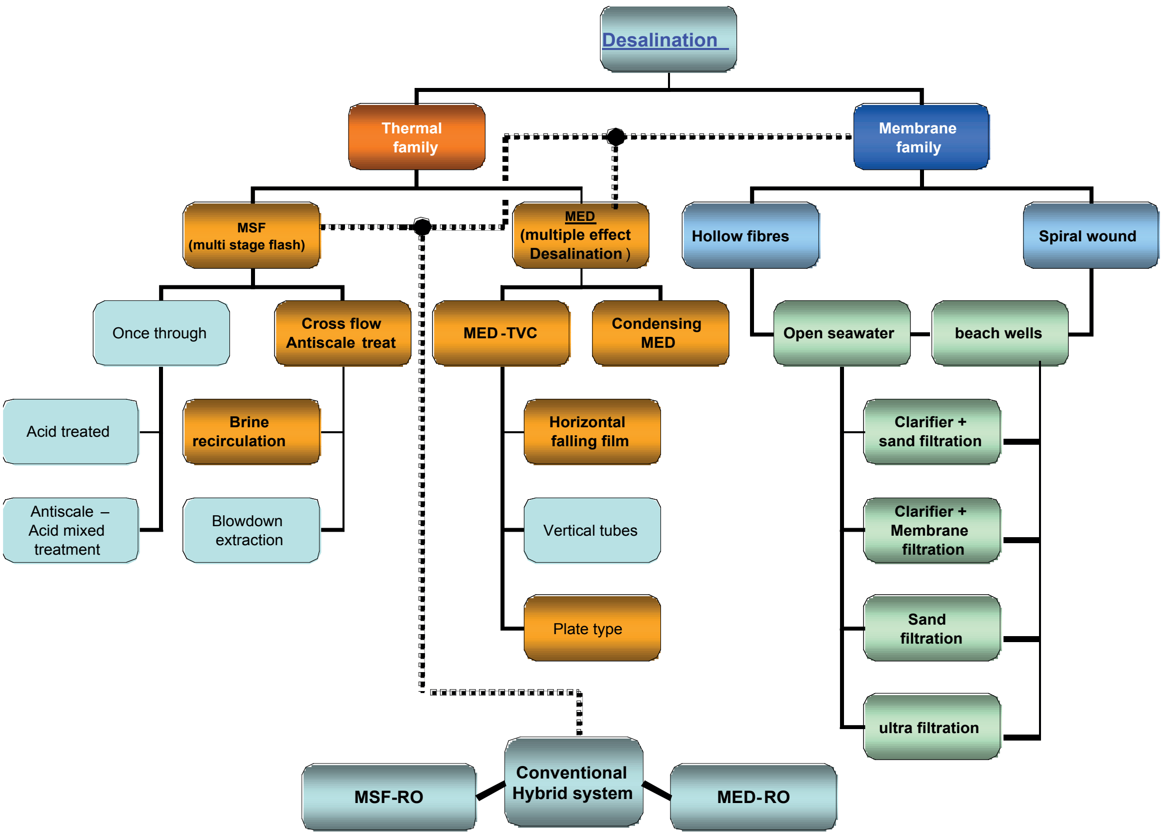

Figure 5.1 desalination technology families

The items in Figure 5-1 above marked with bold character and with colour effect are the state of the art technologies. The remaining items indicate technology and processes that have generally become obsolete and although still surviving in old installations not yet retired form operation they are not specified for new projects tenders.

~~1.1.1~~5.1.1 Thermal family

The thermal desalination family is composed of the Evaporative Processes
These processes use thermal energy to produce pure distilled water from sea or brackish water. Evaporative processes rely on a phase change from liquid (in this case brine) to the vapour phase. In this process only the water molecules pass to the vapour phase leaving the other constituents behind in the liquid. The two dominating systems that have evolved are Multi Stage Flash (MSF) and Multiple Effect Distillation (MED).

(i) Multi stage flash technology (MSF)

The MSF desalination plant is of compact modular construction and provided a well-proven operational feed back in large scale industrial operation since the 1950s. Whereas in the past MSF desalination was adopted for small unit size up to very large unit size, at the present time this process can be considered competitive only for unit size from 12 MIGD onwards in combination with power generation plants.
Compared with other designs the construction features for the MSF desalination plant are quire rigid and very few process differences are present among the design configurations proposed by the various manufacturers.

MSF technology is now considered a mature technology and the thermodynamic design continues to benefit from the operational feedback of several large installations operating for many years. These have normally exceeded the performance projected at design stage and provided information for further refinement of the design tools.

The first MSF design was based on a long tube configuration with an acid dosing scale control system.

Figure 5.2 below shows schematically the main difference between a long tube and a cross flow MSF plant. In the long tube configuration flashing brine indicated as green arrows in the drawing flows parallel to the tube bundle which crosses each stage partition wall but in the opposite direction to the recirculating brine.

In the cross flow arrangement the tube bundle is generally located in the middle of the flash chamber and each stage tube bundle is connected by water boxes external to the vessel.

Whilst long tube arrangements present the advantage to have a large number of stages with relatively low additional costs the expansion in size of this pattern is limited by the tube length and by the limited stage width.

In particular, it is necessary to prevent the flashing brine flow rate per unit length of stage from exceeding a load per unit length of 1200-1500 m3/m/hr to avoid excessive submergence and non equilibrium losses.
This value prevents high brine recirculation flow rates and in turn high distillate production per unit. For this reason cross flow is now the leading technology for large MSF desalination plants.

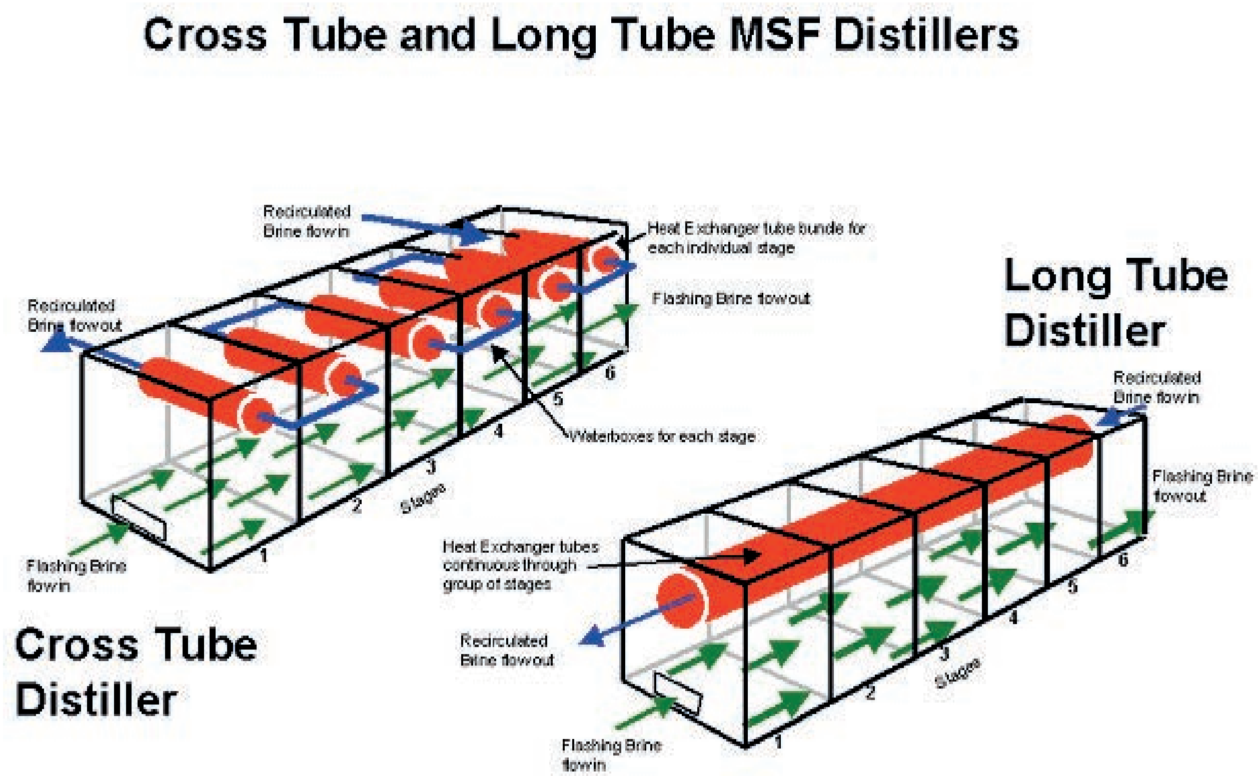

Figure 5.2: MSF long tube and cross flow configuration

However several “long tubes “MSF are still surviving in some plants in Europe and Middle East. The scale control has been changed to mixed acid and antiscale dosing.

With the increase of the plant capacity and unit size, the long tube could not compete with the cross flow configuration and since 1990 the long tube design was abandoned despite the lower specific power and heat consumption that the long tube design could offer compared to MSF.

With cross flow design the unit size has steadily increased over the years up to today’s maximum of around 20 MIGD (3788 t/h). Even larger units shall be considered for new projects providing the tube length does not compromise the cross tube configuration.

From the energy consumption and capital cost view point, MSF is most probably the least efficient among the desalination processes. However in its present form of multi stage/brine recirculation/cross tube arrangement, the technology has proven itself in long term practice to have solved the problems of reliability, scaling, chemical consumption and unit size progression which severely limited earlier MED designs.

The clear advantage offered by this configuration is the long life of the assets that has shown to reach 30 years and above with carbon steel material but will definitely exceed 40 years with the modern material selection. Service factor and chemical costs are also relatively low.

Cross flow MSF distillers can be designed for a range of performance ratio (between water production and steam consumption), with a practical limit of about 11:1.

Capital cost increases with performance ratio, due to the larger heat transfer surface area needed, and greater number of stages. The optimum value is usually in the range 7 to 9, depending on energy cost. .

Long tube MSF could be designed with higher performance ratio as the number of stages could be increased without excessive additional costs For 110°C top brine temperature, the condensing pressure in the brine heater shell is around 1.7 bars (a). Steam is supplied from steam turbine plant (at around 2.5 to 3.0 bar), heat recovery boilers or dedicated boiler plant (at around 15 to 20 bar).

(ii) Multiple effect technology (MED)

MED technology was one of the first technologies adopted for seawater desalination.

This technology was initially very successful because of its ability to produce water with a high performance ratio and the low operating temperature allowed a moderate scale formation.

The first generation of MSF plant encountered severe scaling problems related to the high brine temperature. and the handling and safety problems associated with the acid based scale control.

The scaling problem in MSF plants was gradually overcome by the introduction of sponge ball cleaning systems and by the development of specific antic-scale chemical products. For this reason the MSF capacity of producing water in large unit sizes relegated MED technology to small installations in remote areas. Nowadays MED technology is the principal distillation alternative to MSF.

The main difference between MED and MSF is in the method of evaporation and heat transfer. In MED plant, evaporation is from a seawater film in contact with the heat transfer surface, whereas in MSF plant only convective heating of seawater occurs within the tubes and evaporation is from a flow of brine 'flashing' in consecutive stages to produce vapour

MED desalination plants are generally built in units of about 500 to 46,000 m^3/d (0.1 to 10 MIGD). A dramatic increase in the unit size has been observed in the last 5 years and this has allowed MED technology to gradually take over the market shares belonging to MSF technology for unit sizes below 5-8 MIGD.

Whilst in MSF, the process configuration is unavoidably rigid due to the fact that each stage shares a partition wall and main structural elements with the adjacent stages. This constraint does not apply to the MED process that offers possibility to vary the basic flow configuration in many more patterns with respect to the MSF technology.

The performance ratio, between water production and steam consumption, of a simple MED plant is approximately equal to the number of effects minus 1 to 2. therefore typically for a project a 10:1 performance ratio the number of effects needed is expected to be around 12. This is much lower than in equivalent MSF plant. The smaller number of effects in MED plant gives savings in capital cost.

The thermal compression of the vapour from the low temperature stages to the first effect of the MED offers the possibility of increasing the performance ratio of the unit by recovering the latent heat of the steam that is thermo compressed to the first stage. On the other hand this solution increases the steam extraction pressure and as the desalination unit is matched with a steam turbine, the inherent power losses also increase.

The conceptual difference between a condensing MED process and a MED-TVC is illustrated schematically in Figure 5.3 below

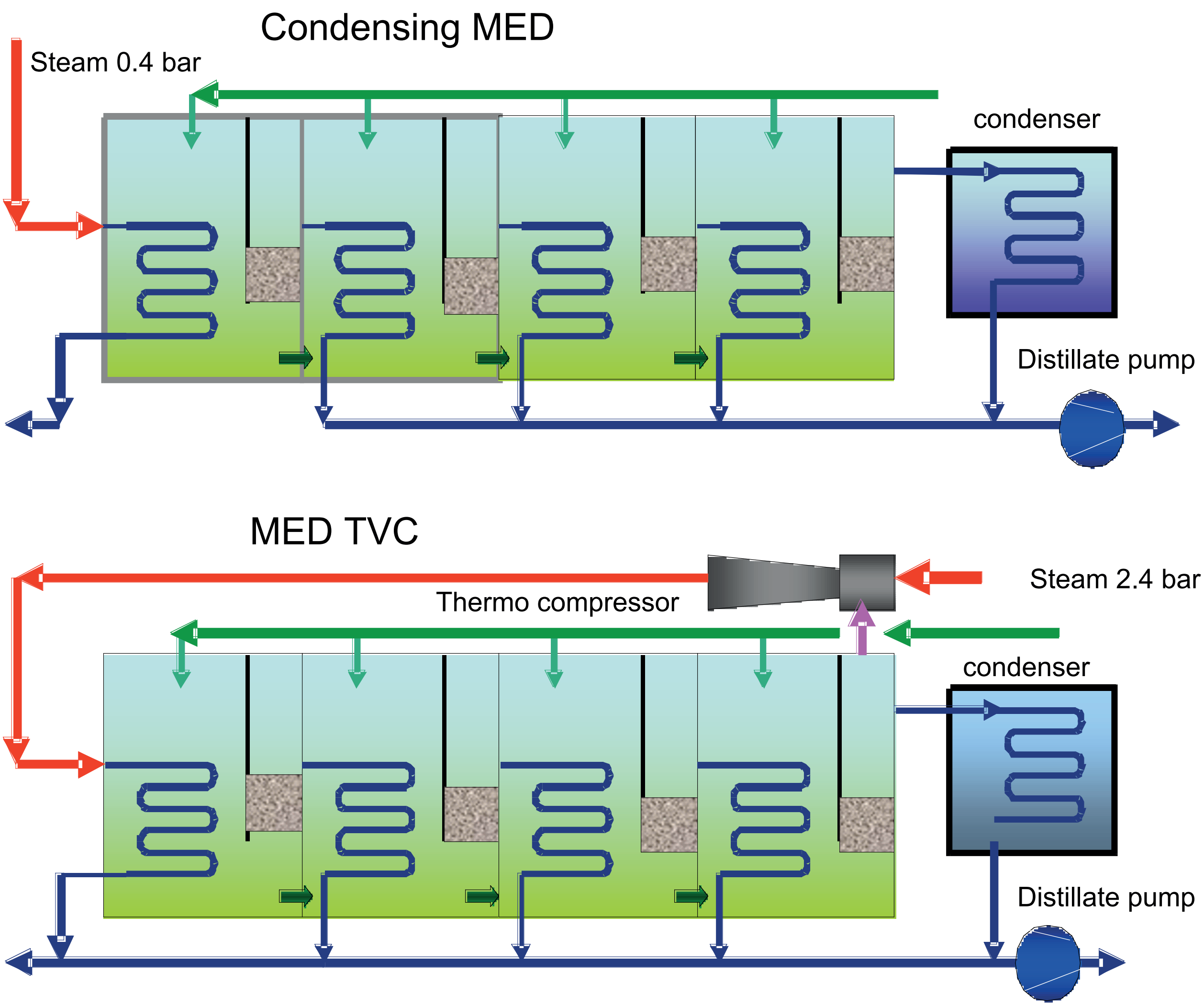

Figure 5.3 condensing MED unit and MED-TVC schematic difference

Internal power consumption of MED plant is lower than MSF, as there is no requirement to recirculate large quantities of brine. The combination of higher performance ratio and lower power consumption results in lower overall energy costs.

5.1.2 Membrane family

Membrane processes may be applied to a variety of raw water from brackish water to hyper saline seawater and recently membrane processes have been successfully applied to the treatment of waste water.

The membrane acts a barrier between two phases that permits preferential and selective crossing of one or more type of fluid mixture from one phase to the other.

The driving forces for membrane separation may be different such as :

- difference in pressure,
- difference in concentration,
- difference in chemical potential

Industrial RO processes are pressure driven. In Reverse Osmosis processes electric energy is used to pump seawater (or brackish water) through a series of semi permeable membranes to obtain a low salinity permeate as a product.

Differing from thermal desalination, membrane processes (with the exception of membrane distillation presently applied only on small scale projects) do not rely on a phase change but on the size and transport mobility of water molecules through a permeable membrane.

For the separation of fresh water from seawater or brackish water this process is known as Reverse Osmosis (RO).

In this moment RO is used for:

- Desalination
- Industrial waste water treatment
- Food industry
- Production ultra-pure water for electronic and food farms

The adoption of membranes for seawater desalination by Reverse Osmosis in the way the industry operates nowadays was put to practical use in the late 1970s. However the initial RO membrane modules were very expensive and of small capacity.

The membrane industry since then has continuously improved both in performance and costs and RO became adopted in large sized plants.

However reliability problems were very severe particularly in the Middle East due to both high temperature and salinity and fouling and bio fouling phenomena.

Seawater RO membranes fall into two main categories, Hollow Fine Fibre (HFF), and Spiral Wound (SW).

The use of Hollow-fine-fibre modules made from cellulose triacetate or aromatic polyamides is now limited exclusively to seawater desalination.

These modules incorporate the membrane around a central tube, and feed solution is quite slow. As much as 40 to 50 percent of the feed may be removed as permeate in a single pass through the module.

Since then, reverse osmosis (RO) technology has made great progress in recent years, increasing in reliability and service factors and has become the technology of choice wherever there is a need for a stand alone desalination plant. The recent success of SWRO is based on the substantially lower energy footprint compared to thermal desalination.

Due to the low energy price and very challenging seawater conditions in the Gulf area SWRO technology has been penetrating the Middle East market only in the last few year

However this trend is rapidly changing not only for the stand alone or hybrid desalination configurations but also in cogeneration schemes with thermal plants.

Session 6 and particularly table 6.11 provide a comparison of the power export possibilities at the same fuel consumption with different technologies. From this table it is possible to understand how as a consequence of SWRO technology lower energy footprint a lower heat rate and therefore a higher net power generation could be achieved in the cogeneration cycle..

5.2 Hybrid systems

The definition of hybrid describes something having two different types of components that produce the final product. In Desalination technology the term hybrid initially was used to refer to the combination of thermal and membrane technologies for the production of a certain desalination capacity.

As shown in Figure 5.2 the hybrid concept refers traditionally to the combination of MSF or MED with SWRO technology in the same industrial yard.

The "hybrid" concept has been introduced in the desalination market as a way to improve matching requirement of water and power. Many arid countries and particularly the Gulf region face an unusual electricity demand profile; which shows a significant peak during the summer, mainly due to the use of air-conditioning, and then drops dramatically to 30-40% of summer capacity. A typical situation is shown in the picture below, which indicates in graph form the typical water and power demand in a Middle East country. As it can be seen from the Figure 4.2-1 below during the winter months the operating conditions of the power generation plant are distant from system peak load demand while water demand remains almost constant.

Due to the water – power imbalance in the winter season, the power required by the network does not provide the generation of enough steam in the power yard to drive sufficient capacity with thermal desalination technology.
As a result of this imbalance about 50% of power generation capacity is idle during winter months.

The imbalance between the water and power generation matching increases during the winter period. In fact due the lower air and to the lower seawater temperature gas and steam turbines could be able to generate more electric power than in summer .

This is schematically indicated by the red line in the graph below.

Since the demand for potable water is almost constant throughout the year and requires steam from the power yard, the power generation plant is required to operate inefficiently.

Typical examples of bad matching between power and water yard in winter is the bypass of the steam turbine.

In this case the power unit is not utilised due to low demand and steam is made available for thermal desalination through the high pressure steam reducing valves that connect the boiler to the low pressure steam manifold. In this case the steam turbine is by-passed so that the steam is directly generated by the boilers. Other plants are equipped with auxiliary boiler that supplement the heat recovery steam generators from the gas turbines.

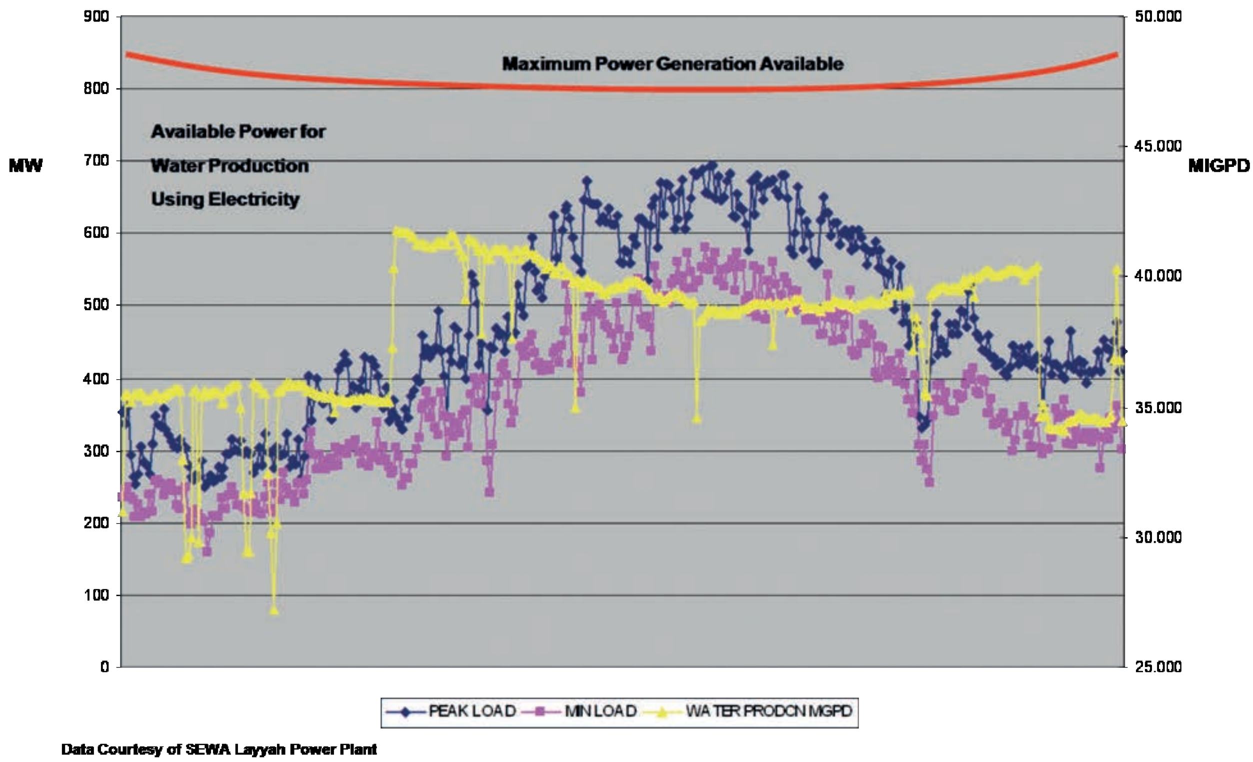

Fig 5.4 Annual Power and Water Production Profile

In this scenario the combination of primarily thermally and electrically driven technologies can reduce the overall energy requirements and operating cost of water production and electricity generation and ensure a better matching of the water and power generation demand across the whole year.

As can be seen from table below, the most efficient and advanced combined cycle desalination plant has a very high Power to Water Ratio (PWR), and therefore the adoption of the most efficient power to water matching configuration would provide a significant surplus of unused power capacity in wintertime.

It is interesting to note, that the more efficient the base load operation for generating electricity, the less effective is the production of water and power in peaking and intermediate modes.

Table 5. 1 Typical Power To Water Ratios

Typical Power To Water Ratios For Different Technologies	
Technology	PWR (MW installed/Million Imperial Gallons per)
Steam Turbine Backpressure – MED	3.5
Steam Turbine Backpressure – MSF	5
Steam Turbine Extraction – MED	7
Steam Turbine Extraction – MSF	10
Gas Turbine GT - HRSG – MED	6
Gas Turbine GT - HRSF – MSF	8
Combine Cycle BTG – MED	10
Combine Cycle Backpressure– MSF	16
Combine Cycle Extraction – MED	12
Combine Cycle Extraction – MSF	19
Low Speed Diesel HRSG - MED	30
Reverse Osmosis RO	0.8 – 1.5
Vapour Compression Distillation TVC	1.4 – 1.6

In the winter period when the demand for power is low and the water demand is continuously high, the selection of an efficient electrical plant will cause significant idle power capacity because of high PWR.

The marginal cost of water rises significantly if it is necessary to use auxiliary boilers or to bypass the steam turbines through a pressure reducing station in order to keep the desalination plant at full capacity.

Hybrid systems are based on the concept that water can be stored while electricity storage is not practical.

With the adoption of hybrid plants excess electricity can be diverted to water production using the electrically driven technology of sea water Reverse Osmosis (RO).

The above data shows that electrically driven desalination processes, such as RO and MVC, clearly require minimum power interfaces and therefore are suitable for stand alone application.

At the same time, where seasonal and daily variations of power occur, electrically driven technology can provide an excellent opportunity through hybrid configuration with a conventional dual-purpose plant to absorb the excess power production and produce additional potable water.

The advantages of a hybrid configuration are represented in Figure 5.5 below. The philosophy of improving the power –desalination matching by hybrid plants consists basically in driving enough thermal desalination capacity to ensure the optimal matching with the steam available by the power plant and supplement the remaining water demand by reverse osmosis .

This approach de-couples the water generation capacity from the power generation capacity and allows to maintain a more efficient heat rate in the power plant throughout all year.

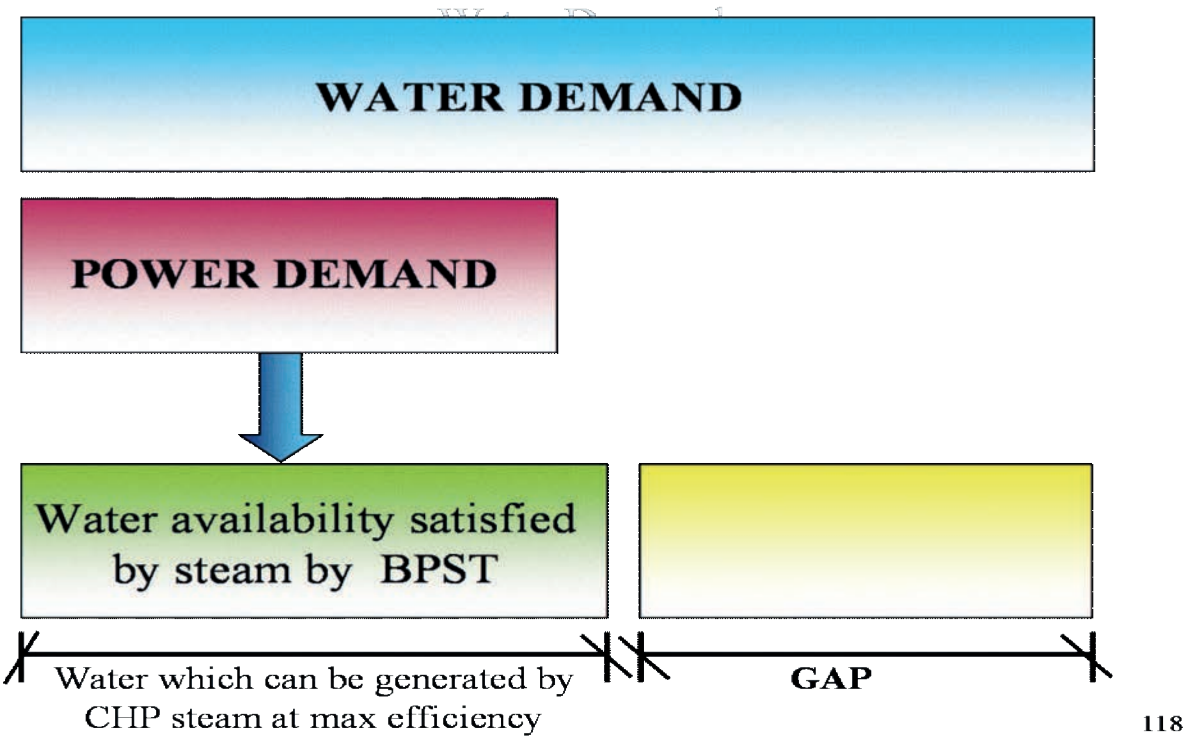

Figure 5.5 : Matching water and power availability with demand

A further consideration is that when there is a mismatch between water and power demand, the potable water produced by desalination can eventually be stored, while storage of electricity is not practical.

In this respect, a hybrid system provide the possibility of indirectly storing the excess electricity occurring during the winter months using the available idle power to produce additional potable water. In this operating scenario the power plant operates in the optimal matching situation for the majority of the time and excess water can be produced and stored and then used in peak periods.

This implies obviously the necessity of increasing the potable water storage capabilities however it should be considered that typical water storage volumes in the Gulf States for desalinated water are limited to one to three days under normal supply conditions.

This represents a highly vulnerable situation. In this respect, aquifer storage and recovery is regarded of strategic importance with respect to the security of water supply.
In particular this solution may provide strategic reserves of potable water, to prevent damage or depletion to existing oasis or aquifers, for controlling salt-water intrusion or improvement in water quality.

The possibility of aquifer storage and recovery (DASR) coupled with hybrid system furthermore has the effect of reducing the power and water demand peaks as the aquifer would be recharged during the winter season and used to supplement desalination from the aquifer during the summer season. Accordingly all auxiliary power that in the peak load is required for water generation would be available to the grid. This is indicated in Figure 5.6 below.

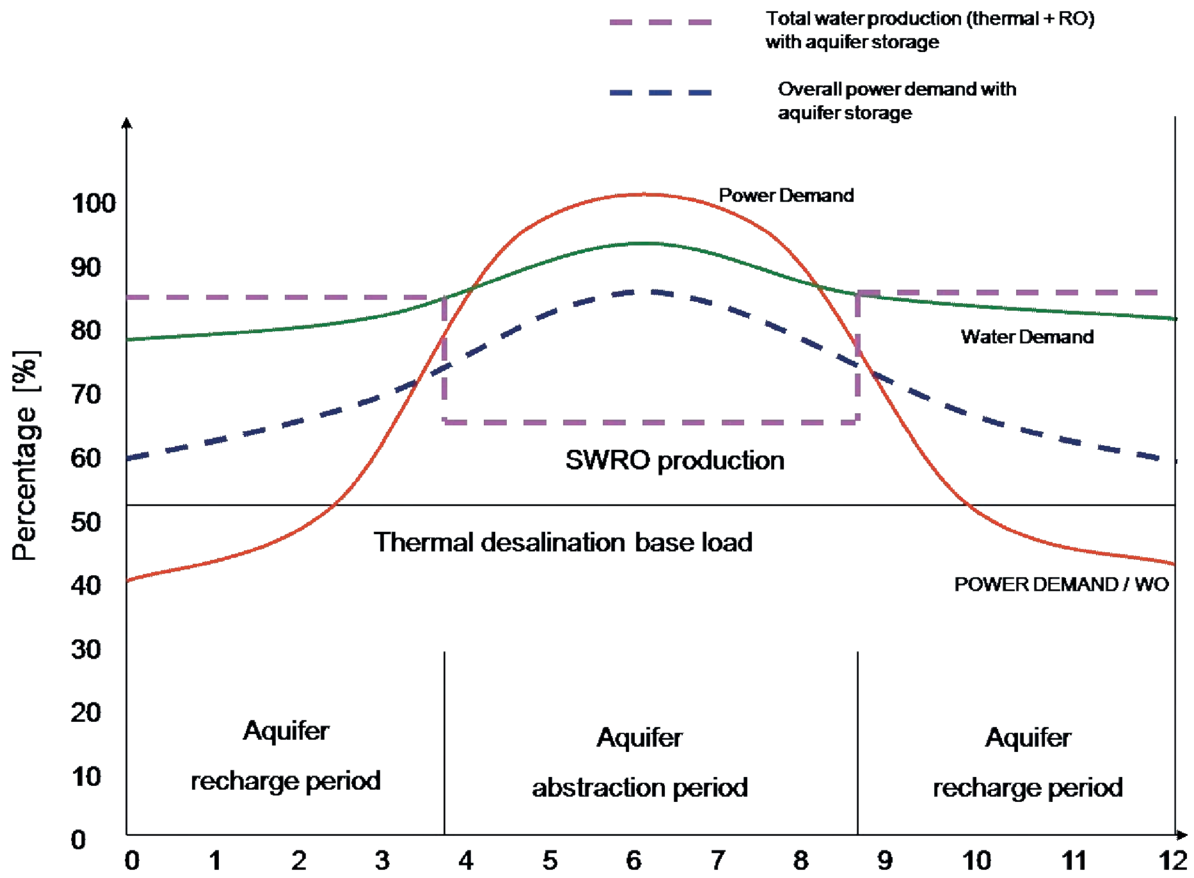

Figure 5.6. Aquifer recharge and recovery (DASR) and peak load reduction effect

In Figure 5.6 the **green and red** lines indicate the water and power demand through the year. In absence of any aquifer storage this line is required to coincide with the water and power production from the plant.

However, taking advantage of the idle power available outside the peak period in summer, water generation could be increased as indicated by the purple dotted line. This water generation is achieved by a share of thermal desalination absorbing the base load and RO desalination operating on a modulating pattern.

It should be noted that despite the increased power generation in the off peak period, the fuel consumption in the same period remains constant as plants can operate in a more efficient pattern. The additional water produced during this period is stored and it is used in the summer period to supplement the water generation. However, with this operating scenario, the water generation in the peak period decreases as does the power required for running the desalination facilities and this consequently has a beneficial effect on the power peak load which is the most inefficient operational scenario occurring in the year.

The hybrid approach could achieve a lower cost of total investment, flexibility in production and contemporary achieve better cost for power and water production. This option would be particularly interesting in retro-fit applications downstream of existing desalination and power complexes.

The hybrid configuration can be placed in two main categories:

♦ Simple hybrid option

♦ Integrated hybrid option

(i) Simple hybrid systems

Simple hybrid systems are based on the concept that adding a stand alone RO desalination plant to an existing MSF complex improves the quality of RO treated water and reduces the cost of the RO process.

In particular the quality of permeate from the RO system can be maintained at high conductivity and Boron levels taking advantage of the possibility of blending it with distillate water from MSF at high purity.

This implies both a CAPEX and OPEX reduction for the RO system due to the deletion of the second pass RO and lower chemical and power consumption.

Figure 5.7 is a typical conceptual flow sheet for a simple hybrid system composed of an existing MSF plant installation and a stand-alone SWRO plant.

As the final potable water quality depends on the mixing ratio between the two plants, the output from the SWRO plant is called dependable output. This definition implies that the capacity of the SWRO plant is tuned according to the capacity of the MSF plant in order to achieve a suitable blending ratio, which achieves the optimal potable water quality conditions.

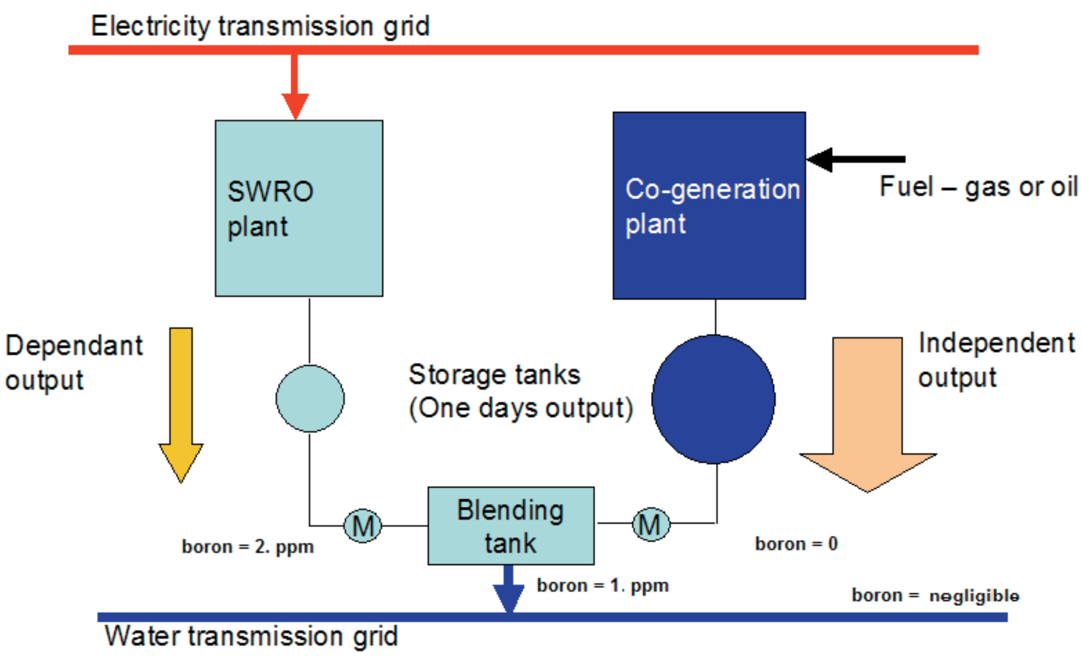

Figure 5.7: Simple hybrid system

In the simple hybrid MSF/RO process, the seawater RO plant is combined with either a new or existing dual purpose MSF/power plant with the following advantages:

- A common, considerably smaller seawater intake
- Product waters from the RO and MSF plants are blended to obtain suitable product water quality.
- Savings in potabilisation costs can be achieved
- A single stage RO process can be used.
- The RO membrane life can be extended.
- Excess power production from the desalting complex can be reduced significantly, or power to water ratio can be significantly reduced.

(ii) Integrated hybrid systems

The integrated hybrid system differs from the simple hybrid system because the plant is designed from the beginning as a combined plant.

In this respect the RO operating cost can be reduced by supplying some of the MSF outlet seawater to the RO plant to raise the temperature of the RO feed water, and both operating and construction costs can be reduced by common post treatment as indicated in Figure 5.8 below .

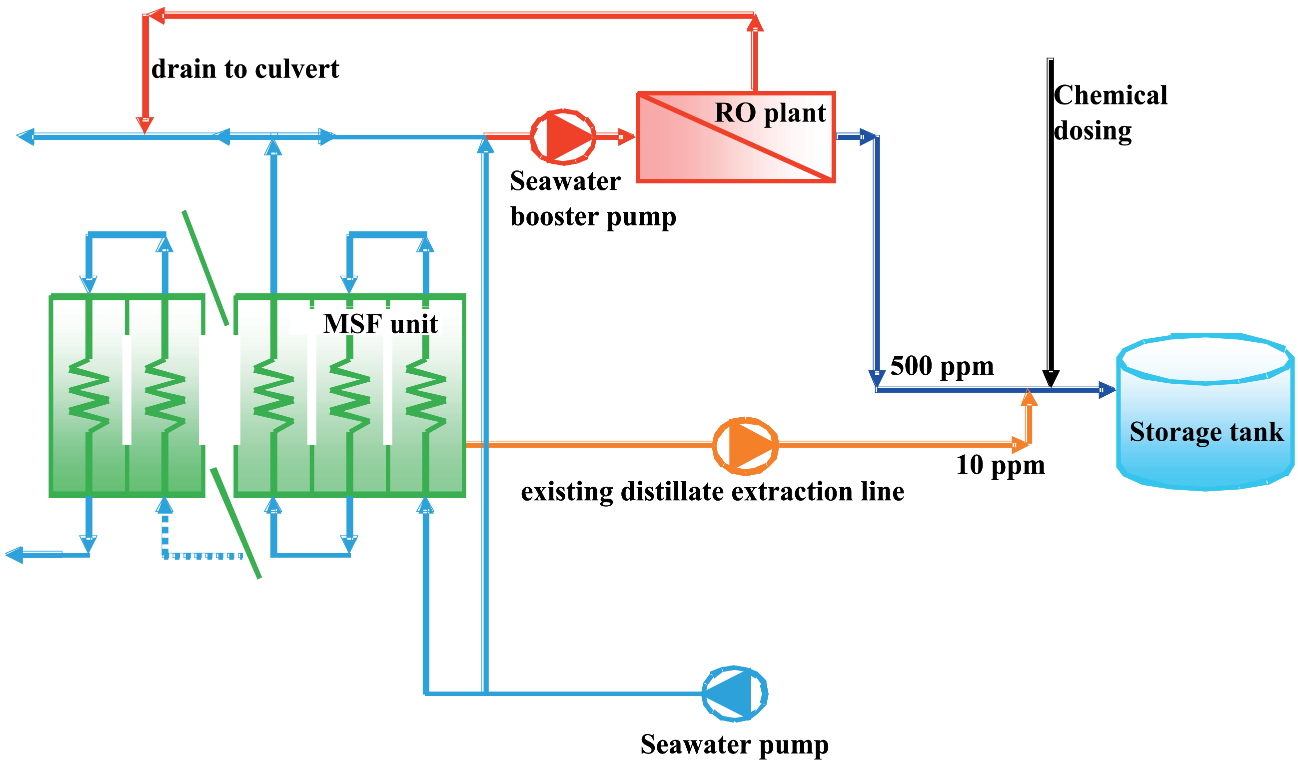

Figure 5.8: Integrated hybrid system flow diagram

The fully integrated MSF/RO desalination power process, which is particularly suitable for new seawater desalting complexes, takes additional advantage of integration features, such as:

- The feed water temperature to the RO plant is optimised and controlled by using cooling water from the heat reject section of the MSF plant.
- The low-pressure steam from the MSF plant is used to de - aerate the feed water to the RO plant to minimize corrosion and reduce residual Chlorine.
- A common post treatment is used for the product water from both plants.
- The brine discharge from the RO plant is combined with the brine recycle in the MSF plant.

In the case of hybrid systems, a single stage system can be specified while maintaining a long membrane life. This is made possible by blending the RO product water with the high purity distilled water.

In addition to the merits stated above, the facility with optimized combined capacities can respond economically to the variation in power demand as found in the Middle East Region.

5.2.2 Degree of hybridisation

As it can be observed from Figure 5.7 and 5.8 above in addition to matching water and power demand the objective of a hybrid system is to achieve a satisfactory water quality downstream of the blended water product from the thermal and membrane streams.

The degree of hybridisation is the ratio of the water capacity that is generated by the membrane component against the overall water capacity of the plant.

Obviously the higher the membrane component (i.e. the degree of hybridisation) the higher also the tendency in the product water to have higher TDS. Boron and chloride and more generally TDS concentration in the product water quality may be constrained by the statutory requirement and particular potable water specifications and therefore an optimum ratio between the SWRO and the thermal capacity needs to be established.

The degree of hybridisation is generally determined through the evaluation of the potable water quality in various scenarios (winter and summer). This includes the projection of water quality downstream the SWRO (first and second pass) in the worst situation an in with a contemporary outage of a certain number of thermal desalination plants. These consideration needs to be done considering that the cost advantage of the hybrid solution are achieved if the SWRO plant can be a single pass only or if the second pass could be limited to the maximum extent.

For example is the Middle East boron concentration downstream the first and second pass of a SWRO generally varies in winter and summer in accordance to the table 5.2 below .

Table 5. 2 Typical boron concentration assumptions to establish degree of hybridisation

		First pass	Second pass
Distillate boron (winter/summer)	0 mg/l	-	-
RO permeate boron concentration Summer	-	1.4 mg/l	0.5 mg/l
RO permeate boron concentration Winter	-	0.9 mg/l	0.5 mg/l

The concentration of boron in the potable water quality therefore will tend to decrease the higher the thermal component of the total desalination capacity as schematically indicated in the graph below with a single pass RO.

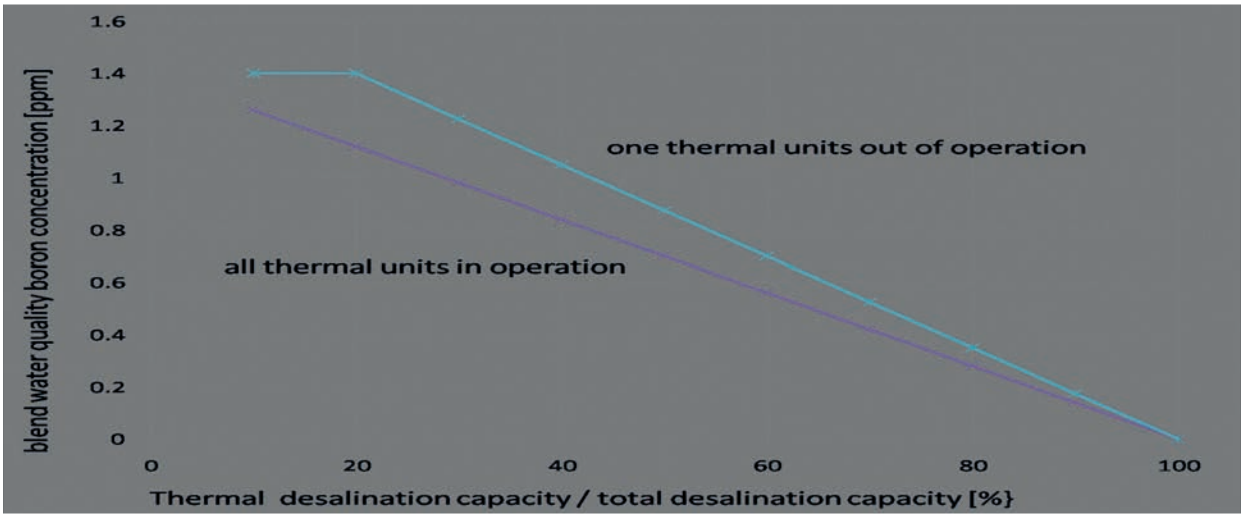

Figure 5.9: product water quality against thermal / total product water capacity

However as it can be seen from the graph above, a 40% thermal capacity versus total capacity (i.e. with a 60% hybridisation) would generate an overall boron concentration of the blended product in the range of 1 ppm.

This degree of hybridisation would be generate, even with one thermal plant in shut down, contemporary to a full stream SWRO production still acceptable potable water quality.

Similar considerations can be done for TDS and chlorides and different ions whose concentration is sensitive for the product water quality.

The first hybrid plant in Fujeirah was designed with a degree of hybridisation of 37.5 %. .However several specifications do not foresee a degree of hybridisation higher than 25-30% as Offtakers had in the past a certain reluctance to install large SWRO capacities in the Middle East. .

5.3 New developments

Figure 5.1 above aim at illustrating the various technology options available to the desalination industry. However desalination and water reuse are fast changing technologies and several substantial innovations have been introduced in the market in the span of few years. As technology develops further, many new processes will be introduced along with new interrelations and ramifications among the desalination technology options available.

There are already several alternative processes to those indicated in Figure 5.1, that at the moment are at the experimental level or are installed on a very small scale but offer a lot of potential in terms of specific energy consumption as well as potential use of renewable energy.

Membrane distillation for instance offers tremendous potential to recover solar energy and achieve a very low energy separation of distillate.

Renewable desalination processes were traditionally related to solar stills however the association of renewable energy source to new desalination techniques may be very promising in the medium and short terms for small to medium size applications such as

- Solar plus low temperature MED
- Solar ponds with salt gradient plus advanced solar still
- Low pressure distillation

There is also a growing interest in the possibility that is offered by the recovery of salt from the desalination plant brine blowdown.

There are innovative desalination – brine salts concentration technologies (both using thermal and membrane techniques) developing along side the traditional solar evaporation ponds.

The coupling of salt recovery and water generation may tremendously contribute to the sustainability of the technology and to the parallel decrease in water costs.

Developments in the technology cover a also new hybridisation concepts such as those indicated in the Table 5.3 below:

Table 5.3 : new potential desalination processes

Item	Process	Description	Advantages – disadvantages	Status
1	MSF 2	The process consists in separating the energy feed to the thermal desalination in 2 streams one at high temperature and one at low temperature with two separate heat input areas	Decrease the thermal input to the desalination plant using part of the steam at a lower pressure and temperature. The concept allows a better power plant heat rate. The disadvantage is that the process involves much higher costs.	Conceptual
3	MSF-NF hybrid MED-NF hybrid	The process consist in treating part of the make up feed water to the plant with a NF plant	The NF plant removes the calcium sulphate risk of scaling therefore allows higher operating temperature, increase of capacity and performance ratio.	Implemented in one plant several feasibility studies
2	MSF–MED hybrid	The process consists in extracting the distillate or hot cooling seawater from the MSF at the last stage of the heat recovery and use it as energy source for a low temperature MED operation	The MSF operation improves as heat is not wasted to the environment in the heat reject section.. Additional thermal capacity can be operated without additional thermal energy	Implemented in one plant several feasibility studies
4	MED hybrid	Development of thermo compressors capable of modulating the flow rate of steam recompressed	Better matching with the power plant and possibility to tune the steam to the desalination in accordance to the steam turbine needs	Under construction 100/30 MIGD MED/RO plant. Implemented in small plants

5.4 The family of advance waste water treatment processes

Nowadays the general view of wastewater treatment has radically changed and water is perceived as an emerging and a unique valuable to be managed properly at any level of the water-cycle, including wastewater treatment. On one hand this generates the development of stricter water-use regulations, more severe discharge policy, whilst on the other hand the water treatment projects are not perceived any more as treatment process to obtain the consent to discharge the residual waste water in the environment but there is an increasing number of wastewater reuse projects.

The membrane component of an MBR acts as a physical barrier that ensures treated effluent is free from particles and pathogens. MBR systems enable almost complete retention of parasites and bacteria and greater than 3 log unit removals of viruses due to their absorption into the concentrated biomass. With these removal rates, MBRs are suitable for treating water to EPA and EU guidelines for discharge, and also for producing water of sufficient quality for unrestricted non-potable reuse worldwide.

The application of membrane to the treatment of waste water has progressed both in terms of technology development and industrial applications in large scale projects. This is a very fast developing branch of desalination and waste water treatment sector and several innovations are likely to occur in the coming year.

Figure 5.10 below illustrates the family of waste water treatment technologies that adopts membrane for the purification of the raw sewage effluent and are adopted for industrial-scale production/ of water.

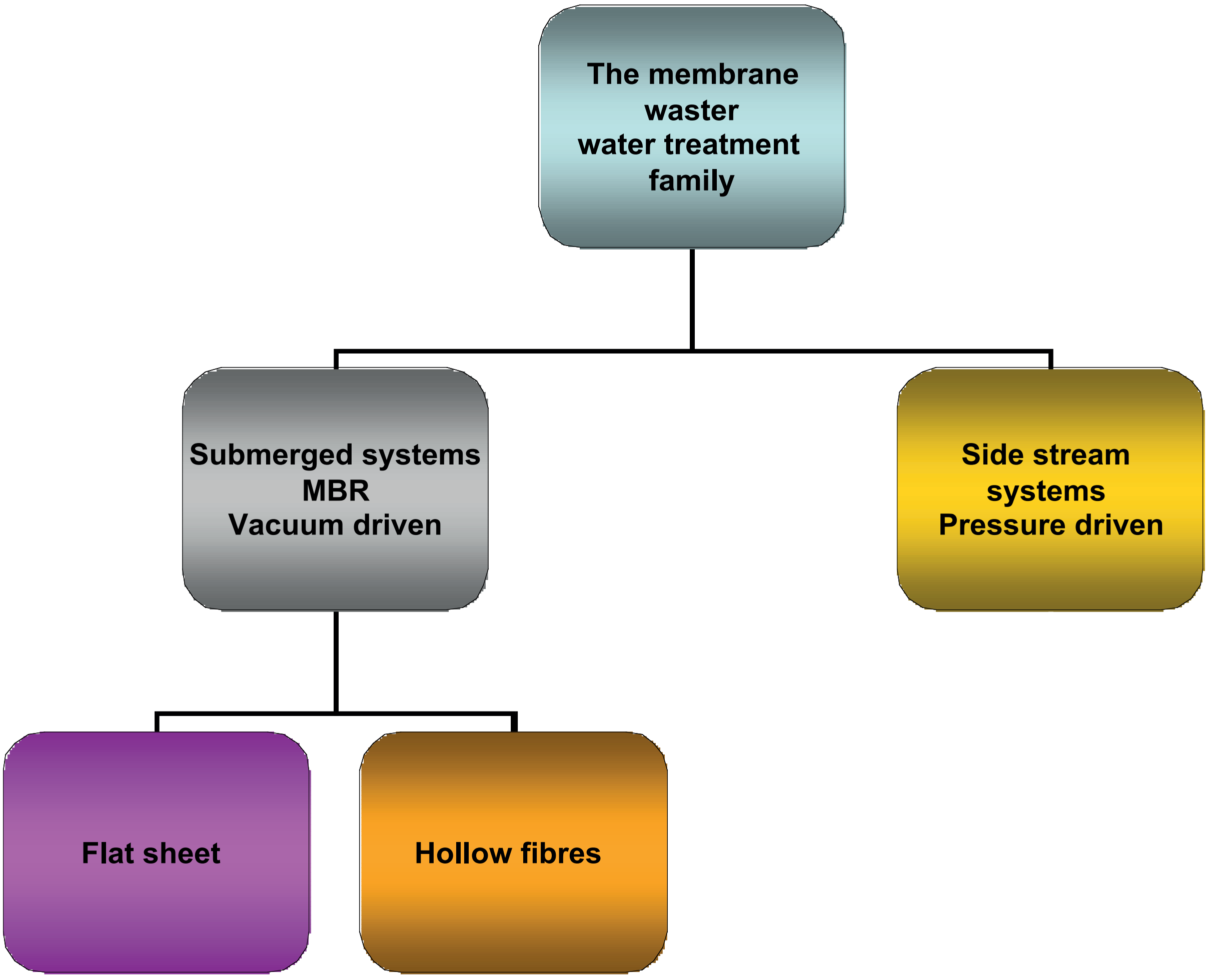

Figure 5.10.4 advance waste water treatment technology families

The difference between the operational philosophy of submerged and side stream systems can be explained by comparing the flow schemes of figure 5.11 and 5.12 that illustrate the basic principle of operation.

