A Sustainable Water Management Concept for Auroville and its Bioregion

Desalination

A Pre-Feasibility study

A report by

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1. Executive Summary

The outcome of an international water seminar, which was held in Auroville in September 2004, was a variety of proposals for the future water supply for Auroville, its Bioregion and for the Matrimandir Lake. One possibility to guarantee a safe and future water supply is to desalinate seawater.

The CO_2 emissions and the impact on the world climate of conventional energy devices are uncontroversial. It is clear that with every liter of freshwater produced with conventional energy; the CO_2 emission has a negative impact on the world climate. Therefore emphasis was laid on an alternative desalination plant combined with renewable energy devices.

In this document the author explains different desalination technologies as well as renewable energy systems. An economical cost calculation was made for selected combined desalination systems with various plant sizes of 500 m^3/d; 1,000 m^3/d; 5,000 m^3/d and 10,000 m^3/d.

The question: "What would be the right desalination plant for Auroville and its Bioregion" was answered by a discussion of different possible desalination methods powered by renewable energy devices, e.g. reverse Osmosis powered by Photovoltaic etc.

Seven important aims with different weight were defined:

1. Easy handling, maintenance and minimum of personnel
2. Economical investment in combination with a long lifetime
3. Flexibility and easy extendibility
4. Maximum efficiency in energy consumption, 24 h production
5. Minimum use of chemicals, Environmental impact
6. Multi Type Plant (brackish/ seawater)
7. Optimal use of the land

All Aims were discussed, rated and assessed with a matrix. The outcome from the evaluation was that a Reverse Osmosis desalination plant powered by a wind turbine is the best solution to produce fresh water. The economical cost calculation showed up that water can be produced for Rs 22 per m^3 with this combination. The low cost price of the fresh water is supported through the re-selling of the surplus electricity.

In case “waste steam” would be available a $MED_{free\text{-}steam}$ system would be the best option concerning the pre set seven aims. For example a 10,000 m^3/d $MED_{free\text{-}steam}$ powered by PV could produce fresh water for Rs 35 per m^3. Again the cheapest option would be to combine the system with a wind turbine; then the water price will be app. Rs 20 per m^3.

Not included in this price are the storage facilities, distribution/ piping network, pump station as well as the necessary treatment facility for the brine. A separate study has to be done to clarify this costs.

For the second planning phase of the desalination plant several questions, like exact location, land availability, well tests, brine disposal treatment, Wind Park and TNEB connection etc. have to be answered by separate studies. It is important to include an environmental and social impact study at this stage already.

Auroville/ Februar 2007

Dirk Nagelschmidt (M.Eng)

2. Introduction

Over extraction, coastal salinisation and pollution of ground and river waters are major problems in India. Missing waste water treatment systems and the necessary awareness support these processes. The International Town planning project "Auroville" and its bio region are facing these problems, too. Auroville was born 1968 from a vision of Mira Alfassa called the “Mother”. The Mother was the spiritual leader of the Sri Aurobindo Ashram in Pondicherry. The city of Auroville is located on the Bay of Bengal, 160 km south of Tamil Nadu’s capital city Chennai in India. Presently the city is under development.

One vision of the Mother was that the Matrimandir, the soul and centre of Auroville should be surrounded by a lake. But where to find the water for the lake, as the Matrimandir is built on a plateau 52 m above main sea level? There is no river nearby and the groundwater aquifers are nearly empty. The safe drinking water supply for Auroville and the app. 45.000 inhabitants of Auroville’s immediate surrounding bio region is in danger.

To find a solution, an international water seminar was held in Auroville in September 2004. It was supported by UNESCO and the President of India, His Excellency Dr. A. P. J. Abdul Kalam.
Experts from India, France, Germany, the Netherlands and Israel participated in the conference too. The outcomes of this conference were different proposals for the future water supply for Auroville, its bio region and as well for the Matrimandir Lake.

In December 2004, a Tsunami hit the coastal line of Auroville’s Bioregion and the ground water in the wells of the affected villages turned salty. These areas have an emergency need for a safe drinking water supply.

One possibility to guarantee a safe and future water supply is to desalinate seawater. In this pre-feasibility study the author discusses the possibility of a desalination plant for Auroville and its bio region.

3. Auroville Region

Auroville is located between Pondicherry on the south, and Tamil Nadu on the north and west side. On the east the city is bounded by the Bay of Bengal. The city area of Auroville is app. 25 km². The city should be home for 50.000 inhabitants. Presently 2000 inhabitants from more than 40 different nations live in 55 communities within Auroville. In the surrounding villages live presently app. 50.000 local people. The total Study Area is 70 km^2.

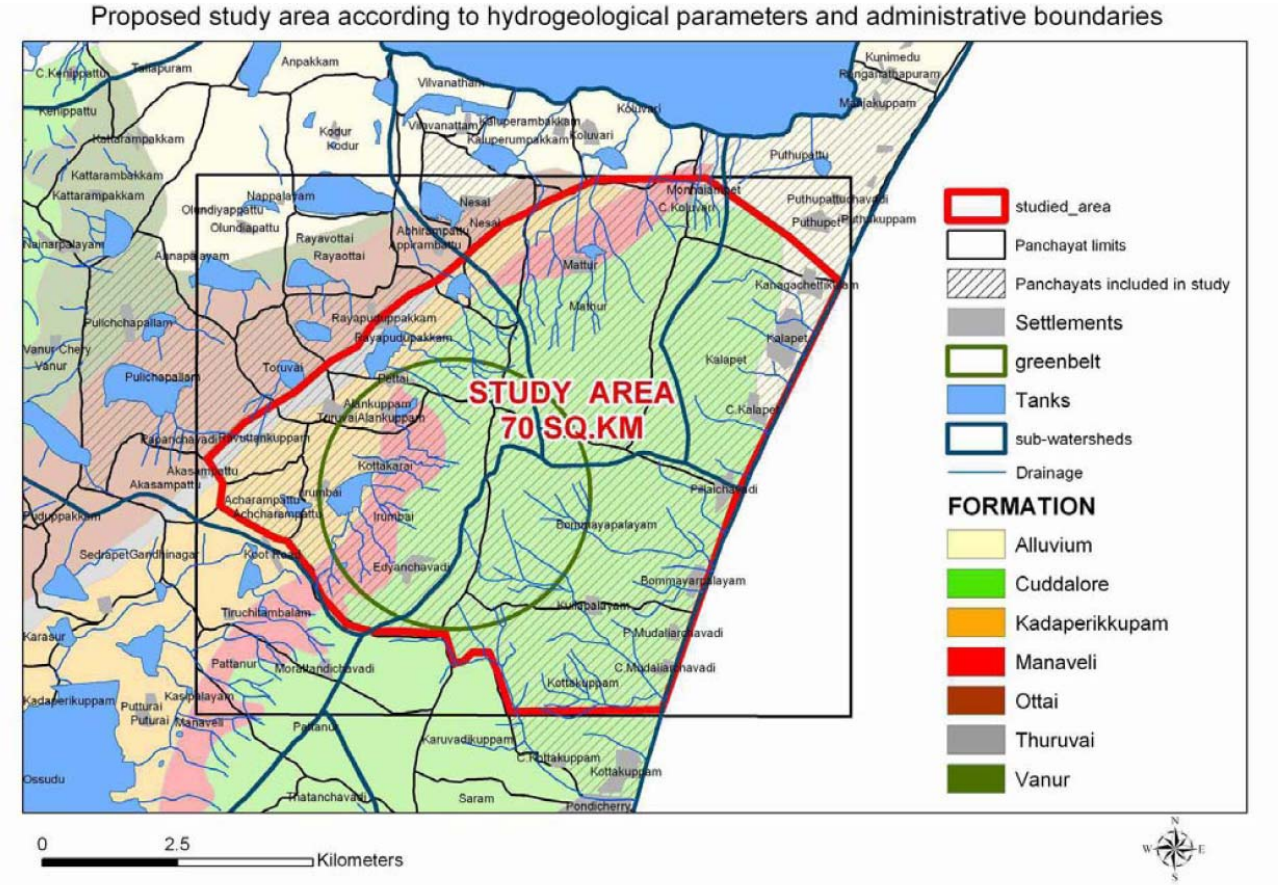


Fig. 1: Study Area

3.1. Physical and chemical data on seawater and brackish water in Auroville's Beach Area

Figs. 2 & 3 show the physical/chemical Parameters of the sea water in September 2003 and in April 2005. Fig. 4 shows a brackish water analysis from April 2005.