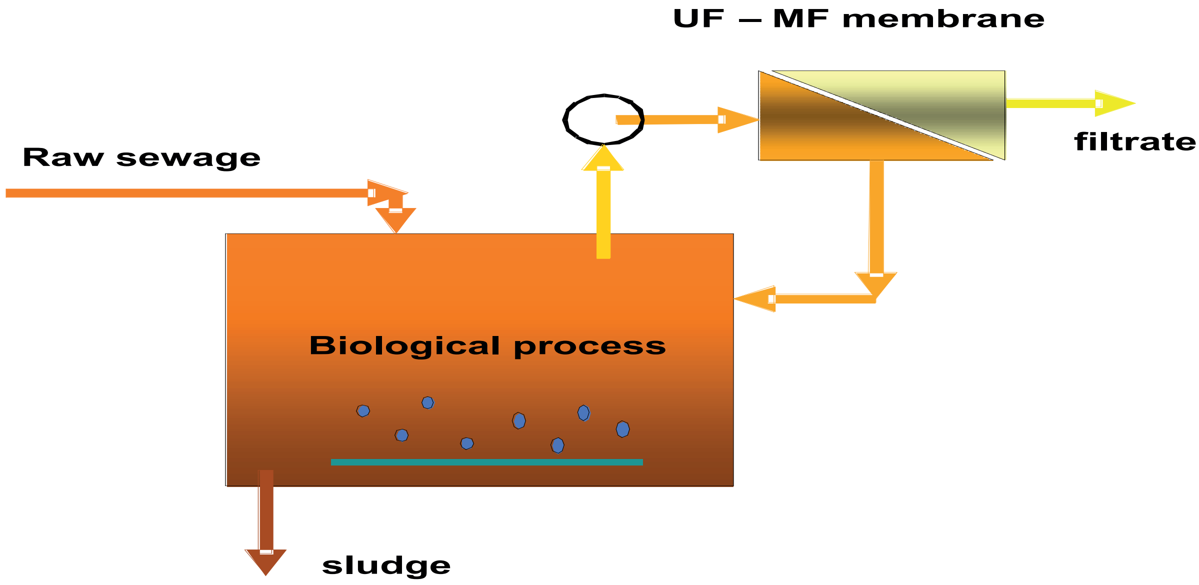

Figure 5.111 side stream waste water pressure system

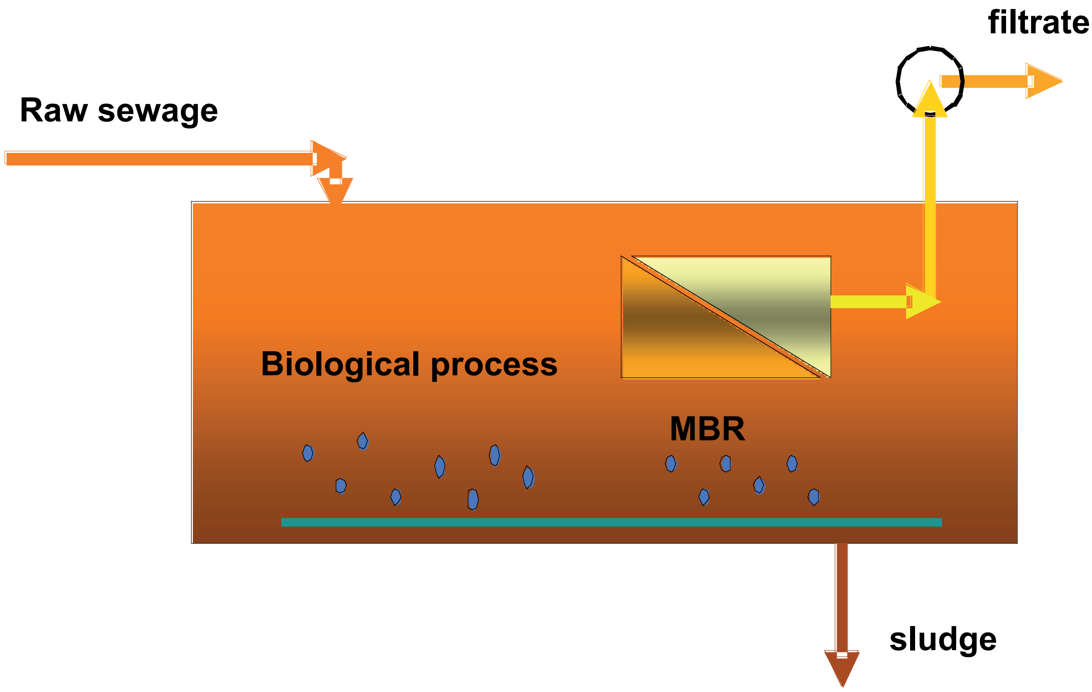

Figure 5.12 vacuum type submerged MBR

The membrane systems could be coupled in different manners to the biological process. Large MBR are installed downstream of the nitrification-de nitrification and oxidation. As the system is a dead end, it offers the advantage of increasing the biomass in the reactor preventing the danger of "wash out ".

The technology of membrane separation of activated sludge, commonly referred to as "membrane bioreactor" (MBR), was first commercialised in the 70s and 80s for small and niche market applications such as treatment of ship-board sewage, landfill leachate or highly loaded industrial effluents. The MBR systems were at that time based on what have come to be known as side-stream configurations, i.e. the membrane separation step was employed in an external sludge recirculation loop, mainly with in-to-out flow through organic or ceramic tubular membranes.

More recently, a new generation of MBR units have appeared, based on the so-called immersed filtration system, working with low negative pressure (out-to-in permeate suction) and membrane aeration to reduce fouling. This resulted in capital and operation cost savings, which rendered the technology viable for the treatment of municipal and domestic waste water.

Although MBRs are a relatively new technology, worldwide public and private R&D as well as feed back from operation of the existing plants has led to significant progress. The level of investment in technology development is especially high in comparison with the current market, which reflects its potential in terms of applications and future commercial revenues.

First-generation MBRs were used to replace activated sludge plants in small packaged plant applications; second-generation MBRs added de-nitrification and phosphorus removal to the systems' capabilities, and third-generation MBRs were able to operate at lower MLSS concentrations and SRTs, to increase flux and decrease membrane surface area.

The fourth and current generation of MBRs is characterised by large scale applications, closer collaboration between MBR designers and end users, and increased market competition.

Presently about 1,500 MBRs are installed worldwide, while more are proposed or under construction. More than 500 currently operating plants are full-scale installations for treating municipal and industrial wastes; numerous smaller MBRs are treating gray water at commercial and residential locations and on-board oceangoing vessels.

Generally in North America and Europe, a large number of MBRs are retrofit projects. Most current MBRs treat a few hundred cubic meters of water per day; the largest treats about 50,000 m^3/d.

Plans are underway to build MBRs that will treat up to 200,000 m^3/d, and studies confirm that potentially, the technology could be used to treat 1,000,000 m^3/day.

6 Desalination technologies selection

One of the most commonly asked questions is "what is the best desalination technology?".

Unfortunately there is no simple and straightforward answer to this question. The best technology to be adopted is influenced by several factors and these factors are also often changing as a result of technology developments and market situation.

However it is a good approach to establish the criteria that can allow both the end user and the developer of a desalination project to determine the most appropriate technology given the particular conditions of the site and of the market.

The approach for a technology comparison is normally based on considerations of so called "quantifiable" and "not quantifiable" criteria that are typical of each technology.

The importance factor given to the various criteria adopted for the technology comparison is subjective and depends on the particular purpose of the technology that has been offered.

Typically we can carry out a comparison of quantifiable criteria based upon the following criteria

(a) Capital costs;
(b) Operating c costs
(c) Energy usage
(d) Availability and reliability
(e) Green house emissions

Tariff costs at generation point

The most frequent factors determining the weighing factor affecting the selection of the technology are:

- Price of energy
- Size of the plant
- Single or double purpose
- Site characteristics
- Product water specification

The conclusions from the quantifiable analyses are generally further screened by non-quantifiable criteria typically as follows:

(f) Reliability and maintainability of technology
(g) Interdependency with power station
(h) Robustness of process,
(i) Flexibility of the technology – response to load changes capacity to tune plant production; and
(j) Future technology developments

All of the criteria summarised above for each of the industrial desalination technologies are examined in the book and hopefully will provide the reader a good tool for technology selection.

However the considerations that are presented in this publication are only typical examples and will require a specific evaluation based on the desalination or water re-use application that is required.

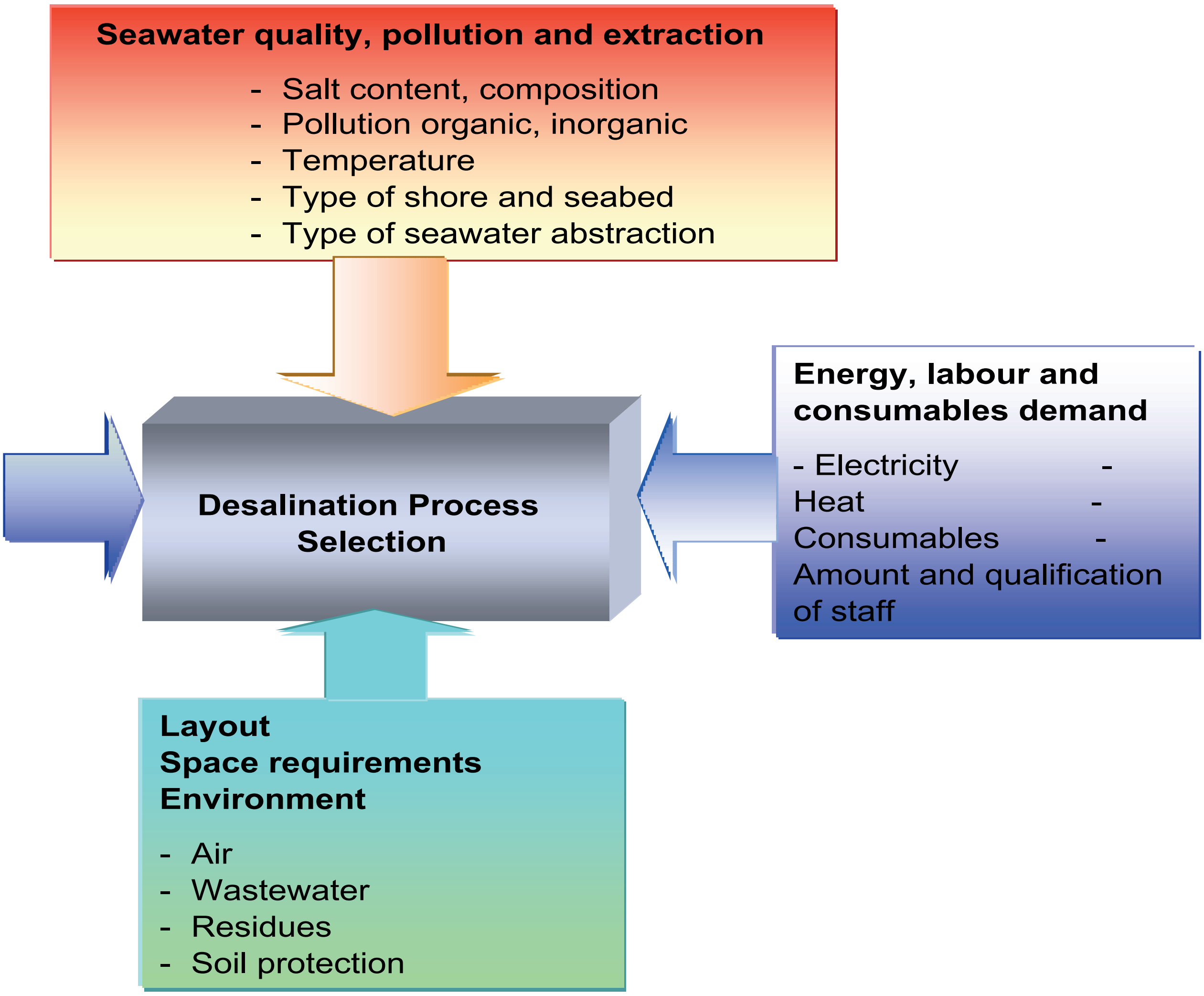

Figure 6.1: technology selection process – typical logic scheme

~~1.1.1~~6.1.1 Seawater requirement

Seawater requirements are very important for the economics of a desalination plant.

Seawater flow rates have a sharp influence not only the construction of the seawater intake and associated auxiliaries but also on the operational costs as power consumption and chemical dosing are directly proportional to the seawater flow rate that is required for the plant.

For thermal desalination plant the term that is generally used to identify the ratio between the distillate produced and the seawater make up flow rate is the term blowdown concentration factor which is governed by equation 1) below.

1) $$Cf_{bd} = \frac{\omega_{bd}}{\omega_{sw}}$$

The blowdown concentration factor is the ratio between the total dissolved solids in the blowdown $_{bd}$ and in the feed water $_{sw}$. The equation 2) below can be easily calculated combining the above definition of concentration factor and the mass flow and salt balance relationships applicable to any desalination plant.

2) $$\dot{m}_D = \dot{m}_{sw} \cdot \left(1 - \frac{1}{Cf_{bd}}\right)$$

The formula above shows that at a given sea water flow rate, the higher the brine blowdown concentration the more the desalinated water that can be produced per unit of seawater.

Theoretically for an infinitely higher salt concentration in the blowdown than in the seawater the flow rate of seawater would match the flow rate of product water that can be produced.

While concentration factor is the term normally used in thermal desalination technology recovery ratio or conversion ratio is the industry term that is used to indicate the capacity of concentrating salts for Reverse Osmosis technology as a fraction of the seawater feed that is converted to permeate.

The recovery ratio Y is indicated by the percentage ratio of the permeate product $\dot{m}_p$ and the seawater flow $\dot{m}_{sw}$ as show in the formula 3) below.

3) $$Y = \frac{\dot{m}_p}{\dot{m}_{sw}}$$

Rearranging the terms, the concentration factor and recovery ratio can be related by the following relation:

4) $$C_f = \frac{1}{(1 - Y)}$$

In actual practise however there are limitations due to formation of scales in both thermal and RO technology.

In thermal desalination processes the concentration factor is limited by the risk of formation of scales at high temperature that brings about a reduction in the heat transfer coefficient of the desalination plant.

For Middle East salinity waters (i.e. TDS concentration of 42000 to 48000 ppm), the risk of scale formation during operation, prevents the achievement of concentration factors higher than 1.4 - 1.5 in the brine blowdown stream.

Also for SWRO technology there are practical limitations to the increase in the recovery ratio (concentration factor); at high seawater recovery, fouling and scaling risk increase. These risks worsen with increasing membrane flux rate and may bring about:

- Increase in membrane flushing frequency
- Progressive deterioration of membrane performances
- Shorter membrane lifetime

Furthermore, for reverse osmosis technology the increase of the recovery ratio brings about an increase in the total dissolved solids in the proximity of the membrane surface which is detrimental to the permeation process. This phenomenon is known as concentration polarisation and is proportional to both the recovery rate and the membrane flux.

Concentration factors differ substantially according to the type of process. SWRO process tends to allow much higher seawater concentration factors than thermal technology.

The table 6.1 shows a comparison between the seawater concentration factors for different processes for Middle East seawater (TDS 45000 ppm). This concentration factors do not include cooling water requirement whose effect is to further significantly decrease the overall seawater consumption for the thermal technologies. This is indicated in table 6.2

Table 6.1: seawater recovery ratio and concentration factors for each technology

	MSF	MED	MED-TVC	RO
Recovery ratio Y %	33%-37.5%	33%-37.5%	33%-37.5%	35%-43% (*)

Concentration factor 1/ (1-Y)	1.5-1.6	1.4-1.8	1.5-1.6	1.6-1.8

(*) including 2nd pass

An analysis of the data shown in Table 6.1 shows a difference between thermal and RO recovery of only 10-15% that only partially explains higher seawater requirements for thermal technologies,

In particular as it can be seen from table 6.2 while for SWRO the concentration factor is only 10-15% higher than thermal technology, the overall seawater flow requirement per unit of desalination water differs from 30% to 40%. It should be noted that with particular feed arrangements MED can concentrate further to a concentration factor of 3 .

The difference can be explained by Figure 6.2 and 6.3 showing the schematics of seawater use in thermal and RO desalination processes.

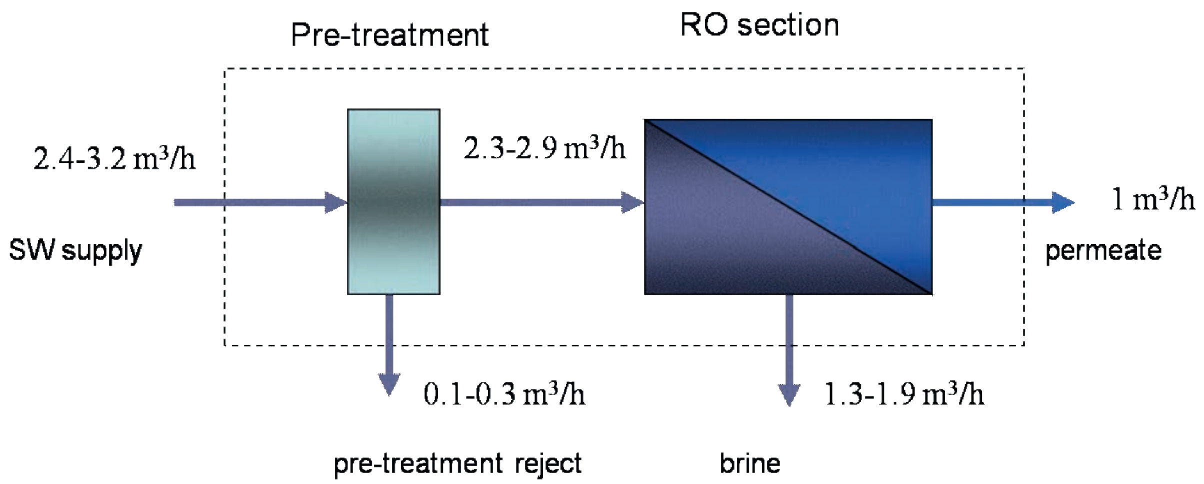

Figure 6.2: seawater requirement SWRO process typical flow sheet

In particular while for SWRO technology all seawater abstracted from the intake (with the exception of seawater discharged from pre-treatment) is used for the desalination process, thermal desalination require additional seawater
cooling in order to maintain the temperature difference between the high temperature stages and the bottom temperature stages.

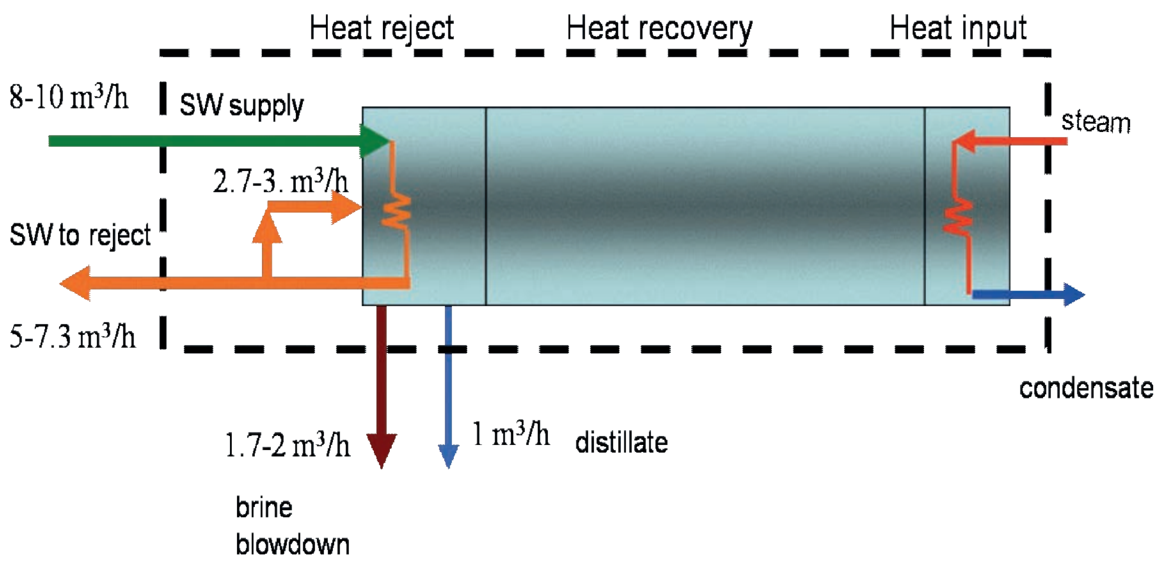

Figure 6.3: seawater requirement MSF process typical flow sheet

Figure 6.3 is typical for a MSF plant but conceptually the seawater flow is similar also for MED and MED TVC projects.

Table 6.2 summarises the specific seawater requirements for each of the major technologies applied today in seawater desalination.

Table 6.2: specific seawater requirement per unit of product water

	MSF	**MED**	**MED-TVC**	**RO**
Cooling water	8-10	5-8	3.2-5	0
Process water (make up-feed water)	2.7-3	2.7-3	2.7-3	2.3-2.9
Pre-treatment back washing losses	0	0	0	0.15-0.3
Brine discharge	1.7-2	1.7-2	1.7-2	1.3-1.9
Cooling water drain	5.3-7	2.3-5	0.5-2	0
Tonnes of seawater required per tonne of distillate water	**8-10**	**5-8**	**5-8**	**2.5-3.2**

The lower cooling water that is required for MED with respect to MSF is due both to generally higher performance ration and use of the vacuum system cooling water a process make up feed.
It should be considered that for SWRO technology the amount of seawater required for seawater pre-treatment differs according to the technology and number of pre-treatment stages.

In some cases seawater filter backwash is carried out with reject brine and the seawater is used only for rinsing. In other cases it is carried out with filtered seawater.
The highest seawater consumption for SWRO technology is when MF or UF is used for seawater pre-treatment. This value may exceed 10% of the seawater flow.

As the temperature difference between the top and the bottom temperature stage of the distillers is the driving force for the thermal desalination process, the heat provided in the heat input section needs to be discharged back to the sea through a process stream that is generally called the seawater heat sink.
As the seawater is drained to the sea, the seawater flow requirement for cooling is inversely proportional to the performance ratio of the desalination plants.

Despite the seawater consumption of thermal desalination is definitely higher than for SWRO a fair comparison should also take into account that thermal desalination are generally installed in a co-generation scheme. In this configuration the seawater supply to thermal desalination in reality substitutes the seawater requirements that would be otherwise required at the steam condenser of the power plant to condense the steam coming from the back pressure of condensing steam turbine

(i) Seawater requirement and heat dissipation

As can be seen from the energy flow diagram illustrated in Figure 6.4 the great part of the heat input to the MSF system is returned to the sea with the seawater drain stream. The heat input section is called the brine heater for MSF and the steam transformer for the MED and MED-TVC.

In a thermal desalination plant the energy that is received from the power plant in the form of steam is gradually degraded across the stages of the evaporator; this process is the driver of the seawater distillation.

Finally the energy at high temperature supplied at the heat input section (brine heater or steam transformer) is discharged at lower temperature to the sea through a heat sink.

The heat sink is typically the heat reject section (or seawater drain) for the MSF process and the condenser cooling section for the MED technology.

Clearly the lower the thermal energy that is required per unit of mass of distillate the lower the thermal energy that is discharged back to the sea. Accordingly, the performance ratio is an extremely important component in determining the thermal impact associated with the seawater reject and blowdown brine discharge to the sea. So clearly the higher the plant performance ratio the lower the energy discharged back to the sea.

In particular for a MSF or MED desalination plant, the energy required as the driving force for the desalination process enters the system at the heat input section in the form of steam which is condensed at the brine heater of an MSF or in the first effect of an MED cell.

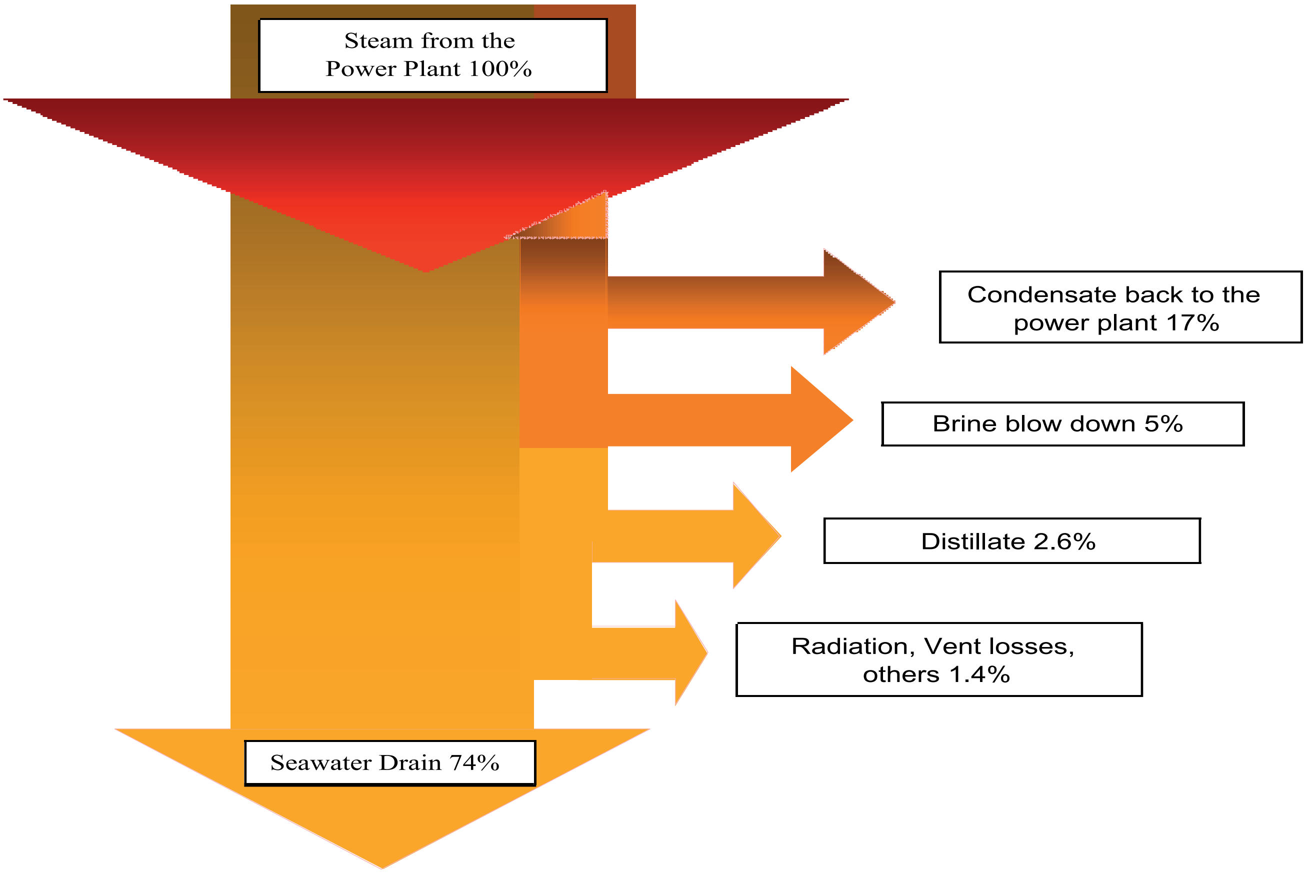

Figure 6.4: Heat flow diagram thermal desalination plants

As it can be seen from the energy diagram of Figure 6.3 above the great part of this energy (74% for the seawater drain and 5% for the brine blowdown) is returned to the sea.

In order to minimize the heat discharged with the seawater drain, it is essential to reduce the energy input to the heat input section of the plant.

The effect of a relatively small increase in the plant performance ratio may bring about dramatic improvements in the overall scenario related to the energy discharged to the sea by the thermal plants heat reject section.

This is indicated in Figure 6.5 that shows the energy dissipated in the ocean through the heat reject section of a thermal desalination plant against the plant performance ratio at different unit capacities..

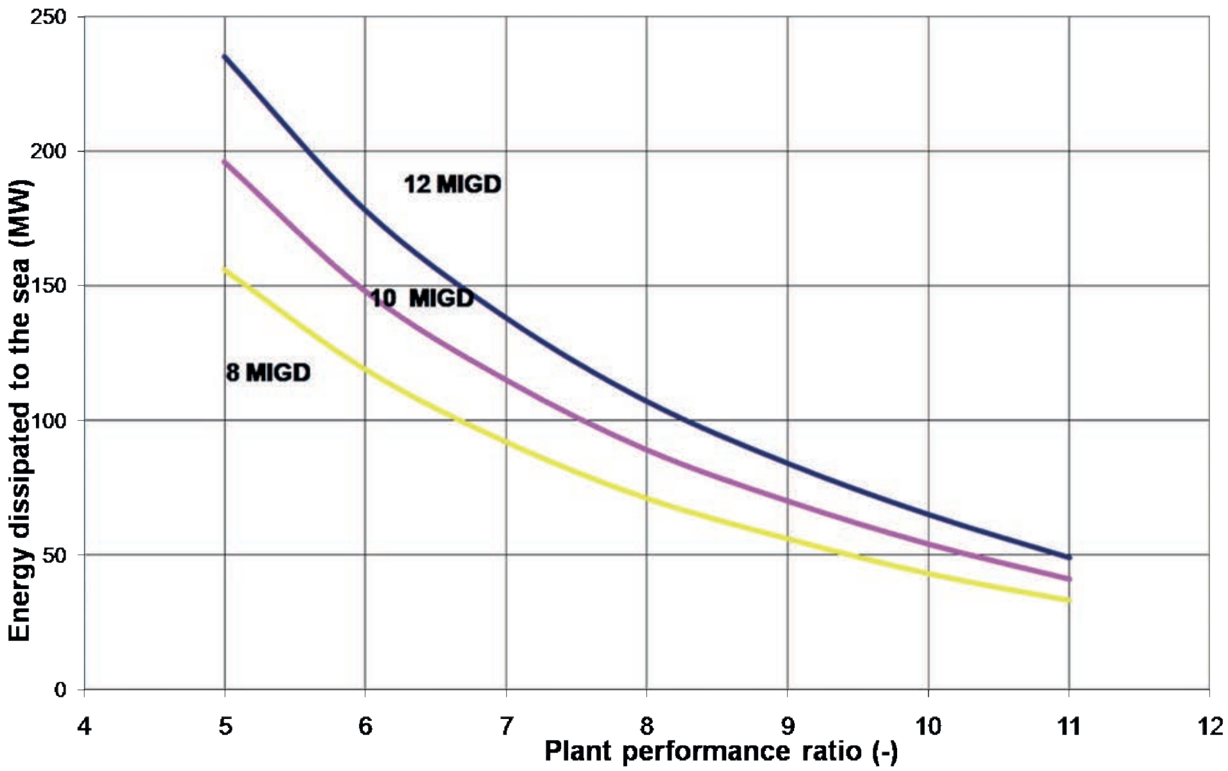

Figure 6.5: energy dissipated with cooling water flow diagram thermal desalination plants

As it can be seen from the diagram, an increase in the plant performance ratio sharply decreases the energy dissipated in the sea as thermal plume from the plant. The gap between the energy dissipated in the sea at increasing plant sizes becomes narrower at higher plant performance ratios.

In particular, it can be seen that at the hypothetical plant performance ratio of 11 the difference between an 8 and 12 MIGD MSF desalination thermal impact system would be less than 3 %.

6.1.2 Land Footprint

Footprint considerations have been traditionally less important in the Middle East owing to a great availability of land where the desalination plant could be installed. Things are also changing in the Middle East as the access to the coast becomes more important with both increasing power and desalination projects and development of residential complexes. In principle, the desalination plants of the first generation were not designed to optimize the footprint requirements this have generated comparatively high footprint requirements. Furthermore as the desalination technology develops plants the footprint requirements tend to decrease . For instance thermal plant require for the same production capacity less heat transfer area as well SWRO with increase recovery ration require a lower number of membranes and smaller equipments and this results in marginally smaller plants as the time goes by.

In the past, footprint considerations were primarily a concern in the case of retrofit of one of more units downstream of a power generation yard. On the other hand several projects are under development to serve new luxury residential areas, and considering the high value of the land in these developing areas and the nature of these developments footprint considerations became very important and it is in the interest of the project sponsor to reduce the footprint of the Plant as much as possible. Additionally, the plant shall preserve the local landscape must be in compliance with building restrictions and architectural camouflage..

A general range of footprint requirement per unit of installed capacity cane be summarised in the table 6.3 below.

Table 6.3 footprint requirement for different technologies

Technology	Area required ($m^2/(m^3 / hr_{installed})$)
SWRO	3.5-5.5
MSF (*)	4.5-5.0
MED-TVC	4.5-5.0
MED condensing	6.5-7.0

(*) single deck

MSF desalination plants could be installed in single deck or double deck configurations. The tendency to install desalination plants in double deck has been abandoned as the maintenance to these unit proved to be more difficult than for single deck, on the other hand there are several double deck distillers installed worldwide.

MED-TVC operates with a higher vacuum than MSF and therefore the higher specific volume tends to require a larger volume.
However MED also operate also with higher heat transfer coefficients and therefore lower heat transfer area this practically counterbalance the effect given by the higher specific volume
Furthermore for MED the major process pumps area is simpler as there are no brine recirculation system that requires a large footprint.

Condensing type MED require more area as both operate under high vacuum and required several additional effects to achieve the required performance ratio.

The information shown in the table above does not include the remineralisation and potable water farms as these may vary according to the project specific requirements and more importantly do not consider the space that is required for the steam production in thermal plants.

This would be not considered if the desalination is installed in a cogeneration cycle but is the thermal desalination plant is stand alone additional space would be required for the auxiliary boilers.

From the table it can be observed that the thermal desalination footprint requirement has a maximum variability of 7-10% whereas for SWRO the difference between one solution and the other may bring about a 50% difference in footprint requirements. This can be explained by the fact that the only factors that have an influence on the thermal desalination plant footprint requirements are plant performance ratio and the specified top and bottom temperature of the unit.

For SWRO technology, the footprint requirements are subject to the extent and type of seawater pre-treatment that is required to obtain seawater of suitable quality. These could be minimal in Mediterranean waters and extensive in Gulf water and accordingly the space requirement can be different. Table 6.4 shows the breakdown of area required for each section of the RO plant.

Table 6.4 area requirement breakdown SWRO

Plant section	Percentage of plant layout
Sea water supply	3- 5%
Pre treatment	35-50%

Cartridge Filters	3- 5%
Chemical Storage	2- 5%
RO	20-25%
HP pumps	
CIP	
Post Treatment	22- 25%

For reverse osmosis technology, the type of pre-treatment technology has a strong influence on footprint requirements. For instance, because of the different process flow velocities, a floatation unit requires a much larger footprint than a gravity filter and a gravity filter require in turn a larger footprint than a pressure filter.

On the other hand because of its modular unit of the SWRO technology presents the possibility to accommodate the plant component with much more flexibility in different floor of the same building. A Desalination Plant that built on two levels can permit a reduction of the footprint up to 35% of the total area; further reduction may be obtained if the water reservoir is arranged on a third level.

UF/MF pre-treatment often presents the advantage of requiring less space if installed instead of two conventional pre-treatment stages; typically, UF/MF provides a 33% saving in plant area, and this can be reflected into capital savings for the plant. It is expected that with the introduction of innovation particularly in the reverse osmosis technology there will be further optimisations in the plant footprint. This can be expected both by the introduction of membranes capable of operating with higher flux and higher recovery rate and also by the introduction of innovative scheme such as the pressure centre arrangements as well as the introduction of new 16-inches membrane elements.

Land footprint for advanced water treatment projects is subject to a greater deal of variation. Generally submersed membrane require a negligible surface with respect to the rest of the plant while the great part of the area is required by the biological process, raw sewage balancing tanks and sludge treatment. The table 6.5 below shows a general footprint breakdown for a submersed MBR system completed with full biological treatment,

Table 6.5 indicative footprint requirement for advanced water treatment systems

Technology	**Area required (m^2/(m^3 / hr $_{installed}$))**
Membrane chemical dosing-aeration	1.2-1.5
Sludge treatment	3.5-7
Biological treatment	4.5
Fine screening	1.1
Balancing tanks	2.5
Pre-treatment lifting station	1.5
Treated sewage effluent chlorination and pumping	1.5
Total	16.0- 20

6.1.3 Seawater quality

Different technologies present different sensitivities to seawater quality.

Thermal desalination is almost insensitive to seawater TDS and other main seawater parameters while SWRO efficiency improves drastically as feed water TDS is lower and water is free from silt and turbidity. In qualitative terms the CAPEX and OPEX trend of thermal and SWRO against seawater quality is indicated in Figure 6.6 below. .

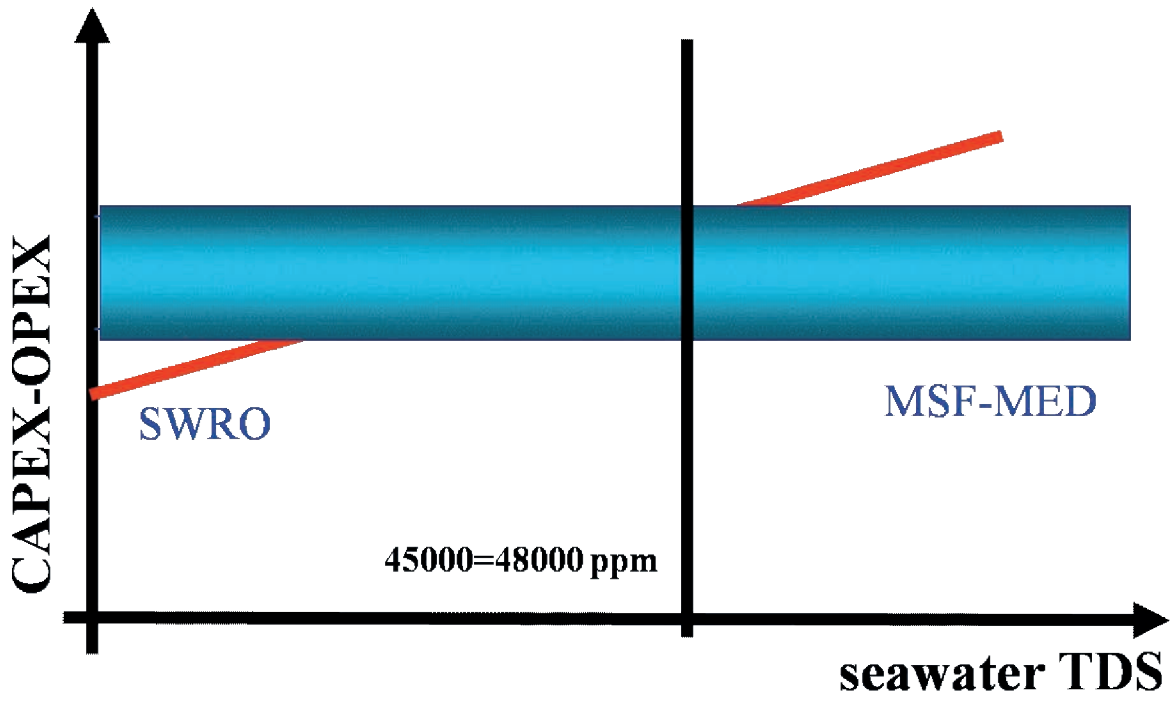

Figure 6.6 typical cost trend CAPEX and OPEX versus TDS thermal and membrane technology

As it can be seen, the lower the seawater TDS, the more the membrane technologies become cost efficient both form a CAPEX and OPEX point of view.

This is due to various aspects. Energy requirements decrease at lower seawater TDS as a result of lower osmotic pressure and brings about a decrease in energy and capital expenditure. Furthermore at low TDS the recovery ratio of membrane process increase. The difference can be quite substantial : a typical recovery ratio at 45000 ppm TDS would be in the range of 40 to 45% whereas with 5000 to 7000 ppm TDS it may be 75-85%. This implies that less seawater is used and therefore less chemicals, leading to smaller equipment..

These advantages would not be significant with thermal desalination technologies that need the phase change liquid to vapour to generate the required desalination process.

6.1.4 Product water quality

The distillation processes, MSF and MED, produce water with very good quality and very low Total Dissolved Solids (TDS), typically less than 25 mg/l (roughly equivalent to 50 micro Siemens/cm) but values down to 5 mg/l could be easily obtained from a high purity distillate extraction stage. The thermal desalination product water is directly suitable for high quality applications such as feed water to a demineralisation plant, boiler feed water, cooling tower make up or other industrial uses as required by the project.

For thermal desalination projects the product water is obtained by a distillation process, therefore there are no CAPEX or OPEX variations that are required to increase the potable water quality or significant savings in producing a lower quality product.

SWRO technology with a single stage design produces water with a TDS concentration of 300 mg/l to 500 mg/l, depending upon feed water composition and temperature. In order to achieve a TDS of 25 mg/l (50 micro Siemens/cm) then the RO plant must be configured as a two stage design. This may have an impact on both the CAPEX and OPEX of the plant.

This is schematically indicated in the Figure 6.7 below.

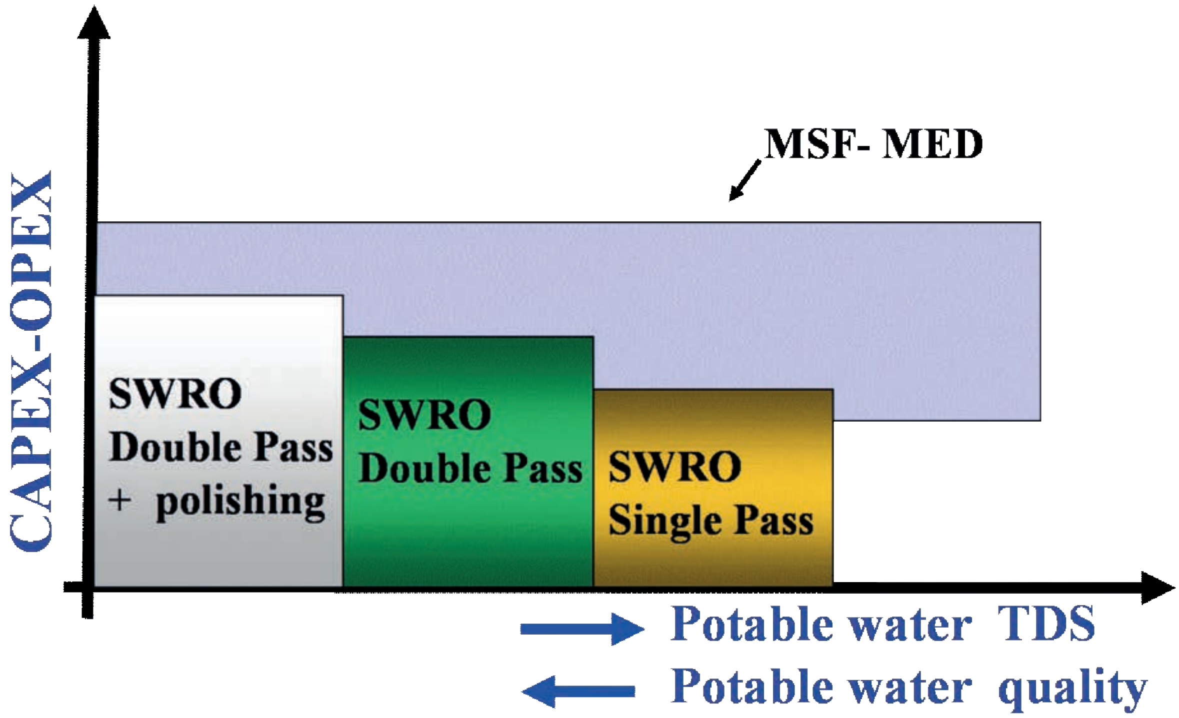

Figure 6.7: CAPEX and OPEX at different potable water quality

A detailed discussion of the impact of the potable water specification on the SWRO system design is elaborated further in the session 13 and 14 related to budgeting.

The product water quality that can be obtained according to the different process is indicated in table 6.7 **below**

Table 6.7: product water characteristics according to different process

	MSF	MED	RO 1st pass	RO 2nd pass	RO 2nd pass plus polishing
TDS [ppm]	5-30	5-50	100-500 (*)	25-100	< 20 ppm
Possibility of High purity extractions	Yes	Yes	n.a	n.a.	n.a.
By products	No	No	boron		

(*) depending on seawater temperature and composition as well as membrane age

For applications that exclude the domestic use product water of suitable quality can be reclaimed from waste water treatment plant. This is typically accomplished by membrane processes operating as a bottoming stage of a biological treatment process. The product water can be utilized for unrestricted irrigation and for industrial purposes.

The product water characteristics that can be typically obtained with a MBR process are according to table 6.8

Table 6.8: MBR plus product water quality

COD	< 50	
BOD_5	< 5	mg/l
TSS$^{(}$	< 3	mg/l
Inert Solids (in percent of TSS)		%
pH		
COD	< 50	
TSS$^{(4)}$	< 3	mg/l
Inert Solids (in percent of TSS)		%
Turbidity	< 0,5	NTU
NH_3-N	< 1	mg/l
TKN	< 5	mg/l
TN	< 15	mg/l
TP$^{(3)}$	< 2	mg/l
Fecal Coliforms	100	MPN/100 ml
Alkalinity(2)		mg/l
TDS (*)	600-1000	mg/l

(*) according to the original raw water TDS

The values of Table 6.8 above could be further improved as indicated in the Table 6.9 if the MBR process is followed by a polishing unit with RO membranes

Table 6.9: MBR plus polishing product water quality

COD	< 50	
TKN	< 5	mg/l
BOD	< 5	mg/l
TP(3)	< 2	mg/l
Fecal Coliforms	N.D	MPN/100 ml
Alkalinity(2)	40	mg/l
TDS (*)	200-250	mg/l

6.1.5 Energy requirements

Desalination plants are energy intensive and the significant increase in fuel-energy and material cost that was experienced in the years 2006 and 2007 had a dramatic impact on capital and operational costs of Desalination and Power plants.

All seawater desalting processes, multi-stage flash (MSF), multi-effect distillation (MED), and seawater reverse osmosis (SWRO) consume significant amounts of energy. A certain amount of energy is required also for membrane waste water treatment systems.

The energy input to membrane processes is provided by electric power that is required for the major process pumps and equipment. For “thermal desalination “the energy input consists of the power required for the process pumps and by the heat required as the driving force of the distillation process.

The heat requirements for large thermally-driven projects are usually satisfied through the development of co-generation plants. In these plants power and water are produced together and the steam extracted from the power cycler is utilised for the distillation process.
The extraction of the steam from the power cycle is at a suitable pressure to produce distilled water through an evaporation process. This typically range between 2.5 to 3 bars for MSF and MED-TVC but can be as low as 0.3 for condensing MED. Old MSF installations were designed for steam extractions of 4-5 bars.

The scheme that is applied is indicated in Figure 6.8 for a traditional condensing steam turbine configuration and in Figure 6.9 for a combined cycle with back pressure steam turbine.

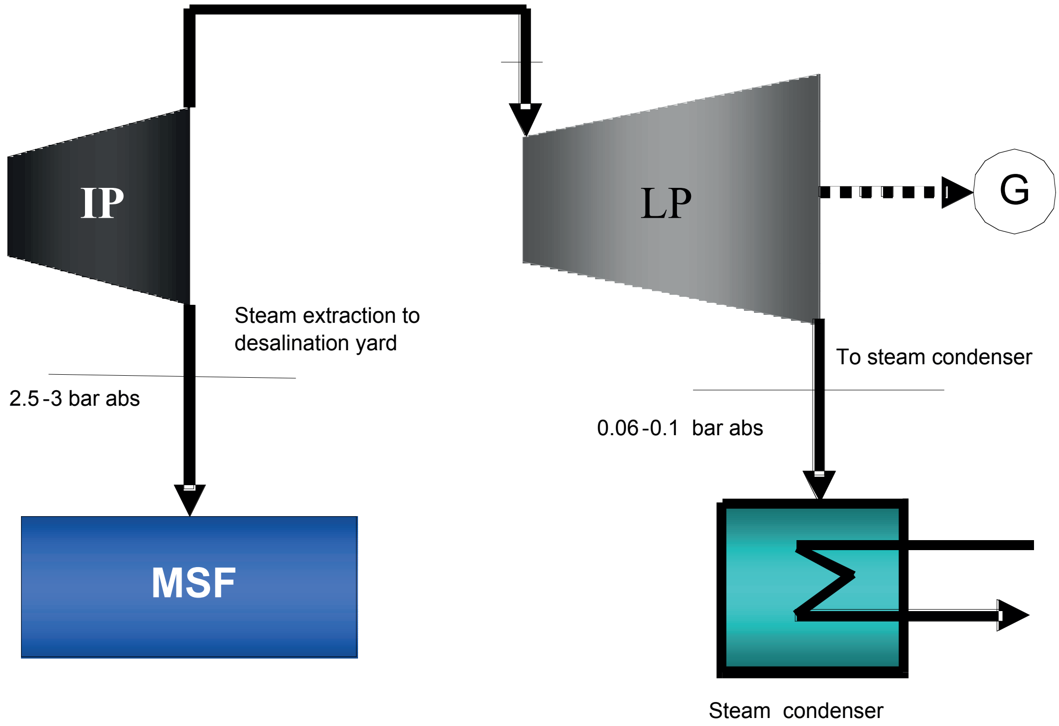

Fig. 6.8 condensing steam turbine feeding an MSF desalination system

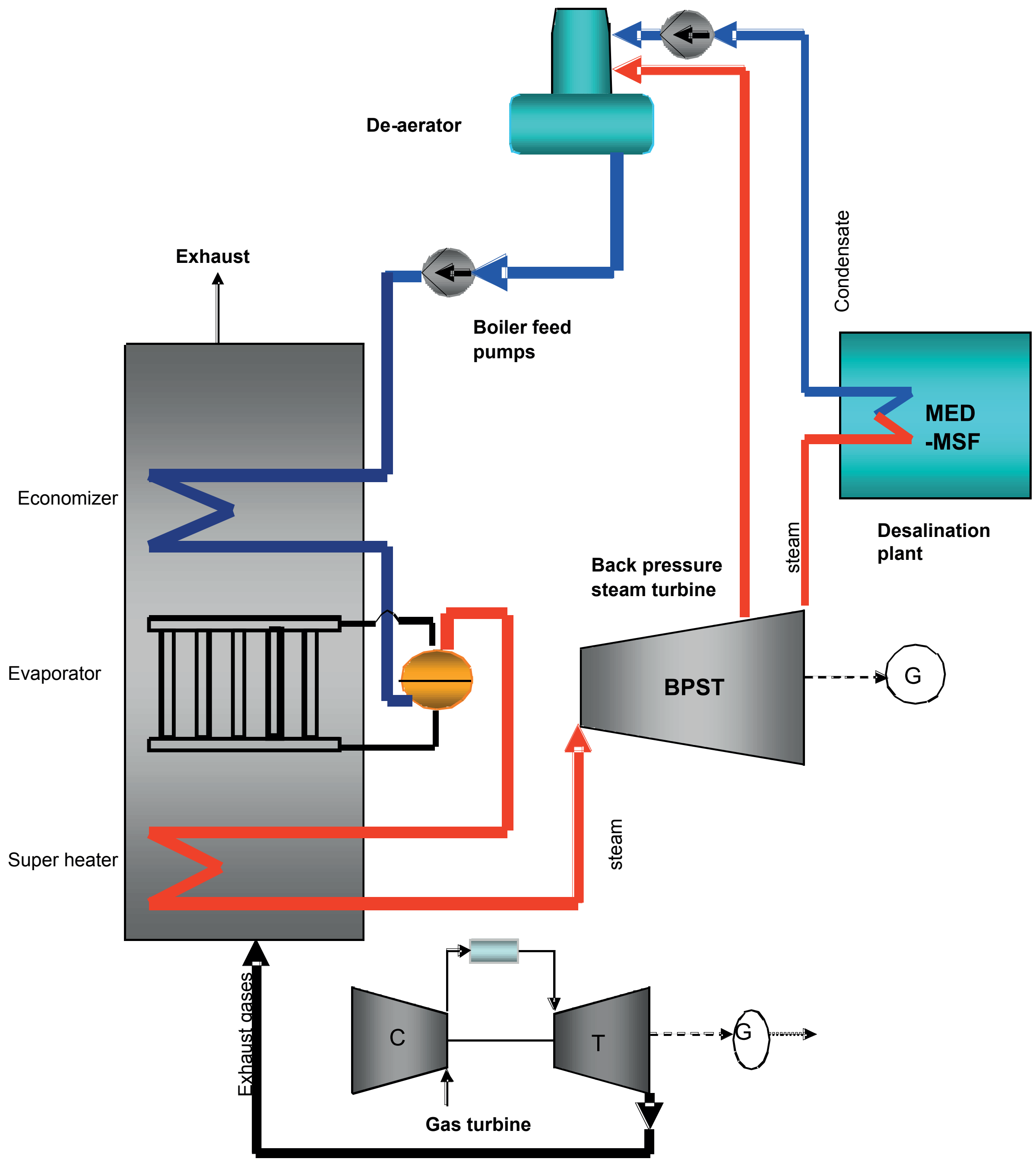

Fig. 6.9 combined cycle with bottoming MSF-MED desalination system

This process is largely energy intensive as the steam is extracted at the pressure of about 2.5-3 bars and therefore has still the potential to produce substantial additional power in the steam turbine

The overall energy requirements according to the technology can be summarised in the table below. These values are based on the current state of the art and include plant auxiliaries such as seawater intake and travelling band screens, potabilisation and chlorination systems etc.