Physical Chemical Parameters, Date 08.09.2003, Seawater

No.	Parameters	Unit	Results	
		distance from sea shore in m	200 m	400 m
1	Alkalinity (as $CaC0_3$)	mg/l	108	108
2	BOD_3	mg/l	5	2
3	Calcium as Ca	mg/l	440	480
4	Chlorides as Cl	mg/l	19100	19200
5	COD	mg/l	56	92
6	Conductivity (at 25° C)	µS/cm	49500	55450
7	Dissolved solids (at 103°-105°C	mg/l	41500	40100
8	Fluoride as F	mg/l	1.2	1.2
9	Magnesium as Mg	mg/l	1299	1323
10	pH (at 25° C)		7.9	7.9
11	Sodium Na	mg/l	10080	10040
12	Sulphate as SO_4	mg/l	3750	3750
13	Total Suspended Solids	mg/l	80	60
14	Total Hardness as ($CaC0_3$)	mg/l	6400	6600
15	Turbidity	NTU	1.2	1.2

Fig. 2: Physical/chemical Parameter of Sea water September 2003

Physical Chemical Parameters, Date 22.04.2005, Seawater

No.	Parameters	Unit	Results	
		distance from sea shore in m	200 m	400 m
1	Alkalinity (as $CaC0_3$)	mg/l	600	600
2	BOD_3	mg/l	9	10
3	Calcium as Ca	mg/l	760	720
4	Chlorides as Cl	mg/l	20100	20100
5	COD	mg/l	20	29
6	Conductivity (at 25° C)	µS/cm	39400	39400
7	Dissolved solids (at 103°-105°C	mg/l	36038	35018
8	Fluoride as F	mg/l	10	10
9	Magnesium as Mg	mg/l	1238	1225
10	pH (at 25° C)		8.3	8.3
11	Sodium Na	mg/l	10470	10670
12	Sulphate as SO_4	mg/l	3500	3470
13	Total Suspended Solids	mg/l	10	10
14	Total Hardness as ($CaC0_3$)	mg/l	6400	6700
15	Turbidity	NTU	4	5