Table 6.10: Desalination technologies energy consumption thermal and electric power cogeneration

	Specific electric power	Specific heat consumption	Steam Extraction pressure	Thermal energy	Equivalent power loss	Total Energy requirements
	Kwh/m^3	kJ/kg	Bar abs	Thermal kwh/m^3	Electric kwh/m^3	kwh/m^3
SWRO (Mediterranean Sea)	3.5	0	N.A.	0	0	3.5
SWRO (Gulf)	4.5	0	N.A.	0	0	4.5
MSF	4-5	287	2.5-2.2	78	10-20	14-25
MED-TVC	1.0-1.5	287	2.5-2.2	78	10-20	11-21.5
MED	1.0-1.5	250	0.35-0.5	69	3	4-4.5

With reference to the second law of thermodynamic, it is impossible to accurately compare the heat and power on the same basis therefore the widely accepted method to align electric power and thermal energy input to the desalination plant is the reference cycle method.

With the “reference cycle” method the energy associated to the steam extracted to the desalination plant is considered in terms of equivalent loss of electric power that would otherwise be rendered by the steam extracted in the power generation yard.

The detail analysis of power loss due to the steam extractions is of course depending on type of power cycle and performance ratio of the thermal distillation plant. As it can be seen from the Figure 6.10 after aligning the thermal and electric input to the desalination process the difference in the energy input per unit of product water between thermal and membrane technologies is quite substantial.

Table 6.11 shows for illustration only the comparison of the main process parameters for a 600 MW combined cycle power plant coupled with a thermal desalination plant through backpressure steam turbine and with a SWRO plant in a full condensing steam turbine.

Table 6.11: SWRO vs. thermal on cogeneration schemes (600 MW-40 MIGD)

	MSF	MED	SWRO
Plant heat rate kJ/kWh	8181	8181	7387
Fuel consumption (kg/s)	33.66	33.66	33.66
Auxiliary power consumption (MW)	34	15	40
Net Power Export	536	585	595

From the table 6.11 above it can be seen that as a result of the overall lower energy consumption the power plant heat rate is lower and therefore with the same fuel consumption more power could be produced in the power plant with if SWRO is used for desalination.

For general desalination projects the energy consumption of RO is considered to be lower than that for thermal processes such as MSF and MED. An exception to this is given by low temperature condensing MED technology. This technology does not require steam to thermo-compressors and uses 400 to 350 mbar(a) steam turbine exhaust to match the inlet temperature required for the MED units.

With this configurations the thermodynamic losses are kept to the practical minimum. In this scenario MED provides an equivalent power consumption very similar to SWRO. This concept is nowadays applied only to relatively small unit size plants . In fact the main challenge related to the low steam extraction pressure and temperature is the large specific volume which in turns require large size steam manifold for steam extraction.

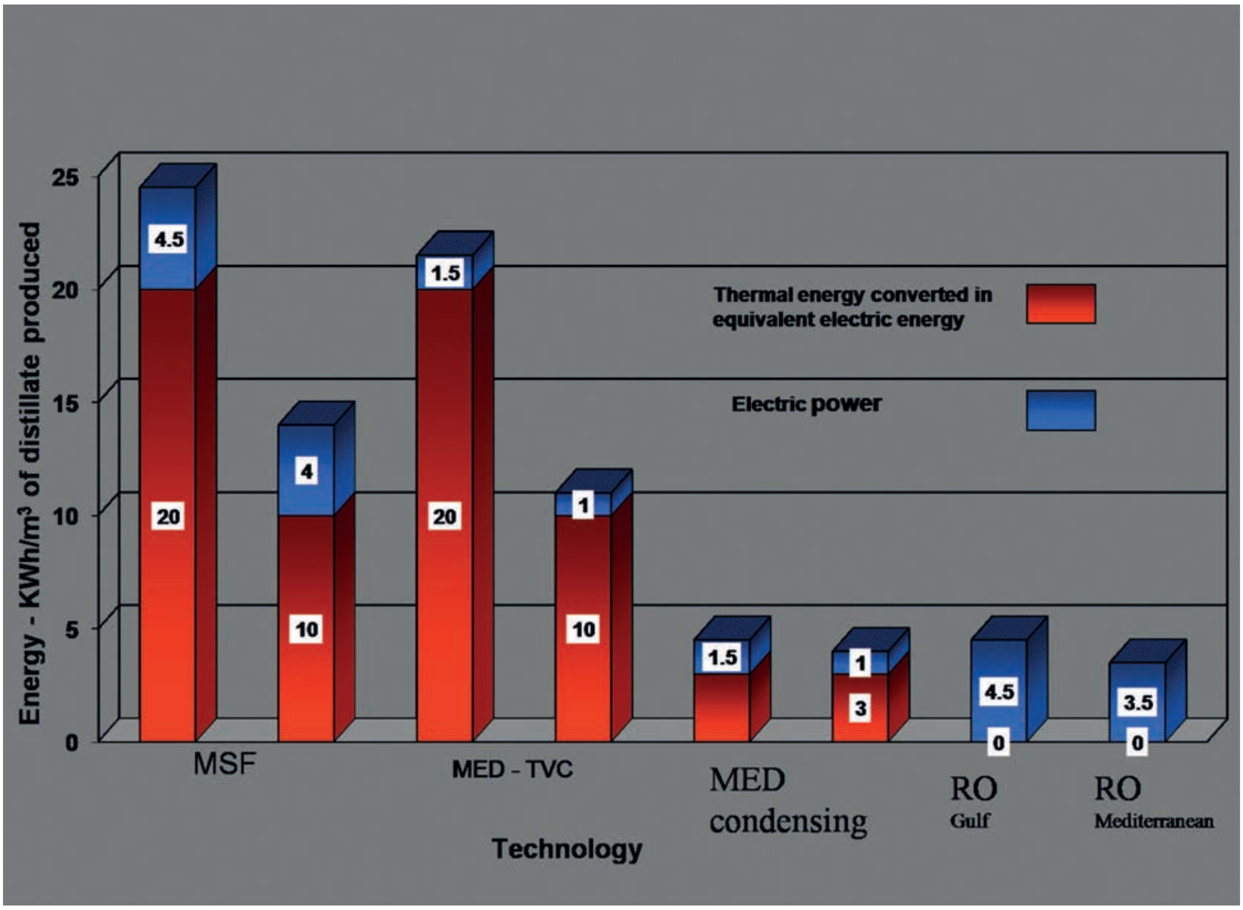

Figure 6.10: Desalination technologies thermal and electric energy consumption With reference to the values indicated in Fig 6.10 above it should be noted that, the difference in the energy requirements among the various technologies can become even larger if the steam for the thermal desalination plant is generated through auxiliary boilers or with large supplementary firing that decreases the plant heat rate.

Nowadays this configuration is normally avoided at planning and design stage. However there are still several large capacity, "stand alone thermal desalination plants" in operation to this day.

Furthermore as examined in the hybrid plant section, power plants are generally sized to meet the peak power requirement that occurs during the summer period. Steam requirements to desalination are designed to match this situation.

Unlike water demand, power demand drops dramatically in the winter season. This creates a mismatch between the steam available from the power cycle and steam actually necessary to produce the required water capacity. The additional steam required is made available via the turbine bypass valves (HP/LP/Reducing Station) as shown in Figure 6.12.

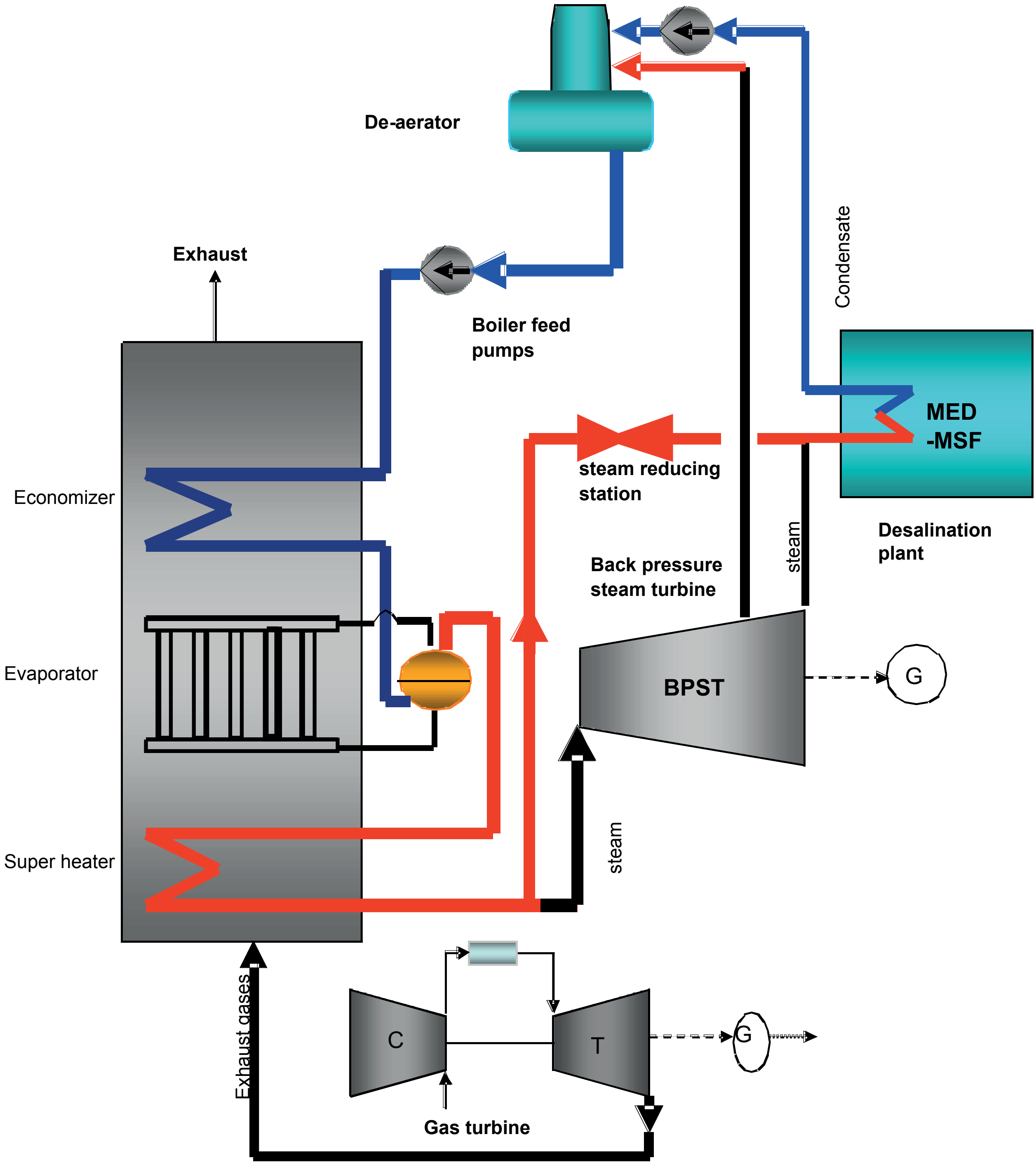

Fig 6.12: Combined cycle with bottoming MSF-MED desalination system: winter operation

The power loss for steam extraction in these operational scenarios is dramatic and can reach up to 40 kWh per m^3 of product water of equivalent power loss.

This very high energy input is the reason why recently even in cogeneration projects in the Middle East, SWRO has been preferred to thermal technology.

In particular, it has often proven to be more convenient taking full advantage of the steam available from the power cycle and condensing it in power plant condenser rather than extracting the steam to drive a thermal desalination process.

The additional power that is rendered by the steam turbine in this manner would be more than sufficient to drive a SWRO process and the electric output generated by the plant will be higher.

The viability of this solution that has been adopted in several cogeneration sites in the Middle East is generally subject to the seawater quality at the site and the extent of pre-treatment required for the SWRO process.

Despite the overall energy consumption of thermal desalination being higher than SWRO, a fair comparison should also take into account that thermal desalination is generally installed in a co-generation scheme. In this configuration part of the energy required to pump seawater to the thermal desalination would be required to pump seawater to the steam condenser to condense the exhaust from the steam turbine.

The energy required for this task divided for an equivalent potable water production could be estimated in the range of 0.3-0.5 kwh/m^3 of product water. In a fair comparison of the technologies this energy amount could be credited to the electrical power demand of thermal technologies.

The energy consumption for membrane technologies is strictly related to the state of the art of the membranes that are employed for the desalination or purification system. New membranes are continuously developed with lower Trans membrane pressures and therefore lower specific power consumption. . Furthermore the SWRO technology has been able to benefit from tremendous improvements in the technique of energy recovery from the reject brine discharged at high pressure from the membranes.

It is considered that the SWRO technology would be capable of reaching a bottom threshold of 2-2.5 kwh/m^3 thanks to planned technological development. As will be discussed in the next section, a judicious use of water resources may bring about a more substantial recovery of the domestic and industrial waste water. Also in this respect, membrane technology is continuously developing. Nowadays some MBR techniques have already achieved a specific power consumption of 0.25 kwh/m^3 (related to the MBR section only).

6.1.6 Energy requirements: re-use versus desalination

One important consideration that should be paid at planning level refers to the use of the product water from the plant. A high percentage of potable water produced by desalination plants in Middle East is used for non domestic purposes such as irrigation landscaping and industrial water. Some typical figures showing utilisation of water resources in the Middle East is indicated in Figure 6.13.

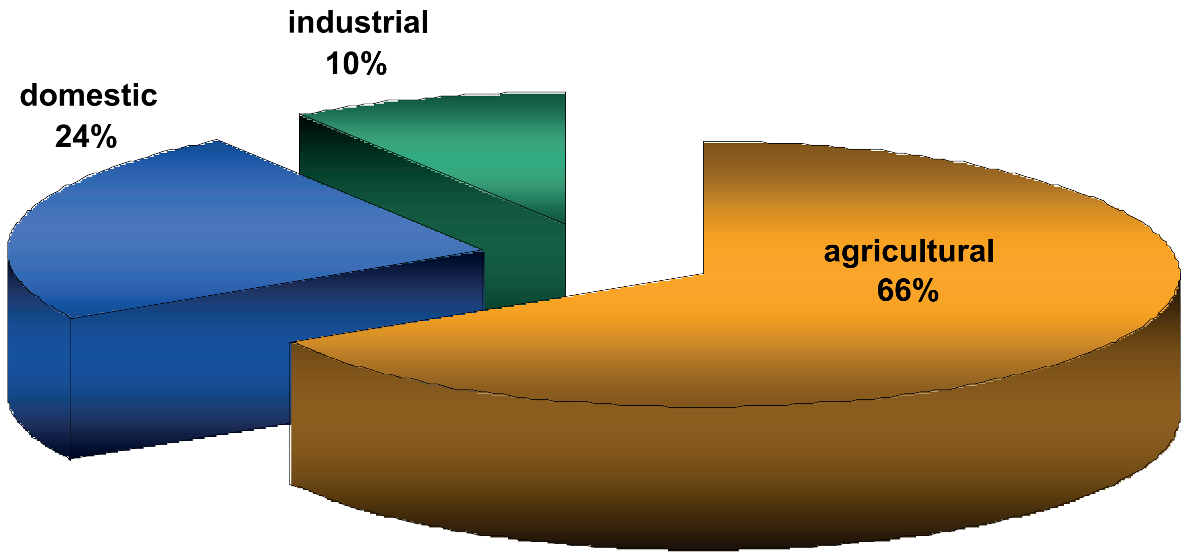

Fig. 6.13: Desalinated water utilisation Middle East

A large percentage of the domestic potable water is used for purposes that do not require desalinated water. The flow diagram indicated in the figure 6.14 shows the main utilisation of the domestic potable water and possibilities for segregation and separate recovery of grey water and black water streams.

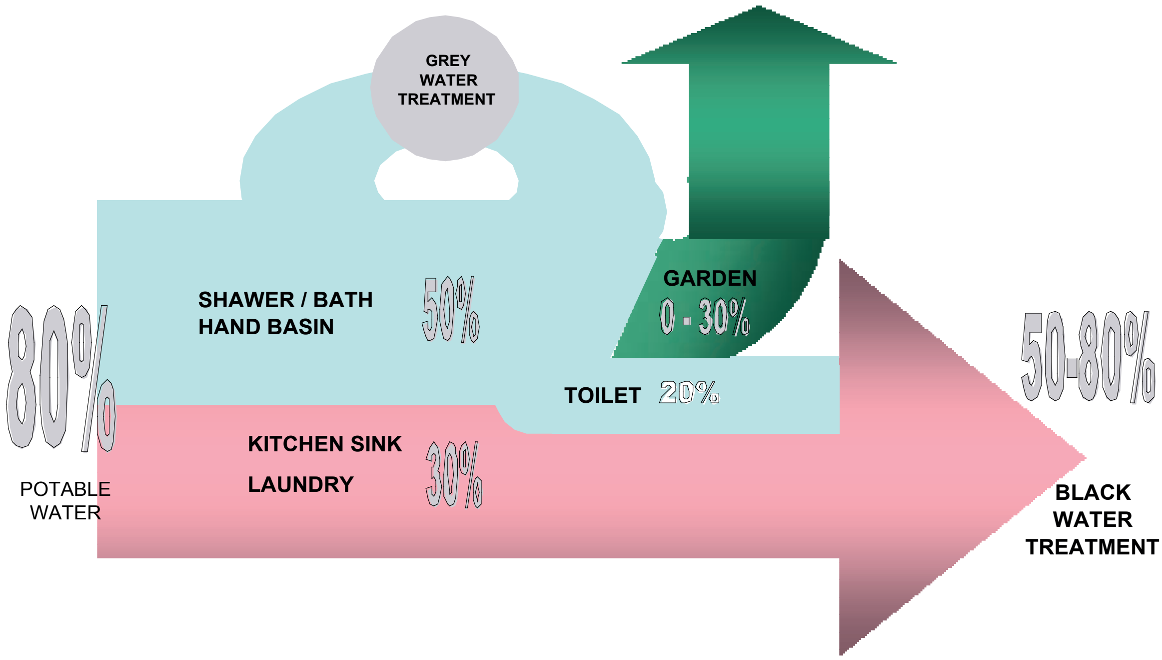

Figure 6.14: Domestic waste water usage

In this context waste water re-use offers great potential for applications in the fields of

- Agriculture
- Industry
- Central cooling
- Air conditioning
- Gardening landscaping
- Cleaning – toilet flushing

And has become extremely important as both a low energy and less expensive resource for water generation

Current advanced waste water treatment produce water for unrestricted irrigation and industrial use from waste water and their energy footprint ranges between 0.5-1.5 kwh/m^3 of product water.

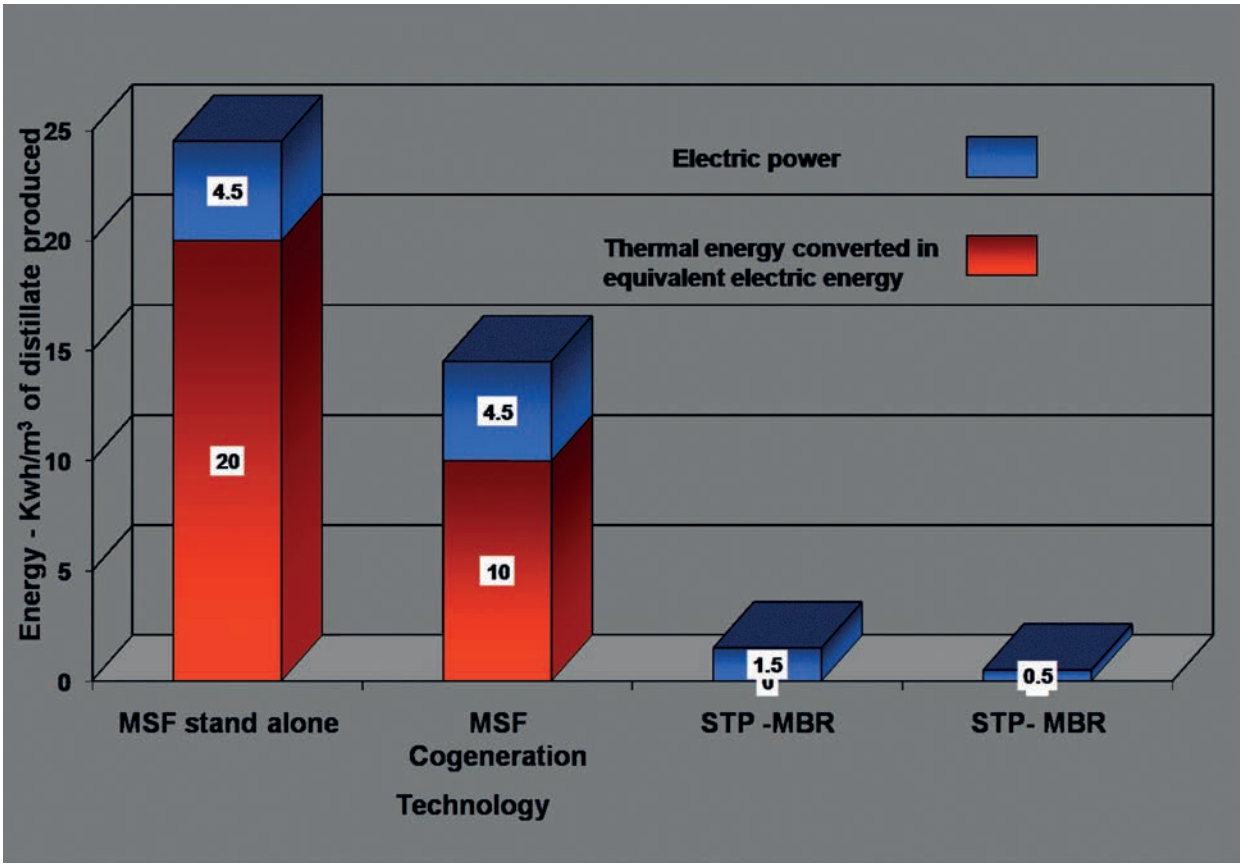

Figure 6.15: thermal desalination and advanced water treatment energy footprint comparison

Figure 6.15 shows the difference between the thermal desalination and advanced waste water treatment energy footprint. This is quite significant and involves a substantial impact on net CO_2 footprint & electricity peak design.

(i) Technology Sensitivity to energy costs

The success of MSF technology, despite its higher installation and energy costs, relates to the strong track record and reliability of the technology combined with its very long design life (which is now estimated in excess of 30 years without major refurbishing). However, outside the traditional area of the Middle East, the dominant desalination technology is Reverse Osmosis.

The energy input to thermal desalination is both associated to the power used to drive the process utilities primarily process pumps and the steam input required to drive the distillation process.

The exergetic value of the steam, or in other words its capacity to generate power depends on the pressure and temperature conditions the steam is extracted from the thermal generation process and fed to the plant.

In order to evaluate the equivalent energy cost associated to the steam fed to a thermal desalination plant on the same basis of the electric power, the "reference cycle" concept was adopted.

Therefore it has been considered that for the thermal desalination plant the steam extracted from the steam turbine (normally at a pressure of 2-2.5 bars) could be expanded further to reach the pressure corresponding at the condensation temperature that would be allowed by the seawater temperature and therefore render additional power at the turbine shaft.
Figure 6.16.below shows for illustration purpose only how SWRO, MED and MSF Variable Operation and maintenance cost are sensible to the price of power.

As it can be seen from the graph of Figure 6.16, due to the lower specific energy (power and steam) consumption, variable operation and maintenance costs for SWRO become more and more competitive as the power price increases.

Similar sensitivity cases can be carried out against other parameters such as price of chemicals and price of membranes as well as against purely technical parameters such as membrane replacement factors.

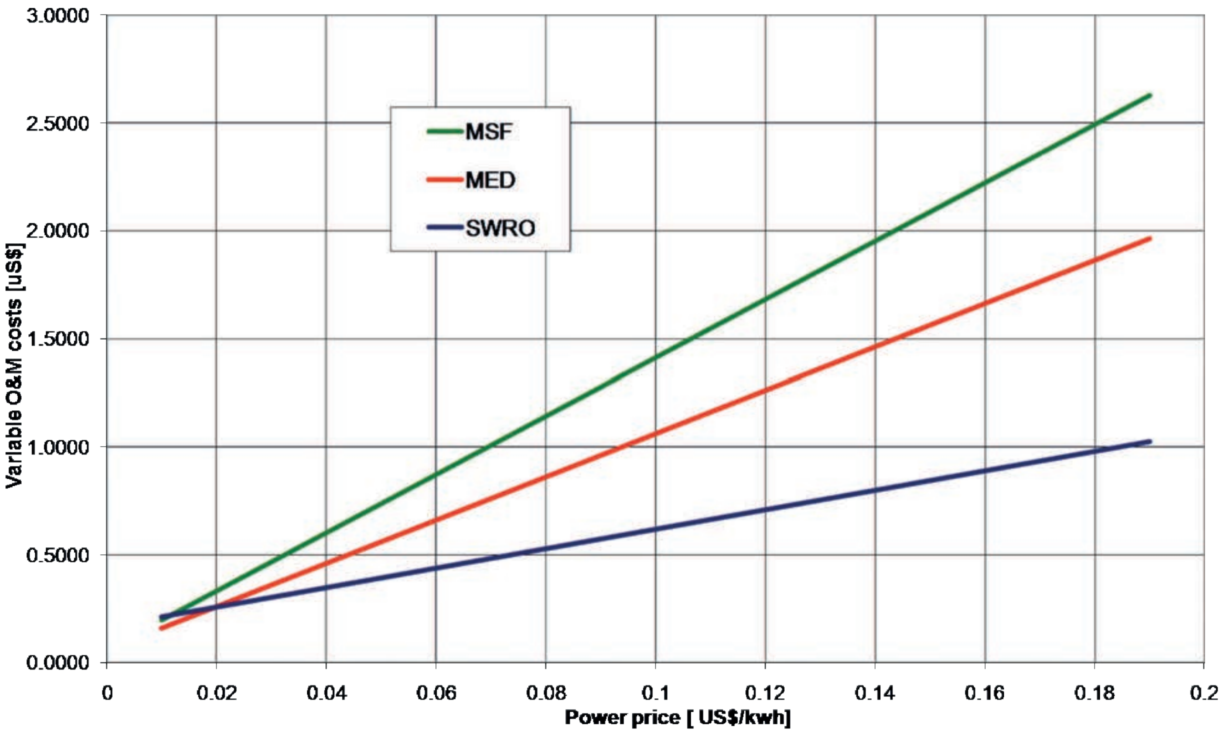

Figure 6.16 Variable Operation and maintenance cost comparison at different power price

It should be noted that Governments particularly in the Middle East are often indirectly subsidising the water tariff by determining a very low fuel – energy price to the power- desalination plant. This solution had the effect of maintaining the water tariff low by decreasing the energy component of the tariff, however it also had the effect of discouraging the adoption of more energy efficient desalination techniques.

Figure 6.16 explains why Reverse Osmosis has gradually eroded the market share previously belonging to thermal desalination, and why technology screening processes in areas outside the Middle East in recent large IWP projects (e.g. Perth and Sydney, Australia, Askhelon Israel, and all north Africa projects) resulted in the selection of Seawater Reverse Osmosis (SWRO) as the preferred technology option

A general analysis of Figure 6.16 and table 6.10 can explain the recent market tendency to give preference to SWRO also for combined power and water projects such as Barka (Oman) , Shuqaiq and Rabigh (in Saudi Arabia) and Ad Dur(Bahrain) have been adopted this concept to achieve a more competitive tariff .

In these projects in fact, the most competitive solution was to make full use of the thermal energy and expand the steam in a condensing steam turbine as schematically indicated in Figure 6.17 below.

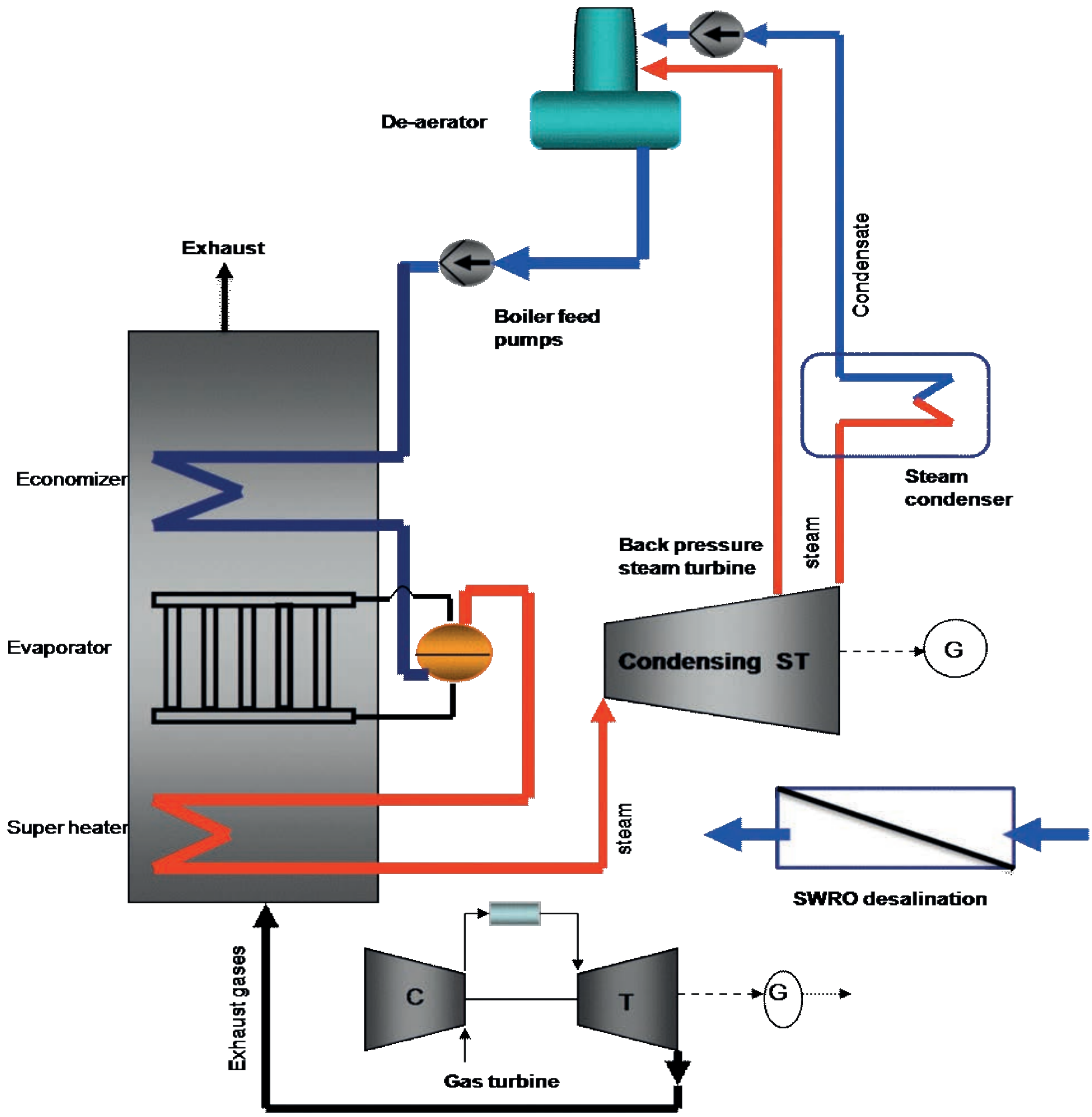

Figure 6.17 Cogeneration scheme with condensing steam turbine and SWRO desalination

This allowed taking advantage of the additional power generated by the turbine and then using part of this additional power to drive the reverse osmosis plant producing the required water with an overall better heat rate and more competitive CAPEX.

Costs of power or of energy in general are taken into account in the evaluation of proposals from various Bidders as part of the overall water cost.

On the other hand fuel, or more generally energy, is passed through by the off taker and discounted from the tariff via a pass –through mechanism.

This approach may discourage the Developer from taking into account the long term impacts of energy costs in the water tariff particularly as the risk of energy cost escalation lies with the off taker.

6.1.7 Construction time

The time required for construction of the project is important as planning and forecasting desalinated water demand is often difficult and desalination plants are often installed in regions where there is no alternative water supply that may buffer the water demand until the project is operational.

Construction time is also related to the economics and technology of the project as the longer it takes to complete the project the larger the working capital since staffing, overheads construction interest, insurance and taxes during the construction period all add to the price of the plant.

Figure 6.18 below shows the length of time required to build the various types of power plant. The timing is indicative for each technology and may be varied in accordance with the project specific conditions.

There were cases where it took only twelve months from order confirmation to first unit water production to install MSF desalination units. However this was done on the basis of a pre-engineered packaged and came along with a price increase as additional expense was required to expedite the material delivery and cover the delay penalty risks.

A small stand alone SWRO can be installed within the shortest time frame because of its standardized design. However much more time would be needed for the completion of a thermal desalination project in a cogeneration plant.

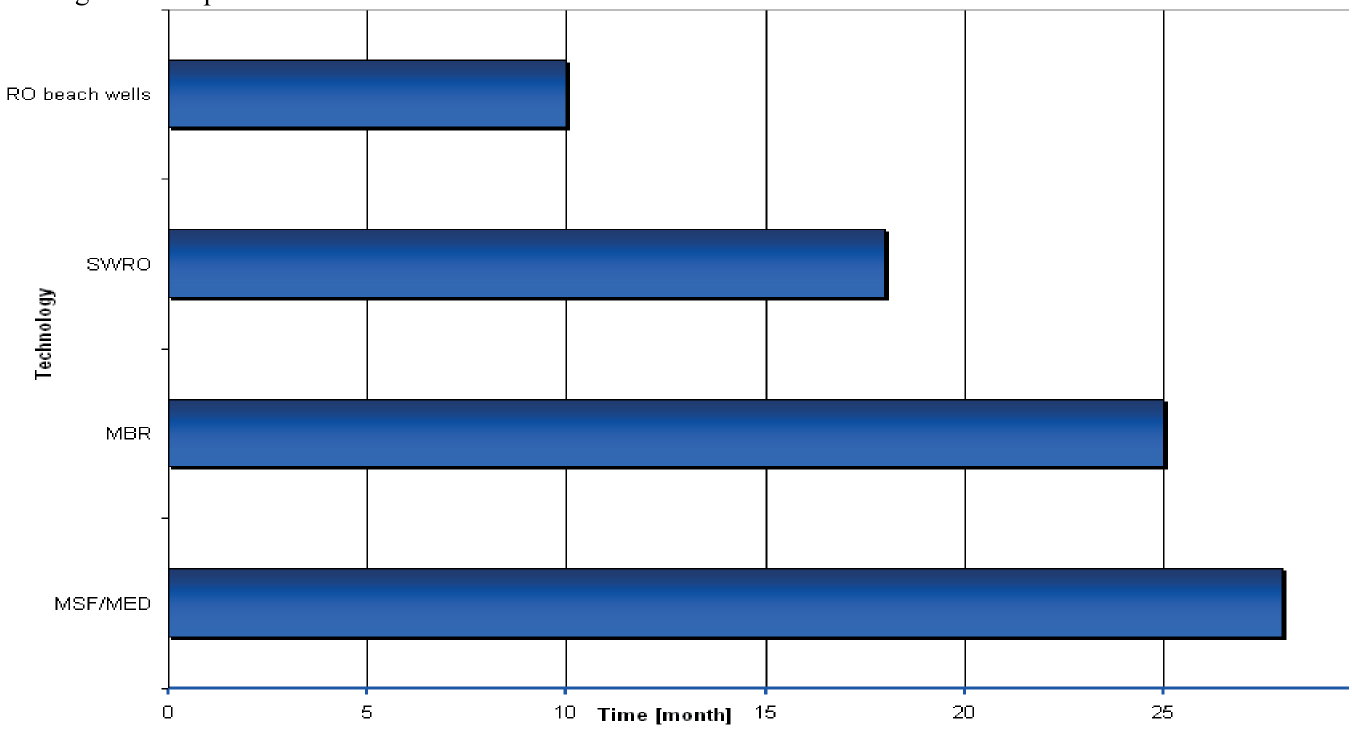

Figure 6.18: typical construction times for different desalination technologies

The SWRO construction time is generally considered to be less than thermal desalination plant construction time. This is generally owed to smaller and intake requirements. For this reason, as indicated in the Figure above generally small plants operating with beach well can be operational in a very short time.

However, the delivery times of a SWRO technology are very much dependant on the characteristics of the seawater that is abstracted and in particular on the extension of the pretreatment requirement.

Often SWRO technology require pilot plant and seawater database before engineering can be fixed and this also may have a detrimental impact on the project delivery times.

Thermal desalination plants are installed in a generally much larger infrastructure. Therefore their matching with the power yard tends to be more demanding in terms of time requirement. It has been often the case that thermal desalination plats were ready to operate but it was impossible to put them in continuous service as steam was not available from the power yard.

The time constraints for waste water treatment plants are represented by the construction of the network required for sewage reclamation.

6.1.8 Environmental issues

Viewed in terms of meeting current environmental regulations, desalination plants have a relatively low impact and it is foreseen that there are no significant problems in meeting such regulations in particular for the seawater abstraction and brine discharge.

The process that leads to the approval of the Desalination plants Environmental Impact Assessment (EIA) is relatively straightforward. This includes the assessment of the various issues that are involved in the development and operation of the project such as air quality, thermal recirculation, marine ecology, noise, water quality, solid waste etc. along with the socio-economic and health impacts. The path to Environmental Impact Assessment for a desalination plant is shown in Figure 6.19 below:

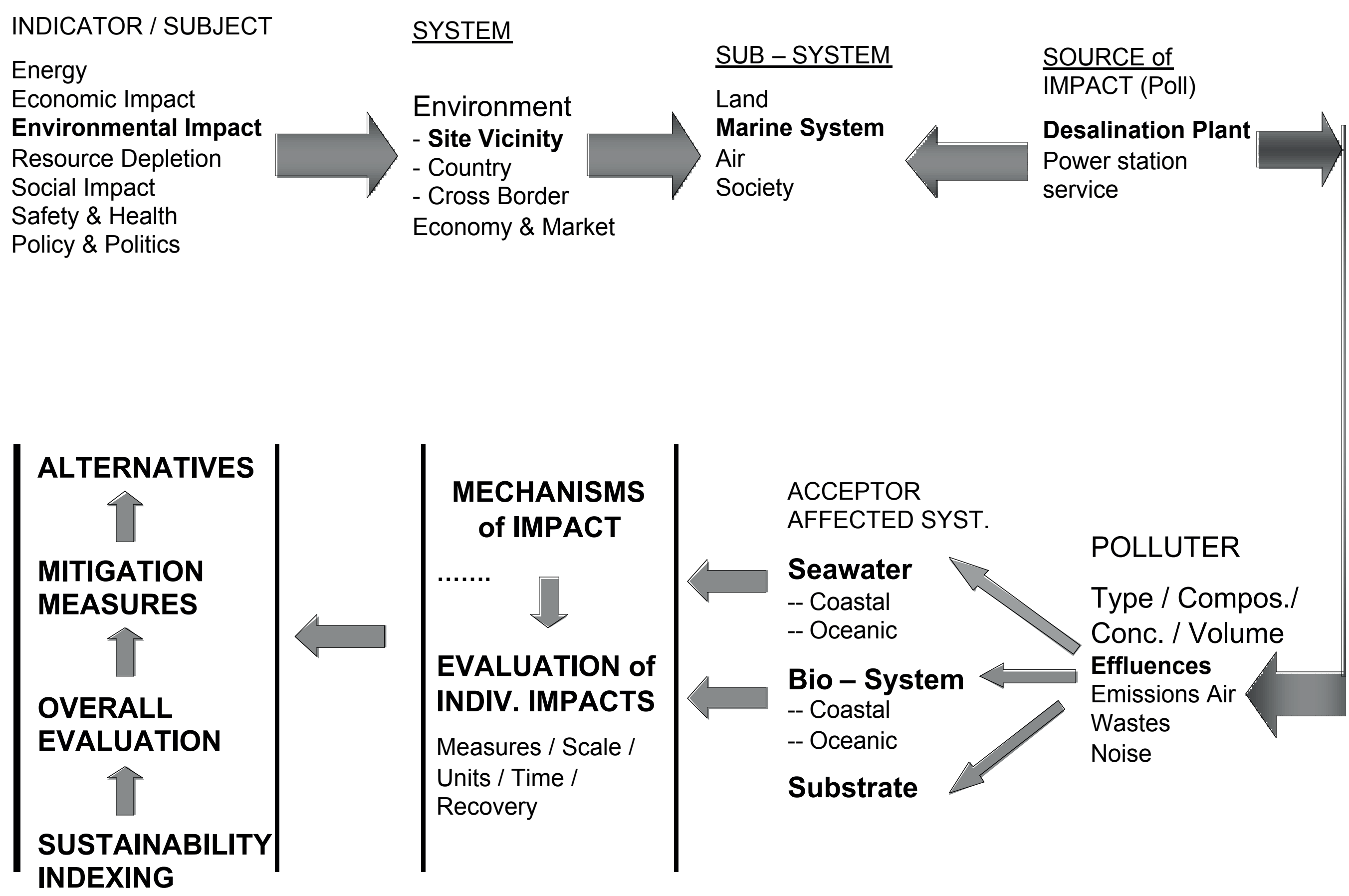

Figure 6.19 : Conceptual flow diagrams for Environmental impact assessment

The EIA compare the project's predicted performance against relevant environmental standards associated with the construction and operation of the project. These are in turn developed in compliance with the relevant National limits and guidelines but also shall be in line with the international guidelines that are nowadays developed in the water and power sector as those included in the World Bank Pollution Prevention and Abatement handbook of 1998, Industry Sector Guidelines, Water and Power Plants.

Like all industrial projects the Stages in the EIA Process include the preparation of

- Scoping of the Environmental Impact Assessment (EIA)
- Environmental Impact Assessment
- Construction Environmental monitoring plan (CEMP)

As desalination develops in countries outside the traditional Middle East region, different environmental issues may arise. This impacts on the time required to obtain the statutory permits in addition to any environmental concerns resulting from the technology adopted.

Sustainability of desalination technology has also posed several important questions due to both the relatively high energy footprint that is required to develop desalination processes and the impact of the seawater discharge on the marine ecology. In particular the development of several thermal desalination plants closely installed along some sites of the Arabian Gulf Coast line has brought about a substantial increase in both the average and maximum seawater temperatures in the surrounding area with respect to the historical seawater benchmarks.

(i) Seawater discharge

There are several publications in the desalination industry providing guidelines on how to approach the issues related to the environmental impact of desalination projects and therefore these aspects are dealt with in this book only in general terms I order to provide a technical and management guideline to the Reader.

It is important to understand the difference in the composition and volumes of discharges of each technology.

Temperature, residual chlorine and Total dissolved solids are issues for thermal desalination.

However heavy metals such as copper, nickel and iron as indicators of corrosion products, and dissolved additives such as antiscalants and antifoaming agents used in the process and discharged with the heat reject to the sea are also important aspects to be considered.

For SWRO process pre-treatment residuals for turbidity/suspended solids treatment such as coagulant chemicals, and residual disinfectants are issues to be considered. Furthermore brine discharge pH, membrane cleaning solutions should be carefully analysed in the plant design

Where combined discharges are produced the quality of the mixed effluents are generally monitored. Discharges need to meet local regional or national requirements established by environment protection agencies and monitoring programs will need to be consistent with these requirements.

The major issues in the development of desalination plants are related to impact on the marine ecology that are caused by the difference in temperature and salinity of the seawater discharged compared to the abstraction point.

The table 6.12 below provides some typical data for thermal energy dissipated in the ocean against the thermal desalination installed and the percentage increase in the salinity of the discharged effluent.

Table 6.12: Heat and salinity dissipation in the Ocean

Technology	Thermal MW dissipated in the Ocean per 10 MIGD	TDS increase in the reject brine compared with the seawater baseli

MSF (performance ratio 9)	150-170	15-20 %
MED (performance ratio 9)	120-160	15-20 %
SWRO	Negligible	50-80 %

As indicated in the energy flow diagram illustrated in Figure 6.4, the great part of the heat input to thermal desalination processes is returned to the sea with the seawater drain stream.

However as it was discussed in the energy session thermal discharges though could be sensibly reduced by increasing MSF and MED plant performance ratio.

There is a cost involved in increasing the plant performance ratio and in general the efficiency of the system. These costs are generally offset by the savings in the fuel and operation cost of the plant. However the pass through of unrealistic energy price aiming at subsidising the water tariff at generation point may discourage the adoption of more energy efficient technical solutions to the advantage of the initial CAPEX savings allowed by less efficient solutions. This is an important aspect that needs to be addressed by the desalination community to avoid the choice of technical solutions that may become unsustainable in the long term.

The difference between the temperature of the seawater drain and blowdown stream discharged to the sea and the baseline temperature is fixed at 10°C in modern plants but there are several old MSF plants operating with a differential seawater temperature across the distiller of more than 14-15 °C. It should be noted that significant more cooling water or higher performance ration would be required if the temperature rise is limited to only 3-5 °C.

(ii) Carbon footprint

The Energy Footprint is one of the most significant challenges in thermal desalination technology and despite technology is driven, mainly for cost reasons, towards more energy efficient configurations, the carbon footprint associated to the construction and operation of desalination and waste water treatment projects is an aspect that will require more and more attention by the industry.

The carbon footprint is intrinsically related to the energy requirements.
in particular the carbon footprint of each desalination technology can be calculated by applying a grid emission factor to the energy input that has been illustrated in Session 6.1.5 above .

In the Middle East where power generation plants are of new construction and operate with combine cycle, it is reasonable to consider an average grid emission factor of 0.5 Tons of CO_2/MWh.

In this case the situation in terms of carbon footprint from the desalination plants can be summarised by the Figure 6.20 below .

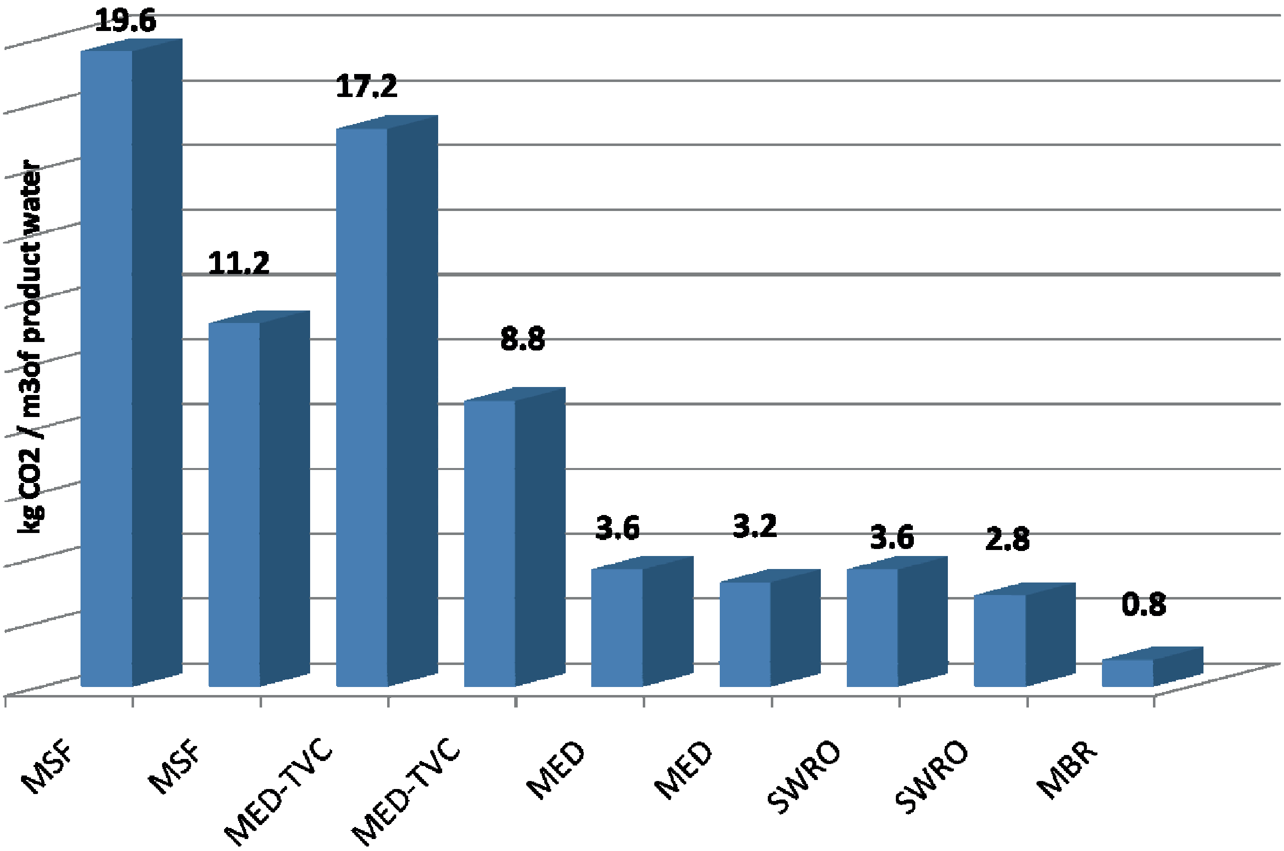

Figure 6.20: desalination technologies operating carbon footprint comparison

There are renewable energy driven desalination plants operating on a relatively small scale. New emerging technologies such a membrane distillation offer excellent opportunities to develop renewable energy driven desalination. Unfortunately low energy footprint technologies are still to be developed on a large industrial scale and the majority of the installations particularly in the Middle East operate with relatively inefficient and obsolete thermal desalination technologies coupled with cogeneration systems.

At least 80% of the water produced by desalination plants is used for non domestic purposes and could be substituted with treated waste water with a much lower energy and carbon footprint.

A lifetime scenario comparison should also consider the impact of the construction footprint on top of the operating footprint

It is difficult to make a reasonable comparison of the CO_2 required to construct a plant, however the impact of the construction footprint can be considered proportional to the weight of the material used for the construction of the plant as well as to the duration of the site work. The difference in weight of material between various technologies can be quite substantial. MED typically requires two thirds of the material used for MSF due to more efficient heat transfer mechanisms. SWRO can require even less material is operating with conventional filtration.

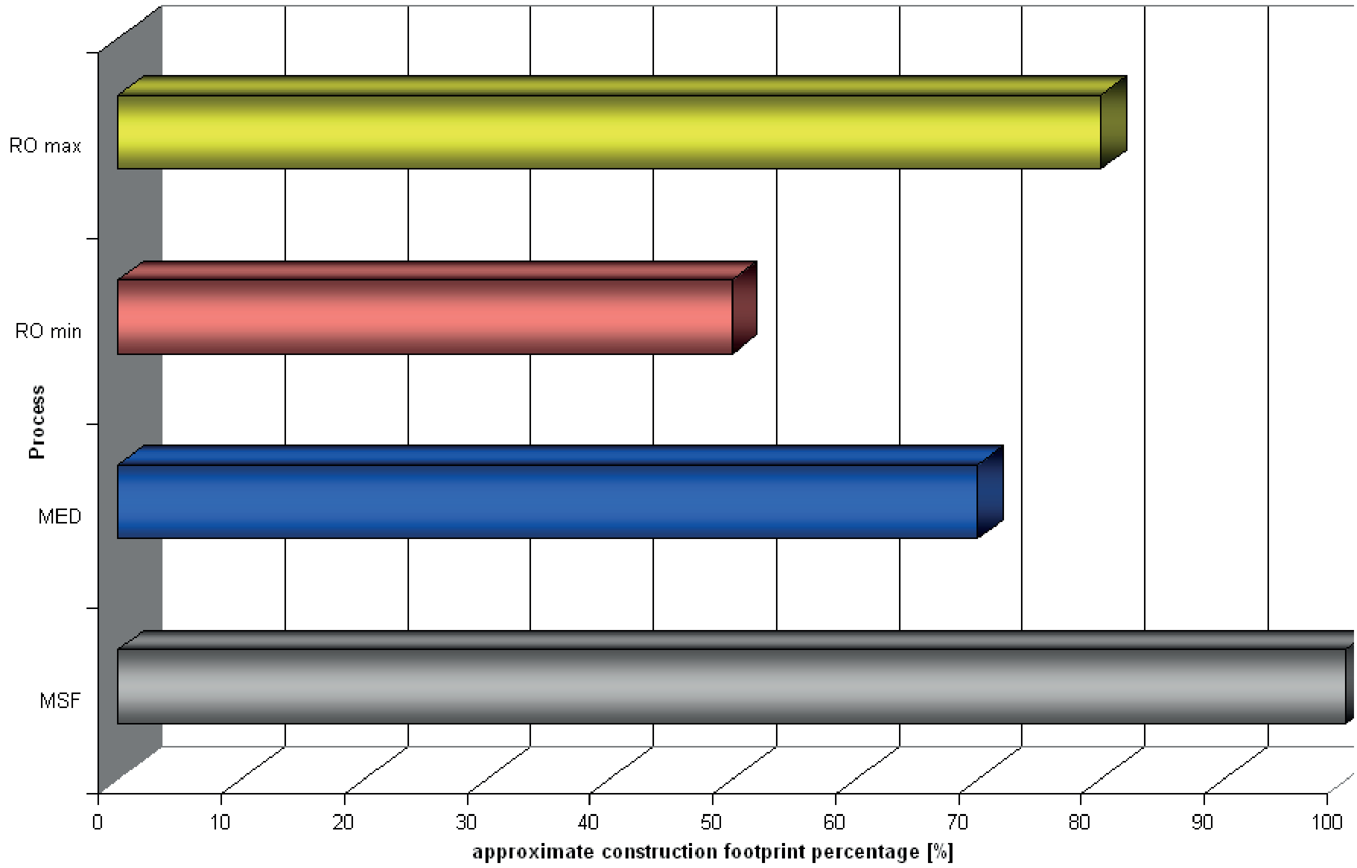

Figure 6.21 construction carbon footprint comparison

The plant lifetime should be also taken in consideration. MSF plants have a lifetime of more than 30 years and a great quantity of materials adopted for the heat transfer tubes and clad sheets can be recycled.

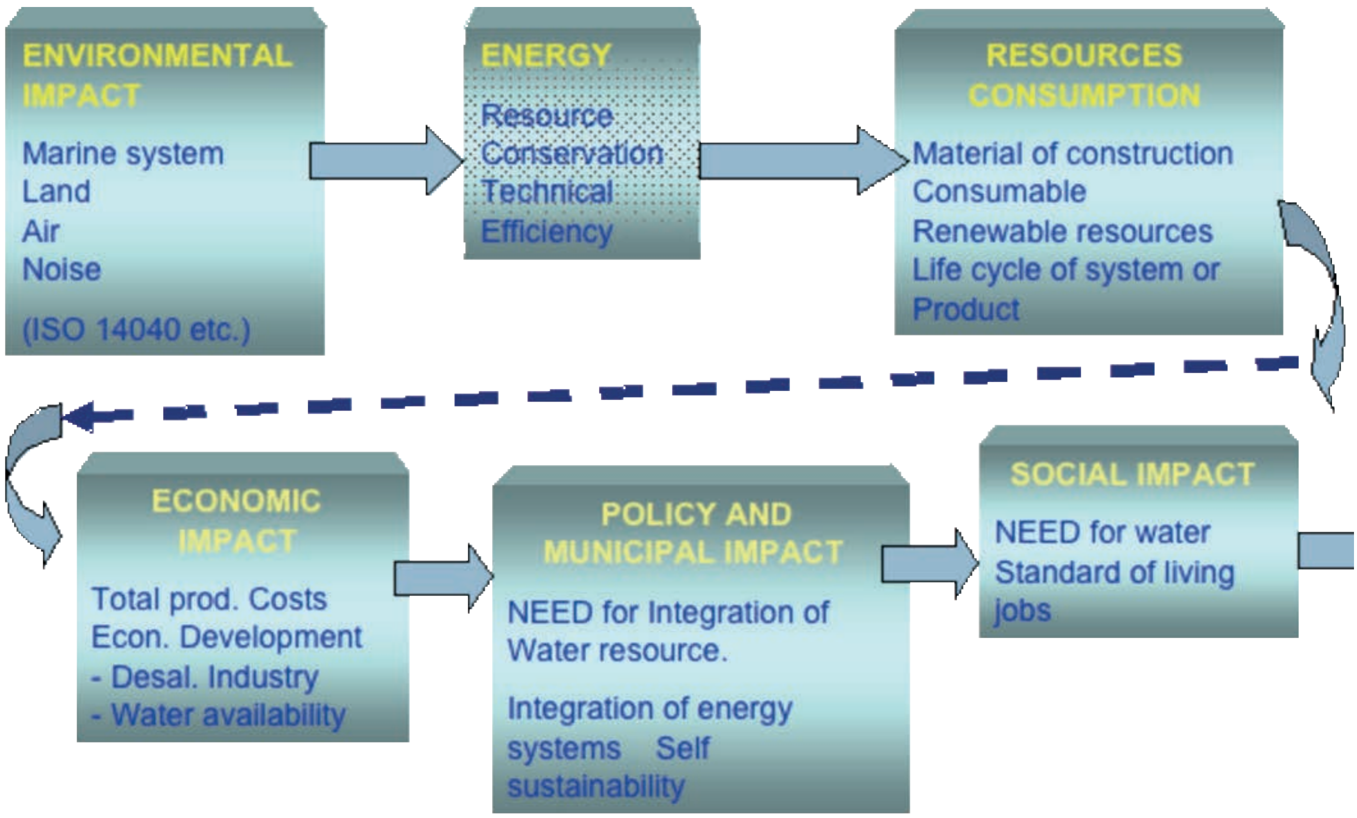

Figure 6.21 : sustainability approach for desalination and water reuse projects

6.2 Comparison of desalination technologies

Previous chapters have summarised in principle the process feature of each technology and therefore aims at describing the main differences in terms of energy, seawater use, land footprint availability etc. of the technologies available..

The table 6.13 below summarises the major features of these | technologies based on today's state of art.

It should be always considered that technologies have developed very quickly over the last ten years and therefore a summary comparison may shortly become obsolete.

Table 6.13 : desalination technology comparison synoptic table

	SWRO	MED-TC	MSF	Comment
Capital Cost	Low to medium	Medium	Medium to High	
CAPEX sensitivity to LME index	Medium	High	Very high	Thermal desalination costs are heavily loaded b heat transfer tubes – tubeplates – clad sheet etc and therefore sensitive to market variation of LME
Electric Power [kWhr/m^3]	3.5-5.5	0.7-1.5	3.0-4.5	Power consumption includes using energy recovery in RO
Performance ratio Kg $_{steam}$ **/ kg** $_{distillate}$	N/A	1:6 to 16	1:7 to 10	Design dependant. Cost increases with efficienc MED can be designed for PR of 16 subject to energy prices. Whereas MSF is practically limit to PR=10
Overall energy requirement	Medium to low	High	Very high	Thermal desalination energy requirement is very high particularly in cogeneration schemes
Chemicals	US$0.06/m3	US$0.03/m3	US$0.03/m3	Pre-treatment/ antiscalant/ Cleaning typical cos at year 2005-2007
Consumables	High	Low	Low	Filters and Membranes. Other consumables
Product Water	<500ppm	<10ppm	<10ppm	Dependant on use. Boron issues for potable exis in SWRO.
Reliability	Variable	High	High	Dependant on pre-treatment
Manpower	Medium	Low	Low	Larger train sizes for thermal means lower manpower requirement
Pre-treatment	High	Low/Medium	Low/Medium	Membrane pre-treatment is critical
Seawater requirements	Low (*)	Medium - High	High	(*) depending on pre treatment
Cleaning	4/Annum	1/Annum	1/Every 2 Years	Normal cleaning frequency. Membrane can be more

Availability	95% to 100% Depending on redundancy	98%	98%	Based on downtime for cleaning
Plant Life	15-20 years	15-25 years	25-40 years	Proven life on large thermal plant

There are particular aspects of each project such as availability of steam, robustness and reliability, particular site conditions or potable water requirements that may render one or the other technology more adequate for the project. The comparison is normally considered on a lifecycle basis. Given the long lifecycle of the desalination assets and their strategic importance both from a political and social view point, a fair comparison should take into account in addition to the present state of the art, the possibilities of future development both in the market price of energy, manpower and environmental requirements. In addition, consideration should always be given to the possibilities of technical improvements in the specific technology and possibilities of retrofitting these improvements in the plant during its life.. If on one hand due to technology obsolescence, the operation of the plant may become uneconomical during the lifetime of the plant through periodic rehabilitation there is the opportunity to upgrade the assets with new technologies and provide plants with increased capacity and efficiency using ideas like NF and integrated upgrading.

7 Financing and contracting desalination and water treatment plants

Desalination plants are long life assets requiring large capital expenditures both at the stage of project development and at the stage of operation and maintenance after the plant has been commissioned.

Historically borrowing directly from the government has been the most popular method of financing this long-term expenditure.

For long term in the water sector this has been in the part the cheapest, most common and in some cases the only available option to finance power and desalination projects.

This was the case worldwide until the 1990s when revenue funds began to be severely restricted and capital expenditure controls became much more stringent and privatization was in most cases the most practical option to achieve the implementation of new processes.

This has been slightly different in the Middle East where the power and desalination privatization process main driver was not the lack of funds but the necessity of improving the efficiency and implementation of the management process

Public Corporations have different types of options for contracting new projects. The main options available foresee both the Public Corporations delivering the project or the involvement of the Private Sector. The options are as follows:

- Public service as Multi-contracts, traditionally specified
- Public service Turnkey contracts, traditionally specified
- management contracts
- Operation and maintenance contracts
- Design build and operate (DBO)
- Concessions in terms of
    - BOT- BOO (Build-Operate-Transfer) – (Build-Own-Operate)
    - IWP-IWPP (Independent Water Projects-Independent Water and Power Projects)

Figure 7.1 below shows some of the most widely adopted options for the management of power and desalination projects. The level of involvement of the private sector both in terms of risk exposure and level of investment increases as the contract strategy goes from public to management structures up to private projects.,

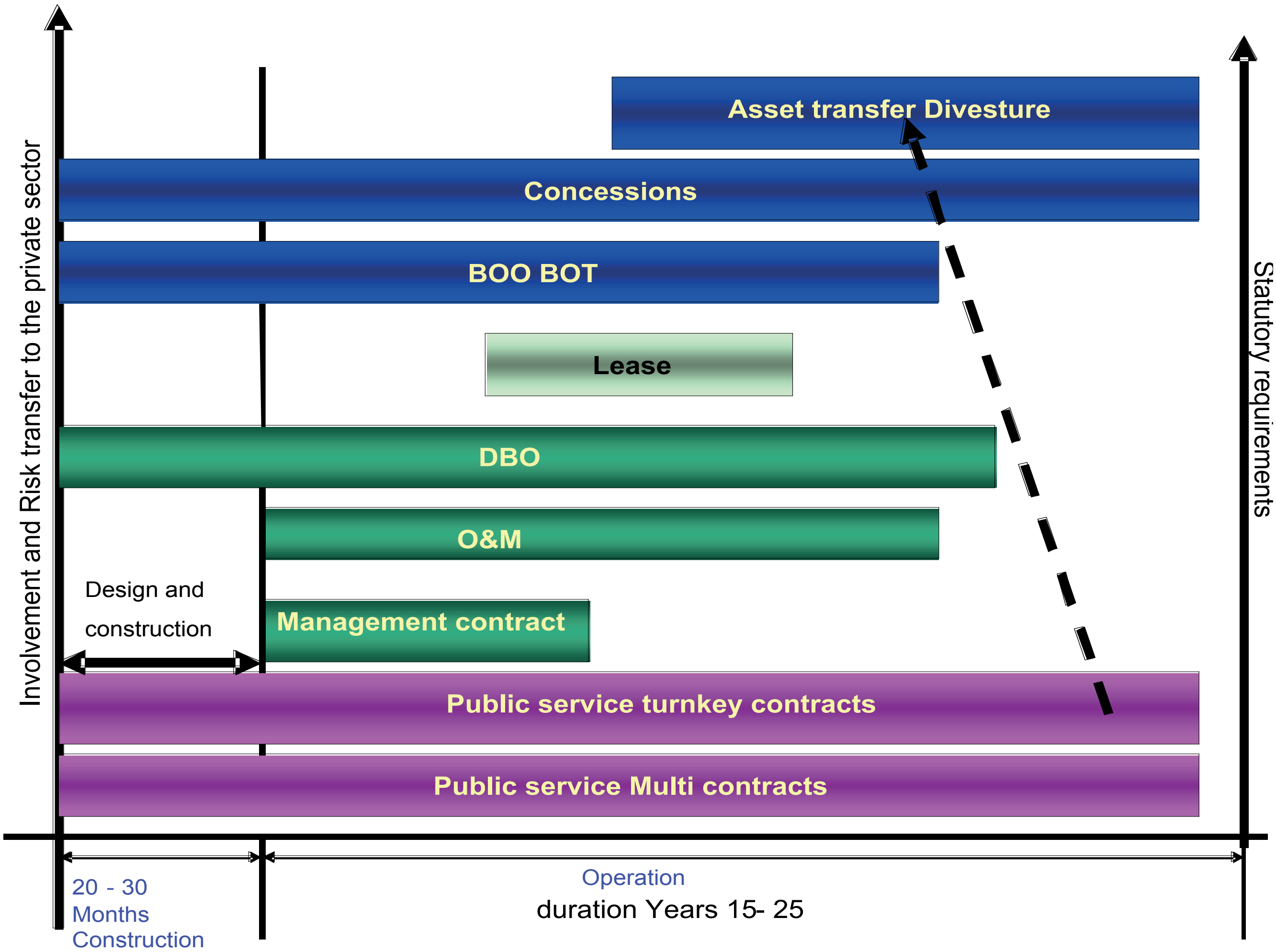

Figure 7-1 desalination plants construction and operation models

As the private sector involvement increases there is a greater requirement for statutory services that regulate the services provided by the private sector and assumes the responsibility of over viewing the matters relating to the economic and financial performance of the sector companies including the sector tariffs and related charges.

The regulatory services ensure that competition in the sector is promoted to ensure the operation and development of an efficient and economic sector, and to protect the interests of water and power consumers regarding the terms and conditions and supply costs.

In Figure 7.1 the projects implemented in a Public Environment and are indicated in purple present the lowest involvement of the private sector.

As it can be seen from Figure 7.1 , in Multi Contracts traditionally specified and in Turnkey Contracts, the involvement of the private sector is limited to the procurement and delivery and commissioning of the individual work packages.

~~1.1~~7.1 Multi contracts

The implementation of Multi Contracts, foresees the Public Corporation to take the responsibility of assembling the various work packages that are separately awarded to several different turnkey contractors.

Each of the turnkey contractors is in turn delivering work packages as shown in Figure 7.2 below.

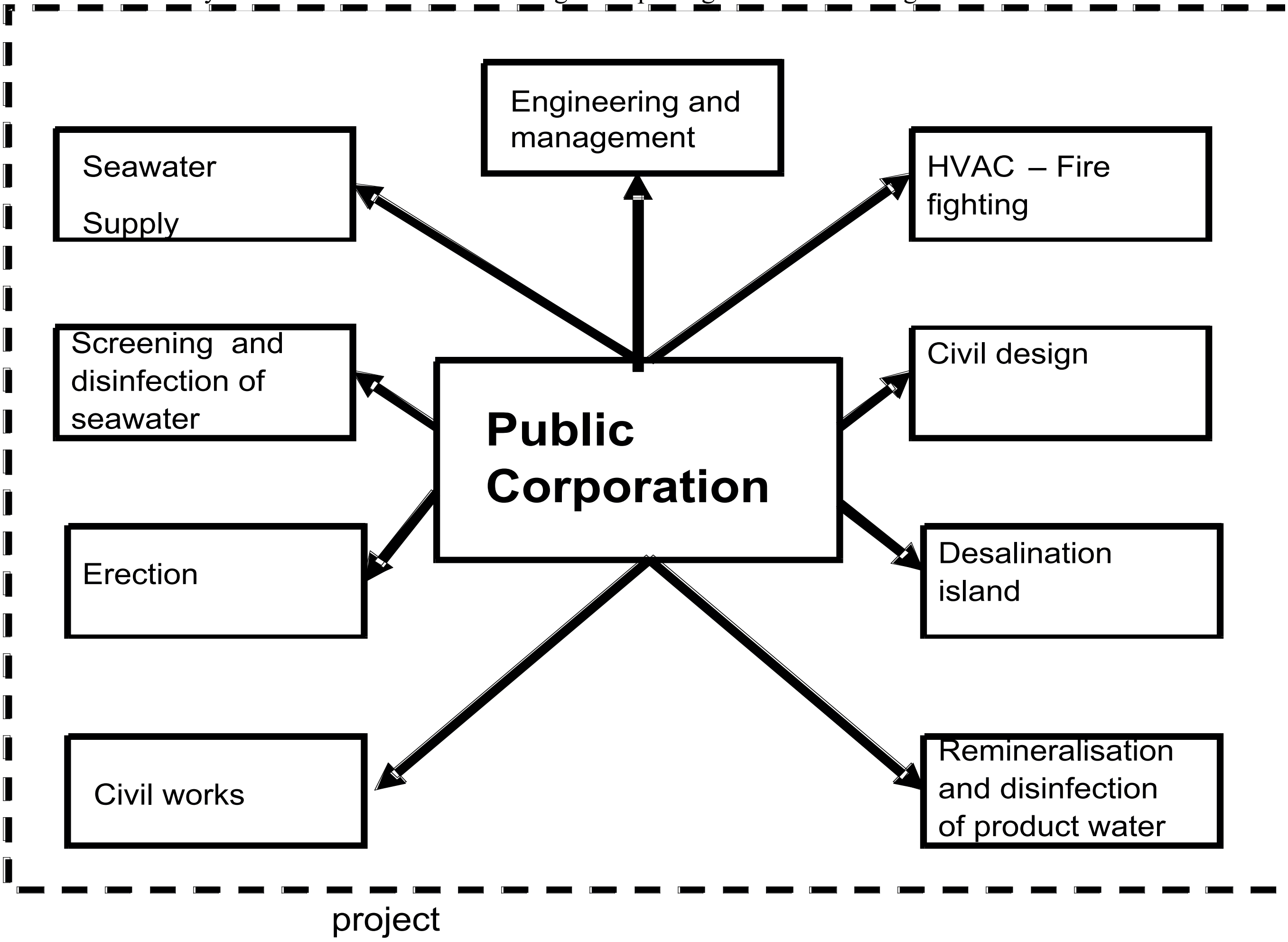

Figure 7.2: Typical Multi Contract Structure

This contracting method allows relatively good control over the assets quality as Public Corporation is directly responsible for the procurement and supervision of each work package.

In addition this procurement method may allow a certain reduction of the capital costs as no overheads, risk factors or profit margins are imposed on the packages as would be the case for full turnkey contracts.

The drawback of Multi Contract approach is that the performance and delays risk lies with the Public Corporation. In particular, procuring various work packages from separate sources may be the cause of interface problems and delays.

This involves managing interface issues between each package, coordinating the delivery times so that a component of the plant is delivered in line with the overall project schedule.

The risk of performance shortcomings and delay in delivery may lead to cost overruns if responsibilities cannot be allocated to a leading Contractor.

For this reason, the Multi Contract requires substantial engineering resources, experienced management and supervision capabilities. Furthermore, Multi Contracts can be successfully applied to projects similar to previous installations where the detailed specification of each package can benefit from the operational feedback gained by the Public Corporation.

However, this method tends to be backwards looking and does not consider the advantage of technology innovation.

The Multi Contract method is no longer fashionable in the water and power sector as Public Corporations tend to outsource their engineering and management requirements. However a modified form of Multi Contract is still implemented in some plants where the turnkey responsibility for the desalination island is with a Contractor and overall plant responsibility with the Public Corporation.

Table 7.1 Typical thermal plant Multi Contract Division of work

Work package	Public Corporation	Turnkey contractor	Notes
Desalination island including - distiller - vacuum system - process pumps - brine heater – steam transformer		X	
Civil works	X		
Erection	X		
Remineralisation		X	In some cases are excluded from turnkey contractor scope
Potable water disinfection		X	Ditto
Potable water storage	X		Ditto
Seawater intake – outfall	X		
Seawater disinfection	X		
Seawater screening	X		
Supervision on erection		X	
Commissioning		X	
Permits	X		
Seawater and steam piping interconnection	X		

The SWRO market tends to be more diversified than the thermal desalination market therefore it is more frequent to encounter suppliers of pre-engineering packages for the SWRO Island or for the ultra filtration or micro-filtration pre-treatment that would not take the full turnkey risk.

Table 7.2 Typical thermal plant Multi Contract Division of work

Work package	Public Corporation	Turnkey contractor	Notes
RO island including - membranes - High pressure pumps - High pressure piping - Energy recovery device		X	
Pre-treatment		X	
Civil works	X		
Erection	X		
Remineralisation		X	May be excluded from turnkey contractor scope of work
Potable water disinfection		X	Ditto
Potable water storage	X		Ditto
Seawater intake – outfall	X		
Seawater disinfection		X	May be excluded from turnkey contractor scope of work
Seawater screening	X		
Supervision on erection		X	
Commissioning		X	
Permits	X		
Seawater and steam piping interconnection	X		

~~1.2~~7.2 Turnkey contracts

Turnkey contracts are sometimes defined as EPC, (Engineer-Procure and Construct) present a certain increase in the private sector participation to the project, as turnkey contractors assume the responsibilities for delays in project completion and project performance.

The risk is transferred to the EPC contractor under the form of liquidated damages for delays and performance shortfalls.

A possible disadvantage of this contracting method is that it is more expensive than Multi Contract and requires the availability of potentially large funding in a short time during the design and construction phase.

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Table 7.3 and 7.4 show the most important parameters linked to liquidated damages in turnkey contracts for delays and performance shortfall.

Table 7.3 Delay liquidated damages key principles

Calculation	Coverage principles
Daily basis per day of delay	Liquidated damages or penalties per day of delay payable to other parties (off takers etc) Means to procure water from alternative sources Debt interest costs (excl. interests on Equity Bridge Loan), Project Company or public corporation Fixed overheads For turnkey contract awarded by a developer, LD generally cover Sponsors' equity return.

The situation in terms of risks and penalties are applied may differ according to the scenario in which the turnkey contract is stipulated.

For turnkey contract awarded to by a Developer providing in turn water to a Public Corporation as the final offtaker of the project, the calculation of LDs is generally carried out projecting the loss of operating revenues (i.e. net of fixed and variable costs) on a discounted basis.

The situation is different for Public Corporation where delays liquidated damages cover the cost to procure water by alternative means, and Public Corporation fixed overheads. In case of termination the LD cover the cost of making the plant good after having removed the turnkey contractor from site.

Performance Liquidated damages referred as lump sum amounts to compensate the plant underperformance. Table 7.4 below shows the parameters that are normally applied to link performance of the Plant to guarantees or liquidated damages for performance shortfall in thermal desalination plants.

Table 7.4 performance shortfall liquidated damages key principles thermal plants

Calculation parameter	Coverage principles
Water Capacity -%: reduction	Fixed Lump sum or \$.XXX per m^3 of performance shortfall
Power consumption	Fixed Lump sum or \$.XXX per kW additional power consumption
Steam consumption	Fixed Lump sum or \$.XXX per additional ton of steam inlet to the plant or per % degradation in the plant performance ration
Specific chemical consumption	Fixed lump sum
Potable water quality	Fixed lump sum

A particular feature of thermal desalination plants is represented by the fact that process performances can be accurately assessed during the early phase of commissioning and generally not later the Final Plant Acceptance.
Shortcoming may still occur due to corrosion or equipment failure but generally these are covered by latent defect warranty clauses and do not affect the process performance of the plant.
The possibility of performance shortfall in thermal desalination projects can be related to insufficient

capacity, higher specific power consumption and scaling and fouling that prevent the achievement of the required performance ratio.

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If such shortcomings are present, they would be clearly identifiable at the time of the performance or reliability test. Therefore, the End User has the opportunity to evaluate the plant performance for comparison with the performance guaranteed by the Turnkey Contractor.

In particular the features of the technology and consolidated operational experience in the last twenty years has shown that in thermal plants only minor reductions in plant performance may be expected and these are the result of scaling of the heat transfer tubes.

In particular as it can be seen in the Figure 6.2.3, after a few months operation, the fouling factor in the heat transfer tubes tends to stabilise and as a consequence the performance ratio as well. No or little performance decline is generally experienced afterwards.

All process aspects that affect the performance and the operating and maintenance costs of the plant can therefore be tested within few months from the start up time.

Figure 7.3 shows the typical behaviour of the performance and product water quality during the commissioning phase of a MSF plant throughout the first year's operation.

As can be seen, after the first two months operation the performance ratio is stable and constant and no decline in performance occurs for the next twelve months. Production of distillate water is also constant since the days of operation from the time the unit operates at the required top brine temperature (TBT) and process flow rates.

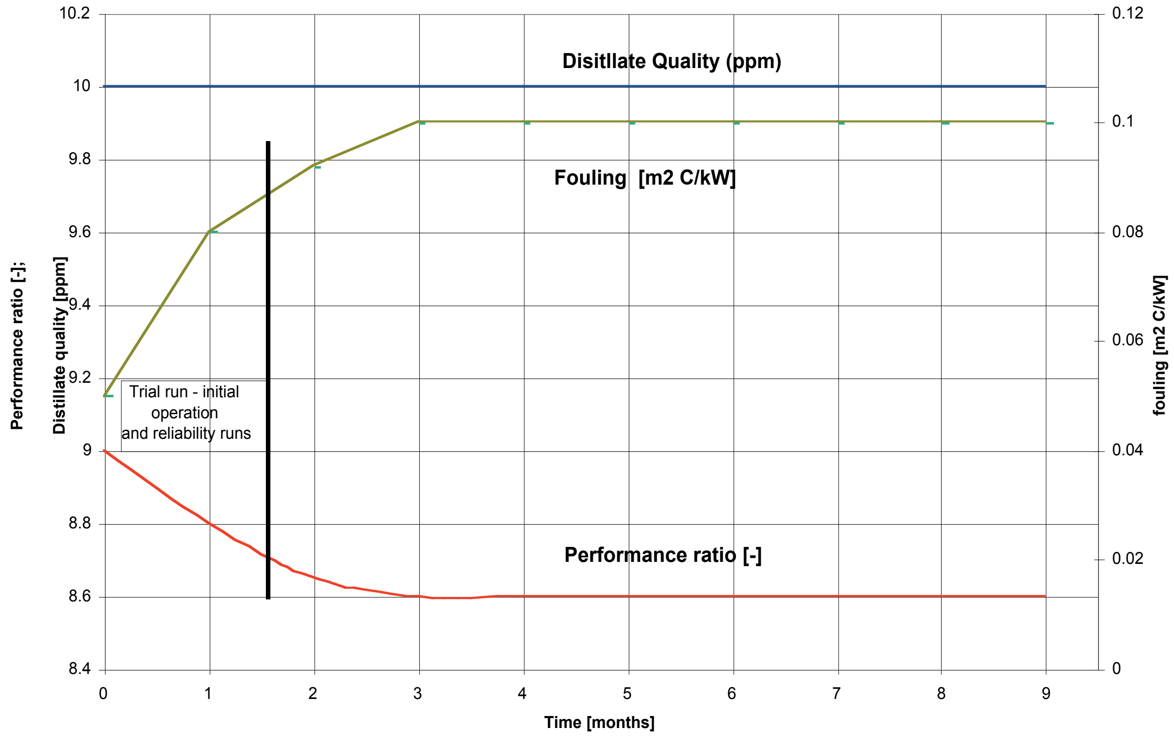

Figure 7.3 Typical MSF performance ratio behaviour between acid cleanings

This trend has been observed on many MSF desalination plants and is now quite a consolidated process pattern, therefore at the time the plant is performance tested (30-60 days after initial commissioning) it is normally possible to have a clear indication of the long term plant process performances.

Clearly in this situation Liquidated Damages are an effective tool to protect the End User from any shortcoming in process performance as the End User has unconditional access to the turnkey contractor both by retaining final payment and through liquidated damages. In this scenario, the turnkey Contractor clearly bears the performance risk.

On the contrary, the application of liquidated damages to SWRO project turnkey contracts has always been more controversial than for thermal desalination projects. This is due to the fact that the performances of SWRO projects are strongly dependent on the performance of the pre-treatment systems that have been traditionally identified as the "Achilles heel" of the SWRO process.

Furthermore, despite the fact that the Reverse Osmosis plant can operate initially in accordance or even better than specified, it is possible that major performance shortcomings become apparent after a few years of operation.

Particularly, many of the main parameters affecting variable operating and maintenance costs such as the membrane replacement rate cannot be verified in practise before handing over the plant to the End User in a traditional turnkey contract.

If, for instance, the pre-treatment and seawater disinfection regime has been inefficient in producing good feed water quality to the reverse osmosis plant, section performance shortcomings may become evident after long periods of operation.

It is not unusual that the plant performance is maintained during the first years (2 to 3) of operation. However, problems will occur after a few years.

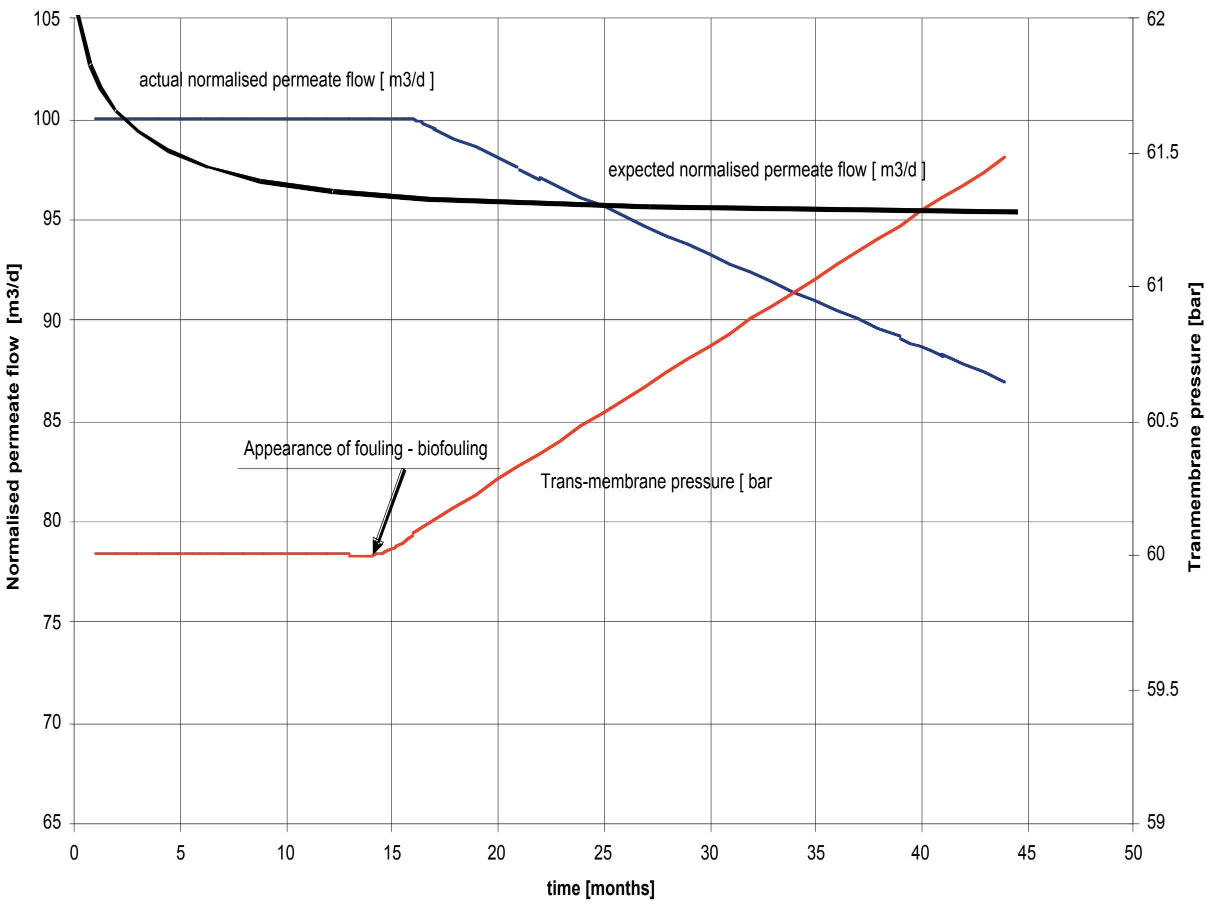

Figure 7.4 Possible SWRO project departures in long time from expected conditions.

These departures may take the form of higher than forecasted membrane and cartridge replacement rates, more frequent cleaning of the system, problems in obtaining the required levels of conductivity in the product water leading to reduced flux higher pressure required to operate the first RO pass or higher chemical dosing and bio fouling phenomena.

The Figure 7.4 and 7.5 shows the situation that would occur with an expected membrane replacement rate forecast that has shown departures after few years of operation and therefore involves a higher frequency of membrane replacement than expected.

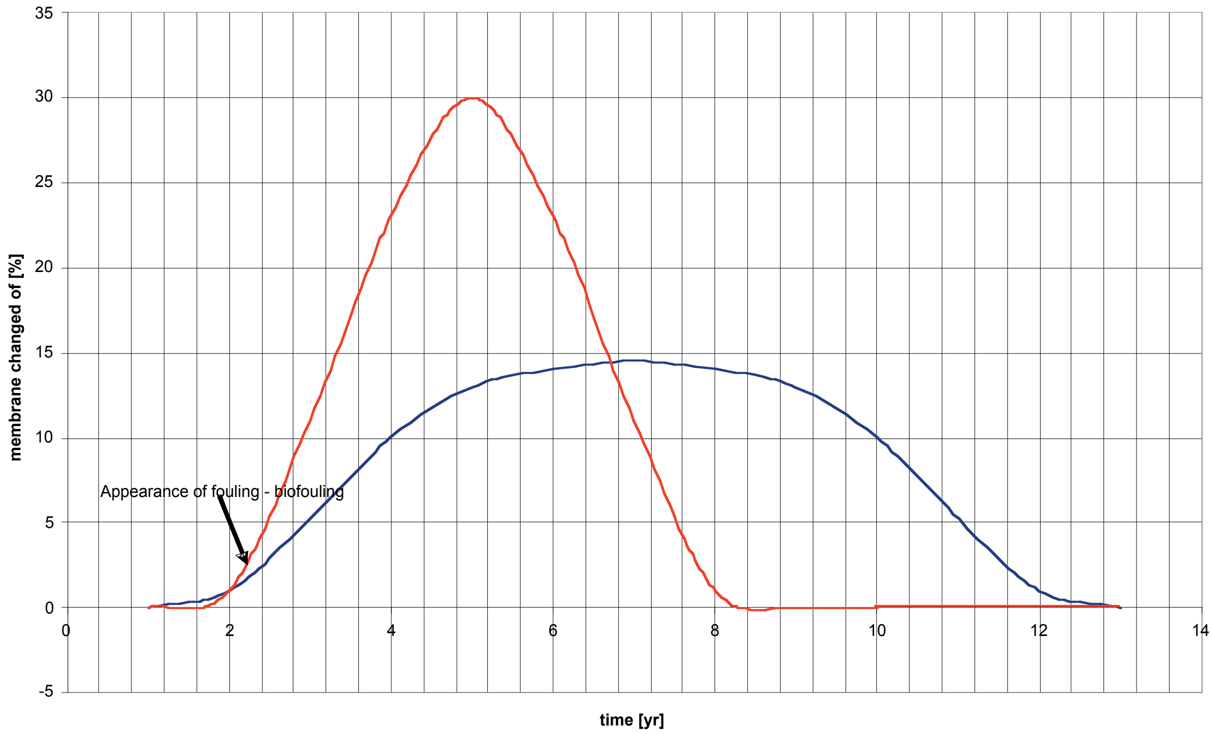

Figure 7.5 Possible projected and actual membrane replacement rate as pre-treatment shortfall result

In this scenario liquidated damages for performance shortfall are not an effective tool to protect the End User from performance shortfalls as the End User would have no access to the Turnkey Contractor cash or any contractual power to request that the plant be made good by the Turnkey Contractor.

The interface between the Turnkey Contractor and the End User may be further complicated if there has been poor maintenance, low replacement, ,tough operating conditions or poor seawater quality in the previous years of operation. In this case, responsibilities are not clearly allocable to any particular party.

The majority of shortcomings in process operations with membrane systems have resulted from poor performance of the pre-treatment system. The most common way to protect the procurer of a reverse osmosis plant from pre-treatment shortcomings is to foresee a guarantee on the seawater quality feed to the membrane that is in accordance with the membrane manufacturer requirements.

The values that are nowadays accepted from membrane manufacturers as raw water quality for the membranes are:

- SDI (Silt Density Index) of incoming water < 4 for 95 % of the time
- SDI (Silt Density Index) of incoming water < 5 for 100 % of the time

Not fulfilling these feed water quality values may invalidate the membrane guarantees. However it may be possible that good SDI values are obtained as a result of the filtration carried out by the cartridge filters that are installed only for high pressure pump protection.

In this scenario it may be possible that the End User suffers higher cartridge replacement rates than scheduled and therefore higher Variable Operation and Maintenance costs. For this reason it is common practise that both cartridge replacement rates and SDI are guaranteed so that the End User may request the plant to be made good in case of departures from the guaranteed values.

Table 7.5 performance shortfall liquidated damages key principles for SWRO plants

Calculation parameter	Coverage principles
Water Capacity -%: reduction	Fixed Lump sum or $.XXX per m^3 of performance shortfall
Power consumption	Fixed Lump sum or $.XXX per kW additional power consumption
Potable Water quality	Fixed Lump sum
Guarantees	
	Membrane replacement 1st pass 2nd pass UF MF if applicable Chemical consumption Silt density index of pre-treated water upstream cartridge filtration (SWRO-BWRO)

Same concepts can be applied to waste water treatment plants using membrane as MBR or side stream ultra filtration/micro filtration since ultimately membrane performances can become evident only after the plant is in operation for a few years. Also water treatment plants present nuisance issues such as odour and noise whose performance may also may become apparent after few year of operation and therefore operational departures may be hard to verify at the initial plant operation. Furthermore, the operation of waste water treatment plants is generally affected by the availability of sufficient waste quantity to maintain the biomass inside the plant in line with the influent water operating envelope.

This has been a problem in MBR plants in the Middle East serving new development as the occupancy of the residence served by the treatment plant was slower than envisaged and therefore the plant could not operate in stable conditions let alone be tested.

Table 7.6 performance shortfall liquidated damages key principles for MBR plants

Calculation parameter	Coverage principles
Water Capacity -%: reduction	Fixed Lump sum or $.XXX per m^3 or % of performance shortfall
Power consumption	Fixed Lump sum or $.XXX per kW additional power consumption or % increased power production
Guarantees	
Membrane replacement	
Chemical consumption	
Noise	
Odour	
Sludge Dryness	
TSE quality	

~~1.3~~7.3 Management contracts

Particularly for SWRO and water treatment projects a very effective and popular contracting method has been the design build and operate (DBO) scheme.
This contracting scheme involves the private sector in the design and construction of the plant and a follow up with a 10 to 20 years operation and maintenance contract.
Since in this case the turnkey contractor assumes the responsibility for the long term operation of the plant, both capital and operating costs will be optimised and the likelihood that pre-treatment design shortfalls may turn into a reduction of capacity are reduced.

~~1.4~~7.4 Private finance initiative

With the increase of the water demand and the need of more desalination plants, the public sector has been seeking the help of the private sector in order to develop large infrastructure projects in order to relieve the financing burden of the government. Private finance initiatives foresee the financing of infrastructure projects with an upfront spend element in a way that removes recourse by the lenders to the Sponsors (non recourse financing), or limits such recourse (limited recourse financing). In such projects the sole security of the lenders is the revenue stream and assets of the project. Project financing initiative are generally deals structured to move liabilities from the Sponsor's balance sheet and contain the risk in the project vehicle company.

Privatization of desalination projects began in the Middle East at the end of the 1990's. This process was accompanied by a progressive restructuring of the water sector.
Private finance initiative is an alternative method of raising finance for capital projects such as power and desalination without adding to the national debt.
The Public sector acquires services cost-effectively through a competitive process rather than directly owning and operating assets.
The private sector is invited to put together consortia that bid to provide a specified power and water outcome through a process of negotiation.

The public sector then pays for the delivery of the water (and electricity in combined power and desalination initiatives) by the private sector partner, rather than procuring power and desalination assets that are used to provide that service.

In financial terms, shifting from a publicly-funded capital scheme to a publicly-funded *revenue* scheme.

The introduction of privatization in the desalination business at the end of the years 90's and beginning of 2000 has greatly contributed to generate lower desalination costs and introduce new technology innovation in the sector.

This process has allowed to obtain :

- A lower overall cost, i.e. improved value for money.
- A level of service better than that delivered to customers when assets have been procured and operated by the public sector.
- Transfer to the private sector of many of the risks of delay and potential cost increase that it is best placed to manage.

The project finance model tends to generate lower CAPEX and OPEX costs due to a more market service oriented basis and despite (as it can be seen from the Figure 7.6 below) the financing costs tend to be marginally higher, the general effect is a reduction of OPEX and CAPEX that is capable of generating a lower final water/power tariff.

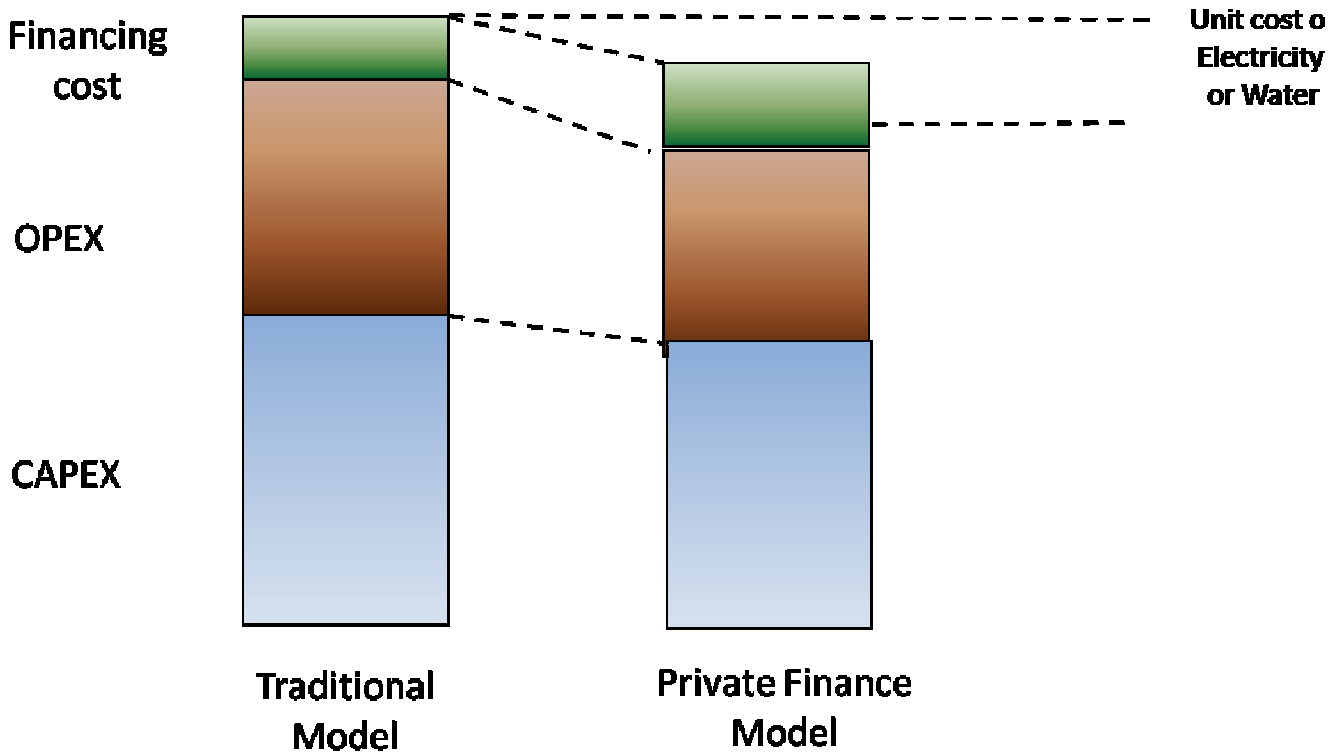

Figure 7.6: traditional turnkey versus private project typical CAPEX OPEX and financing cost structure

In a Private Finance Initiative project, private sector consortium establishes a company, **a Special Purpose Vehicle** (SPV) which then raises the finance necessary via the means available to all private sector companies such as the issue of risk capital (shares), borrowing etc. The **Public Service Body** then pays for the delivery of service via an agreed payment mechanism relating to volume, quality and performance.

It has been discussed whether the cheaper way to provide the public with water (and power) services is to procure them with public money through the direct funding or borrowing from the government
Despite the traditional funding system may provide cheaper capita, it should be considered that Public Corporations are generally oriented at emphasising engineering robustness to minimise future risk, and do not intend in general to manage a technological and commercial risk.
In the past this has often resulted in expensive plants, whose performances are not optimised and difficulties in the implementation of new technologies capable of enabling lower water costs.

In this respect, the Private Finance Initiative has allowed :

- The private sector to inject risk capital (which is not available to the public services) into the water sector
- The Special Purpose Vehicle to assume responsibility for raising the funds from the private sector,
- The Special Purpose Vehicle to provide the management and expertise to manage the development efficiently and in the process accept the risks – particularly in time and cost which would previously have rested with the Public sector,
- There were several cases where the Public Sector has not been able to pay for the plant and this has caused difficulties in borrowing capital for power and desalination plants.
- Because of the open tendering, have in place a firm, committed and competitive contract,
- Use of public money will have been delayed until the scheme is operational and will then be revenue. This allow the Public sector a better cash flow and disbursement profile
- Appropriate contract rewards against the risks assumed by the private sector and therefore a more industrially oriented approach to water generation

When a private project is implemented, Public Corporations have the choice to retain a certain amount of equities in the newly created Special Purpose Vehicle. This allows retaining some control of the project but also gives confidence to the Private Sector

Private projects generally foresee a program to develop a comprehensive policy for training and development of locally employed staff and a detailed training plan addressing all key aspects of plant operation, maintenance and management . It is customary that during the plant operations period, the Project Company (subject to suitable educational qualifications, experience and cost competitiveness) commits to employ local nationals at various project levels.

Figure 7.7 shows a typical structure for an IWP (or IWPP = independent water power project) with Government and Public Corporation participation. This structure was implemented recently in several projects in the Middle East.

In the example indicated in Figure 7.7 the Private sector retains Y% of the equities of the Project Company while the Government through different sectors of Public Corporations retain X % and Z % of the project Company equities.

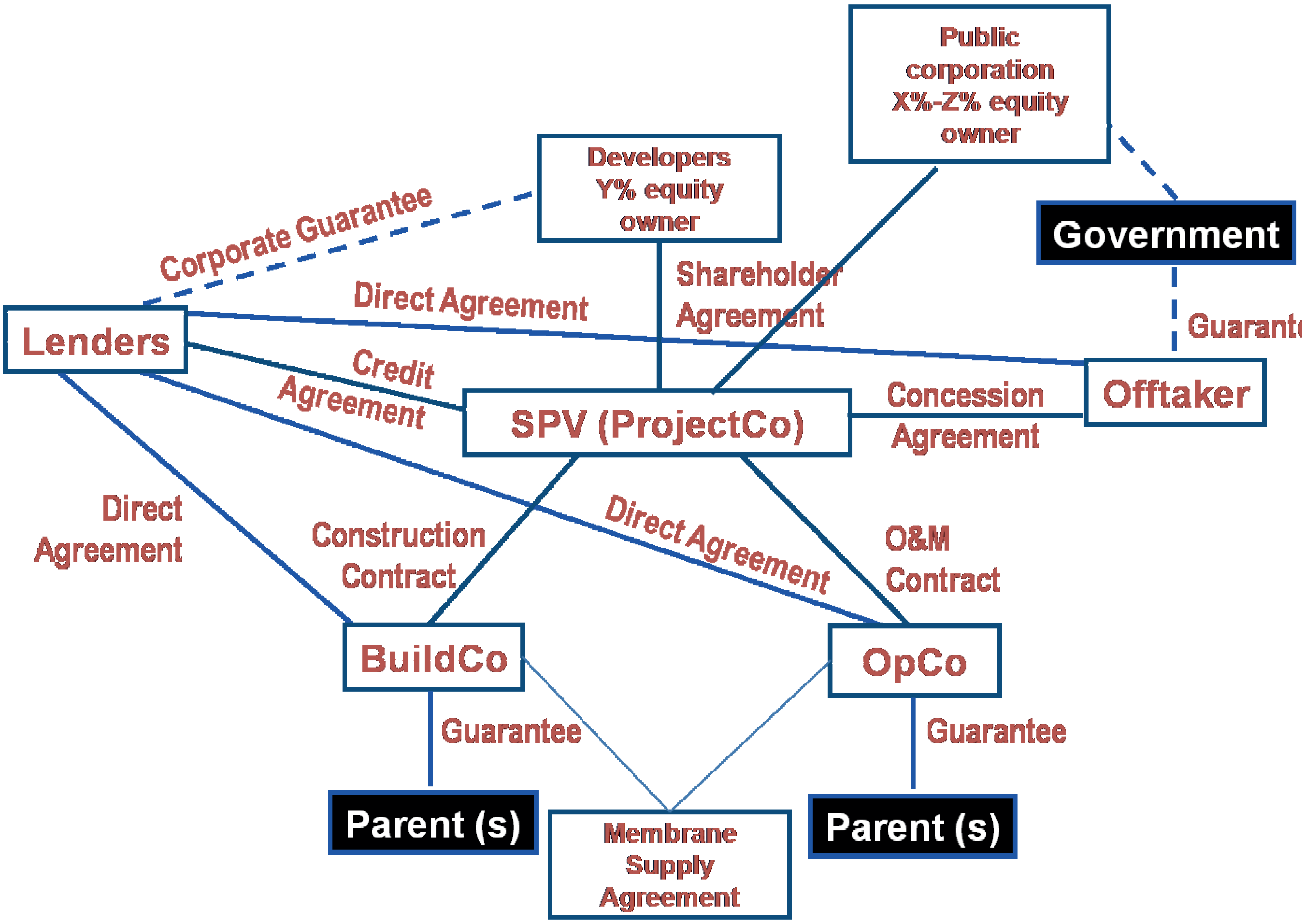

Figure 7.7: private project typical structure governmental participation

~~1.1.1~~7.4.1 Main agreements

The implementation of a private project generally involves the definition of the various agreements that define the relationships between each party contributing to the project. The agreements may differ according to the project and the region. The typical main agreements that follow a private project are indicated and briefly discussed below:

(i) The Joint Venture Agreement or Project Founder Agreement:

The Joint Venture Agreement or Project Founder agreement is stipulated between the shareholders of the project company, the sponsor(s) and the off-taker or another state-owned entity. This agreement sets out various warranties and undertakings to be given by the Founders to the Government in respect of the disposals of shares in the capital of the Project Company. Generally this agreement foresees some restrictions on the Project Founders to initiate any Offer for Sale or Listing of the project shares unless they are in compliance with certain obligations.

Typically the obligations are that Founders may not reduce their interest in the shareholding with respect to the initial proportion of shareholding in the Project Company below a set threshold before the project Commercial Operation Date. These obligations persist with a different threshold of interest for a certain period after the Commercial Operation.

If project Company Listing has occurred, generally the Project Founders may further reduce their interest in their shareholding in the Project Company.

(ii) The off-take agreement(s):

The off-take agreement(s) are stipulated between the project company and the water and, if any, electricity off-takers for the sale of the water and electricity produced by the project. The typical off-take agreements that are separately applicable are:

- Water purchase agreement
- Power purchase agreement (for cogeneration plants)
- Tertiary treated effluent agreement

These agreements can be further distinguished in two main categories that are based on the philosophy of dispatch. In particular the off-take agreement can be :

- capacity based
- volume based

The capacity based agreements are identified as those agreements whereby the producer of water and electricity is provided with a dispatch schedule and is compensated according to the dispatch requirement by a capacity charge and a volume charge. The nature of these charges will be further discussed in session 10 and 11.

The volume base agreements foresee that a minimum amount of product water is delivered by the producer within a certain period of time. With this arrangement both fixed and variable costs of the Developer/ Producer are compensated by the volume of the product delivered. To cover water demand market risks, the off take agreements are structured with a take or pay mechanism or minimum take off guarantee. These mechanisms will be analysed in more details in the following chapters of this book.

(iii) Water Connection Agreement

The electrical Connection and Supply Agreement is stipulated between the Project Company and the Licensed Distribution System. This agreement sets out the terms and conditions upon which the Generator connects to the Water Transmission System and establishes a framework between Offtaker, Government and Producer for the operation of the project and matching the Water Transmission System requirements.

The Water Connection Agreement covers also the mechanisms for the plant dispatch, outage period and delivery of product water o the system.

Generally the water connection agreement foresees the payment of a connection fee by the Producer to the Offtaker.

The water connection agreements may define several process variable among which the most notable are the "Water Supply Pressure" as the minimum pressure required at connection point for the operation of the Water Transmission System, and the water quality specification for introduction into the Water Transmission System under the WPA.

(iv) Turnkey contract

The turnkey contract is stipulated between the project company and an industrial contractor for the construction of the plant. The contract takes the form of an EPC contract as described earlier and is generally ruled by standardised forms that are framed around the FIDIC guidelines. FIDIC is an international organisation of consulting engineers that has published a suite of typical Conditions of Contract for a range of different types of projects. Typically turnkey contract conditions are framed around the Silver Book – EPC / Turnkey Projects or the Silver Orange book.

In some cases for projects with an international contractor or international procurement, the EPC contract is split into a number of separate agreements, such as "on-shore" and "off-shore" contracts with an umbrella agreement. This split is carried out for tax avoidance reasons on the offshore portion. In large desalination projects EPC contracts are often undertaken by a consortium of contractors covering their relevant areas of expertise.

In this case one of the consortium partners takes the overall responsibility as the consortium leader of the EPC contract and often the consortium agreement among parties foresees that each partner is joint and severally liable towards the EPC contract.

The EPC contractor provides equipment and services for a period of one or two years after the plant has been taken over. A longer guarantee period is provided in the case of more innovative technologies.

(v) O&M contract:

The O&M contract is stipulated between the project company and an industrial operator for the operation and maintenance of the plant

In broad terms, the O&M Agreement can be either of the following:

- Fixed price type
- Cost plus type

In the fixed price agreement, the Operator carries out the O&M activities in exchange for a fixed fee, which may include the supply of all membranes, cartridge, spares chemical etc.