Fig. 3: Physical/chemical Parameter of Sea water April 2005

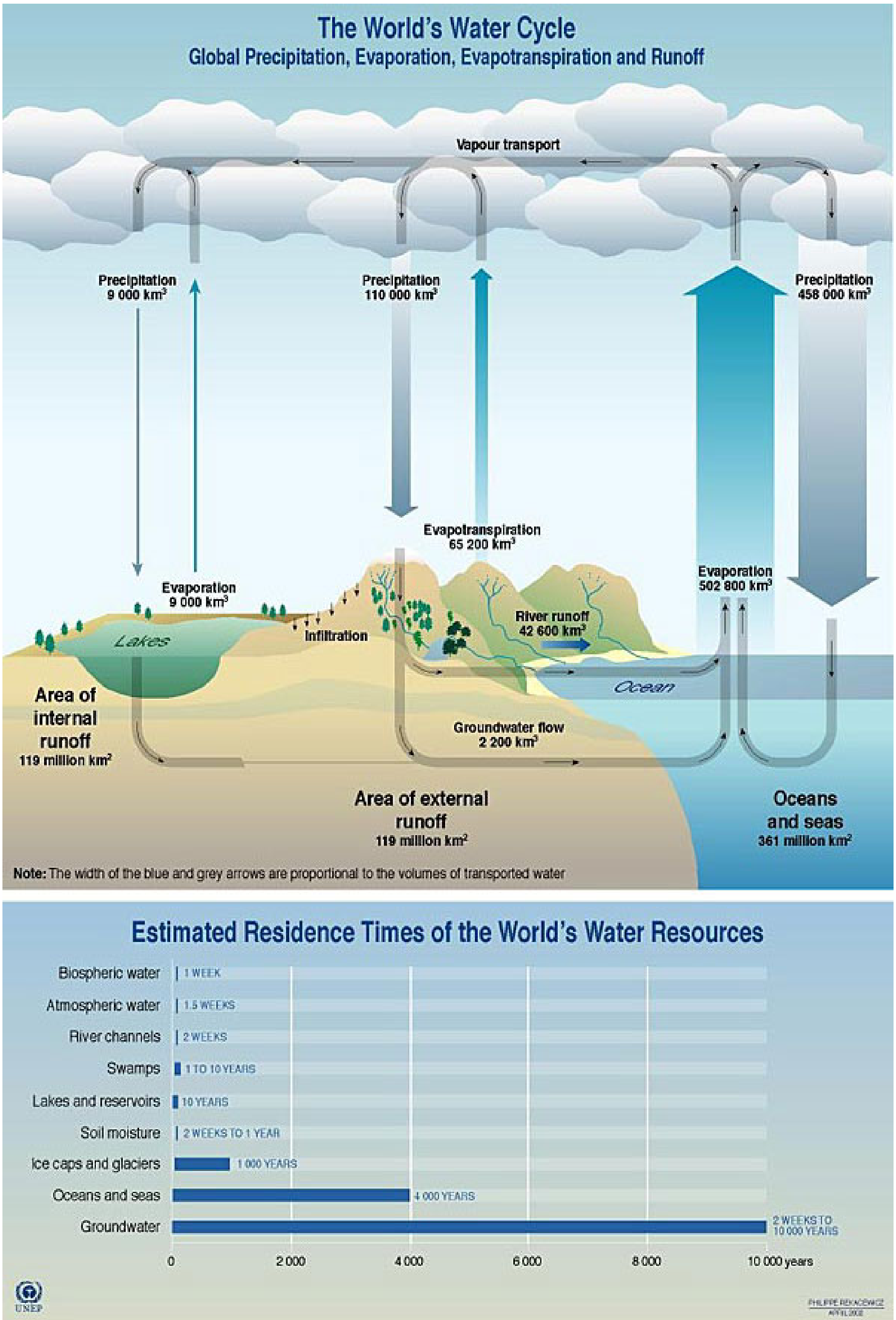
Physical Chemical Parameters, Date 18.4.2005, Brackish water				
No.	**Parameters**	**Unit**	**Results**	
		Open well	**Sri Ma**	**Gokulam**
1	Alkalinity (as $CaC0_3$)	mg/l	40	240
2	BOD_3	mg/l	3	7
3	Calcium as Ca	mg/l	132	272
4	Chlorides as Cl	mg/l	1160	3760
5	COD	mg/l	8	32
6	Conductivity (at 25° C)	µS/cm	2769	7930
7	Dissolved solids (at 103°-105°C	mg/l	2020	7426
8	Fluoride as F	mg/l	0,8	0,9
9	Magnesium as Mg	mg/l	59	232
10	pH (at 25° C)		6,2	7,6
11	Sodium Na	mg/l	600	2100
12	Sulphate as SO_4	mg/l	212	525
13	Total Suspended Solids	mg/l	< 1.0	26
14	Total Hardness as ($CaC0_3$)	mg/l	570	1640
15	Turbidity	NTU	0,7	1,8

Fig. 4: Physical/ chemical Parameters of Brackish water April 2005

The above analyses give a first information of the water quality in the Auroville beach area. In a feasibility study, the data have to be collected weekly to show the fluctuations of the water quality.

The analyze was done by EMS (Environmental Monitoring Service), Aurobrindavan, Auroville)

4. Desalination processes, a general introduction



Source: Igor A. Shiklomanov, State Hydrological Institute (SHI, St. Petersburg) and United Nations Educational, Scientific and Cultural Organisation (UNESCO, Paris), 1999; Max Planck, Institute for Meteorology, Hamburg, 1994; Freeze, Allen, John, Cherry, *Groundwater*, Prentice-Hall: Englewood Cliffs NJ, 1979.

Fig. 5: The world's water cycle

Hundreds of millions of years ago, the water of the world oceans was sweet water. In the water cycle water evaporates and falls as rain on the ground. Once on the ground, the water flows into rivers and the rivers flow back into the oceans. During the journey, people use the water for various purposes. As well, the water dissolves minerals and other materials as it moves over and through the earth and it becomes increasingly salty. Fig. 5 shows a sketch the world's water cycle.