In the cost plus agreement, the Operator carries out the O&M activities, the costs are passed to the Owner with a mark up for the management fee. With cost plus arrangements, costs such as staffing, security etc are typically borne by the Owner or if a plant includes different developers by a dedicated shared facility company.

These Operation and maintenance strategies involve a different risk profile for the Owner. The fixed price approach, transfers all operation and maintenance risk to the Operator who is responsible for the operational and budgetary control of the plant and attempts to cover these risks in its overall price. Despite the advantage of the low risk fixed price, O&M contracts tend to be expensive to the Owner. As time goes by the Operator should gain experience of the plant and may manage to operate the plant more efficiently. Savings gained in this respect would not be transferred to the Owners of the plant.

In a cost plus approach, the Owner obviously takes a higher risk. On the other hand this approach tends to generate a lower overall operating cost and a possible advantage to the Owner from continuous optimisation of the plant performance.

The protection for the Owner on a cost plus contract is the application of liquidated damages that are generally triggered by the operator shortfall in O&M performance, whilst on the other hand with this contractual approach, the majority of operating risks are held by the Owner.

Many SWRO and waste water treatment turnkey contractors have developed O&M capabilities within their organisation and they can a offer DBO solution whereby the plant is operated by a parent company of the turnkey contractor. In this case the Operator generally tends to be engaged into a fixed O&M as cost plus is generally regarded as low-risk and low-reward.

There are other cases where the developer has also operation and maintenance capabilities, and therefore in this case the cost plus O&M agreements would be the preferred solution.

It should be noted that within the two basic types of agreements, there are numerous other alternative arrangements. This is particularly applicable for the plant manpower arrangements where often secondment arrangements are applied.

In this case the O&M personnel (sometimes including the senior staff) are employed by the Project Company, and the "Operator" seconds senior staff, provides offshore management and technical support.

For Reverse Osmosis contracts, the involvement of the RO EPC contractor or of the membrane supplier in the Operation and Maintenance agreement is required. The membrane manufacturer in particular is requested to provide a membrane guarantee covering both the replacement rates and the pressure conditions across the membranes that is formalised in a Membrane Supply Agreement that will be discussed later in this hapter of the book.

(vi) The lease agreement:

The lease agreement is drawn up between the project company and the owner of the land on which the plant shall be erected. The owner is often a state-controlled entity. This can take some time in the form of a Usufruct Agreement between the Government and the Project Company whereby the Government grant the Usufruct Right over the Site for the purpose of the project. The lease agreement may be substituted or supplemented by an Usufruct Agreement for the temporary areas dedicated to construction and site camps.

(vii) The financing agreements:

The financing agreements are drawn up between the project company and the lenders for the financing of the project.

These include loan agreement and security documentation such notes, bonds, indentures, security agreements, registration or disclosure statements, subordination agreements, mortgages, deeds of trust, credit agreements, note or bond purchase agreements, hedging agreements, letters of credit, direct agreements, financial guarantees, participation agreements and other documents entered into by Project Company in relation to the financing of the project.

(viii) The direct agreements:

The direct agreements take place between the lenders and all the parties that have promoted the project. The direct agreement has the aim of facilitating the Project Company in raising finance from the Lenders in connection with the Water Purchase Agreement and sets forth rights and obligations of the Off Taker, Project Company and the Lenders.

Generally in the Direct Agreement, the Off Taker accepts that the Lenders have no obligations under the Water Purchase Agreement and agrees not to make any material amendment to the Water Purchase Agreement without the prior consent of the Lenders.

(ix) The investment convention:

The investment convention is stipulated between the State and the Project Company.

(x) The Membrane Supply Agreement:

The membrane supply agreement is between the Membrane Supplier and the EPC contractor and there are provisions for this agreement to be novated in the name of the O&M contractor once the project is in operation or in the name of the End User should the End User wish to exercise the step in rights.
The Membrane Supply Agreement provides the framework under which the Owner, the EPC Contractor, the Operator and the Membrane Supplier shall set the mode of operation and the terms of supply and replacement of the membranes required for the project

The Membrane Supply Agreement defines the terms for Performance and Workmanship Warranty of the Membrane and specifies the operating conditions that are mutually agreed at the design stage between the EPC contractor, the O&M contractor and the membrane supplier.

Typically the performance guarantees covered in the membrane supply agreement are:

- Membrane Replacement Rate Guarantee
- Permeate Water Quality and Quantity

The Membrane Replacement Rate Guarantee: specifies that the maximum replacement rate for the membranes per year for the 1st pass and 2nd pass membranes does not exceed a replacement schedule indicated typically in the schedule below:

Table 7.7

Replacement Schedule in %	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6		Year n	CARR (*)
- 1st Pass	-	-	-	-	-	-	-	-	-
- 2nd Pass	-	-	-	-	-	-	-	-	-
Fouling factor	-	-	-	-	-	-	-	-	-
Membrane feed pressure	-	-	-	-	-	-	-	-	-

(*) CARR = cumulative annual replacement rate

Nowadays, good system design can allow CARR of 12% and 10% respectively for the 1st and 2nd pass.

Furthermore the Membrane supply agreement sets forth the terms for the sale of the membranes for subsequent years beyond the replacement guarantees and escalation formulas for the determination of the element prices.

It is generally expected that the membrane supply agreement foresees the involvement of the membrane supplier both in the design phases with an “endorsement” of the turnkey contractor design and in the operation of the project with regular inspections and monitoring activities.

(xi) The Sale Assets Agreement:

The sale of assets may be carried out in conjunction with a new green or brown field development in an adjacent area to the site or may be simply carried out when an operating plant is privatised

In the case of sales asset the Project Company conducts a due diligence exercise with respect to the assets and must satisfy itself on the adequacy, suitability and fitness for the performance of the assets that will then operate on a new Water Purchase Agreement with the water company.

The Sale Assets Agreement is stipulated in case the project involves the sale to the Developer of assets belonging to the Public Corporation. The Sales Asset Agreement is stipulated between the project company and the water company and, if any, electricity off-takers for the sale of the water and electricity produced by the project.

When the sale of assets takes place, the Project Companies shall generally have responsibilities towards the existing employees that are set out in the Privatisation Law.

(xii) The shared facilities agreement:

The shared facilities agreement is entered into between the Project Company and the Shared Facilities Company. The Shared Facilities Company is generally a limited liability company that manages all the assets that are common at site to various developers and has no profit or losses at the end of a period.

This agreement occurs in the case of very large plants that are developed on a plant site. In this situation it often happens that a site is developed in various phases and for convenience, different developers share some common services such as:

- Site access security including perimeter fences and gatehouses
- Fire fighting
- Infirmary – Hospital - first aid
- Training and conference facilities
- Buildings (garages, mosque, cafeterias.),
- Roads and lighting
- Perimeter lighting.

In some cases Shared Facilities are constructed within the Project scope are subsequently passed through to the EPC Contractor and on completion, will be transferred to the Shared Facilities Company.

However there are more complex cases where shared facilities include also a common seawater intake and screening system which include the seawater chlorination plant and the related outfall channel.

This situation is indicated in Figure 7.8 showing a plant with three different Developers sharing common seawater settling basin and screening system

Figure 7.8 showing a typical share facility configuration for a plant developed in three phases by three difference developers.

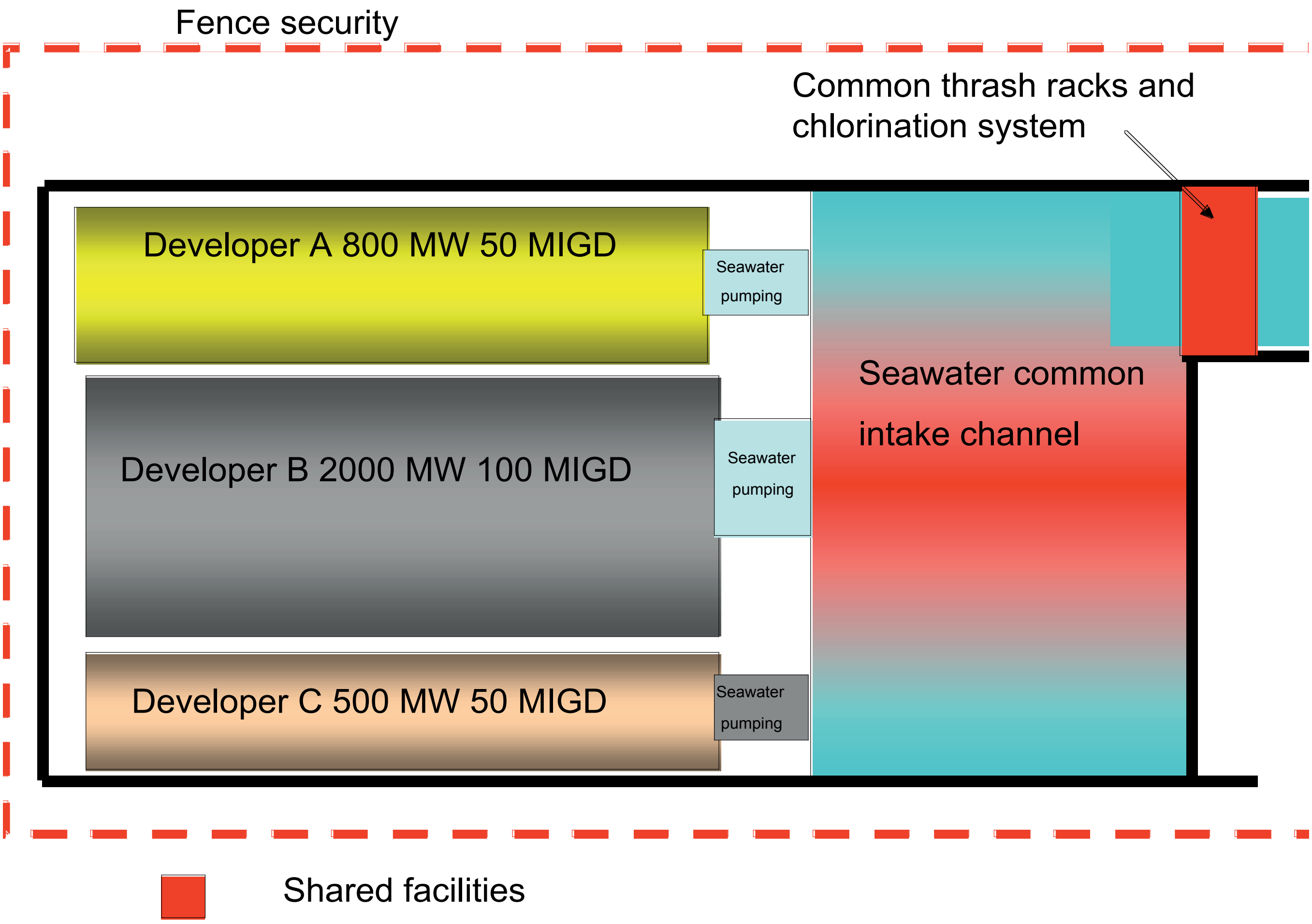

Figure 7.8 shared facilities scheme

Under this scheme, the maintenance operation of the common seawater screening system for the three sites is carried out by the shared facilities company along with other necessary operations such as the dredging of the common settling basin.

Each developer bears pro rata the running costs of the shared facility company.

7.5 Funding and gearing of desalination projects

In private projects the level of funds that can be made available by the Lenders is dependent on the level of exposure that the project and of the country the project is implemented.

The steps for the evaluation process for financing the project involves:

- Project level risks
- Institutional / market risks
- Currency risks
- Sovereign risks
- Credit enhancements

As indicated in Figure 7.9, generally for large desalination projects implemented in the Middle East the equities fund from 20 to 30 % of the total financing requirements in desalination plants

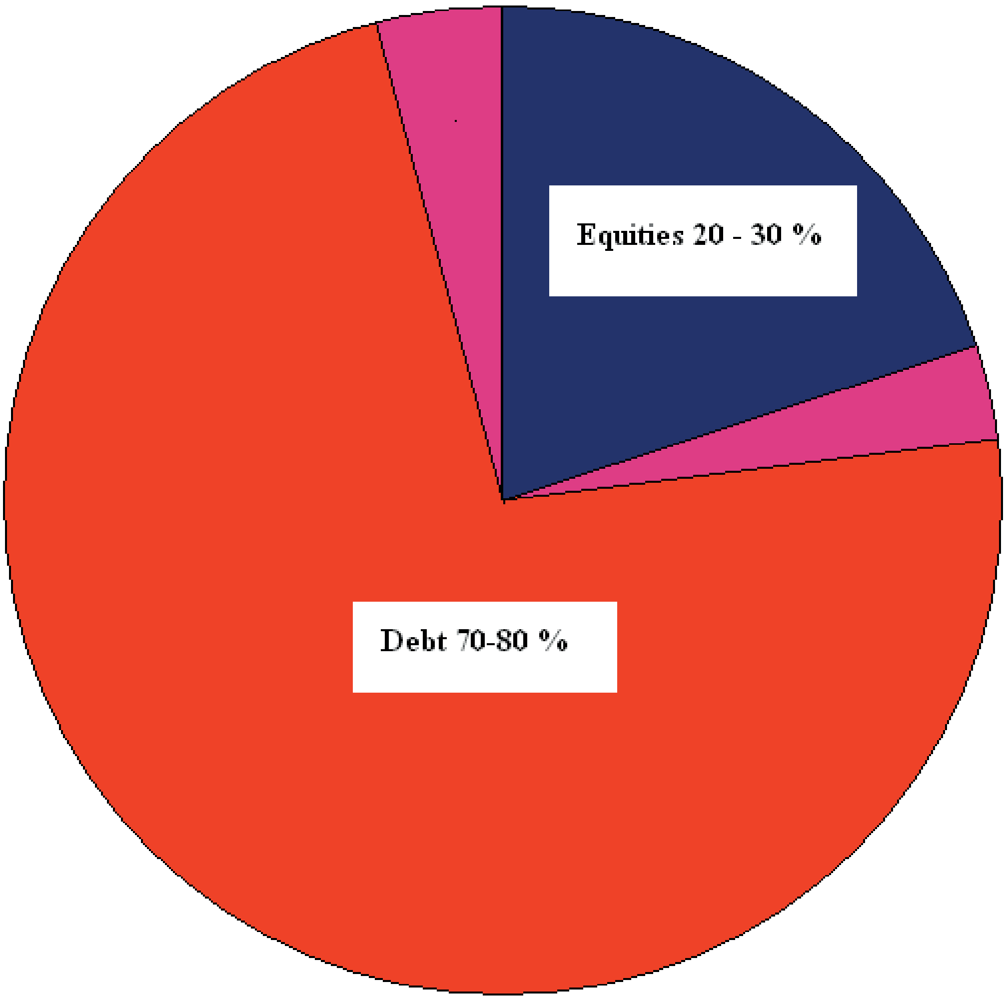

Figure 7.9: ratio debt – finance portion for desalination projects

There are credit facilities provided by lenders to fund 70 to 80 % of the total project financing requirements. The rest of the capital is provided by equities financed directly by the investors (developer) of the project company or by commercial loans. The typical project finance structure takes the form that is schematically indicated in the Figure 7.10 below.

Generally there are standby facilities provided by shareholders and by lenders to fund up to 10% of the total financing requirements.

In countries where the project has a higher probability of default, the amount of debt covered by the project finance portion tends to be lower.

The criteria to establish the credit rating scale were set forth as S&P (Standard and Poor) and range from a AAA level where the probability of project default is less than 1% and level BBB where the probability of default increases to 5% and therefore the debt cover ratio decreases.

There are lower levels in the Standard and Poor credit rating scale but generally for significant desalination and power plants developments the investment cut off scale range is BBB.

It should be considered that the percentage of the debt that is covered by project finance is also dependent on the actual investment financing climate.

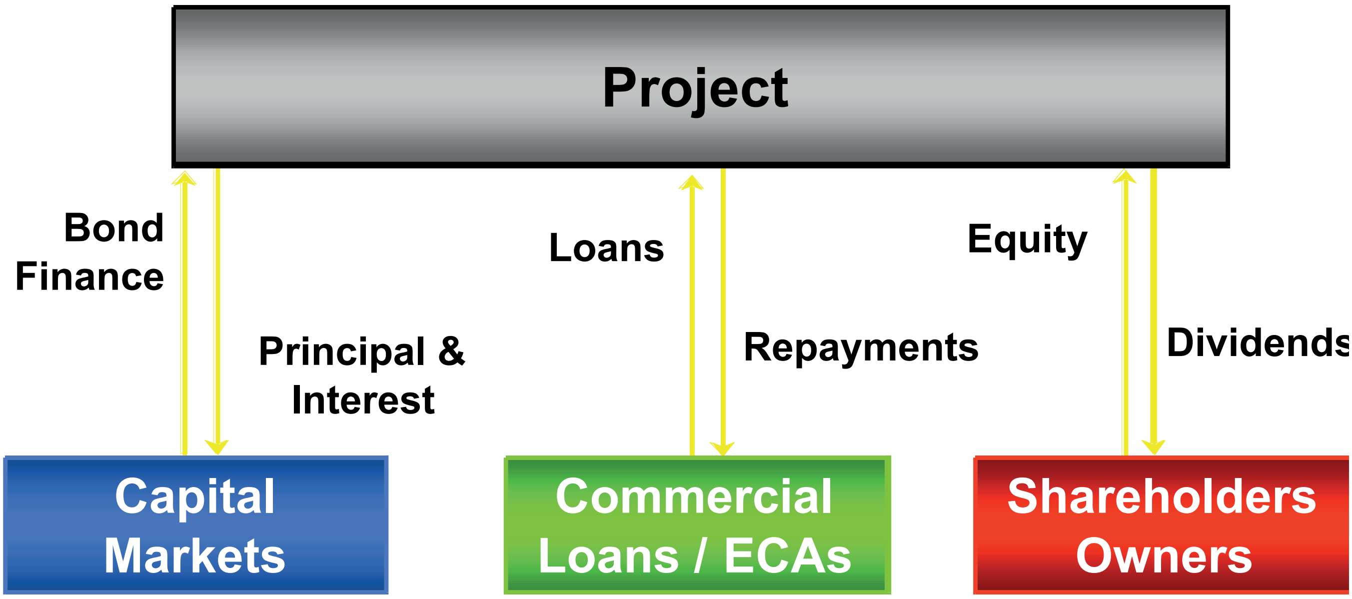

Figure 7.10 typical project finance structure

As it can be seen from the picture above a great proportion of the Project Company's capital employed is tied up in loans, a relatively smaller amount is provided by shares.

~~1.1.1~~7.5.1 Bond finance

Desalination projects therefore are generally defined as highly geared; in this case the great part of the risk in project performance is borne by Lenders with a relatively low return on capital especially if as in the majority of cases the loan is given as non recourse finance.

The term "non recourse finance" indicates loans of a size where the Lenders are satisfied with the risk mitigants introduced in the key agreement and do not secure their funds though a collateral in company assets.

For this reasons, Lenders want to understand the technical risks in a project and the mitigants available through a due diligence process

The due diligence process aims at defining in broad terms the following key areas:

- Demand risks, need for the project
- Capability and track record of the key players (Sponsors, EPC and O&M contractors, offtakers, other Equity Owners)
- Achievement of project design and expected performance
- Completion and operation risks and possible mitigation
- Capital and operational costs and sustainability of the sponsors financial model
- Applicability of the key agreements (WPA, Electricity supply agreement etc.)
- Social settlement and Environmental issues

Lenders generally require that risks are mitigated and during construction and operation the key agreements have provisions for accessing EPC and O&M payments via liquidated damages.

This arrangement is generally profitable and it is one of the reasons why private projects lower water costs are generated.

In particular, high gearing in a water project presents the advantage that debt capital is cheaper with a non recourse loan than with equity capital.

This in turn is due to the fact that the return earned on equities is much higher than the interest on loan capital.

In other terms the reward required by debt owners is usually lower than the reward required by equity holders as in general the debt is secured by security provisions in the project agreements.
Generally, desalination private project solutions are structured with the following,

- High debt/equity ratio
- Limited or non-recourse loans
- Long term loans
- Cash flow based
- No collateral support

Another advantage of a high loan component in private water projects is that the payment on interest loans are eligible to obtain some tax relief whereas the equities do not allow this.
The Lenders presence in private projects is therefore essential in order to obtain a competitive water price.
It has been seen in recent IWPP that Japanese developers have been particularly successful in securing water concessions in power and desalination plants.

This can be explained by the fact that a portion of the loan is secured by the Japanese Bank for International Cooperation (JPIC).

JBIC provides overseas investment loans with very attractive interest rates to meet long-term financing needs of Japanese firms for their international business development, including projects that will establish/expand production bases and develop natural resources overseas

Figure 7.11shows a typical financing arrangement for a Saudi Project where JPIC support commercial banks in the disbursement of the loan.

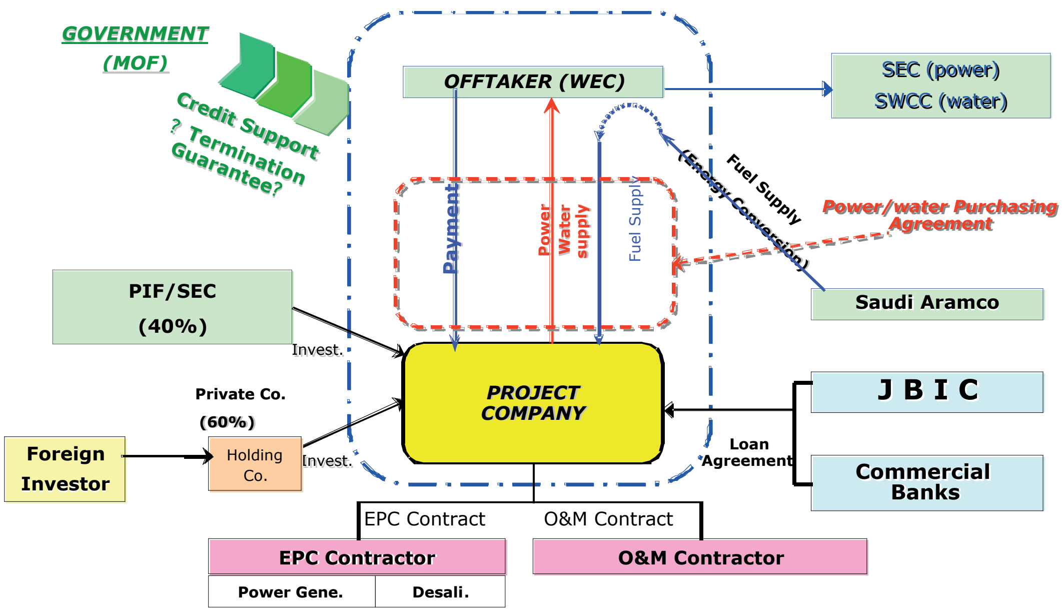

Figure 7.11 : typical structure Saudi project with JBIC participation

~~1.1.2~~7.5.2 Commercial loans

Generally the overall debt portion cannot be entirely covered by Project Finance. Therefore commercial loans need to be adopted by the developer in order to cover the outstanding debt portion. Commercial loans bring about a number of collateralised Loan Obligations that include:

- Bonds issued in capital markets
- Pool of project loans

These obligations are reflected as liabilities in the developer balance sheets.

The typical funding platform structure for a commercial loan developed in the manner above takes the structure indicated in the Figure 7.12 .

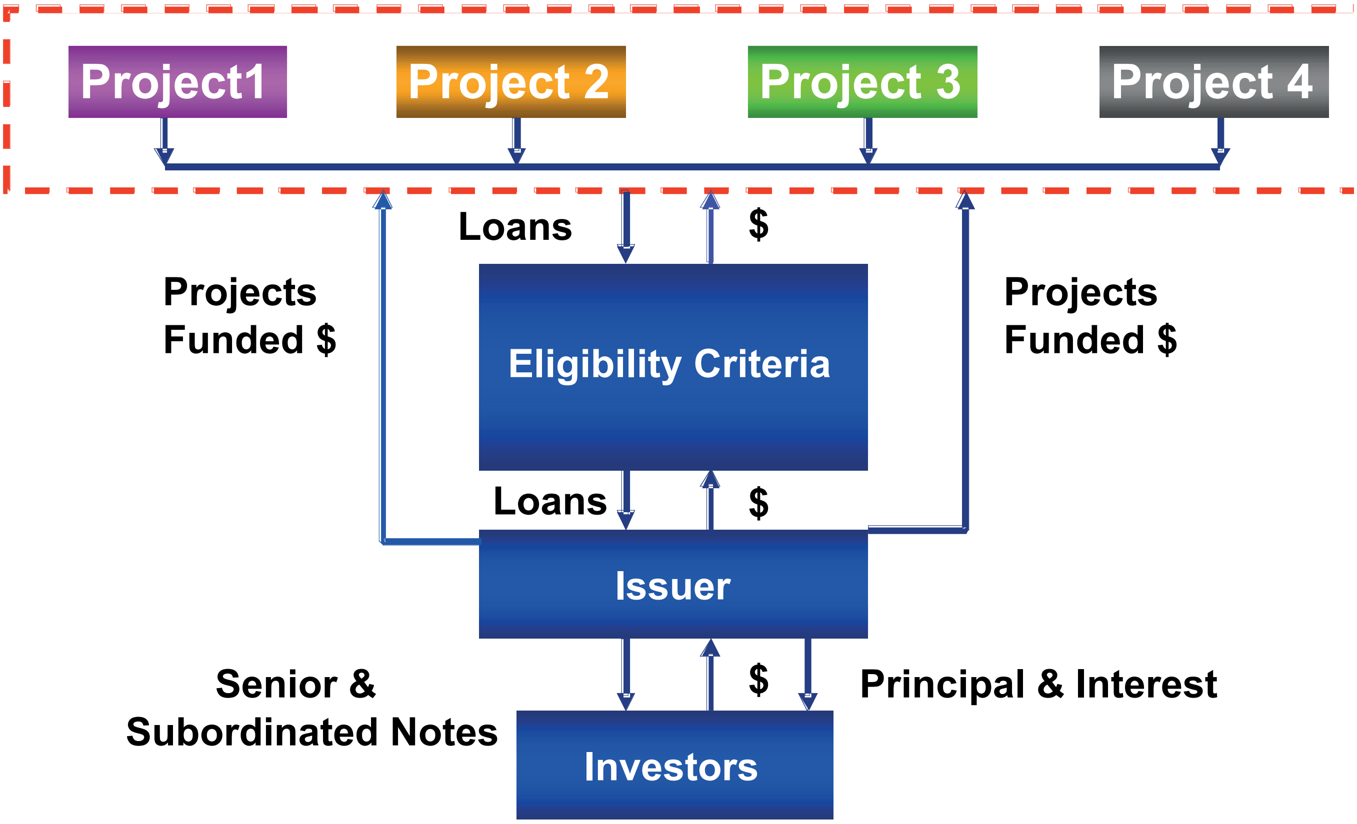

Figure 7.12: Funding Platform Structure

~~1.1.3~~7.5.3 Equities

In highly geared projects it is essential that the plant performance parameters are maintained at the scheduled level as a fall in profit will greatly affect the return on equities that are limited to only 20 to 30 % of the project Capital.

However if on one hand high gearing allows the project Company to raise extra capital if there are several projects and the project Company has already a great proportion of capital provided by loans, it may be difficult for a Project Company to raise extra capital and Lenders may take the view that the Project Company represents a business risk,.

7.6 Steps in privatisation process

The process of privatisation in the Middle East was initiated in Oman and United Arab Emirates (Abu Dhabi) who have pioneered the steps of privatisation with large IWP and IWPP projects launched in the early 2000. This process has been followed in other countries such as Bahrain and Saudi Arabia.

The steps followed to introduce the privatisation process in the water sector in the Middle East are illustrated in the Figure 7.13 below. However these steps can be taken as a reference approach for similar projects in other areas.

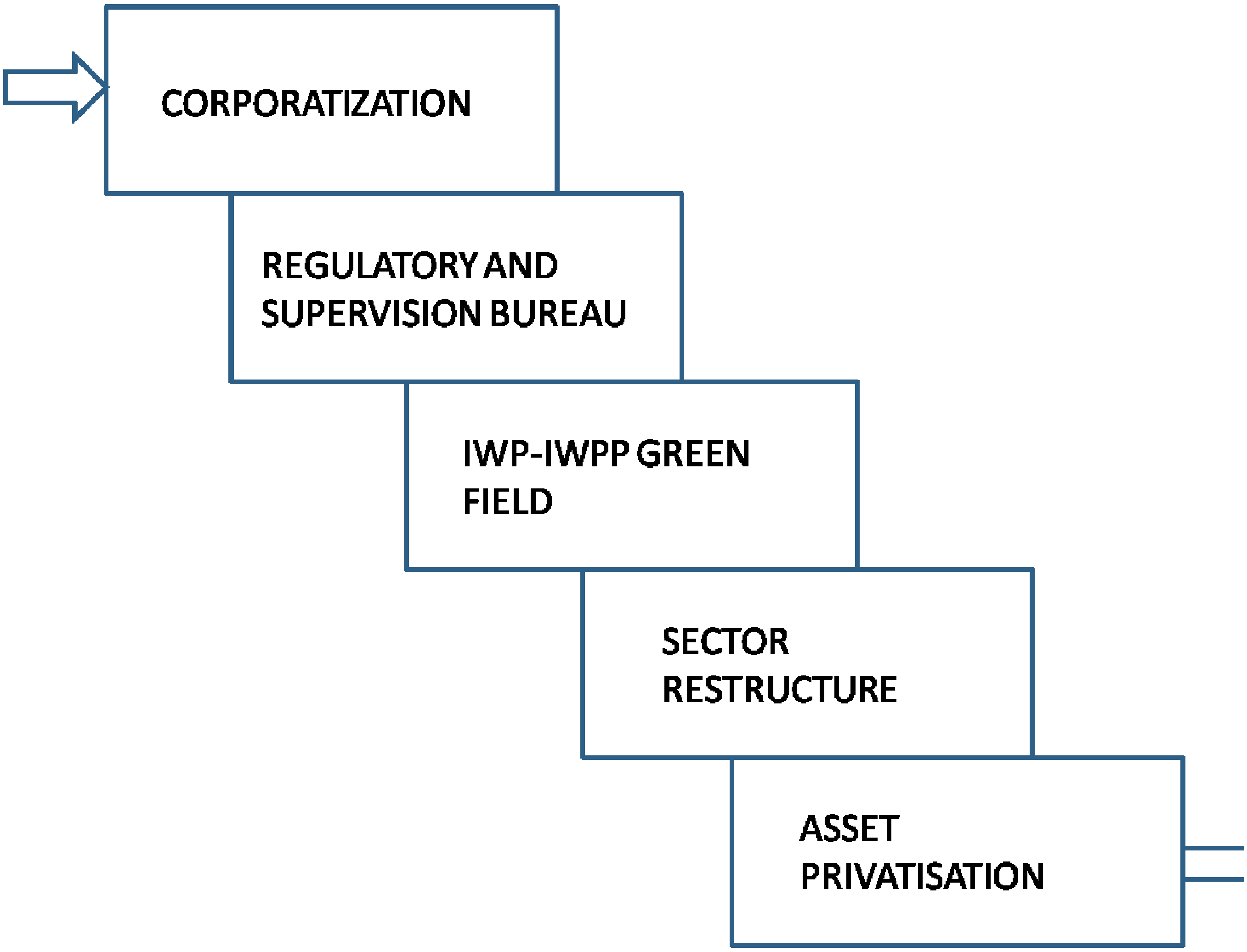

Figure 7.13 privatisation process milestones

The process steps adopted in the involvement of the private sector in the water sector are gradual and start with the process of unbundling generation, transmission and distribution activities followed by the transfer of separated businesses to independently managed, government owned companies progressively made available to private investors with a divesture model.

Generally the introduction of private capital commences through the development of a "green-field" independent power and water project and is followed by the establishment of a single "government buyer" model which maintains control and ownership of the transmission and distribution sector. A

typical situation that may be encountered in this case is illustrated in Figure 7.14 below .
It also important to understand for brown-field projects the value and ability to upgrade existing assets to improve the capacity and efficiency of existing plants before expansion to the new additional facilities.

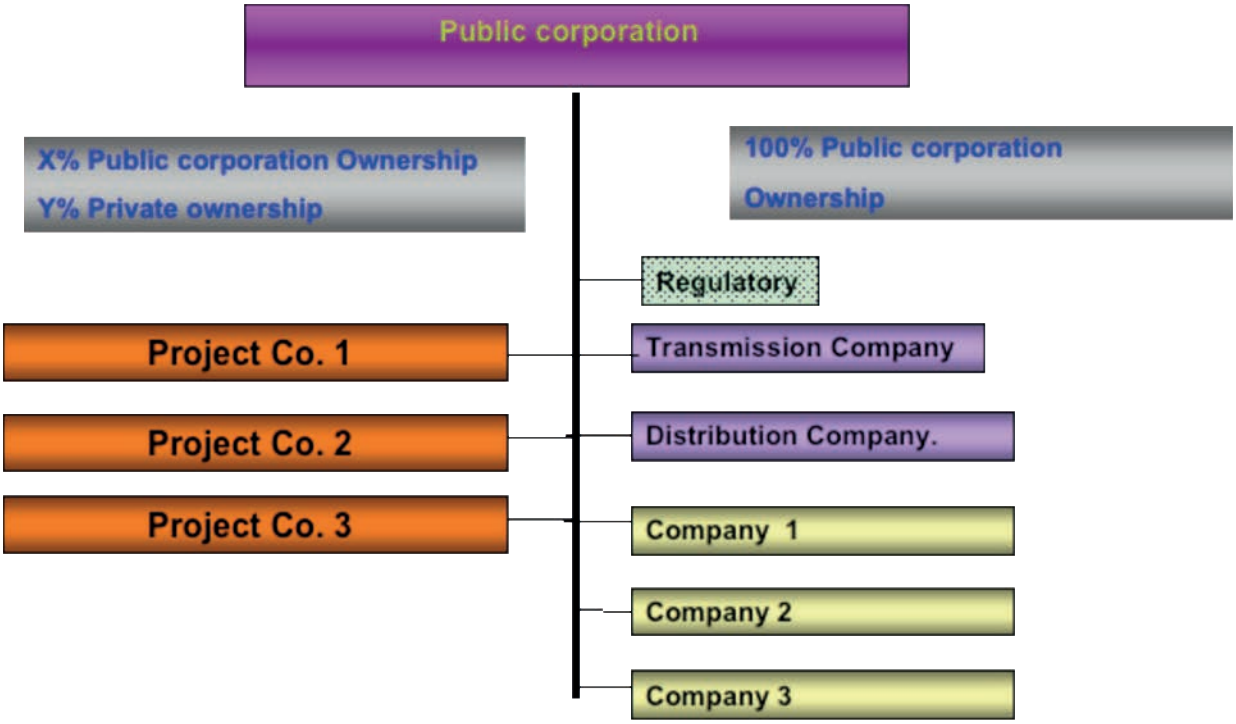

Figure 7.14 unbundling services

These activities are carried out along with the development and implementation of legal and regulatory frameworks and the establishment of a Regulatory and Supervisory Bureau.
Part of the functions that in traditional public projects are covered by the Public Corporations in a private environment are generally addressed by Regulatory and Supervision bodies.

In a private environment the regulatory body has the sole and exclusive authority to regulate the water sector and establish the license for operators in the market. This includes providing a structure to the sector, regulating tariffs and buyers.

The Regulatory body has the responsibility of over viewing the matters relating to the economic and financial performance of the sector companies including the sector tariffs and related charges.

Water quality standards are also generally set up by the Regulatory body on the basis of the directives of international guidelines.

When a public corporation manages several assets it may wish to transfer part or all of these assets to the private sector with a divesture model.

Maintaining an efficient operation of obsolete desalination assets is a burden to Public Corporations.

It may happen for instance that these plants are designed with obsolete technologies and require rehabilitation and upgrading to continue operating. If these are not properly managed they require large budgets for maintenance and operation.

The involvement of the private sector in these plants is more delicate as a longer time is required for assessing the plant status and to forecast its performance until the end of the concession through a process of due diligence.

Under the divestiture model, the government transfers the water business, including the infrastructure, to the private company on a permanent basis through the sale of some or all of the shares in the company. This model has only been adopted initially in Europe but has been also widely introduced in the Middle East with the privatisation of several power and desalination stations both in Abu Dhabi and in Bahrain.

It is generally a relatively complex process that is preferably carried out in a country where privatisation has been already established successfully through the previous implementation of green field projects.

8 Risk allocation

In the Desalination and water treatment market different contracting mechanisms are applied and each of them presents advantages and disadvantages and a different allocation of the risks.

It is important that the End User, the Developer and the Off Taker understand the risks involved and their allocation.

The following section of the book describe the risk allocation for some types of the most frequent contracts (EPC, DBP, IWP) applied in the water sector and illustrates the mechanism of risk transfer from the Public to the Private sector in IWP projects.

There may be contracts where due to particular conditions of the End User or the Developers, the allocation of the risks may be different from the one indicated in the Tables below. This table therefore may serve as a general indication of the most frequent risk allocation that may be encountered in real cases.

~~1.1.1~~8.1.1 Market demand risk

The market demand risk can be related to an incorrect water shortfall forecast and planning therefore is the risk that the project is producing water but the sales of product water are lower than anticipated because of market conditions.

This is also a risk that may occur in waste water treatment plants in the case where there is insufficient raw sewage effluent (RSE) for the treatment plant

As shown in Table 8.1. the Market Demand risk is primarily a public risk. On the other hand there are cases where a desalination or water treatment plant is installed in an industrial areas and there is no long term supply agreement with a single off-taker but the water producer may sell product water to various industrial premises in the area covered by a number of different water purchase agreements with different customers. In this case the water demand risk is primarily borne by the developer

Table 8.1 Market Demand risk allocation

Public Multi Contract	Public EPC Contract	Design Build and operate	Private Project

Government or Public Corporation assumes demand risk	Government or Public Corporation assumes demand risk	Government assumes the demand risks to a higher or lower extent as the DBO is on a period lump sum or cost plus .	Government or Public Corporation assumes demand risk by paying Capacity Charges or the minimum off take charges as long as the Project is available. In the event there is no request for dispatch the Project Company loses the variable payments

~~1.1.2~~8.1.2 Specification and design risks

There is a great difference between turnkey and multi contract and private initiative on the specification and design risks allocation.
With turnkey contracts and multi contracts, Government / Public Institution and Offtaker select the most suitable technology and prepare detailed specifications that include detailed equipment specifications individual packages performance etc.
When the project is implemented with private initiative, the Government issues minimum functional specifications (“MFS”) for the Project. These specifications are generally restricted to basic design information such as seawater conditions, volume, quality and availability of product water and minimum material selection guidelines.
The Project Company is then responsible for satisfying itself as to the adequacy of the Minimum Functional Specification for the Project, select the most appropriate technology for the site and issue detailed specifications that become part of the turnkey contract.

Table 8.2 Specification and design risk allocation

Public Multi Contract	Public EPC Contract	Design Build and operate	Private Project
Government or Public Corporation	Government or Public Corporation	Government or Public Corporation	the Developer assumes the design and specification risks. The seawater design envelope is specified by the Government who bears the risk for departing seawater qualities

Within this philosophy the Project Company bears the full risk of site suitability for the purposes of the Project. This risk is transferred to the developer at the bidding stage through site visits.
In Multi contracts, Government / Public institutions exposure to specification and design risks is even

higher as segments of engineering are directly done by the End User.

The same criteria can be also considered for the selection of the site and for the resulting seawater quality. In Public contracts, the Government bears all the risks related to the site construction whereas in a private initiative the Government only bears a limited risk of increased water treatment costs due to deterioration in sea water quality. As described in session XXXX, the tariff is automatically adjusted by predetermined cost correction curves for a limited number of sea water quality parameters. The Government bears the risk of non availability of water as a Force Majeure risk if the sea water quality is outside the technical operating limits of the Project.

On the other hand, in private projects the Project Company assumes all risks associated with the site (including its condition and environmental suitability). In this respect Developers are requested to inspect the site and take account of its condition in the bidding process.

It is the responsibility of the Project Company to provide sufficient quantities of seawater of appropriate quality for processing in the desalination facility and ensuring a continuous seawater supply.. This has relevance in well field developments as a deterioration of the well field yield can occur during the concession period imposing upon the Developer to seek an alternative seawater supply .

The specification and design risk follows a time profile that is indicated in the Figure 8.1 below.

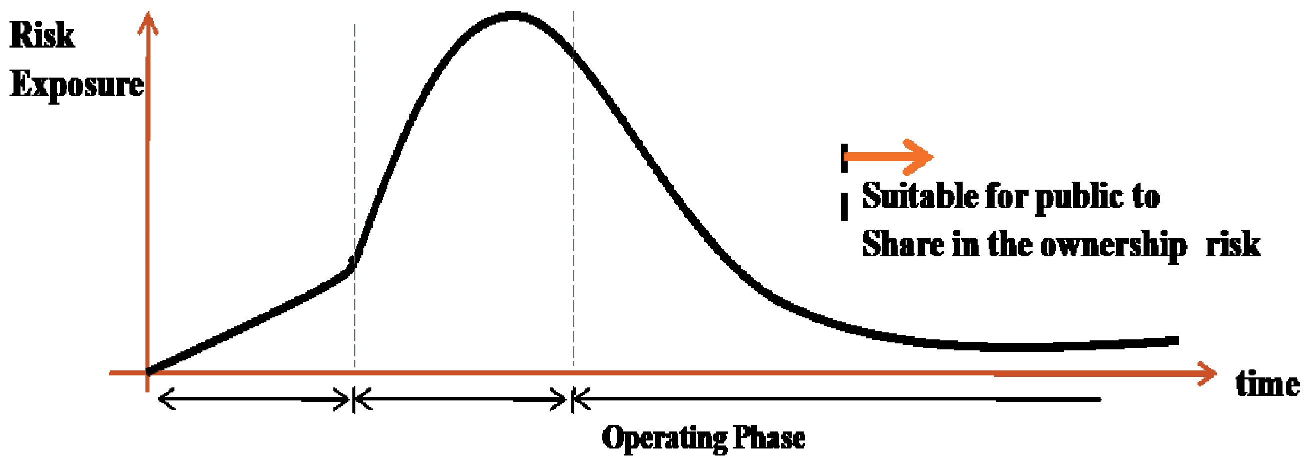

Figure 8.1 technology – specification risk profile with time

During the initial phases of the project, the design risk exposure is relatively low as the plant is in the engineering phase and any potential shortcomings in the design could be rectified when the plant is not in an advance procurement and construction status.

As the constructions activities progress, the risk exposure increases and reaches its peak when the plant is in the commissioning and initial operation phases.

Some time after the initial operation, the design risk exposure decreases and this is generally the reason why opportunities are offered to the public to participate as a shareholder in the project company / utility services.

The risk level exposure becomes in fact more suitable for public ownership.

~~1.1.3~~8.1.3 Force Majeure

All Force Majeure events can be identified as full Government risk in Turnkey, DBO and Multi contracts. These risks are partially transferred to the private sectors in private projects as indicated in the table **8.3** below.

The Force Majeure risks can be identified in two different categories:

- Force Majeure during construction
- Force Majeure during operation

During the construction period of private developments,, the Government bears the risk of delays caused by Force Majeure through applicable extension of the construction period. On the other hand the Developer / Project Company bears the risk of increased costs attributable to Force Majeure. For example, in the case where the plant is delayed by a unforeseeable event, (cyclone or earthquake) the government does not apply liquidated damages to the Project Company for delay but the Company bears the risk of increased construction costs due to prolongation of the site erection phase.

During operation, the Government bears the risk of Force Majeure affecting availability, on the other hand during Force Majeure, the Project Company receives only capacity charge payments in relation to the demonstrated plant availability.

Table 8.3 Force Majeure risk allocation

Public Multi Contract	Public EPC Contract	Design Build and operate	Private Project
Government or Public Corporation	Government or Public Corporation	Government or Public Corporation	Shared betwe Government and Develo / Project Company

8.1.4 Financing risks

In private initiative it is the Project Company who takes the responsibility of availability of finances and is responsible for arranging the required loans. Accordingly the Developers bear the risk for the cost of financing for the performance of its obligations in respect of the Project.

The government or public institution bears the risk of currency exchange as there is a component of the tariff covering Part of the Investment Charge and part of the Fixed Operating Charge and the Variable O&M costs that is adjusted in accordance with the major reference currency (Euro-US) /local currency exchange rate movements (both up and down). In this respect Currency Exchange Rate risks are partially transferred to the Government through tariff indexation.

Government also bears inflation risks as both the Fixed Operating Charge and Variable Operation Charge are related to the inflation index and the major currency inflation index of the country where the project is located.

This is applicable also to the price of electricity that is generally passed through in the Water Purchase Agreement tariff. This means that the electricity is provided by the Government who bears the risk of any electricity price increase. However this is restricted to the project achieving the predetermined guaranteed electrical efficiency level that is set up during the tender process.

8.1.5 Operating risks

Table 8.4 below shows a typical operating risk allocation according to the project implementation scheme. As it can be seen in Public, Multi or Turnkey contracts, the Government or Public Corporation bears full operating risks.

On the other hand in private projects it is the Project Company who takes the responsibility for the operation and maintenance of the project including the seawater intake/outfall and the auxiliary facilities.

In this respect the Project Company bears the revenue risk as the capacity charges are not payable when the plant is not operational and the project is therefore considered unavailable.

Furthermore the Project Company bears the risk and the costs of electrical efficiency. The risk of increasing operating costs due to departing seawater conditions are in some cases excluded through the application of specific power consumption and variable operating and maintenance costs correction curves. In other cases, the Project Company bears the seawater quality risks within predetermined technical operating limits set up for the Project. Outside these limits, Force Majeure events relieve the Project Company from the obligation to remain available.
However in the case of Force Majeure the Project Company bears the risk of loss of revenue and any increased costs arising related to the quality of sea water exceeding the technical operating limits of the Project.

It should be noted that only a limited number of sea water quality parameters are subject to cost correction curves. These cost correction curves are provided by the Project Company during the Tender phase for the project according to the scenario points that are set up by the off-taker and are designed to compensate for the increased costs of water treatment and power consumption arising as a result of deterioration in sea water quality within the technical operating limits of the Project.

Table 8.4 Operating risk allocation

Public Multi Contract	Public EPC Contract	Design Build and operate	Private Project
Government or Public Corporation	Government or Public Corporation	Operator	Developer

9 Cost of Water

The term ‘cost of water’ generally refers to the water produced at the battery limits with the water generation plant before being dispatched to the potable water network and to households. The cost of water is determined by capital costs, energy (in some cases fuel) costs, and operation and maintenance costs.

In the current trend driven towards deregulation of the water , the lifecycle cost of the water generated by IWP/IWPP is a primary element of evaluation in the selection of the desalination technology for a given application.

Other factors that are evaluated include:

- Plant availability service factor
- Permitting procedure
- Financiability of the initiative - loan structures
- Environmental concerns (discharge emissions, water consumption, heat rejection, noise)
- Construction time, depreciation period of the project, etc.

Desalination plants are usually tendered in a competitive manner and the aim of the competition is generally to keep the production cost as low as possible.

Legislation and environmental protection give boundary conditions to this goal.

In the following pages, various formulas to arrive at a cost of water for different types of desalination plant are determined.

It should be noted that the information presented can vary depending on local and regional conditions. For instance fuel gas prices can regionally be below half of world market prices making plants making less energy efficient technologies more competitive.

Capital costs per unit of water for a given desalination plant depend on the price and the amortization rate for that plant, also on interest or on the desired yield on capital investments (annuity factor), and on the load factor of the plant. Capital costs are also influenced by the interest during construction.

Energy costs per unit of water are proportional to the specific price of the energy and inversely proportional to the average electrical efficiency of the installation.

Operation and maintenance costs consist of fixed costs of operation maintenance and administration (staff, insurance, etc.) and the variable costs of operation and maintenance, and repair (consumables, spare parts, etc.)

By adding the capital costs, power costs, fuel, energy or steam cost and operation and maintenance cost, the cost of water can therefore be approximately calculated.

The Net Present Value is generally the basis used for economic comparisons of water prices. The various costs for both power and desalination projects are costs incurred at different times and for financial calculations are corrected to a single reference time, which is generally the date on which commercial operation starts. These converted amounts are referred to as ‘present values’. A simplified approach to obtain the cost of water (US$/m^3) can be obtained by the following formula

$$C_w = \frac{\Sigma Capex \cdot \psi}{W_c \cdot \tau_{eq}} + \frac{FO\,\&\,M}{W_c \cdot \tau_{eq}} + \lambda \cdot Y_p + VO\,\&\,M$$

As it will be identified in the following chapter related to the payment, the first two terms of the above equation refer to the Capital Cost component of the water tariff whereas the second two terms relate to the volumetric, or otherwise called output component of the water tariff.

The term _Capex indicates the total capital requirement to be written off. This value amounts to the current value of all expenses during planning, procurement, construction and commissioning such as the price of the plant, construction interest, etc.

_ Annuity factor = [1 /annum]

$$\psi = \frac{z}{1-(1+z)^{-n}}$$

W_c	Rated water output in m^3
_eq	Equivalent utilization time at rated power output, in hours/ annum (h/a)
_	Specific power consumption (kwh/m^3)
Y_p	Price of power (US$/kWh)
FO&M	Fixed cost of operation, maintenance and administration (US$/a)
VO&M	Variable cost of operation, maintenance and repair (US$/m^3)
z	discount rate (%/a)
n	amortization period in years

The equivalent utilization time at rated output is the water generated by a plant in a period of time divided by the rated output. This definition enables corrections to be made for the effects of different operating modes (e.g., part-load operation) for the desalination plants under consideration, so that they can be analyzed on a comparable basis.
The present example refers to the net present value of the water cost and while it accounts for energy cost and operation and maintenance cost, no escalation rates have been applied to calculate the cost of electricity and the price escalation factors that affect the FO&M and VO&M.

The cost of electricity can use the equivalent utilization time and the fuel price as variables, but it must be understood that the calculated cost of electricity is an average figure. In a deregulated power generation market, power stations do not quote on an average cost of electricity basis of demand and supply. Therefore, it is important to understand that the above equation contains fixed and variable costs.

Fixed costs are:

• Interest and depreciation on capital
• The fixed costs of operation, maintenance and administration (e.g., staff)

Variable costs are:

• The fuel used
• The variable costs of operation, maintenance and repair (e.g., spare parts)
• Chemicals and consumables

As indicated in the previous session of the book the impact of energy - power on the water cost may be substantial. SWRO technology is much more energy efficient with respect to the other thermal technologies furthermore it offers the possibility to benefit from low energy cost when this technology is used in off peak power demand situations.

This concept has been one of the reasons behind the success of hybrid concepts as for the time of low demand (e.g., night hours – winter seasons), power stations can quote a price as low as the variable costs whereas investment charges and fixed operation and maintenance charges could be discounted to the power tariff supply to SWRO as the power supply would not be required from the network. During this period water may be produced at much lower costs. If there were sufficient storage facilities to safely store this surplus water, these could be used to face peak water requirements. This solution would therefore enable a reduction of both water and power peak network demand.

9.1 Plant life and capital cost amortisation

The amortization period of the plant is an important parameter to consider and to relate to the technical specification that is adopted for the plant.

Generally concessions are based on 20 to 25 years. This is the time that the Project Company has available to amortise the initial investment cost and generate the projected revenues and profits.

Figure 9.1 below shows, for illustration purpose only , the behaviour of the water cost based on the formula above with amortisation time increasing from 20 to 40 years assuming a 7% discount rate and considering an investment cost covering 40% of the total water costs.

As it can be seen from the Figure 9.1 the longer the amortisation time, the lower the water cost. The reduction is substantial and may increase as the percentage of the investment component and the discount rate in the cost of water increase.

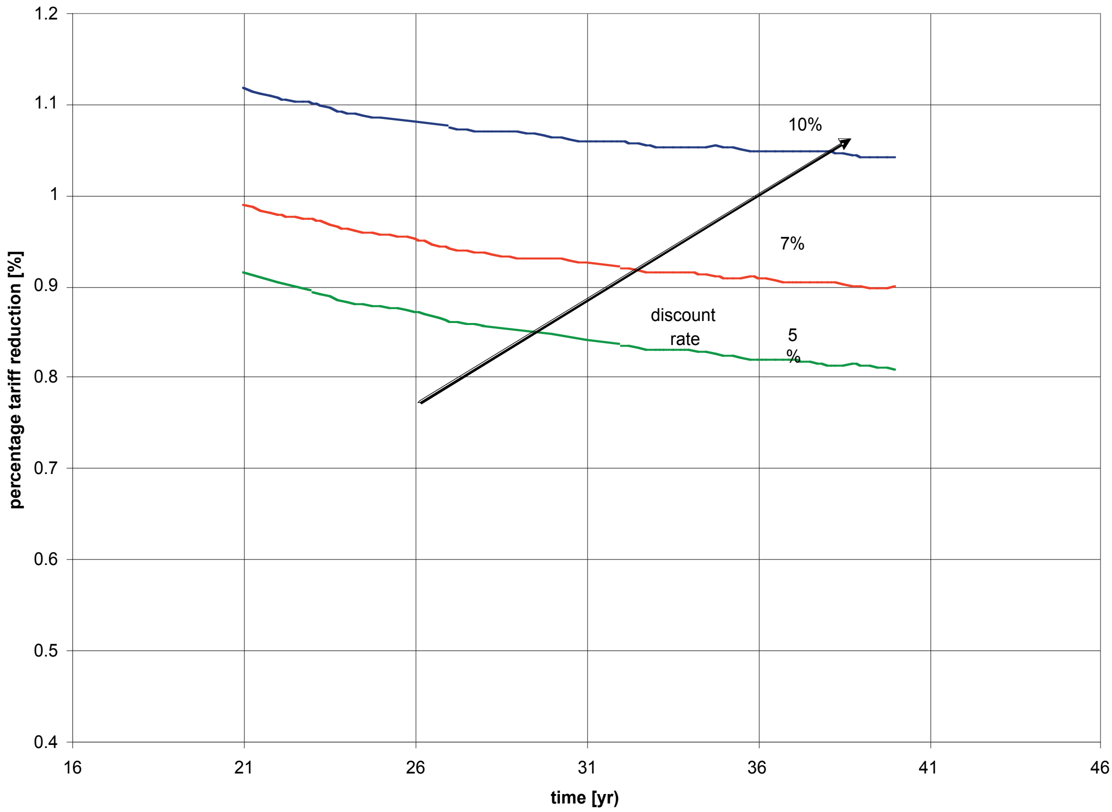

Figure 9.1: Effect of plant life on tariff

The material selection of the desalination plant must therefore be consistent with the planned duration of the concession and in addition, opportunities to further reduce water costs arise from the possibility to extend the useful life of the desalination plants beyond the original plan.

This has been the case particularly for the first generation of MSF plants. These projects largely employed carbon steel as a material for construction. The initial duration of the equipment was planned for a maximum of 15 years. The operational experience with these plants has revealed that the industrial life can be substantially longer than originally anticipated and several rehabilitation and refurbishment projects have been launched to extend the original life for 20 years and beyond.

Developments in material technology and a more in-depth knowledge of the corrosion aspects in seawater have resulted in the economical adoption of nobler materials. It is expected that the second generation of large MSF desalination plants installed in the last ten years will last for more than 40 years with minimum maintenance and minor overhauling, and the application of super duplex or super austenitic alloys for the high pressure component of the SWRO projects would also bring about a substantial enhancement in the industrial life of this technology.

The expected life of a desalination plant is indicated in the table below against the type of technology employed.
The value of existing assets allows the rehabilitation and upgrading with new technologies to provide plants with increased capacity and efficiency using ideas like NF and integrated upgrading.
The results illustrated in the table 9.1 below have been practically demonstrated for a large number of MSF plants installed in the 70's. Many of these plants are still operating in good order despite the material used the construction was mainly Carbon Steel having a much lower corrosion resistance that stainless steel or duplex steel used nowadays in modern plants
Table 9.1: plant life and maintenance regime against desalination technology

Technology	SWRO	MED-TC	MSF
Plant Life	15-30 years (*)	20-40 years	25-40 years
Maintenance regime	Medium	Low	Low

(*) membrane replacement carried out in a regular manner.

The maintenance regime for SWRO technology is based on the present state of the art. Continuous development in SWRO technology brings about membranes having a longer life and therefore a lower replacement rate. In addition, the development of larger train sizes or of the pressure centre arrangement will reduce manpower requirements.
Financial models for SWRO, STP generally consider a depreciation of the plant that is calculated at a rate of 12% to 18% of the total construction costs so that at the end of the concession period the terminal value of the plant is considered zero. The Equivalent Asset Value during the plant life is therefore calculated as indicated in Figure 9.2 below.

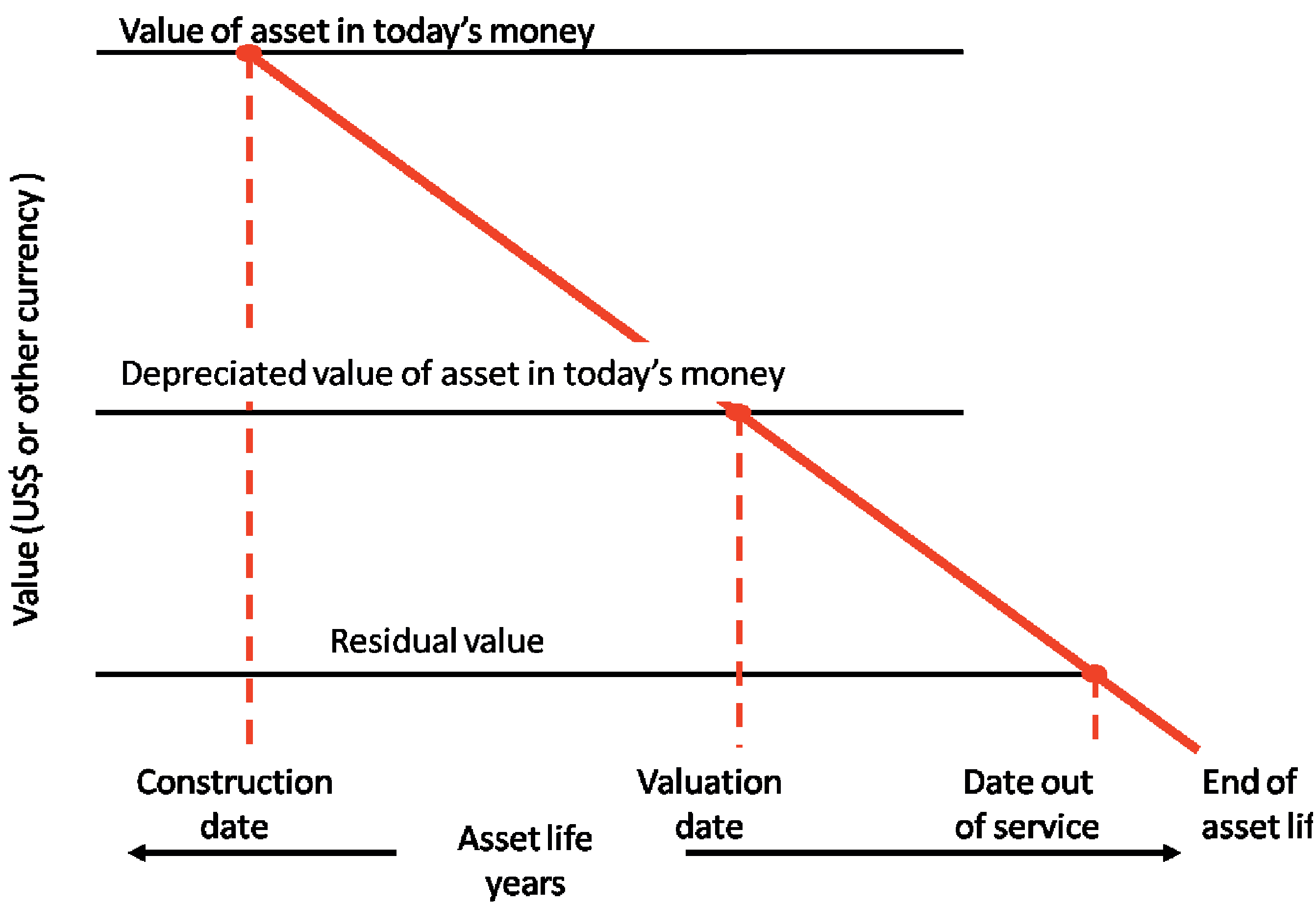

Figure 9.2: equivalent assets value scheme

Upgrading the existing plants represents an opportunity for optimization of low cost assets, which in the majority of cases have already been amortized. These activities can also remove some of the causes behind bad operation and optimize O&M costs.

Tariffs will also benefit if at the end of the operational period of the plant, the assets are transferred back under a BOOT (Build, own operate and transfer) to the public Corporation that has issued the concession.

In such a case, assets must be considered to have a terminal value (TV).

The plant Terminal Value is calculated as a percentage of the total construction cost of desalination and treatment plants. It is normal practise to assume that the plants will be maintained in good operating condition for the duration of the Concession Period, up to and including the last year of operation. This is often an issue of concern especially for membrane plants as during the last years of the concession the Operator may not renew membranes with the required frequency Generally the concession agreement and the operation and maintenance contract foresee a certain level of control from both the Public Corporation and the Developer on the tenure of the plant even in the last years of operation.

In this case and as long as the civil works are maintained, and equipment replaced and updated from time to time (eg – membranes, pumps replaced, etc..), plants can often be expected to have a residual life of 10 to 20 years beyond the Concession Period.

Given these assumptions, the estimate for the Terminal Value is based on the "replacement method" calculated as:

$$\text{TV} = \text{Terminal Value} = C_R \cdot \frac{L_R}{L_t} \quad (1)$$

$$C_R = C_0 \cdot (1 + f)^n$$

Where:

C_r = Replacement cost
L_r = Remaining life of the plant in years
L_t = Expected economic life of the plant, assuming it is maintained in operating condition to meet demonstrated capacity
C_o = Original cost of the plant
f = annual inflation rate measured by the CPI in the area where the plant is operating
n = Concession period measured in years

The term C_r is the depreciates value of the plant to present day values which is symbolically indicated as a straight line in Figure 9.2

The above considerations are valid if, at the end of the plant commercial life the plant technology has not become obsolete and therefore continuing the operation with the existing technology would not be sustainable with respect to operation and maintenance costs and therefore it would be cheaper to replace the technology with an entirely new process.

In this case the terminal value may be negative as it may involve the expenses necessary to clear the site from the existing plant followed by recovery and re-structuring of the area.

10 Tariffs

This part of the book is related to the description of tariff and payment settlement mechanisms in private projects. The chapter contains a few examples of concession agreements that have been applied to major IWP/IWPP and other examples of wastewater concessions. However it should be taken into account that there are several possible mechanisms that may be applied to structure water tariffs in the industry.
The formulas and conditions applicable to payment are generally related to the terms and conditions of the concession and therefore vary from one project to another. The data and methodology provided in this session is a general model that despite being widely adopted remains for illustration purposes only.

~~1.1~~10.1 Payments

When a private project is completed payments are due in a period of time to the project Company and these can be basically classified in two categories

1. Water Capacity Charge (W_{CC})
2. Water Output Charge (W_{OC})

The ratio between capacity and output water charges varies from one project to another, however, for desalination projects that have been initiated by a Public initiative, this ratio is generally between 40% and 60%.

The relative percentage between capacity and output water charges depends on the plant availability or on the volume output that is requested by the offtaker within the billing period.

The lower the plant availability the higher the amount of cost recovery profit and return on equities that the Project Company needs to allocate to the capacity charge.

In large IWP-IWPP models, the return on equity is generally a requirement that is established in the bidding documents and there are provisions that do not allow the Project Company to have a component of their profit or equity return linked to the Water output charges. With this provision, the demand risk is covered by the Government – Offtaker by securing payment for the Water Capacity charges.

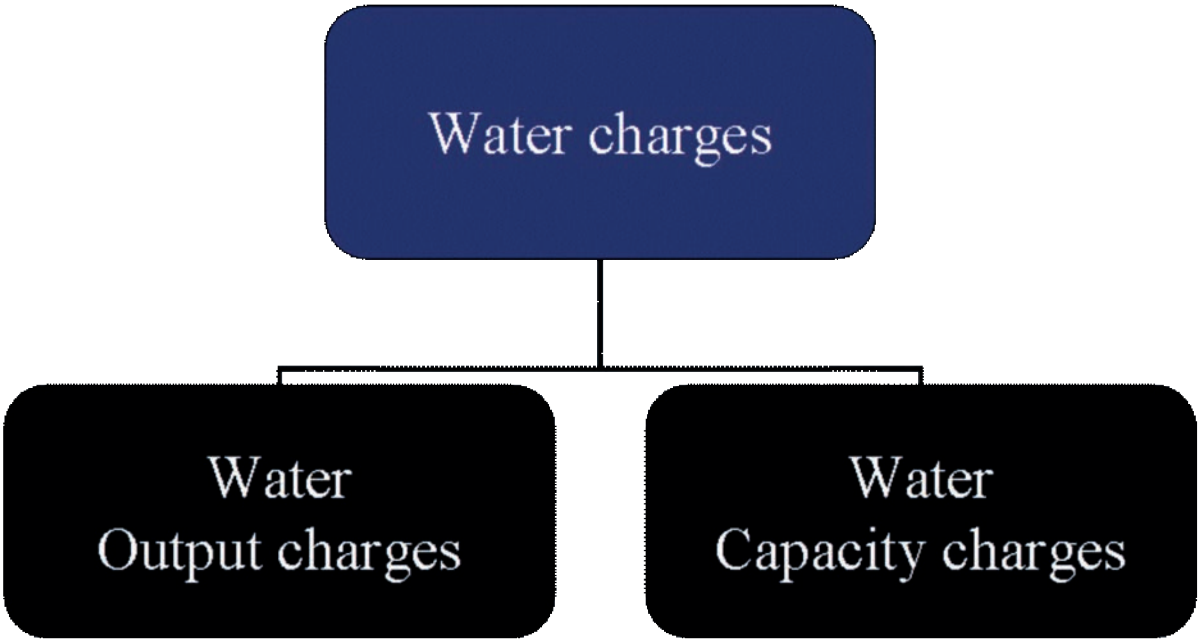

Figure 10-1 : water charges

~~1.1.1~~10.1.1 Water Capacity Charges – WCC

To appreciate the general philosophy of water capacity charges, it is necessary to understand that even if water is not produced by the plant, the Developer has spent money and resources investing in the construction of the project, in staffing and maintaining the plant, and insofar has made the water capacity available to the Public Corporation and the offtaker. The fact that a plant is available to satisfy public demand is a value for the Public Corporation independent from the fact that water is not being produced.
The Water Capacity Charge (sometime defined as Capital Cost Recovery Charge Rate for Water) is a component of the water payment that in an ideal situation tends to be unaffected by increases or decreases in the volume of water produced.

Water charges are structured as period charges, therefore they relate to a span of time.

The behavior of the water capacity charges versus the output volume is shown in the following diagram.

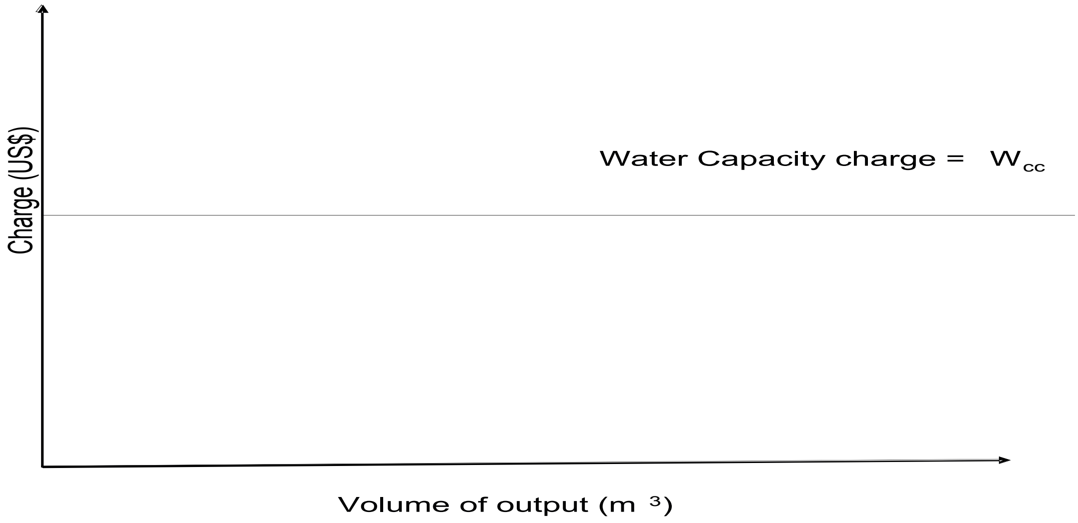

Figure 10-2: water capacity charges typical trend

Water capacity charges indemnify the Developer for the plant being installed and available and include the Developer investment costs (capital amortisation). This includes all costs arising from the total project budget and includes the payment for the debt service, such as

- Construction cost of Plant
- Development Costs
- Returns on Equity
- Financing Costs during Construction
- Taxes etc.
- Operating Costs prior to the Project Commercial Operation Date
- Insurance
- Maintenance
- Staff salaries
- Fixed O&M charges

Water capacity charges are payable in full or in portions on completion of the Reliability Test Runs or Net Dependable Capacity Test of the plant or of sections of the plant until the final plant performance test which designates the commencement of the Project Commercial Operation Date.

~~1.1.2~~10.1.2 Water output Charges – W_{OC}

The water output charge (sometime defined as Variable Operation and Maintenance Cost Recovery Charge Rate for Water) is the component of the payment that is related to the water output from the plant both during the commercial operation and during the construction period. The Water Output Charge is a cost that varies directly with the volume of output. In a simplified situation where we exclude adjustments due to indexation or correction curves for departures from design parameters, water output charges are the same for each unit of water output produced wherever total variable cost increases as volume of output increases. A sketch of variable output charges is shown below.

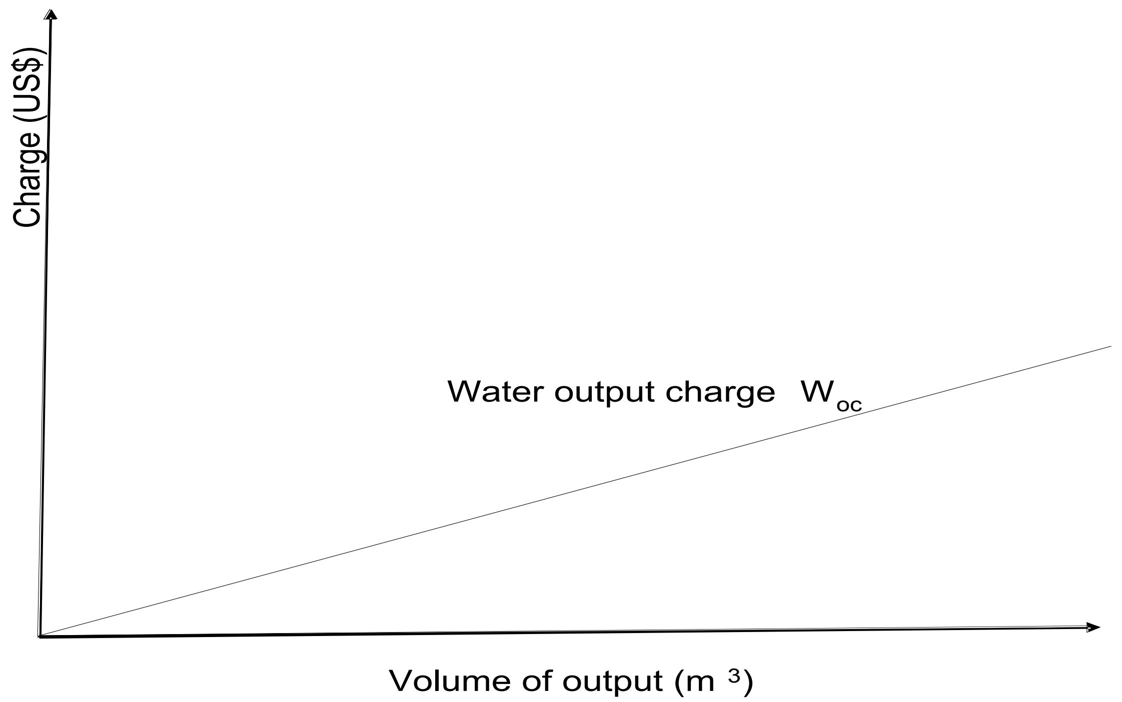

Figure 10.3 : water output charges typical trend

The Water Output Charge includes the payment for variable costs and electricity related to Output Delivered and is calculated on the basis of the following two principal elements:

- Water Output Operation and Maintenance Charge Rate, the amount payable to compensate the Project Company for variable operation and maintenance costs to produce Output Delivered. These in turn could be identified as
    - Variable spares
    - Consumables / renewables
    - Cartridge filters replacement
    - Membrane cartridge replacement
    - Chemicals
    - Ion exchange resins replacement (as required)
    - Utility services (excluding electricity supply)
    - Variable Plant operation costs
- Electricity Charge, the amount payable to compensate the Project Company for electricity costs to produce the output delivered;

Electrical Power for the Project is generally provided by a connection to the overhead line from the national electricity grid; however there are cases of SWRO plants with Self-Generating Energy Supply System by natural nas and captive power generation. Depending on the stability of the grid system, the Developer – Public corporation may opt for redundant sources for power supply to the plant.

In this case, the electricity charge should be considered as an electricity – fuel charge.

Output charges are different from fixed water charges as they are payable to the Project Company as soon as the off taker accepts product water to his network.

In particular, payment of variable water output charges is independent from the fact that the plant has been performance tested and meets the guaranteed performances but it is only linked to the fact that the product has been accepted as in conformity with the specifications for potable water .

The Project Company therefore receives payment for the Variable Output charges during initial operation trial run and commissioning tests.

This is quite different from the traditional turnkey payment pattern where the Operation and Maintenance cost of the plant remains with the EPC contractor until the plant acceptance tests have been passed.

A further breakdown of Figure 10.1 is given in Figures 10.4 and 10.5 below show where the various components to water capacity and output payments can be identified against each cost elements contributing to the overall payment.

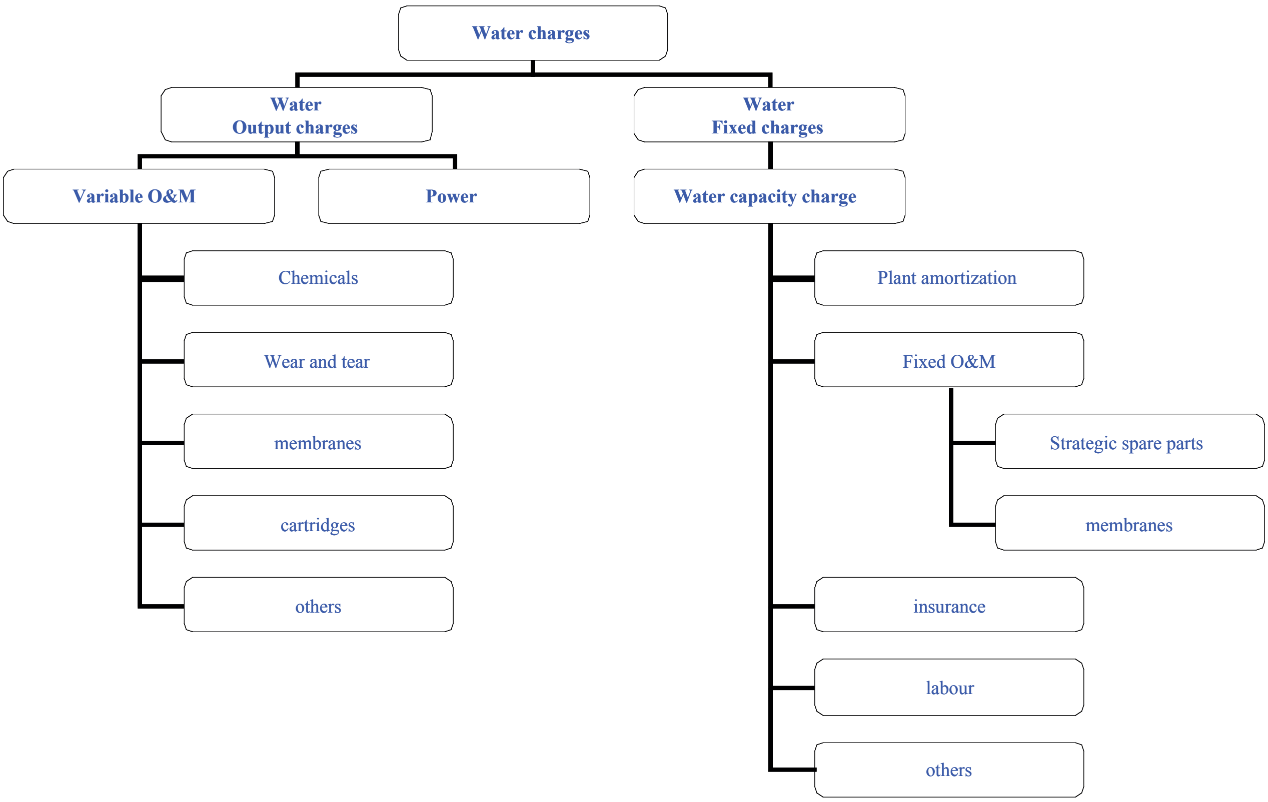

Figure 10.4 : typical tariff structure for SWRO project

The same charge structure can be applied to both thermal and membrane desalination projects with some modifications according to the configuration of the plant. In some cases thermal desalinations are importing steam as an energy source from an adjacent yard. In this case the water charge structure would be as indicated below.

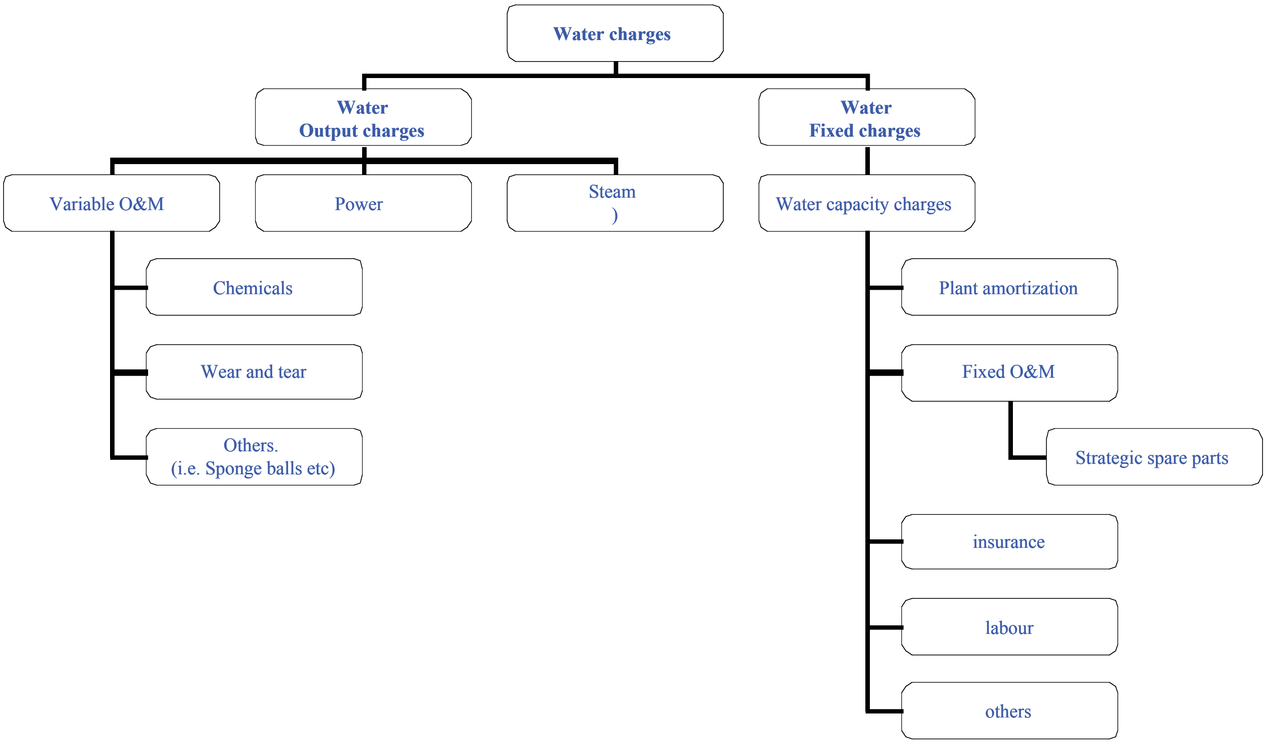

Figure 10.5 : tariff structure for thermal project

~~1.2~~10.2 SWRO – MBR and UF projects : Membrane charges

It can be seen from the figure 9.1-5 that for a reverse osmosis project membranes appear both in Water Output charge and in Water Fixed charges.

The replacement of membranes increases as the plant operates. However a certain number of membranes should always be available as inventory in store. Membrane degrade to a certain extent whether the plant is operating or not.

The tendency is to reduce the inventory to 5% - 7% of the total membranes installed or the level or membrane expected to be replaced every year. This set up is also applicable to sewage treatment plants using membrane technologies such as MBR or side stream ultra filtration.

Generally the allocation of membranes in the tariff structure is a trade off for the developer at the bidding stage between the optimisation of the tariff proposal and flexibility and margin in operation.

In particular allocating a large component of the membrane cost to water output charge allows proposing a more price competitive tariff since the fixed charge for Water Capacity will be lower and membrane costs will be chargeable only if the plant produces output. On the other hand this structure is more risky and less flexible due to the fact that membranes degrade whether or not they are capable of producing output.

~~1.3~~10.3 Total charges

Therefore, in an ideal and theoretical situation, the water charge payable to generators in private projects is a semi variable charge that is partly affected by the level of output produced. The behaviours can be presented graphically as indicated in the Figure below:

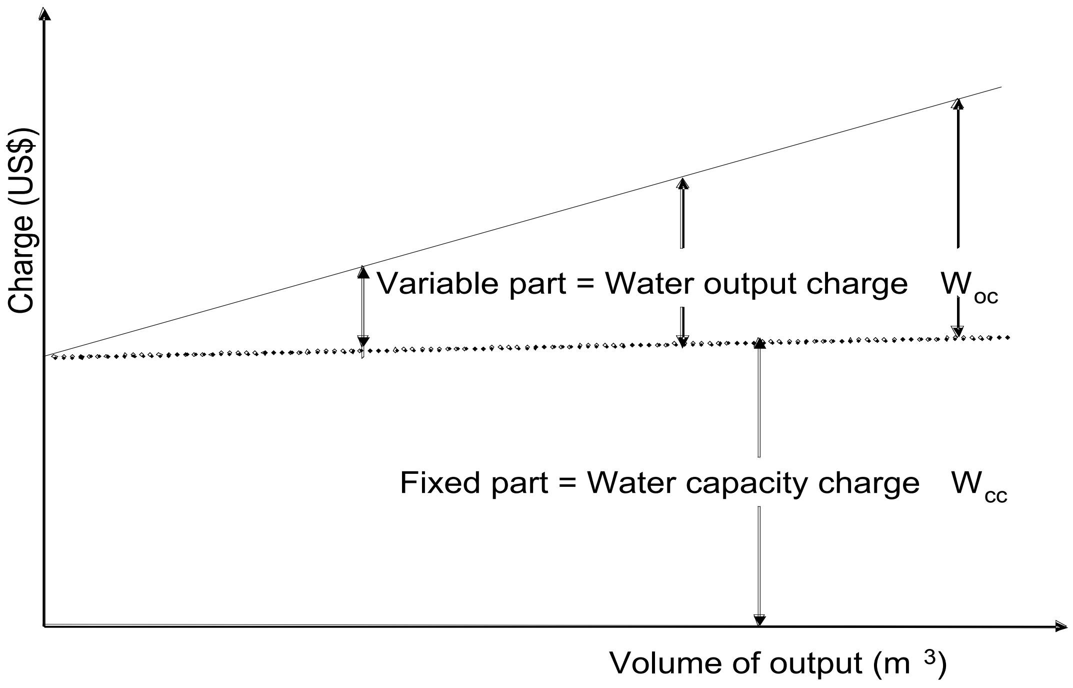

Figure 10.6 : fixed and variable charges against volume of output delivered

Despite the payment philosophy indicated in the figure above is the one most commonly applied in the desalination industry for major IWP-IWPP projects where different alternatives may be encountered in relation to the approach to the water charge calculation.

For examples there are cases of concession where the off taker instead of paying a fixed capacity charge for a billing period commits to purchase a minimum volume of product water during the same period. This approach is generally called" take or pay".

This minimum take of pay volume, more frequently defined as the minimum offtake is generally defined as a percentage of the the volume that the plant can generate in a determined billing period, generally quarters.

As the compensation for the Developer investment is provided by the sale of the product water minimum off take volume is generally quite high . Generally, this value is ranging between 80% to 95% of the Scheduled production volume multiplied by the number of operating days in the relevant billing quarter.

In the case of Minimum off take structure the schematic diagram indicated above can be re-represented by the Figure 10.7 below.

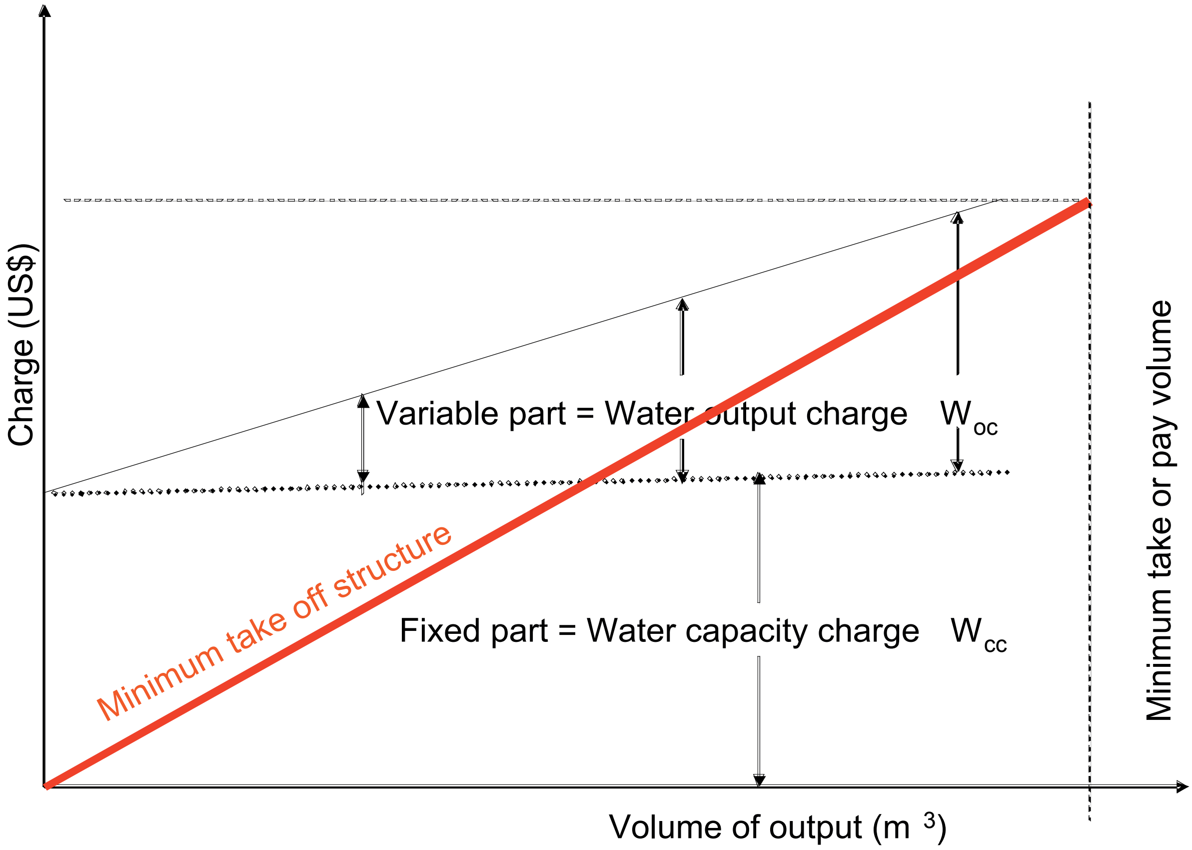

Figure 10.7: fixed and variable charges and take or pay

~~1.4~~10.4 Indexation

Both the Water Capacity Investment Charge Rate and the Water Capacity Operation and Maintenance Charge Rate for the plant need to be adjusted for changes occurring between the overall market scenarios.

There are different sophisticated ways to index the tariff. The typical Middle East structure for major IWP IWPP projects is shown in the following illustration:

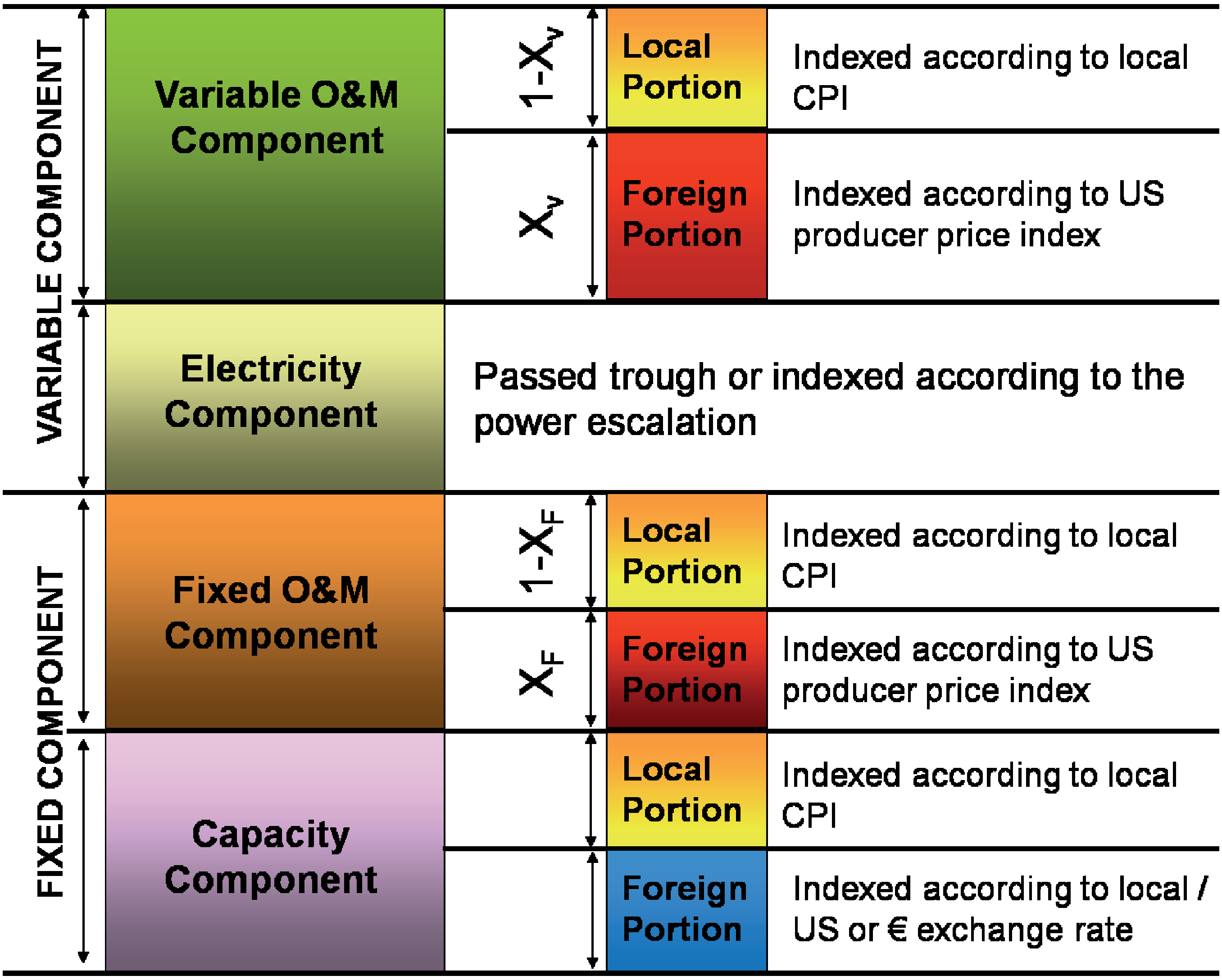

Figure 10-8 : indexation on fixed and variable components

As can be seen from the Figure above, the Fixed Charges are subdivided into a fixed operational and maintenance component. In a capacity component both charges are then broken down into a local and foreign portion X and 1-X.

These portions are subject to different indexes according to the component of the costs that they reflect in the tariff.

The Fixed O&M component of the Water Capacity charge includes both an indexation for the local and foreign portion.

The local portion of the FO&M Water charge recovery is adjusted according to the local consumer price index against a reference Consumer Price Index that is typically the one at the time of contract award. This indexation reflects adjustments in local costs such as salaries, local services etc.

The foreign portion of the FO&M Water is both adjusted according to the international Consumer index as well as in accordance with the fluctuations in the exchange rate between US$ or € or any major currency exchange rate against the currency of the country in which the project is implemented.

The adjustments made for the indexation are given for the Fixed O&M in the formulas below.

$$W_{AdjFO\&M_{cr}} = W_{FO\&M_{cr}} \cdot X_f \cdot \frac{USP_a}{USP_{ref}} \cdot E_f + W_{FO\&M_{cr}} \cdot (1 - X_f) \cdot \frac{CPI_t}{CPI_r}$$

The adjustments made for the indexation of the variable O&M are indicated in the formula below

$$W_{AdjVO\&M_{cr}} = W_{VO\&M_{cr}} \cdot X_v \cdot \frac{USP_a}{USP_{ref}} \cdot E_f + W_{WO\&M_{cr}} \cdot (1 - X_v) \cdot \frac{CPI_t}{CPI_r}$$

Where:

- $W_{FO\&M_{cr}}$ is the fixed O&M charge rate for water
- $W_{VO\&M_{cr}}$ is the variable O&M charge rate for water
- $W_{AdjFO\&M_{cr}}$ is the fixed O&M charge rate for water adjusted for indexation
- $W_{AdjVO\&M_{cr}}$ is the variable O&M charge rate for water adjusted for indexation

- E_f is the exchange factor local international currency
- X is the foreign portion percentage of the fixed and variable O&M charge respectively
- CPI is the local consumer index price
- USP is the US. Producer Price Index

This indexation adjustment is carried out in general to reflect the adjustments in foreign costs such as maintenance of strategic spares, membranes inventory whose cost is increasing or decreasing proportionally to the consumer index price and in some cases as these plant components need to be procured outside the country where the project is implemented.

Variable Operation and Maintenance charges indexation is based on the same principles detailed before for Fixed Operation and Maintenance charges indexation.
This reflects that some of the variable operation and maintenance costs such as cartridges, and some chemicals are related to international market pricing and others (such as chemicals for remineralisation etc.) are linked to related to local market behaviour.

11 Tariff modelling

This session of the book aims at describing the formulas governing financial models and water payment settlement mechanism. The procedure for payment calculation and the application of the formulas indicated below have been complemented with some examples showing how operational scenarios result in adjustments of the applicable formulas in real practise. The formulas can be considered applicable after the plant has reached the Commercial Operation Date.

~~1.1~~11.1 Water capacity charge

The theoretical maximum charge in a Billing Period is the sum over all of the Hours of the Billing

Period, of the multiple of the Demonstrated Capacity of the Plant for each Hour and the Capacity Related Charge Rates per Hour (equal to the sum of the respective Water Capacity Investment Charge Rates and the Water Capacity Operation and Maintenance Charge Rates). Two adjustments are then made as applicable for:

- Scheduled Unavailability for planned maintenance
- Unscheduled Unavailability (Forced Outages)
- Reduction of capacity and De-rating

The Water Capacity Charge for Billing Period _ can be calculated as indicated in the formula 10.1 below:

10.1)

$$W_{cc}(\tau) = \sum_{i=1}^{\tau} W_{CD} \cdot (W_{I_{cr}} + W_{FO\&M_{cr}}) \cdot \tau - W_{CDO}(\tau) - W_{CDR}(\tau)$$

Where:

- W_{CD}: Represents the Water Capacity in m^3/hr that has been demonstrated by performance test. It should be noted that this capacity may increase as the plant commissioning progresses and more units come into stream
- W_{CC}: Water Capacity Charge applicable in the period of time _.
- W_{CDO}: Deduction for Scheduled and unscheduled plant unavailability in the period of time _.
- W_{CDR}: Deduction for De-rating or capacity reduction of the Plant in the period of time _.

The term $\sum_{i=1}^{\tau} W_{CD} \cdot (W_{I_{cr}} + W_{FO\&M_{cr}}) \cdot \tau$ is often called Water Capacity Base Charge and is the maximum payment that can be due to the project Company during the period of billing.

- W_{Icr}: is the capacity (investment) component of the water charge rate and is indexed as indicated in Figure 1.4.1 .
- $W_{FO\&Mcs}$: Is the FO&M component of the capacity charge rate.

Both components are indexed as indicated in Figure 10.8

11.1.1 Deduction for Scheduled and Unscheduled Unavailability of the Plant

Any plant during its operation needs maintenance. Generally desalination plants have a very high demand and maintenance is scheduled according to the periods of lower product water demand. During the maintenance period the plant is not considered available and therefore capacity payments are subject to various deductions according to the number of units that are out of service.

Desalination plants can also be unavailable because of operational problems such as forced shut down resulting in non-availability of product water to the offtaker.

It is general practise that the producer notifies the offtaker of the Declared Available Output for the next day and therefore shall take into account the Planned Outages, Short Notice Outages and other scheduled downtime.
Also in this case the plant can be considered in part or entirely unavailable and therefore this situation attracts deductions in the capacity payment related to the investment charge rate component of the water capacity charge.

The deduction for Scheduled Unavailability and Forced Outages of the Plant is calculated multiplying the investment charge rate by the maximum difference between the scheduled and the actual output delivered in the period and including a correction factor (1+ _).

10.2) $$W_{CDO} = \sum_{i=1}^{\tau} \max(WO_S - WO_D) \cdot \tau \times (1 + \mu) \times W_{I_{cr}}$$

Where:

- WO_D: Water output actually delivered by the plant during the period (m^3/hr)
- WO_s: Scheduled Water Output m^3/hr

Table 11.1. shows the typical _ factors in IWP-IWPP projects. These can vary from project to project, however the principles are generally consistent.
As can be seen from the table 10.1 the component _ is considered 0 if the plant is shut down as per scheduled maintenance otherwise is > 0 for unscheduled unavailability.
The term (1+ _) indicated in the formula therefore generates a penalty to the Developer in case the plant has not been available due to forced outages.
These penalties are generally higher if the plant outage occurs in the summer period when the demand from the network is the maximum and therefore the problem and inconvenience to the offtaker in facing a sudden unavailability of product water are also higher. If the project includes the tank farm, minor failures could be theoretically handled by Project Company through the potable water stored in the storage tanks. This could be limited to a forced outage of few hours.

Table : 11.1 typical _ factors in IWP-IWPP projects

Period	**Event**	**_ Value**
Operational period	Scheduled unavailability	0
Summer	Forced Outage	Y > X ranging between 0.05 and 0.08
Winter	Forced Outage	X ranging between 0.01 and 0.03
Operational period	Force Majeure	0
Operational period	Bad Faith Declaration	Z > Y ranging between 0.1 to 0.2

The values Y and X for the Summer and Winter _ factor are based on the Northern Hemisphere where summer has generally the highest water demand.

On the other hand, as it can be seen from an analysis of the table above, private projects give through tariff modelling and payment settlement mechanics a lot of emphasis to availability and reliability of the plant.

If the plant is not capable of matching dispatch requirements when it is needed, this event triggers a severe deduction in the investment component of the capacity charge rate. Through this mechanism in the tariff adjustment the developer is encouraged to design the plant with sufficient redundancy and to ensure operation conformity with the planned schedule of operation and maintenance.

It is general practise that at the beginning of the plant operation, the Off Taker provides the producer an estimate demand profile of the potable water from the plant for the relevant contract year. This demand profile is further refined on a daily basis for the subsequent day for each hour and it is given with an hourly accuracy. On the other hand the provision of a demand profile represents an obligation for the producer and not for the Off Taker.
As it can be seen from the table above, in the event of Force Majeure the _ Value is generally 0.

This means that the Project Company receives capacity charges during Force Majeure events that affect availability, only to the extent of the actual availability reached by the project. In this event, the off taker bears the risk of Force Majeure affecting availability of the plant and adherence with the potable water schedule but despite the Project Company not being penalised for unavailability, capacity charges are deducted from the payment pro rata to the reduction of the capacity of the plant.

11.2 Availability and reliability

In deregulated markets, availability is an extremely important factor as, during the time the plant is out of service, the water generator does not receive revenues from his assets or, in worse scenarios, may be obliged to procure water more expensively from alternative sources.

Furthermore, when the plant is unavailable, the fixed costs of the plant (amortisation, salaries etc) are still incurred by the water producer and this will have an impact on the water tariff.

The availability _ of a plant is generally defined in the formula 10.3as:

$$10.3)\quad \alpha = \frac{\tau_y - \tau_{FO} - \tau_{SO}}{\tau_y}$$

In this formula $_y$ indicates the scheduled operating hours in a year and is generally intended as 8700 hrs and $_{FO}$, $_{SO}$ indicate the time lost for forced and scheduled outages respectively.
The reliability _ of a plant is generally defined as indicated in the formula 10.4:

$$10.4)\quad \rho = \frac{\tau_y - \tau_{FO}}{\tau y}$$

Reliability therefore defines the time the plant is unavailable for operational problems.
Therefore, considering the previous definition of availability and rearranging we can obtain formula 10.5.

$$10.5\,)\quad \alpha = \rho - \frac{\tau_{SO}}{\tau_y}$$

Comparing the two formulas above clearly the availability of a plant is always lower than the reliability. It should be noted that both availability and reliability have a substantial impact on the design of the desalination plant; in particular they affect the choice of technology and the degree of redundancy required in order to achieve the required availability factors.

Reliability therefore can be defined as the percentage of the time between planned overhauls where the plant is ready to answer the call for production, whereas the availability is the percentage of total time where water could be produced. Both availability and reliability have a large impact on plant economy.

In deregulated markets, reliability is crucial. Scheduled outages can be planned for off-peak periods when tariffs are close to or even below variable costs. Then, only a small loss of income results from the planned outages.

It is very difficult to indicate reliability values that are valid against each desalination and water treatment technology. in all operations scenarios, since factors such as preventive maintenance and operating mode have an impact on reliability. However, statistics indicate that all types of plants under consideration have similar availabilities and reliabilities when operated under the same conditions.

Typical figures for the availability and reliability of well designed and maintained plants are detailed in Table 11.2.

Table 11.2: Typical Availability and Reliability against each Technology

Type of Plant	Availability	Reliability
MSF	90-95%	97-99%
MED	90-95%	97-99%
SWRO (N-2)*	95-100%	100%
MBR (N-2)*	95-100%	100%
SWRO (N)*	80-90%	95%

These figures are valid for plants operated at base load.
For thermal desalination the availability figures should be multiplied by the availability of the power generation plant as power plant outage will result in a lack of steam to the desalination yard. For stand alone SWRO plants this availability will have to be multiplied by the network availability.

They would be lower for peak or intermediate-load plants because frequent start –ups and shutdowns reduce plant lifetimes and increase the schedule maintenance and forced outage rates.

In the table above we have used the terminology N-1and N-2 for SWRO and MBR technology. This terminology refers to the current design philosophy adopted for both SWRO and MBR projects that foresees an inherent train number N redundancy.

According to this approach, in normal conditions the plant operates with all N trains and in the event a train needs to be shut down for scheduled or unscheduled maintenance (for instance during the membrane cleaning or for a pump problem) there is an inherent train redundancy whereby the plant may still run without reducing the product water flow rate with N-1 or even N-2 trains in operation.

Obviously there are several design conditions that need to be considered to ensure that this philosophy is sustainable during scheduled or forced maintenance. These are both the recovery ratio and in particular flux.

If _ is the flux at the membrane at design conditions, if a train is brought off line the flux through the remaining trains will be :

$$\phi_{N-x} = \phi_N \cdot \frac{N}{N-x}$$

Where $_N$ is the design flux with all trains in operation, N is the number of trains and x are the trains that are not in operation.

Figure 11.1 below shows the average flux in the first pass of a SWRO system with a train out of service at various design fluxes in normal operating conditions.

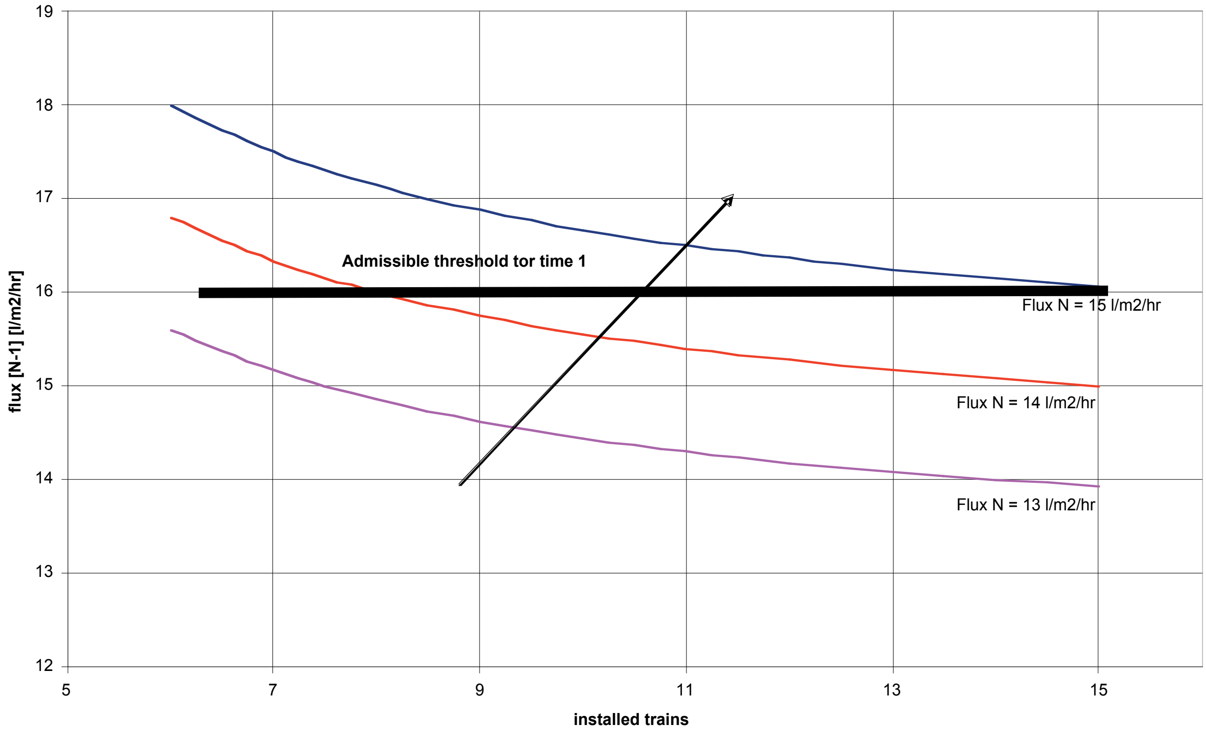

Figure 11-1 : flux behaviour under maintenance at various train – flux configuration example

Depending on the approach that was taken in the design of the original membrane flux and on how many trains the water production has been divided, the $\_{N-1}$ flux value can still be acceptable for a limited time by the membranes without irreversible scaling and fouling phenomena.