A major step in the development of desalination came in the 1940s, during World War II, when various military establishments in arid areas needed water to supply their troops. The potential that desalting offered was recognized more widely after the war and work was continued in various countries. The ability to obtain fresh water from the sea has transformed semi-arid areas like the Virgin Islands where seawater desalination units were first installed in 1960. [3]

By the late 1960s, commercial units were beginning to be installed in various parts of the world. These mostly thermal-driven units were used to desalt seawater, but in the 1970s commercial membrane processes such as Electro Dialysis (ED) and Reverse Osmosis (RO) began to be used more extensively. Originally, the distillation process was used to desalt both brackish water and seawater. This process was expensive and restricted the applications for desalting to municipal purposes. When Electro Dialysis (ED) was introduced, it could desalt brackish water much more economically than distillation, and many applications were found for it. This breakthrough in reducing the costs for brackish water desalting was significant because it focused interest all over the world on the potential municipal use of desalted water for countries or areas with limited fresh water reserves. [3]

By the 1980s, desalination technology was a fully commercial enterprise. The technology benefited from the operating experience (sometimes good, sometimes bad) achieved with the units that had been built and operated in the previous decades. [3]

By the 1990s, the use of desalting technologies for municipal water supplies had become commonplace. A variety of desalting technologies have been developed over the years and, based on their commercial success, they can be classified into the major and minor desalting processes shown in Fig. 7. [3]

Desalting equipment is now used in over 100 countries. Most common is desalination of sea or brackish water in the Middle East and North Africa. Saudi Arabia ranks first in total capacity (about 24 percent of the world's capacity), with most of it being made up of seawater desalting units that use the distillation process. In chapter 3.1 the author describes the different possibilities for desalination processes. [3]

4.1. Overview of different desalination processes

A desalting device essentially separates saline water into two streams: one with a low concentration of dissolved salts (the fresh water stream) and the other containing the remaining dissolved salts (the concentrate or brine stream). The device requires energy to operate and can use a number of different technologies for the separation. This section briefly describes the various desalting processes commonly used to desalt saline water. Fig. 6 shows the principle of a desalination process, Fig. 7 shows the different possibilities to desalt sea or brackish water. [3]