This technical solution offers more flexibility as should one or two of the trains are required to be brought off line for cleaning or unscheduled maintenance, the balance of the flow cane be treated and produced by the remaining trains for a limited time.
Figure 11.2 shows the behaviour of the formula above in the first pass of a SWRO system designed with a normal average flux of 14 $l/m^2/hr$ against the number of trains that are taken out of service.

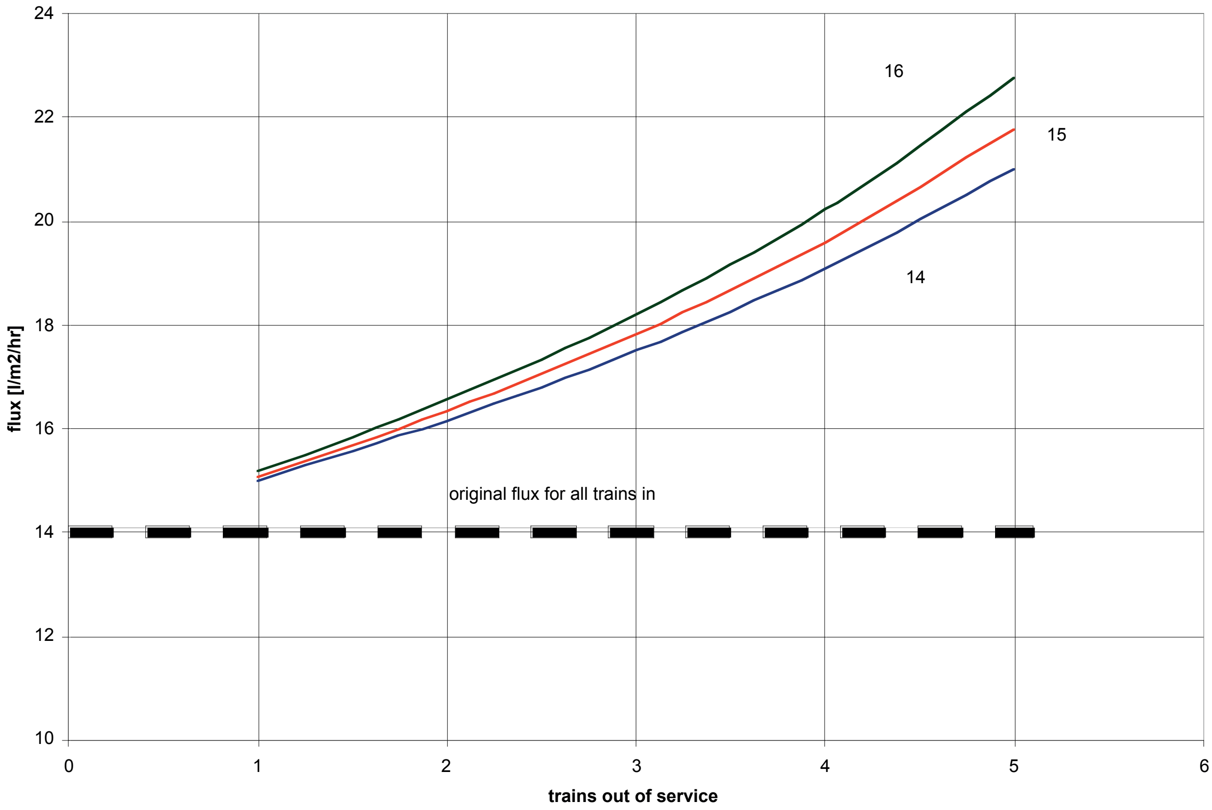

Figure 11.2: flux behaviour with various trains off service example ???

While the redundancy concept can easily be applied to SWRO technology, its application to thermal desalination is not easy. Thermal desalination technologies are designed for base load and their commercial competitiveness is given by the large unit size with a smaller range of operation and flexibility than SWRO. Therefore in the distillation unit it would not be economical to have redundancy.
If a thermal unit shuts down, it would not be possible to compensate the loss in production by increasing the production of the remaining units.

For this reason as indicated in the table, reliability and availability of reverse osmosis can increase up to 100 % if the system has been designed with sufficient redundancy.

Major factors that determine the plant availability are:

- Degree of redundancy and equipment standby.
- Design of the major components

  Engineering of the plant as a whole, especially of the interfaces between the systems

  Mode of operation (whether base, intermediate, or peak load duty)
- Seawater treatment
- Qualification and experience of the operating and maintenance personnel

Availability is not used in the cost of electricity calculation because the equivalent utilization time is the variable. However, it may be considered that a high availability allows an operator to run a desalination plant with a higher utilization time per year and therefore achieve higher income.

Despite the term, “reliability” is generally never present as a defined term in contractual documents.

Reliability is an essential component in key agreements.
Particularly in the Middle East where little or no storage facilities for potable water are available, desalination and water treatment plants operate under very tight instructions from load dispatch centre.
As indicated in Table 11.1 above if the plant is not dispatching product water in the period of scheduled operation due to a technical fault, deductions to the base charge for water capacity for unscheduled outage foresee a penalty component reducing the base charge rate.
The penalty factor tends to be higher the higher is the demand from the network as the outage from the plant results in a higher disservice to the public.

11.2.1 Deduction for De-rating of the Plant

The deduction for De-rating of the Plant is a terminology that is derived from power generation plant where as a consequence of plant aging, a reduction in capacity occurs. In thermal desalination plants, once the capacity has been demonstrated during the performance test no deductions in capacity are likely to occur in the plant lifetime except if scheduled rehabilitation and overhauling have not been carried out and this leads to a reduction in heat transfer surface due to tubes plugged or a reduction in process pump capacity.
Membrane technology may experience a de-rating if membranes are not replaced with the scheduled frequency and therefore as a consequence of the reduced flux though the membrane, the plant recovery ratio and in turn the capacity needs to be reduced .

11.3 Water Output Charge - W_{OC}

The 10.3as Water Output Charge are calculated according to the following formula

10.8

$$W_{oc}(\tau) = \sum_{i=1}^{\tau} W_{CD} \cdot W_{VO\&M_{cr}} \cdot (1 + CF_{VO\&M} \cdot x) \cdot \tau + W_{CD} \cdot \lambda \cdot Y_p \cdot CF_E \cdot \tau$$

Where:

W_{OC}: Water Output Charge for Billing Period.
$W_{CVO\&Mcr}$: Water Output Operation and Maintenance Charge rate that is indexed as indicated in the previous section of the book for changes in the local Consumer Price Index, in the US Price Index and the local /USD exchange rate .
$CF_{VO\&M}$ is the variable O&M cost correction factor
x%: The percentage of the Water Output Operation and Maintenance Charge adjusted for the Variable O&M Correction Electricity Charge
Yp is the electricity price

Both the electricity and the variable O&M cost correction factors have the function of adjusting the variable O&M and electricity cost component in the water tariff when the seawater conditions have departed from the reference conditions. The Electricity and Variable O&M correction factors have the function of indemnifying the Developer and the Operator for keeping the plant in production with more adverse seawater conditions.

Therefore, in this case a percentage of the Water Output Operation and Maintenance Charge Rate for the Plant is adjusted to reflect the increased costs of operation of the plant using seawater that is outside the Reference Conditions by applying the relevant Variable O&M Correction Factor for the actual conditions.

The Electricity and Variable O&M cost correction factors are often represented as in the form of diagrams such as Figure 11.2 below reporting for illustrative purpose only the behaviour of a SWRO plant Variable Operation and Maintenance costs against the seawater SDI..

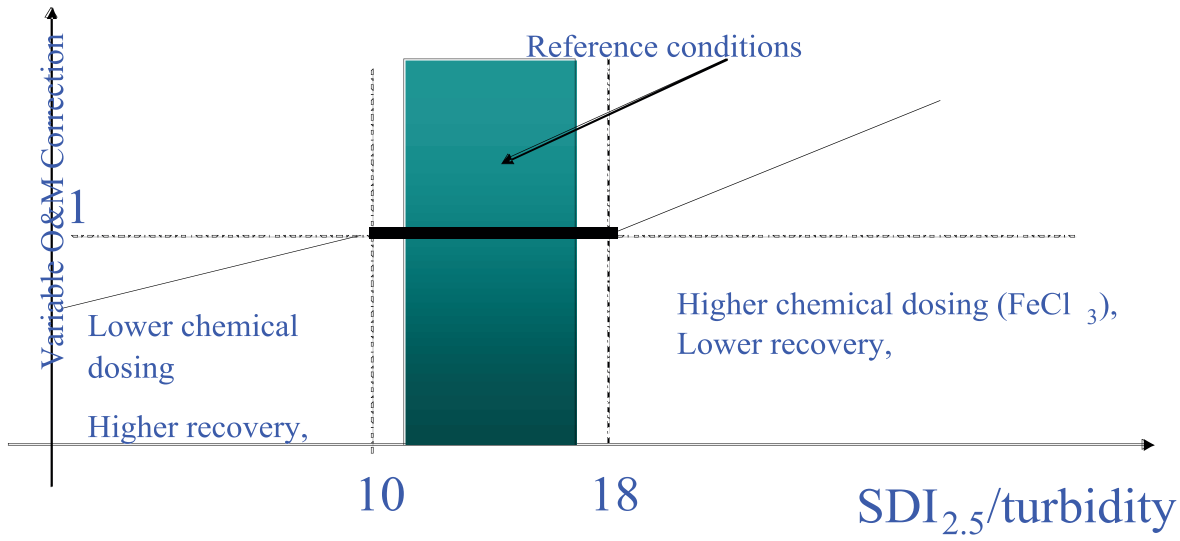

Figure 11.3: variable O&M correction factor against seawater SDI

It can be seen from the figure above there is an envelope of operating conditions between the $SDI_{2.5}$ values of 10 to 18 where the Variable O&M cost correction factor is 1.

Within this operating envelope the water tariff does not benefit from any adjustment for VO&M cost correction and it remains constant.

However, there may be within the yearly life of the plant situations where the seawater quality is poorer.

This may occur in the case of stormy weather or algae blooms.

As seawater has a higher SDI, additional chemicals may be required in order to maintain the plant in operation with the seawater quality upstream of the membrane section in accordance with the prescribed parameters.

Alternatively, the developer may incur higher cartridge filters replacement rates, or the operation and maintenance contractor may be required to operate the system at lower recovery rates.

All these operational scenarios are generally reflected in a tariff adjustment factor for additional variable O&M costs. However, the Variable O&M cost correction adjustments may also trigger a decrease in the water tariff. As it can be seen in the figure above, in days of clean and calm water, the operator can reduce the chemical dosing or increase the plant recovery rate and the savings from these more economical operating conditions are passed to the Off-taker through the tariff cost correction factor calculation.

In order not to make the bid evaluation process too complicated and in order to avoid cumbersome evaluation criteria, there are only limited parameters that may be considered for payment settlement. It should be good practise that these parameters are measurable on line in order to be directly connected to the metering and settlement system where all the algorithms indicated above are cabled and the adjustments are automatically carried out.

One of the aspects that has been particularly difficult for the introduction of seawater reverse osmosis in the Middle East is the variation of VO&M costs against seawater quality.

Multi stage flash or in general thermal desalination plants normally relate to the VO&M costs to seawater temperature and seawater total dissolved solids (TDS). In general an increase in TDS reflects some variations (albeit usually very minor) to chemical consumption. The mechanism the payment under IWP project is adjusted to take into account these operating conditions is set forth in session 13.2.

Reverse osmosis technology is subject to many more variables and there is no available high accuracy measuring system for these variables.

Unfortunately no reliable on line seawater SDI measurements have been developed. In order to compensate for this aspect adjustments for departing seawater conditions are generally done via turbidity.

A typical curve for specific power consumption correction against seawater temperature at various values of TDS is shown in the Figure 10.4 below where the specific power consumption Variable O&M cost adjustment factor is plotted against seawater temperature at various TDS at parameters.

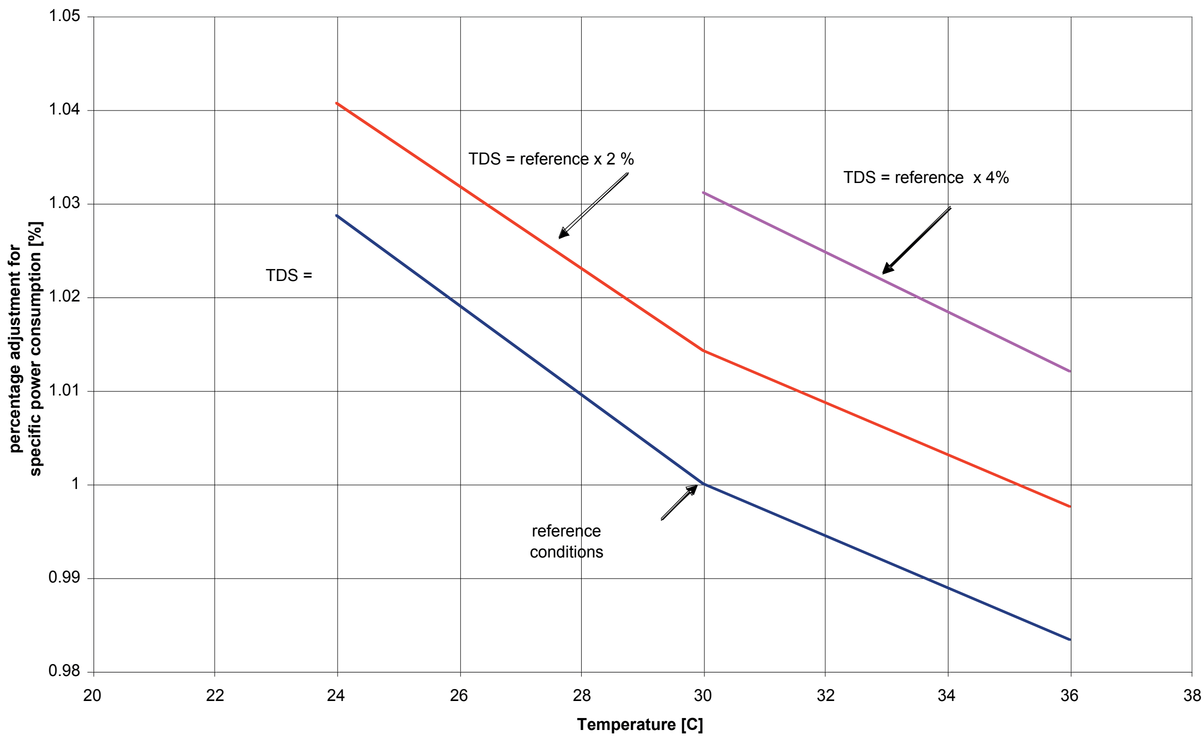

Figure 11.4: variable O&M correction factor against seawater SDI for SWRO technology

As can be seen, the specific power consumption value at a seawater temperature of 30 C and reference TDS is considered as the base specific power consumption, adjustments are therefore carried to take into account the variations in specific power consumption at cooler seawater conditions and in the event that seawater TDS would depart from the original envelope of design values.

A similar curve may be drawn for the Variable O&M cost correction against seawater temperature. The curve of Figure 11.5 below illustrates the behaviour of the variable O&M cost correction factor against the seawater temperature that reflects the different H_2SO_4 and NaOH requirements for the seawater conditioning as the temperature increases.

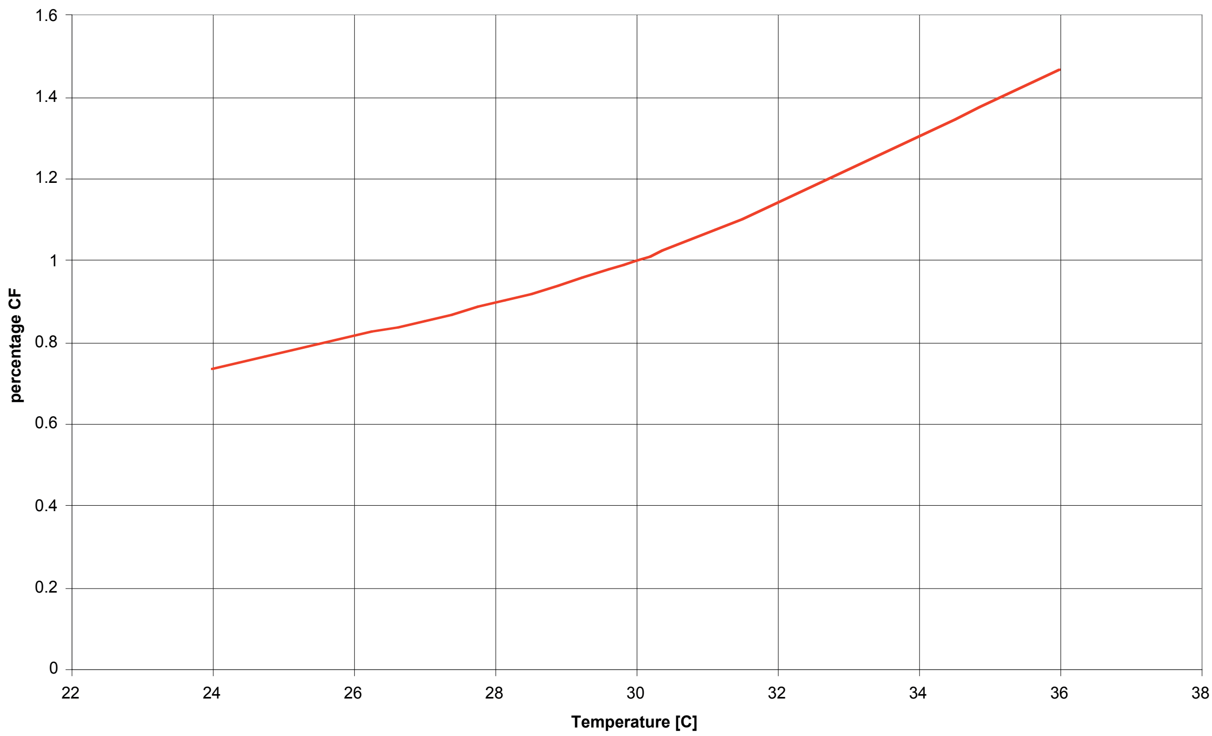

Figure 11.5: variable O&M correction factor against seawater temperature for SWRO technology

~~1.1.1~~11.3.1 Evaluation of tariffs and scenario points

All the formulas reflected in the requirement of the Water Purchase Agreement and indicated above are implemented in a financial model which normally takes the format of an electronic spreadsheet. The Model is set up to allow simulation of the operation of the Plant and the relevant payments under various operating scenarios and therefore include Variable O&M Correction Factors and Contracted Specific Power Consumption Correction Factor values.

Tariffs can be substantially different from one proposed configuration to another as seawater conditions change.
The application of Correction Factor values for Variable O&M and electricity may significantly alter the original tariff. Therefore financial models are generally referred to a scenario point table that is provided to evaluate the total payments under the assumed scenarios the plant is going to operate.
The developer normally submits details of VOMCF in the form of graphs providing details of the percentage increase or reduction in the Variable Operational and Maintenance charge rate in the event that the seawater is outside the Reference Conditions.

A typical scenario point table is shown in the table11.3 below whereby the value of SDI differs with a statistical frequency. The reference envelope covers the majority of the SDI values occurring in real terms but there are days in the year where the SDI is better than the reference envelope and therefore the off-taker should benefit from a tariff reduction and days when to operate the plant where the variable O&M costs are higher.

Table 11.3 : typical scenario points

SDI value	Reference:	Frequency (day/year)	VO&M correction factor
12-18	Reference envelope	300	1
8-12	Better water	15	1 or <1
Below 8	Better water	5	1 or <1
18-25	Departing conditions	35	1 or > 1
Above 25	Departing conditions	10	1 or >!

~~1.1.2~~11.3.2 Sensitivity analysis

The application of variable O&M correction factor against seawater temperature or seawater SDI may bring about substantial differences in the overall payment that should be disbursed by the off taker to the project Company.

There may be cases where differences in the design of the system bring about a drastically different tariff if seawater conditions have departed from the reference conditions.

A typical example (provided for illustration only) is given in Figure 11.6 below and shows how a relatively minor variation in the seawater SDI would affect the tariff outside the point of tariff evaluation **[x]**.

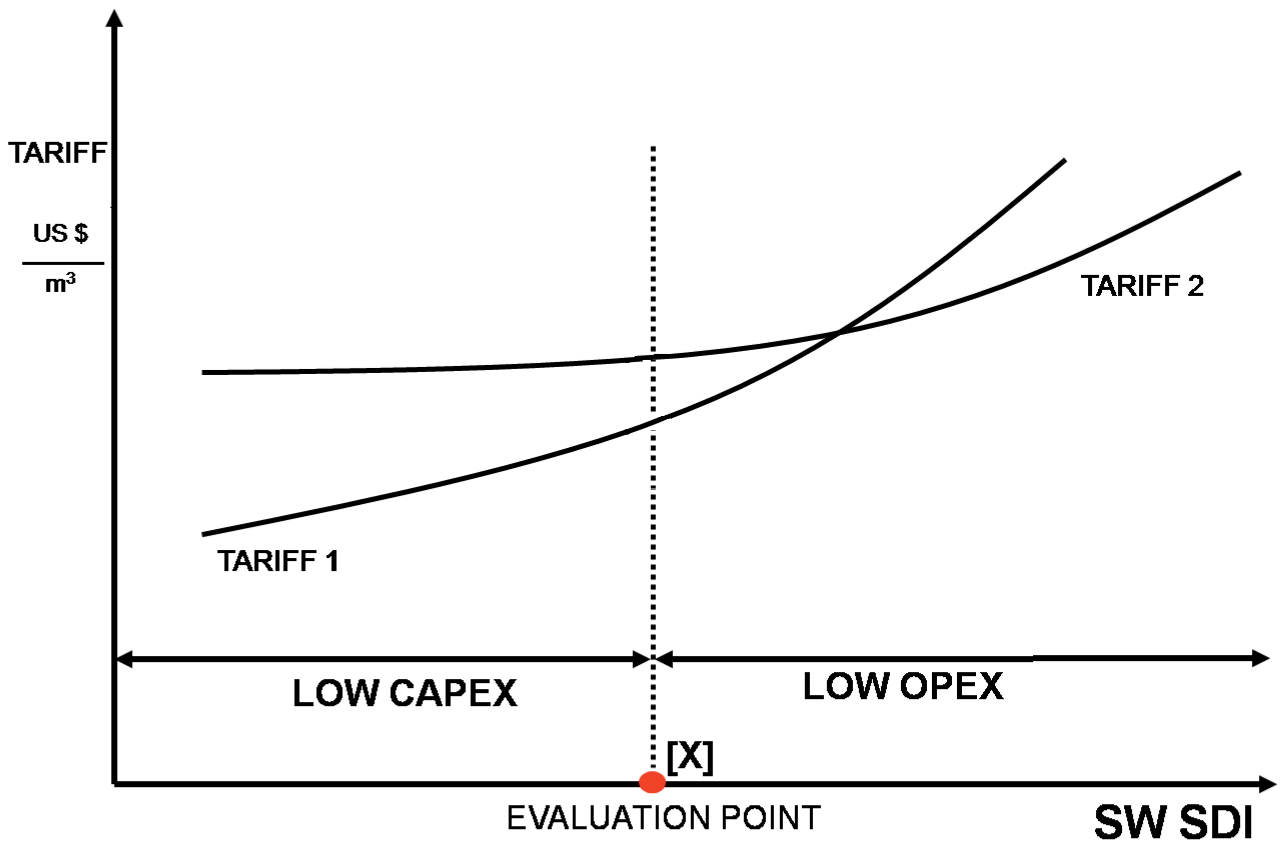

Figure 11.6:tariff sensitivity examples against seawater SDI variations

This Figure relates to the comparison of two different projects for the same site: one is based on a two stage pre-treatment (Tariff 2) and the other (Tariff 1) is based on a single stage. In this case the better the water quality, i.e. the lower the seawater SDI the more the single stage pre-treatment tariff is attractive. This is based on the lower CAPEX that give an advantage to Tariff 1.

However as it can be seen from the Figure 11.6 in the close proximity of the evaluation point X when seawater SDI increases (i.e. when seawater quality deteriorates), Tariff 2 becomes more attractive. This means that the more robust pre-treatment design does not require additional chemicals or any reduction in the recovery ratio to handle the more difficult seawater conditions. Therefore the lower OPEX of Tariff 2 prevail.

Sensitivity analyses become very important in tariff comparison during the evaluation of tenders in private projects particularly when the scenario points are not based on consolidated statistics or future deteriorations in seawater quality may be expected. Sensitivity analyses can be carried out also to compare tariffs on energy and fuel costs forecasting the energy cost escalation during the period of concession.

12 Minimum functional specifications

In the initial development of desalination plants, Governments, either directly through Ministries or via Regional Government bodies, have procured plants that have been designed and built to detailed specifications. In this regard, the risk associated with plant performance has remained with the purchaser, ie the Government body.

As privatisation of the water industry has developed, Government bodies are reluctant to accept risk for plants that they no longer own and this risk has been transferred to the plant developer. Developers are invited to bid for the plant against Minimum Functional Specifications (MFS) that have been drawn up and issued by the Government. This is the current trend in desalination and water treatment. The governmental bodies in turn use Minimum Functional Specifications and any other project requirements (such as performance guarantees) in the Water Purchase Agreement (WPA) to invite offers from developers.

The Developer is contracted to the Government body via various agreements, one of the most notable being the Water Purchase Agreement, which stipulates the quality and quantity of water that the developer must supply for a given tariff. In turn, the agreement guarantees capacity payments and a revenue stream for the developer.

The main problem in this situation is finding the correct balance between commercial competitiveness and long-term reliability.

Public projects are designed and built to detailed specifications, while private projects are generally specified by the off-taker on the basis of minimum functional specifications that generally provide (as design input to the developer) the following information:

- Required capacity
- Envelope of seawater conditions for reference operation, design and technical limits
- Potable water quality specification
- Available dispatch ability
- Projected lifetime and consistent material guideline

The information is translated into detailed technical specifications by the developer who incorporates them into the EPC contract agreement.

One of the advantages of the minimum functional specifications is that the plant is optimised around the operating conditions occurring with a statistical higher frequency (reference envelope) but can operate when seawater conditions depart from these conditions with limited increased Variable Operation and Maintenance costs. This new approach in plant design has given a further contribution to improve the water tariff in private projects.

The traditional procedure for designing and procuring desalination plants with detailed specifications would be as indicated in Figure 12.1.

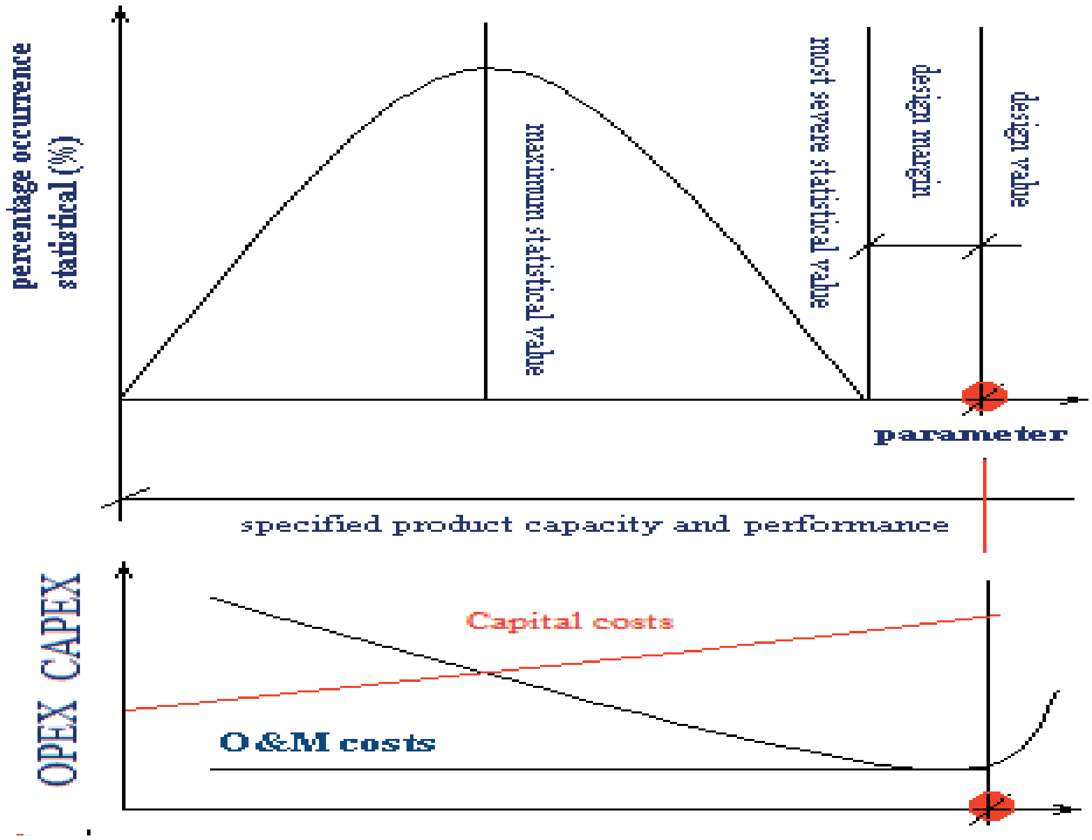

Figure 12.1 : traditional turnkey approach

1. Provide raw water analyses for particular parameters over an extended period, usually a minimum of one year
2. Select peak values
3. Add a design allowance to cater for degradation of the parameters over time

The traditional turnkey approach centres the design of the plant on the most severe seawater conditions regardless that these are occurring statistically only for a fraction of the operational time. This often resulted in a plant overdesigned for the day to day operating parameters.

Furthermore the operating costs of the project are optimised for those operational condition that do not occur more frequently and this results in higher production costs.

As schematically indicated in Figure 12.2, in the minimum functional specification the approach is different. The plant is optimised for the operating conditions (i.e. seawater temperature, SDI, TDS, TSS) statistically occurring more frequently, however the plant can operate for a limited time with extreme conditions.

The mechanism the minimum functional specifications operate is the definition of a reference envelope of operating conditions. These are based on values that occur at the site more for the longest time. The designed is given scenario points where each parameter is defined to occur for a certain duration of time and therefore the plant designer and developer are set to optimise the lifecycle costs of the plant in this reference envelope.

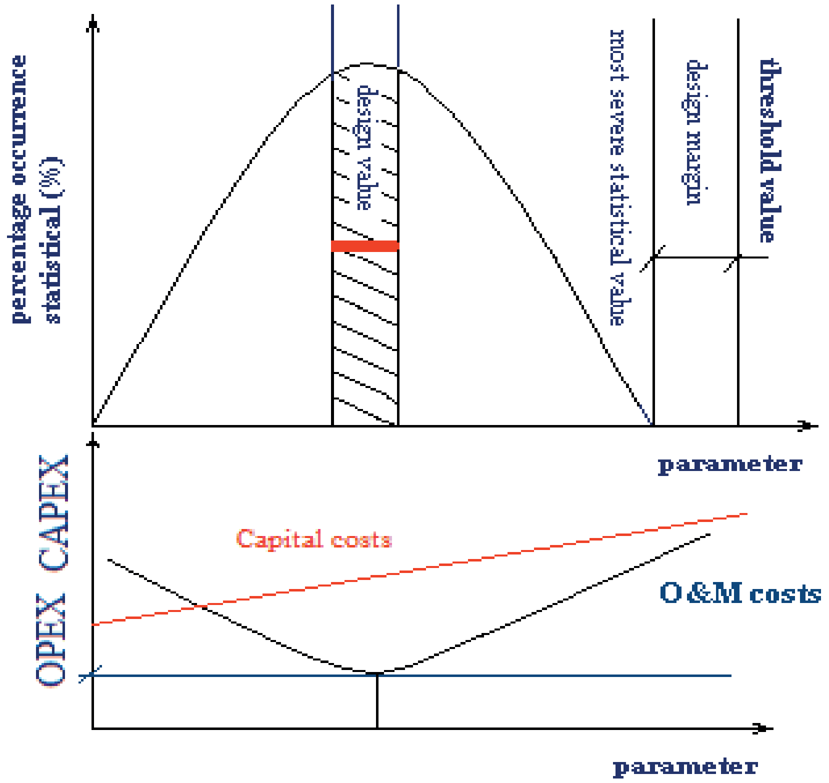

Figure 12.2 : Minimums functional specification approach

On the other hand minimum functional specifications allow plant operability in more difficult operating conditions up to the technical limits that specify the range of operability of the plant.

In other words, through the application of minimum functional specifications, the Project Company is required to construct the Plant so that it is capable of continuous and reliable production of water under the full range of expected prevailing seawater conditions ("Reference Conditions") (i.e. seawater quality risk is born by the Project Company).

When seawater conditions are outside the "Technical Limits" of the plant, the Project Company is relieved of its obligations to supply water.
When seawater conditions are between the Reference Conditions and Technical Limits, the Project Company is obliged to deliver water but is compensated for the increased operating costs through a predetermined correction factor applied to the water output tariff.

In recent concession agreements, three operating envelopes are defined as summarised in the table 12.1 below:

Table 12.1 MFS typical envelopes definitions

Envelope	Output	VO&M costs
Reference	Undiminished	Undiminished
Design	Undiminished	Subject to VO&M correction
Technical limits	Subject to Capacity correction	Subject to VO&M correction

A typical curve (for illustration purposes only) indicating how the three envelopes reference, design and technical limits could theoretically be related to seawater SDI is shown in Figure 12.3 below.

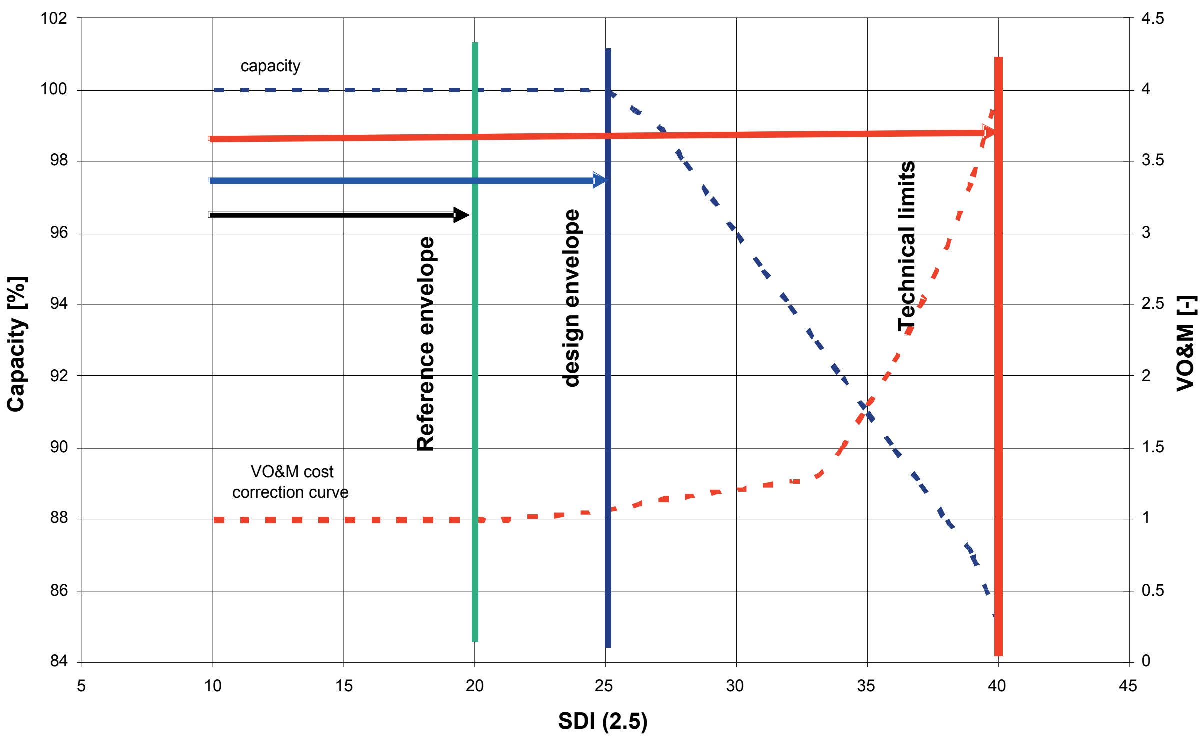

Figure 12.3: reference, design and technical limits envelopes

As it can be seen from this curve, in the reference envelope ($SDI_{2,5}$ <20), the capacity is 100% and the VO&M cost correction factor is 1.

The plant capacity remains undiminished until the design envelope ($SDI_{2,5}$ <25), while there is a relative increase in the VO&M cost correction factor.

In the area between the design envelope and the technical limits, both the capacity and the cost correction factors are decreasing.

13 Concession agreement and payment structure for sewage treatment plants

The waste water market is more and more oriented towards achieved treatments of the sewage effluent that allow the reclamation and re-use of waste water for unrestricted irrigation and industrial purposes and in some case even for domestic purposes (new water).

This process is accomplished by the use of membrane techniques such as MBR, or ultra filtration and micro-filtration along with traditional biological processes.

Several contracts have been signed for very large membrane bioreactors or waste water effluent ultra filtration plants that have the form of private initiative.

Also in these cases there are several possible mechanisms that may be applied in the industry to structure sewage treatment and treated effluent tariffs.
The main problems that are encountered particularly in newly developed regions are related to the obligations of the Master Communities for the treatment of Wastewater.

The Project Company may be not efficient in respect to billing and collection charges to the Master Community for Wastewater Tariffs, therefore they may find it convenient to implement an alternative arrangement with the power and water distribution company for billing and collections of these charges for a fee. These agreements are typical for waste water projects and are based on the distributor's capacity to enforce restrictive or punitive actions towards those users that are failing to pay the waste water charges.

The structure of the IWP-IWPP models in the Middle East is generally based on a single off-take model. This structure is typical for power and desalination plants that are designed to match a tight dispatch schedule on base load conditions.
On the other hand it may be possible to encounter, especially in the waste water re-use market, private initiatives where the product water (either desalination or treated sewage effluent) can be dispatched and billed to alternative off-takers.
The sale tariff to alternative off takers in this case is generally determined by the Project Company at its absolute discretion based on the market value and on the specific arrangements with the alternative off-taker.

~~1.1~~13.1 Payments

The payment structure tends to be different than for a standard desalination plant, the main difference is due to the fact that there is a volumetric component both at the inlet (Raw Sewage effluent) and at the outlet (Treated Sewage Effluent) of the plant.

The charges for a waste water treatment plant can be basically classified in two categories

1. Service Charge (S_{SC})
2. Input - Output Charge (V_{OC})

The two charges then can be interrelated with a take or pay mechanism whereby there may be a component of the Service Charge that can be recovered by the sales of the treated sewage effluent.
Figure 13.1 below shows a typical payment schedule for a Membrane Bioreactor (MBR) plant

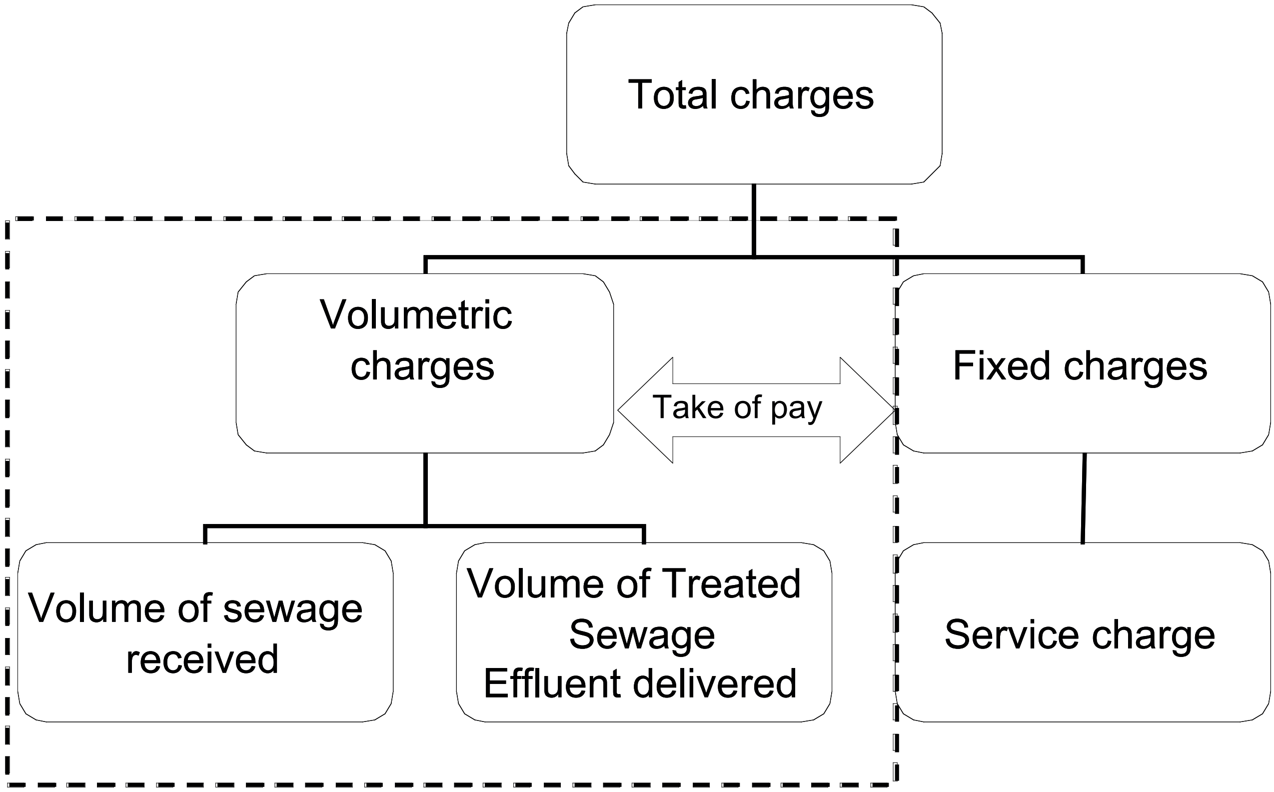

Figure 13.1 : sewage treatment plant payments Take or Pay scheme

Similar to the water capacity charge for desalination projects, service charges in waste water treatment plants are structured as period charges.
It is common practice to observe (in water treatment projects) a minimum take off mechanism related to both the volume of sewage received and the volume of tertiary treated effluent dispatched. The service charge component of the tariff is normally indexed against local CPI.

Modern advanced water treatment plants make use of membranes either immersed in the to allow for a high recovery of tertiary treated effluent from the raw sewage. The treated effluent and sewage influent conversion ration can reach and exceed 95% recovery as a ration.

The conversion factor is generally taken into consideration in the evaluation of the minimum TSE off take.

~~1.2~~13.2 Payment settlement mechanisms

Generally the payment for private project is integrated into a Integrated Accounting and Settlement System that contains the Tariff Calculation Model projected water Demand and is generally defined in the Water Purchase Agreement signed between the project Company and the off-taker .

The system includes a comprehensive listing of variables necessary to derive all values identified in the WPA and includes for the following data

There are different type of payment settlement system however the most common systems are:

Contract variables

Process variables

User Variables

These variables are schematically interrelated as indicated in Figure 13.2 below

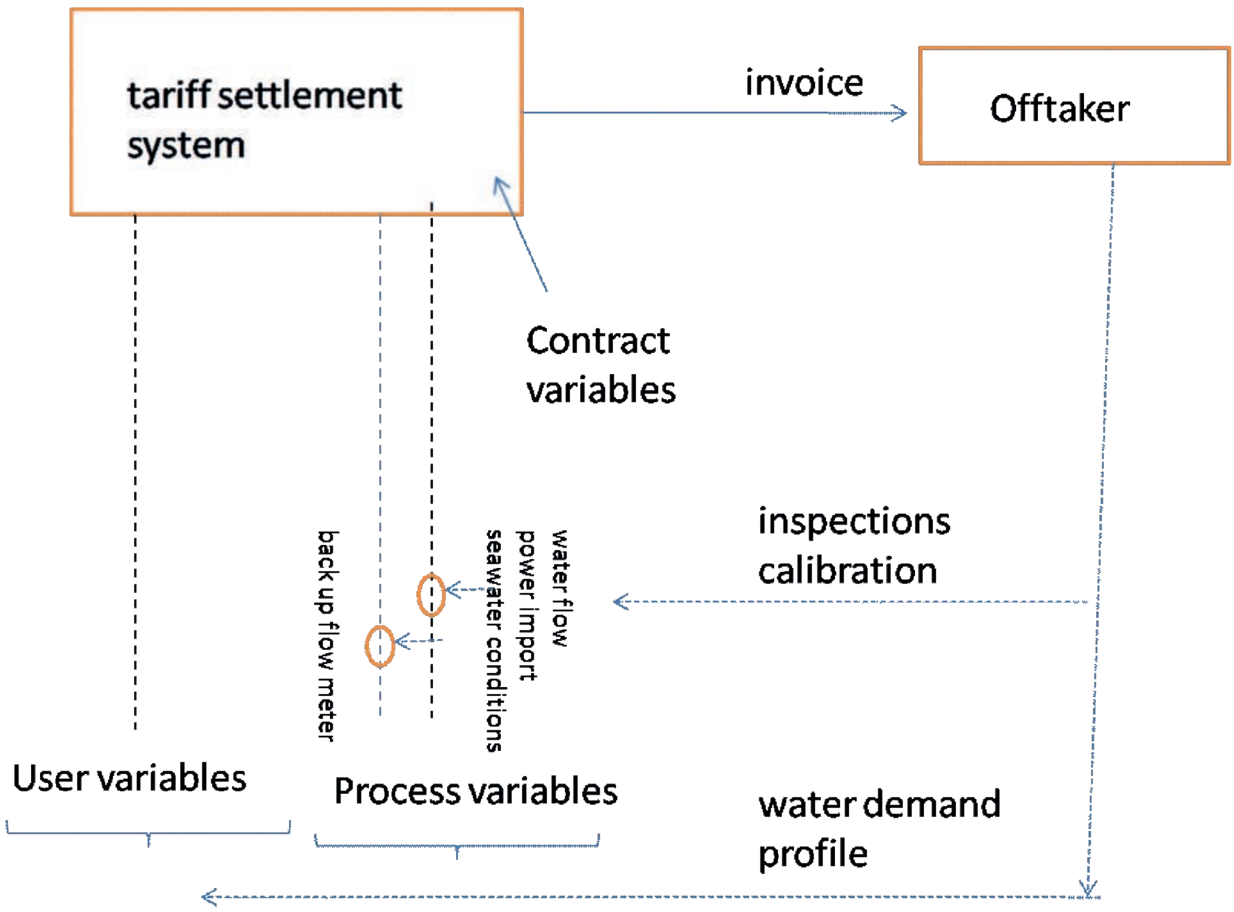

Figure 13.2 typical water payment settlement scheme

Contract Variables are specifically identified within the WPA and indicate the information related to tariff rates, outage allowances, contract inflation indices, contracted capacities, contract specific power consumption, capacity and availability factors, outage criteria, etc.)

Process Variables are generally the electronic values generated by the plant control systems and indicate the seawater conditions (temperature, conductivity etc), output capacities, , projected electrical power consumption etc.

The user variables are manually input by equipment operators, and include monthly variations in inflation/exchange rate indices, period capacity output, daily requested water output .

The date indicated above will be used for implementing the tariff calculations.

Accordingly the accounting system generate period (generally monthly) invoices taking into account capacity payments, output payments, variable costs payment including adjustment for electricity consumption, penalties and bonus payments, value of outputs adjusted for inflation, values of outputs adjusted for exchange rate variances, availability periods, outage periods, intermediate values requested by client/owner for back-up reports, start-up cost.

14 Budgeting

14.1 Introduction

The second most frequently asked question in desalination is “what is the cost of a desalination plant and the tariff per cubic meter of desalinated water”.

Various mechanisms were developed to forecast CAPEX of desalination plants based on formulas and benchmarking, however there have been substantial limitations to the applicability of these mechanisms.

The main reason for this is derived from the fact that the costs of a desalination plant particularly for thermal technologies but also for membrane technology is greatly driven by the costs of materials

Indeed there are other parameters that may affect the budget and the market price of a desalination plant. Some are purely technical and are related to the technical specification or performance requirement of the plant. Others are purely commercial and are related to the specific market situation such as level of competition, client historical track record etc. at the time of tendering and contracting.

Compared to other manufacturing processes, there are no precise rules to establish a cost for a desalination plant. There are several theories about how cost criteria should be developed and how costs should be allocated. However there are no systematic and consolidated approaches to desalination plant budgeting except the two traditional approaches of benchmarking with incremental budgeting and zero base budgeting.

Some papers published in international magazines and at conferences proposed algorithms to estimate the plant costs according to the unit capacity and performance ratio.

However, these algorithms were valid in limited circumstances and only for a certain market and historical situations.

Also, in this case there is no simple answer as, in view of the fluctuating fuel costs, the amount and cost of energy consumed to desalinate seawater becomes one of the main factors determining the operational cost of desalted water. Similarly, the materials selected and the extreme variability in the cost of materials employed in desalination projects has a significant impact on the capital cost.

A general price breakdown among materials and manpower shows that desalination plant turnkey costs are heavily affected by the price of materials.

Thermal desalination technology in particular makes large use of nickel alloyed components for the heat transfer tubes and are therefore more sensitive to metal cost escalations.

~~1.2~~14.2 Turnkey costs developments approaches and overview

The baseline for water cost computation has been the subject of great discussions. In particular, the fluctuation in the costs of materials and energy has become in turn a major factor in determining the method and the technology to be used. In the publication “Desalination Management and Economics”, information was provided on both CAPEX and OPEX of the main desalination technologies at the time of publication.

Cost of desalination, particularly as far as thermal technologies are concerned, is primarily governed by the cost of material.

In the first years of the new millennium, turnkey costs of thermal desalination plants reached the lowest statistical point in the history of the industry.

There were several reasons contributing to this achievement and these are both related to the development of the technology and the concurrent decrease in the costs of the material. In the first year of the millennium, substantial innovation was introduced thanks to the gradual process of privatisation.

Particularly in the Middle East, the gradual introduction of MED technology or hybrid solutions initially and full scale SWRO solutions were made possible in the tariff competitive process that was generated in the privatisation market.

In the years 2005-2008, pushed by the increasing cost of raw material (particularly nickel and copper), CAPEX price in the desalination industry suffered from a non-negligible cost increase. For thermal desalination technology the specific CAPEX trend based on the major development in the Gulf is represented in the Figure 14.1below for MSF-MED and SWRO technologies.

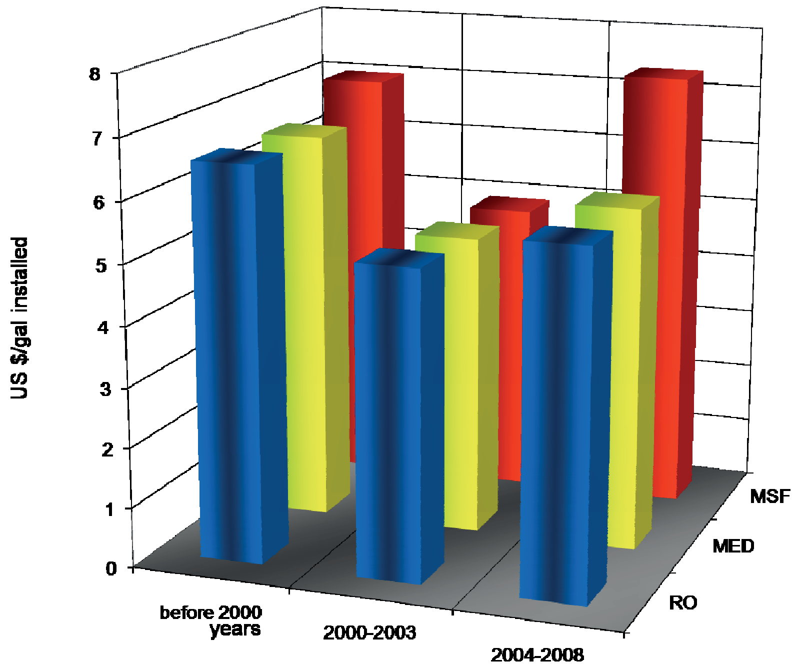

Figure 14.1 : average turnkey price for installed MED MSF and SWRO (Gulf) years 2000-2008

The costs are considered covering the overall turnkey package and therefore including the seawater intake and outfall structure as well as the main ancillaries of the plant such as remineralisation, seawater and potable water disinfection potable water storage and town water pumping station.

From an analysis of Figure 14.1 above it is possible to observe from the figure that the inflation in material costs affected thermal desalination technologies to a much larger extent than membrane processes.

Recently, material and fuel prices have abruptly dropped again and variations in material market prices were so sharp that any CAPEX information may become rapidly obsolete and unreliable.

As indicated before, the vast majority of the costs for the construction of desalination and advance waste water treatment projects is generated by the materials that are employed.

These costs were worked out on an incremental "Top down " budgeting principle based on actual project costs and adjusted to take into account differences between the statistical price information obtained and the actual scope of each project, performance and efficiency requirements.

~~1.1.1~~14.2.1 SWRO CAPEX interpretation

It should be noted that for SWRO technologies a rigorous specific CAPEX comparison should take into account a further adjustment due to the site specific design difference particularly in relation to the TDS and SDI parameters.

As indicated in the initial part of the book, difference in seawater conditions in fact do not have a major impact on the thermal desalination design and costs but may greatly affect the specific CAPEX of a SWRO plant.

Differences in seawater conditions may impact quite substantially on some key cost elements in the SWRO plant design particularly with regard to pre-treatment, recovery ratio (and therefore the overall size of the plant including membranes, intake etc), HP system etc.

In this respect, while for MSF and MED, a price comparison is relatively straightforward; for SWRO technology the comparison with the benchmark performance depends significantly on the quality of the raw water which is treated. As referred to above, SWRO technology is a "site sensitive" technology, since both capital expenditures and operation and maintenance costs depend on several seawater quality parameters, primarily:

- TDS – Total dissolved solids
- SDI – Silt density index
- Turbidity
- Biological content

Due to SWRO's site sensitivity, a fair comparison of the economic performance of different plants requires consideration of the regional characteristics where the plants have been installed. The overall project construction costs therefore need to be compared with data available for a number of reference plants and adjustments need to be made to take into account differences in the turnkey scope of work.

From the CAPEX point of view, compared with the private market benchmark occurring between 2007 in the Middle East, (1320 to 1760 US$/[$m^3$/d]) it can be observed that projects in North Africa present substantially lower specific CAPEX; this is due to both a very competitive tendering process and favourable water conditions.

The comparison between the plant specific cost in the Middle East and in North Africa (primarily Algeria) is shown in Figure 14.2.

The data summarised in the graph below has been reconciled from a statistical benchmark considering also in this case, difference in the scope of work and design philosophy adopted for the plant construction. For instance, in some cases the CAPEX of the plant excluded the shore protection to the proposed site as this was covered under a separate contract and the external network to the proposed storage reservoirs. In other cases the potable water did not include boron compliance with WHO requirements in the off taker specification resulting in lower CAPEX. Furthermore for some plants in the Gulf, extremely challenging nuisance requirements (good aesthetics and visual impact low noise etc) resulted in additional CAPEX.

The adjustments were carried out in many cases with the information that was available on the separate cost items and if unavailable using various cost assessments to budget the scope difference.

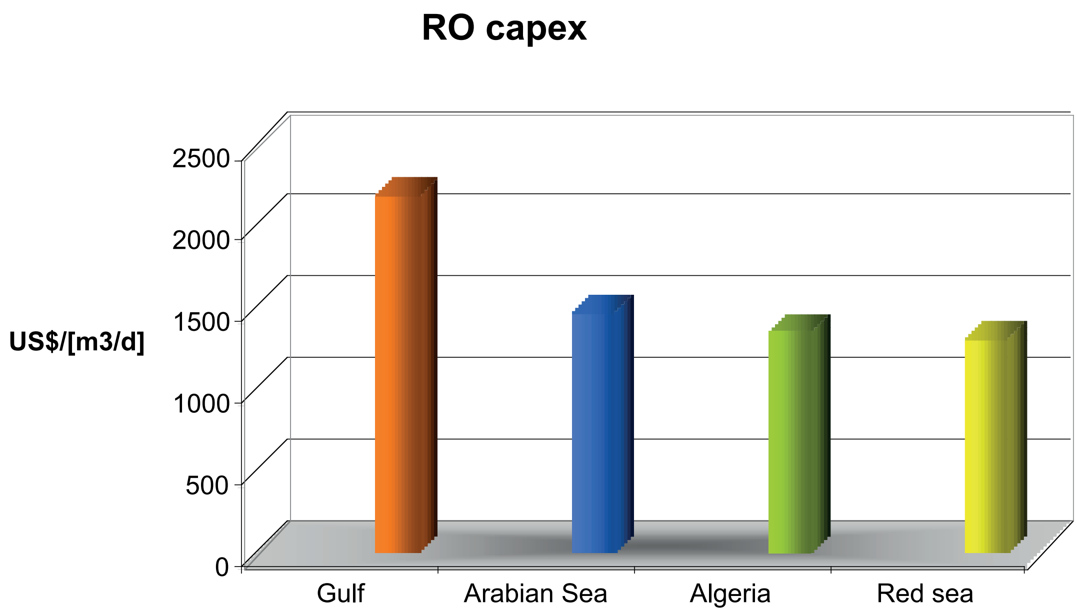

Figure 14.2 : average turnkey price for installed SWRO against seawater conditions

As it can be seen, analysing the data reported in the Figure 14.2 above there is a substantial difference in the specific CAPEX according to the geographical area and in particular CAPEX for the Gulf appears to be substantially higher than for Mediterranean and Indian Ocean area. However it should be mentioned that in addition to poor water quality, the costs have been affected in the Gulf by several non technical items such as :

- Rising material costs
- Labour shortages
- Strong Euro currency affecting the price of equipment such as pumps as their highly alloyed material is traditionally linked to the Eurozone
- High number of competing water and waste water projects, resulting in fewer turnkey contractors and therefore lower market competition
- High demand for long lead items such as pumps, piping and certain electrical parts, reducing availability or extending ordering times and pushing up prices

In order to better analyse the information above, the following economic data on the technology adopted for the pre-treatment should be also considered and in particular the adoption of membrane based pre-treatment against ultra filtration. This is further described in session14.3.2 below.

~~1.3~~14.3 Analysis of turnkey costs

The incremental budgeting technique that has been the basis of the statistical benchmark illustrated above becomes less accurate when looking at detailed price breakdown and presents some difficulties when the database used for the costs requires updating based on the market values.

The objective of this book is not only to provide some information related to the prevailing historical market benchmarks, but also to provide some general guidelines on the interpretation of the data that would enable the reader to forecast the market trends for the project CAPEX in a highly volatile material market.

The traditional bottom up approach (sometimes defined as "zero base" budgeting), consists of preparing a " shopping list " for all the components required in the plant and is generally used by all EPC contractors in the tender phase and executive budget preparation.

Rather than providing an itemised shopping list of each component of the plant, the turnkey costs have been analysed using a bottom up approach .

This analysis is important in order to establish the dependence of the turnkey on each component and to evaluate the sensitivity of turnkey costs to various market conditions such as material costs, manpower costs and inflation.

~~1.1.1~~14.3.1 Thermal plants

The items that comprise a thermal desalination plant can be subdivided in different categories. The most commonly adopted approach is to divide the quantities of a thermal desalination plant into various categories.

These could be both according to the particular discipline of the desalination plant or in accordance with each system (i.e. seawater supply, brine recirculation, brine blowdown etc) of the plant.

An initial break down in accordance to the discipline costs (mechanical, electrical C&I etc) could be prepared in accordance with the general breakdown indicated below.

- Mechanical equipment and piping
- Electrical equipment
- Instrumentation and control
- Civil items

However, to better understand the costs and the individual items contribution to the overall project cost, the table 14.1 below provides a further breakdown for civil and mechanical costs components.

Table 14.1 : thermal desalination typical cost break down

Plant component	cost percentage
SW (offshore) intake civil works	8.5%
SW (onshore) intake civil works	13%
Outfall civil works	2%
Desalination plant mechanical	50%
Seawater mechanical system	3.5%
Balance of plant mechanical	4%
Electrical works	5%
C&I works	4%
External fees (legal, financial etc)	1.5%
Development cost	4%
Insurance and initial working capital	0.5%

Contingency	4%

The great majority of the costs are associated with the procurement of material, particularly for the evaporator equipment. However there is a component of the cost of the evaporator that is associated with the works necessary to realise the plant. These costs are embedded in each cost component listed in table 13.1 and the table does not identify these costs separately.

The costs not associated with the material procurement of a thermal desalination plant can be grouped in the following categories:

- Engineering and commissioning
- Site erection (including painting and insulation)
- Vessel prefabrication at workshop
- Civil works

A typical cost subdivision between material costs and manpower for a thermal desalination (MSF or MED) is reported in the diagram below

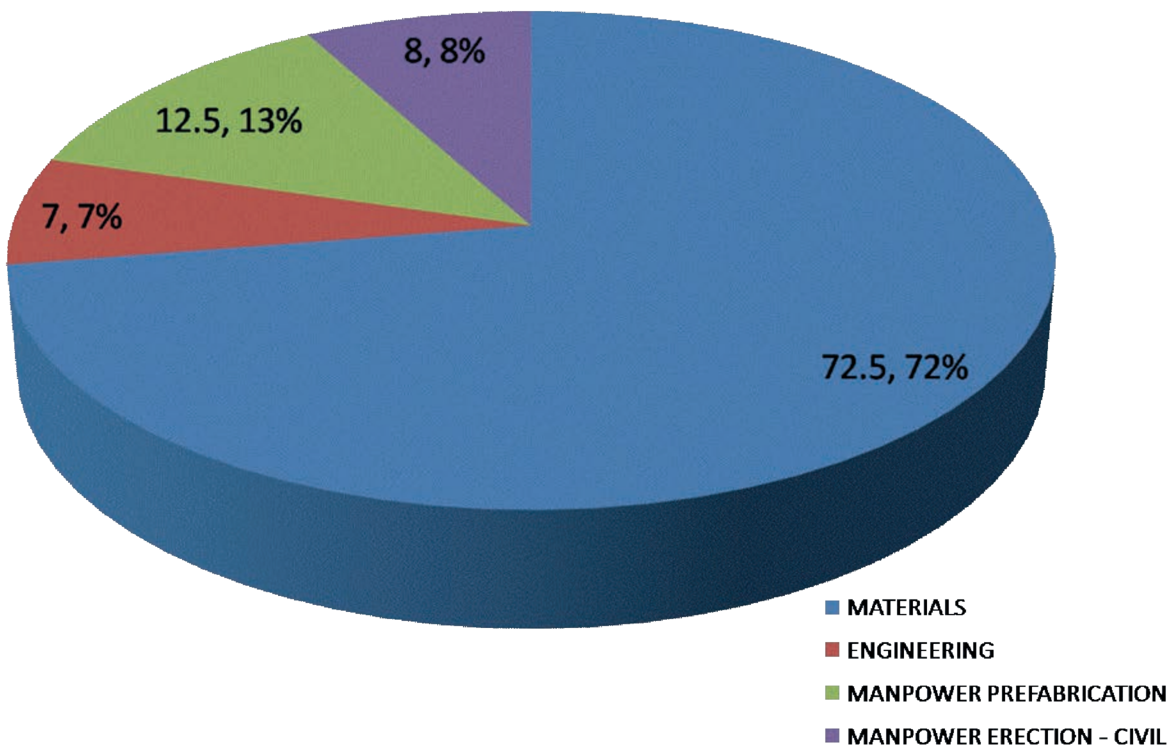

Figure 14.3 : typical cost break down material – manpower for a thermal desalination plant

The evaporator (for MSF plant including the deareator) is the most important component in the plant and its costs are generated mainly by the material costs related to the procurement and fabrication of the following items :

- Heat transfer tubes
- Tubeplates
- Stainless - duplex steel metal sheets
- Evaporator internals (demisters, vent baffles, tube supports etc)
- Water boxes (for MSF process) - steam boxes (for MED process)
- Stiffeners for the structural rigidity of the plant (carbon steel)

Mechanical equipment can be in turn subdivided as illustrated in the following break down :

- Major process pumps
- Brine heater – steam transformer
- Vacuum systems (non-condensable gases extraction system)
- Major balance of plant work packages such as
    - Distillate remineralisation system and potable water disinfection
    - Seawater chlorination system
    - Town water storage farms
- Major process piping and valves
- Pipe rack piping support etc

Despite the costs of these components being subject to fluctuations dictated by the prevailing market conditions, there is generally a certain constancy among the cost components of the items indicated below within the overall project costs.

Another way to look at the overall cost breakdown in a thermal desalination project is illustrated in the graphs of Figures 14.4 and 14.2 below. In these graphs the dependence of thermal desalination turnkey costs on raw materials could be analysed.

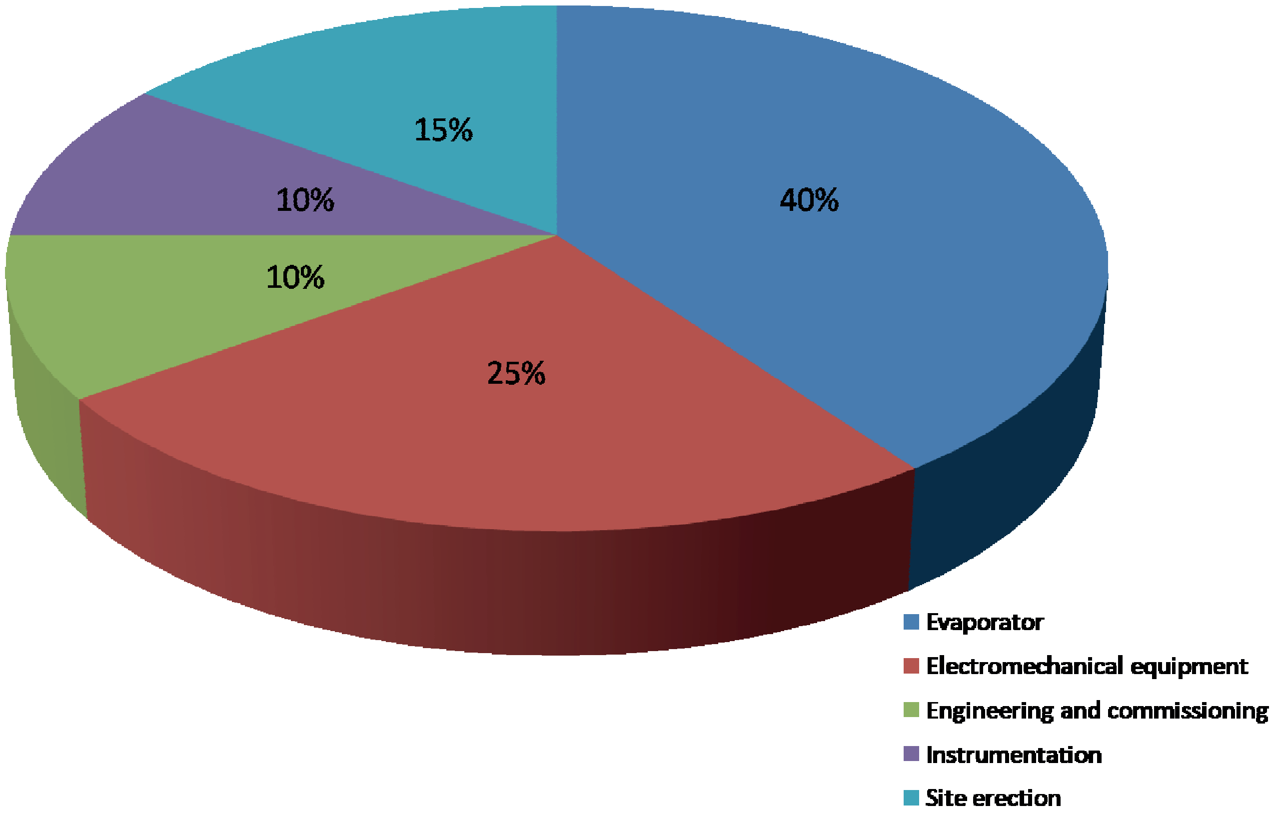

Figure 14.4 : Thermal desalination plant cost component subdivision

As it can be seen from the illustrations above, the majority of the costs of a thermal desalination plant is represented by the evaporator itself. This includes all the construction material of the desalination vessel that in turn includes all the pre-fabrication activities at the workshop such as preparation and cutting of the stainless or duplex steel sheets, preassembling and construction of the modules, welding materials etc.

If the cost breakdown of Figure 14.1 for the evaporator island is further broken down, it clearly appears that the evaporator tube bundle is clearly the most significant component of the turnkey costs.

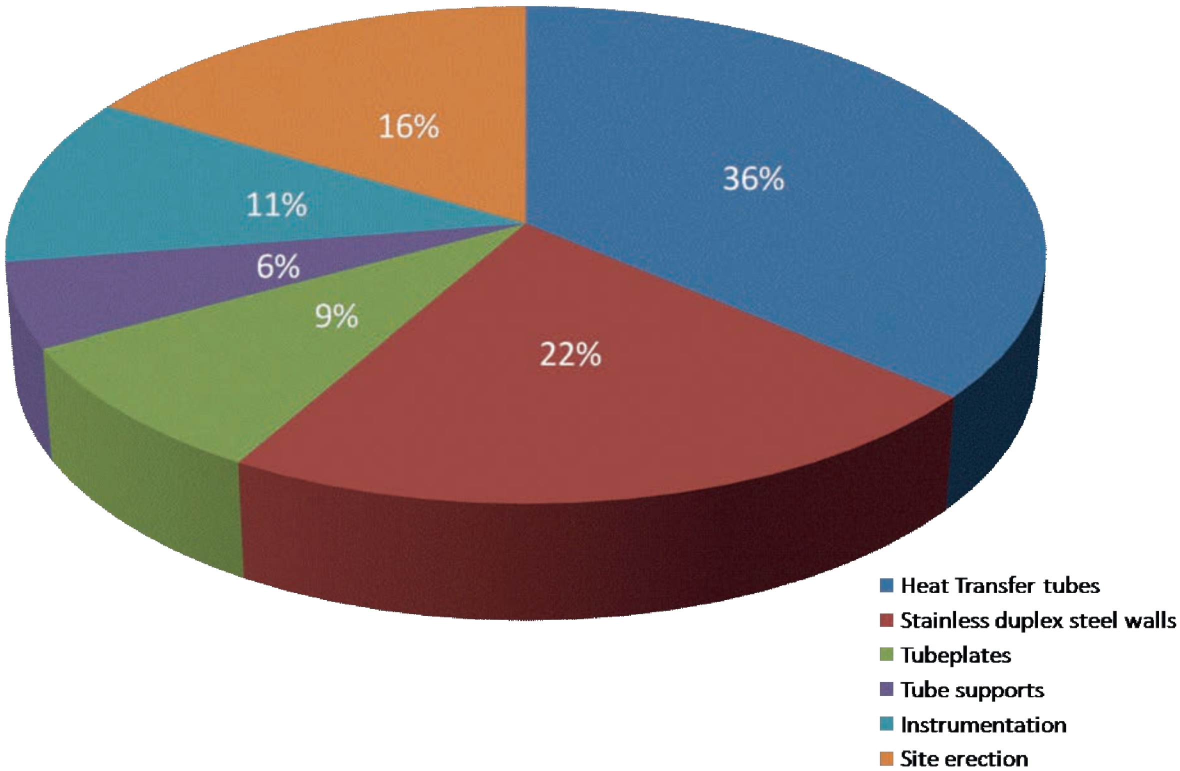

Figure 14.5: Evaporator cost component subdivision

As it can be worked out by analysing the cost component composition in the graph above, the dependence of thermal desalination technology on raw material costs is quite dramatic and this is obviously reflected in substantial variations in the turnkey costs with material price variations particularly heat transfer tubes.

Generally the material selection of a thermal desalination project varies according to customer specification, as indicated in the paragraphs above the objective is to ensure a material selection that is consistent with the assets lifetime.

However the material selection specification has a considerable impact on the project cost.

Particular attention is required by the heat transfer tubes material selection. The metal alloys regularly employed in desalination for the heat transfer tubes are as follows:

- UNS C68700 Aluminium Brass (Traded as Cubral)
- UNS C70600 Copper-Nickel 90/10 (Traded as Niton 10)
- UNS C71500 Copper-Nickel 70/30 (Traded as Niton 30)
- UNS C71640 Copper-Nickel 66/30/2/2 (Traded as IperNiton)

There are several plants where an alternative to Niton 30 welded Titanium tubes in accordance to ASTM B338 Gr 2 are used.
The composition of the copper nickel alloyed heat transfer tubes above is indicated in the following table 14.1.

Table 14.1 : thermal desalination heat transfer tubes material composition

	Niton 10	Niton 30	IperNiton	Cubral
Copper – Cu	90%	70%	66%	76%
Nickel – Ni	10%	30%	30%	-
Zinc – Zn	-	-	-	22%
Aluminium – Al	-	-	-	2%
			Fe 2% Mn 2%	

In the cost of the heat transfer tubes there is a component of manpower, energy, packing and transportation. However the prevailing contributor to the heat transfer tubes is given by the value of the metal. This value is quoted on the market (London Metal Exchange) and is in turn subjected to daily fluctuations.

In a highly volatile market, the price of the metal alloy for the required heat transfer tubes can be obtained by the following formula:

$$PCu_xNi_y = [(LME_{Cu} + P)\cdot X + (LME_{Ni} + P)\cdot Y]\cdot m$$

Where:

LME indicates the London Metal exchange value for Copper (Cu) and Nickel (Ni) respectively
P indicates a premium value imposed by the metal traders on the material costs, X and Y are the respective compositions in the material and can be considered as a margin or as a mark up factor.

Premium values are subject to fluctuations given by the market but the values could range from US$ 100 to 500 per ton of material.

As it can be seen from Figure 14.7, showing LME value of Nickel in the last 5 years, the price of Nickel and Copper has been extremely volatile and again this has been reflected in the cost of the evaporator..

In comparison with Figure 14.7, Figure 14.8 shows the evolution of the specific price per gallon installed for MSF plants constructed for the same Client in the Middle East with very similar material specifications.

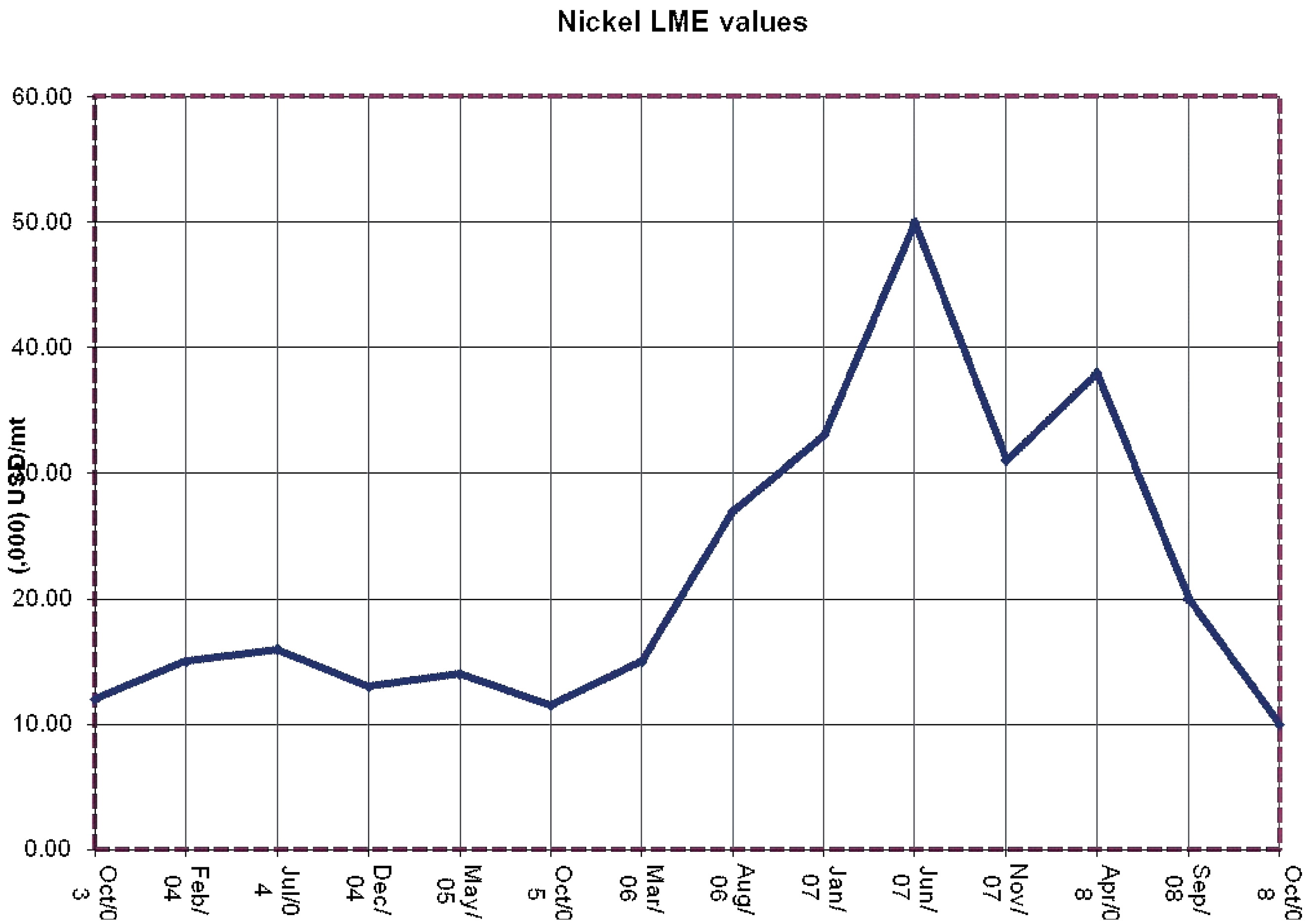

Figure 14.7 : Nickel price hystorical fluctuations

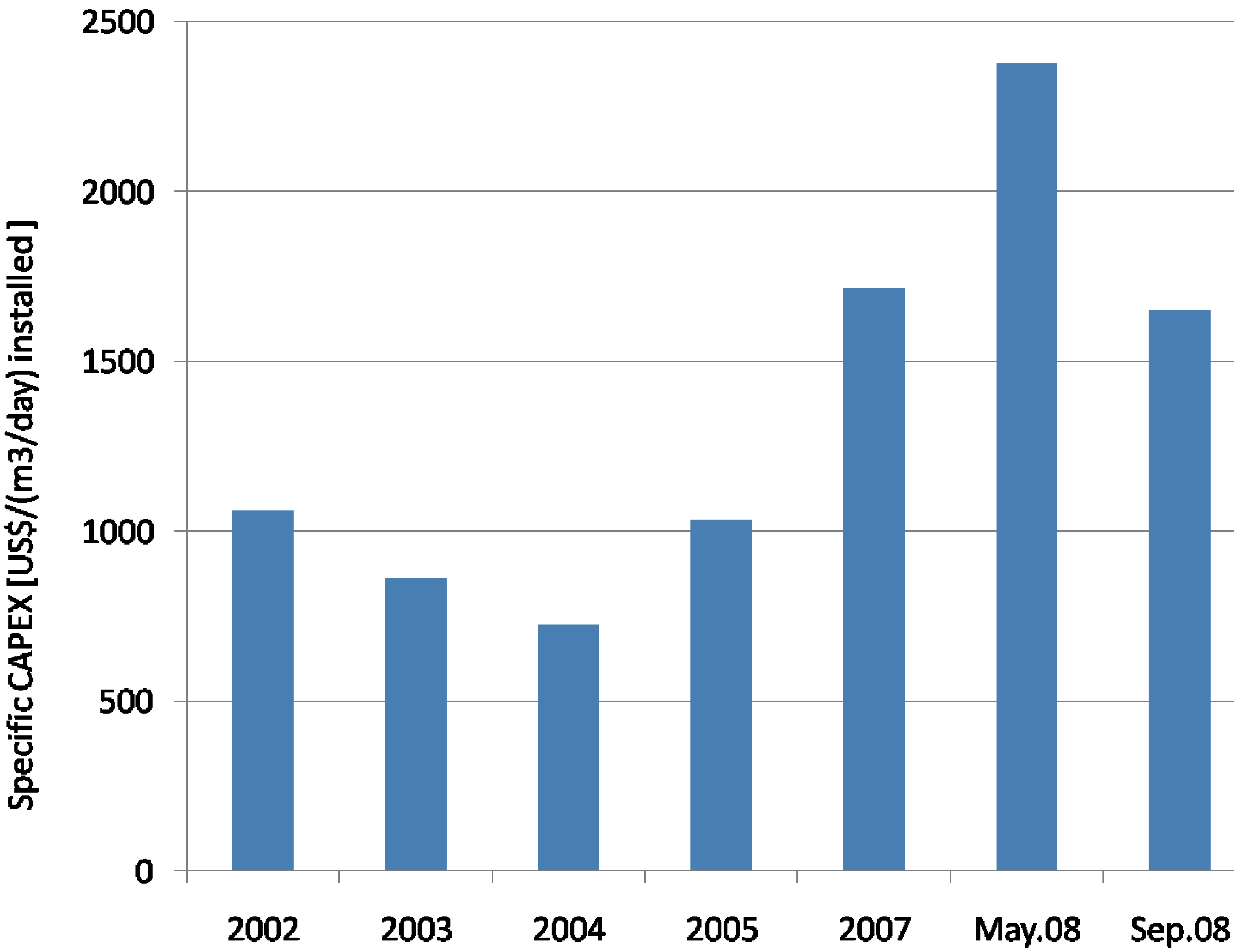

Figure 14.8 : Client X : MSF CAPEX trend profile

As can be seen when comparing the two graphs 14.7 and 14.8 above, it appears that there is a direct proportional relationship between the sudden increase in the cost of Copper and Nickel in 2006 – 2007 and the corresponding ramp up in turnkey costs in the same years and in general in the EPC and material cost trend lines.

~~1.1.2~~14.3.2 Membrane plants

The variability of the CAPEX for a SWRO plant is by far greater than for thermal plants. This depends on the seawater quality that is available at site, on the degree of availability of the SWRO plant as well as the trade between OPEX and CAPEX expenditures.

Table 14.9 below shows a typical membrane desalination cost break down. A similar approach as the one used for thermal desalination was used in order to be able to appraise the main differences in the project construction cost.

Table 14.9 : Membrane desalination typical cost break down

Plant component	Cost percentage
SW (offshore) intake civil works	15%
SW (onshore) intake civil works	7%
Outfall civil works	3%
Desalination plant mechanical and membranes	38%
Seawater mechanical system	6%
Balance of plant mechanical	7%
Electrical works	6%
C&I works	9%
External fees (legal, financial etc)	1.%
Development cost	3%
Insurance and initial working capital	0.5%
Contingency	4%

The variation in the cost breakdown of each element for a SWRO project is much wider than for thermal desalination . For instance, an increase in the seawater abstraction system may result in a decrease in the pre-treatments system and an increase in CAPEX may result in a decrease in OPEX .

Figure 14.9 below shows a possible cost breakdown against the process system of a seawater RO plant installed in the Gulf.

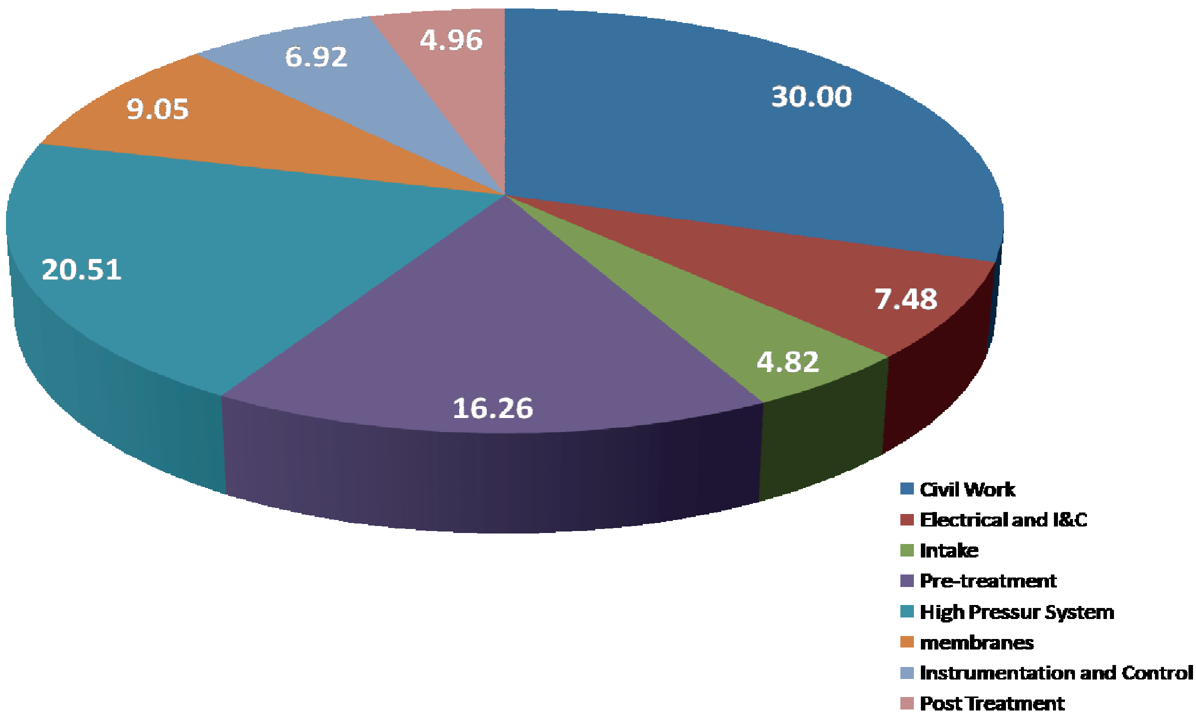

Figure 14.9 : SWRO cost breakdown

The use of membrane pre-treatment for SWRO presents a different cost profile than conventional filtration) systems.

In particular, while the characteristics of the membrane based pre-treatment (such as decreased vulnerability of UF filtrate characteristics to seawater quality) are an advantage, it should also be pointed out that the capital cost of membrane pre-treatment may be substantially higher than the cost of conventional pre-treatment.

Also in this case, the information available in the market can be subject to drastic changes. Membrane technology for seawater pre-treatment is changing very quickly and therefore new membranes with advanced recovery and lower costs are entering the market.

However, articles in literature indicate that for a traditional pre-treatment system composed by a single dual media filter stage followed by cartridge filtration the specific investment cost, including site and utilities would be 10% to 20% higher. These figures are expected to reduce. However it appears that the UF process can be particularly advantageous for sites with poor seawater quality, which would require very expensive conventional pre-treatment, or where a wide fluctuation of raw water quality is expected.

For instance, UF technology as pre-treatment has offered an extremely positive feedback to the development of SWRO technology in the Middle East thanks to the applications in Jumeirah Palm operating under extremely severe seawater conditions as well as during intensive construction works.

Since SWRO projects may be installed as stand alone complexes for water production for communities, rather than in industrial processes CAPEX can be subject to variations due to more complex architecture and the requirement to reduce nuisance values on the project are more stringent .

This may bring about a greater variability in EPC costs with an increased civil component that results from additional architectural and landscaping requirement. A typical example of cost breakdown in this case is shown in Figure 14.10

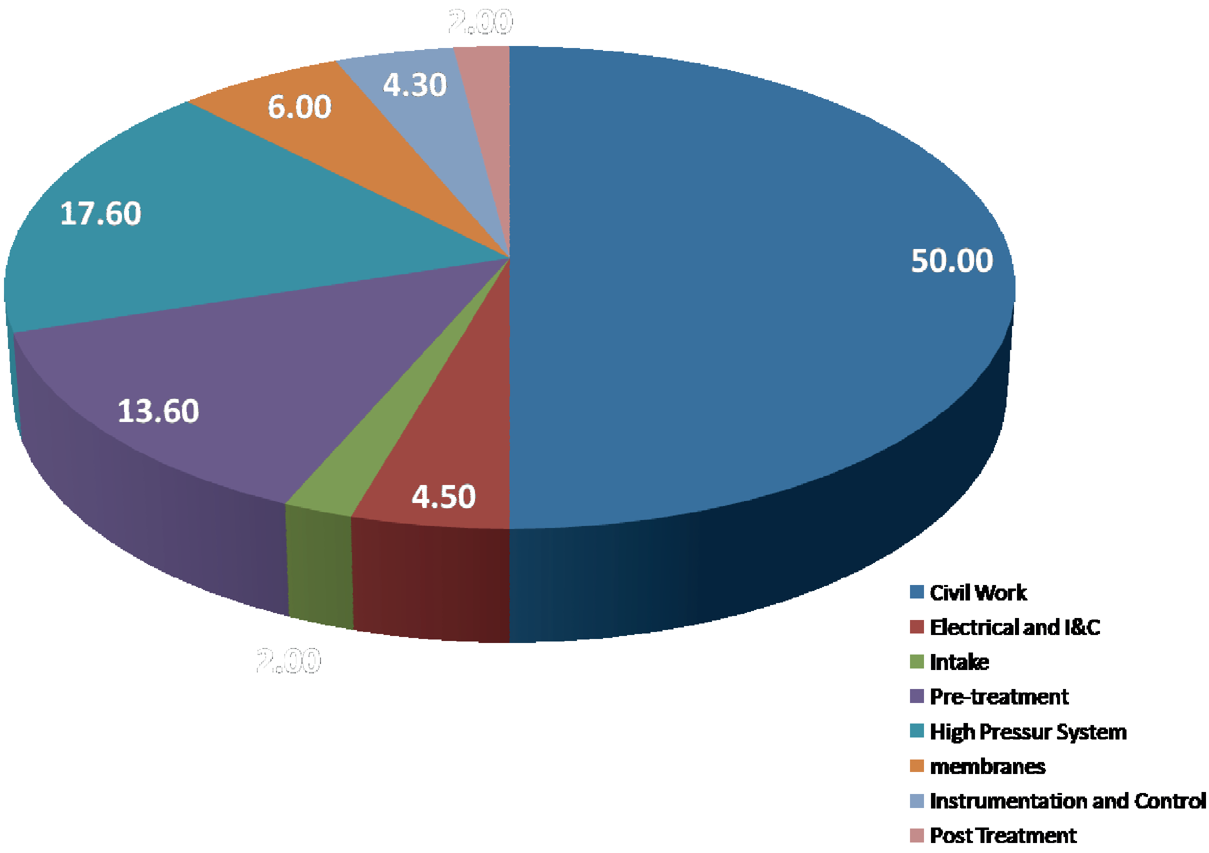

Figure 14.10 : SWRO cost breakdown : alternative case

15 The cash flow and operating cycle of a plant

In general, working capital for desalination projects tend to be quite high
Desalination and water treatment turnkey contractors buy raw materials and equipment using cash of an initial down payment granted by their Client or on credit.

The equipment and raw materials are then held by the turnkey contractor for some time before being issued to the construction workshop or used for site erection and therefore being billed, as finished completion and invoice milestones.

By this time, the turnkey contractor has already paid for the raw materials and therefore some time generally elapses before the cash from the achievement of project profit milestone is eventually received.

A diagram illustrating a typical cash or operating cycle in a desalination – power or waste water treatment plant is indicated in the Figure 14.1

The Figure 15.1 below shows the time sequence between the purchase of materials and equipment and the receipt of cash from Clients and therefore can an idea of the time interval elapsing between cash is paid out by EPC contractor and the time cash is received

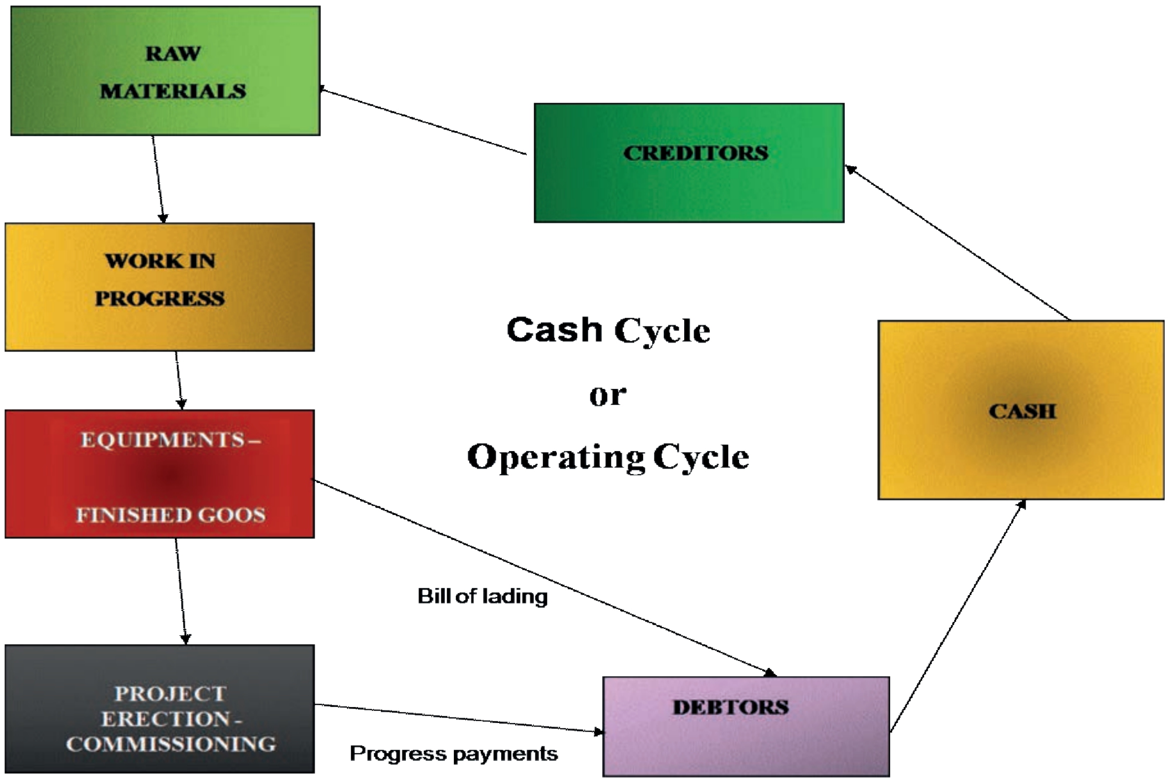

Figure 15.1: typical cash operating cycle in a large seawater desalination project

Therefore cash flow may be a very challenging aspect in lump sum turnkey contracts.
A further risk may arise by the currency and raw material variation between the cash disbursement and receipt time.

These aspects need to be considered in the estimation of the contract conditions in order to avoid that negative cash flow pushes the turnkey contractor to increase the price.

16 Tariffs

The previous chapters have been dealing with tariff at production points.
The tariff at production may differ from the tariff at households to a great extent. It may be possible that the tariff at production points may be incongruent with each other due to reasons such as different construction times, different technology and market demand.

Therefore the generation tariffs unavoidably differ from one development to the other. It should be further considered that the power and water sectors are traditionally susceptible to political and regulatory interventions.
In this respect, the role of the regulatory supervision bureaus is to provide harmony between the tariffs at production points and the bulk tariffs to the end users along with the provision for subsidies.

This mechanism is indicated in Figure 16.1 showing the process of setting out tariffs for licensees and existing public owned plant .

This also offers the possibility of harmonizing the tariffs from different production assets and setting up the provision for subsidies .

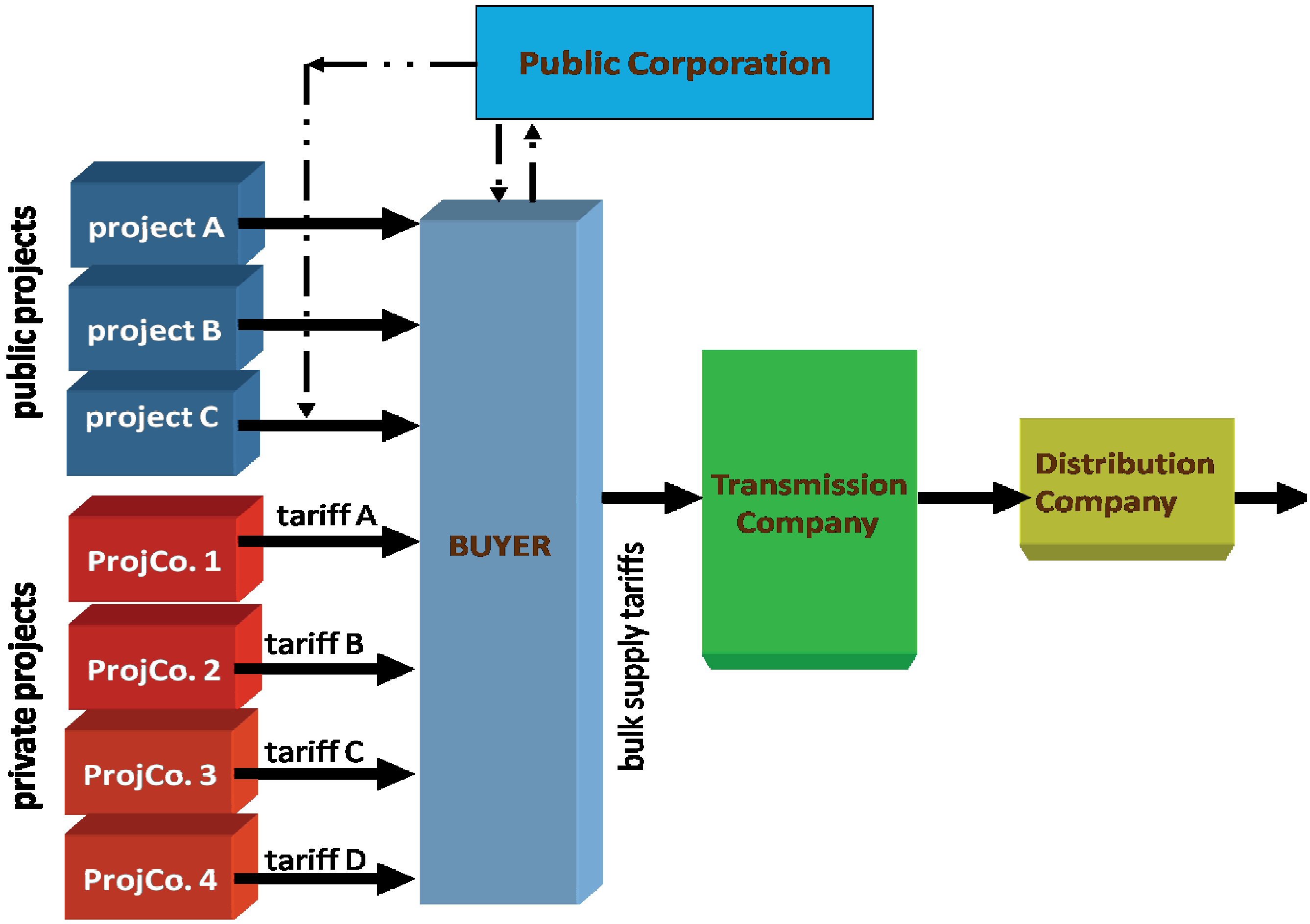

Figure 16.1: generation and bulk tariffs schematic diagram

It should be considered that political and social demand thrives to maintain household tariffs as non-inflationary as possible while, on the other hand generation tariffs may be affected by inflationary factors generating higher CAPEX and subsequent tariff escalations.

The water sector therefore has been recently promoting both technical and commercial innovative solutions, and because desalination and water treatment technologies have been very conservative for long time and regularly fixed to old prototype design and contracting schemes, this has managed to continually improve the water costs.

Tariffs at production are adjusted to local-major currency exchange rates and local international inflation values while the tariff at the distribution points are generally controlled by social and political factors.

Competition in the water sector is promoted to ensure the operation and development of an efficient and economic sector, and to protect the interests of consumers of water and electricity as to the terms and conditions and price of supply.

Figure 16.2 below shows the prevailing water tariff at the production point obtained from market researches' and public tender openings . For uniformity, the tariffs have been , converted to US$/$m^3$.

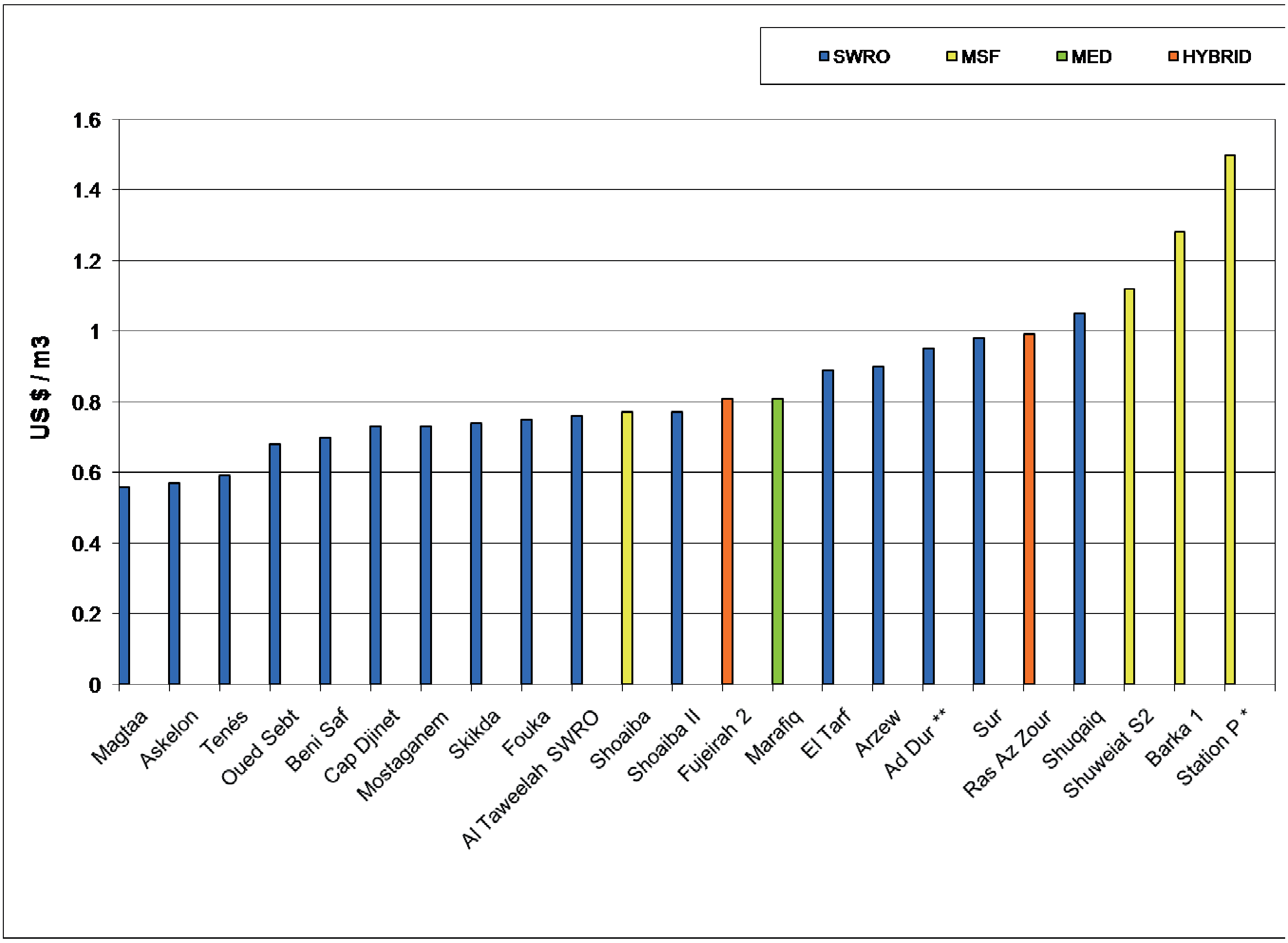

Figure 16.2: current commercial generation tariffs

As can be seen from the table above, the tariff trend reflects the behavior of the specific CAPEX indicated in the previous chapter.

Generally the tariffs above contain an investment rate of return (IRR) ranging between 8% for the Mediterranean projects and 13% which is the value typically assumed in the Middle East.

According to many tender practices in privatization projects, the investment rate of return needs to be generally kept fixed according to project sponsors requirements. In addition to this, operation and maintenance expenditure charges do not include any profit or investment return for the project Company

However there are cases where the investment is fixed in the tariff structure. The real internal rate of return due to O&M fees etc. may reach 18-20%.

Tariffs are also heavily dependent on the energy price that ranges between 0.5 US$/MBTU in the Kingdom of Saudi Arabia to 5 US$/MBTU for the Emirates

17 Acknowledgement

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A special thanks to my friend and colleague Jim McTaggart, indefatigable champion of hundreds desalination sites, who has embarked on a lifetime mission of straightening my English and who has graciously reviewed this book

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The book makes reference to material that has been published in IDA and EDS conferences and publications that have been of great support.

Finally I would like to acknowledge the support of my Company ILF consulting engineer who has encourage me to complete this publication.

18 Glossary

BOD	Biological Oxygen Demand
BOOT	Build Own Operate and Transfer
BOT	Build Own and Transfer
BOP	Balance of plant
BWRO	Brackish Water Reverse Osmosis
CAPEX	Capital Expenditure
CARR	Cumulative Annual Replacement Rate
CEMP	Construction Environmental Monitoring Plan
CPI	Consumer Index Price
C&I	Control and Instrumentation
DASSR	Desalination Aquifer Storage and Recovery
DBO	Design Build and Operate
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
EPC	Engineer Procure and Construct
EU	European Union
FIDIC	Federation Internationale Des Ingenieurs Conseils
GT	Gas Turbine
HRSG	Heat Recovery Steam Generator
IWP	Independent Water Project
IWPP	Independent Water Power Project
IRR	Investment Return Rate
LME	London Metal exchange
MBR	Membrane Bio Reactor
MED	Multiple Effect Distillation
MF	Micro-filtration
MFS	Minimum Functional Specification
MVC	Mechanical Vapour compression
MIGD	Million Imperial Gallons per Day
MLSS	
MSF	Multi Stage Flash
MBTU	Mega British Thermal Units

NF	Nano-filtration
O&M	Operation and Maintenance
OPEX	Operational Expenditure
PWR	Power to Water Ratio
R&D	Research and Development
RO	Reverse Osmosis
SDI	Silt Density Index
STP	Sewage Treatment Plant
SWRO	Seawater Reverse Osmosis
TDS	Total Dissolved Solids
TSE	Treated Sewage Effluent
TSS	Total Suspended Solids
TV	Terminal Value
TVC	Thermal Vapour Compression
UF	Ultra Filtration
WHO	World Health Organisation

Dedicated

This book is dedicated to my children Bianca, Guglielmo and Valeria and to my wife Mariana. They are the never ending inspiration to my life.