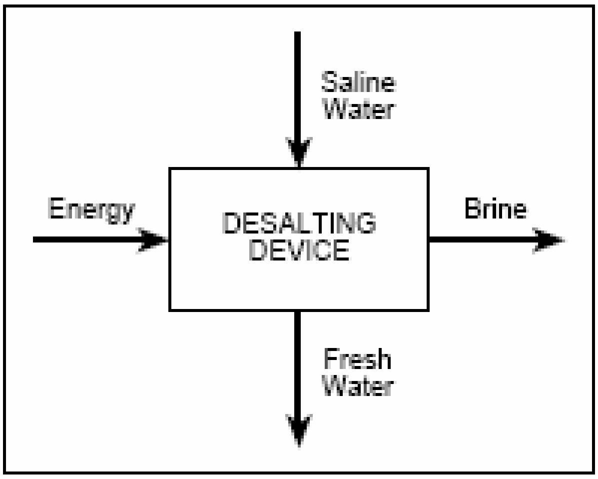


Fig. 6: Desalting Process

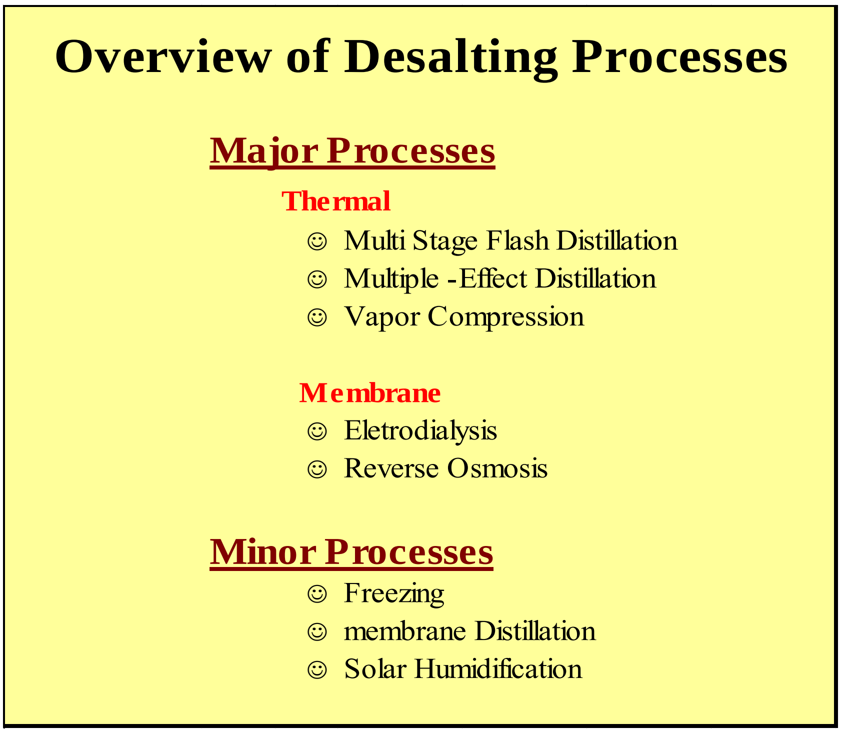


Fig. 7: Desalting Technologies

4.2. Thermal Processes

About half of the world's desalted water is produced with heat to distill fresh water from sea water. The distillation process mimics the natural water cycle (Fig. 5) in that salt water is heated, producing water vapor that is in turn condensed to form fresh water. In a laboratory or industrial plant, water is heated to the boiling point to produce the maximum amount of water vapor. [3]

To do this economically in a desalination plant, the applied pressure of the water being boiled is adjusted to control the boiling point. Because of the reduced atmospheric pressure on the water, the temperature required to boil water decreases as one moves from sea level to a higher elevation. Thus, water can be boiled on top of Mt. McKinley, in Alaska elevation 6,200 meters at a temperature about 16 °C lower than it would boil at sea level. This reduction of the boiling point is important in the desalination process for two major reasons: multiple boiling and scaling controls. [3]

To boil water, one needs two important conditions: the proper temperature relative to its ambient pressure and enough energy for vaporization. When water is heated to its boiling point and then the heat is turned off, the water will continue to boil only for a short time because the water needs additional energy (the heat of vaporization) to permit boiling. Once the water stops boiling, boiling can be renewed by either adding more heat or by reducing the ambient pressure above the water. If the ambient pressure were reduced, the water would be at a temperature above its boiling point (because of the reduced pressure) and would flash to produce vapor (steam), the temperature of the water will fall to the new boiling point. [3]

If more vapor can be produced and then condensed into fresh water with the same amount of heat, the process tends to be more efficient. To significantly reduce the amount of energy needed for vaporization, the distillation desalting process usually uses multiple boiling in successive vessels, each operating at a lower temperature and pressure. [3]

Typically GOR is 8 to 10 tons of distillate that can be produced from 1 ton of steam (GOR=GAINED OUTPUT RATIO). This process of reducing the ambient pressure to promote additional boiling can continue downward and, if carried to the extreme with the pressure reduced enough, the point at which water would be boiling and freezing at the same time would be reached. Aside from multiple boiling, the other important factor is scale control. Although most substances dissolve more readily in warmer water, some dissolve more readily in cooler water. Unfortunately, some of these substances, like carbonates and sulfates, are found in seawater. [3]

One of the most important is calcium sulfate ($CaSO_4$), which begins to leave solution when sea water approaches about 115 °C. This material forms a hard scale that coats any tubes or surfaces present. Scale creates thermal and mechanical problems and is difficult to remove. One way to avoid the formation of this scale is to control the concentration level of seawater and to control the top temperature of the process. Another way is to add special chemicals to the sea water that reduce scale precipitation and permit the top temperature to reach 110ºC. These two concepts have made various forms of distillation successful in locations around the world. The process that accounts for the most desalting capacity for seawater is Multi-Stage Flash distillation, commonly referred to as the MSF process. [3]

4.2.1. Multi-Stage Flash Distillation (MSF)

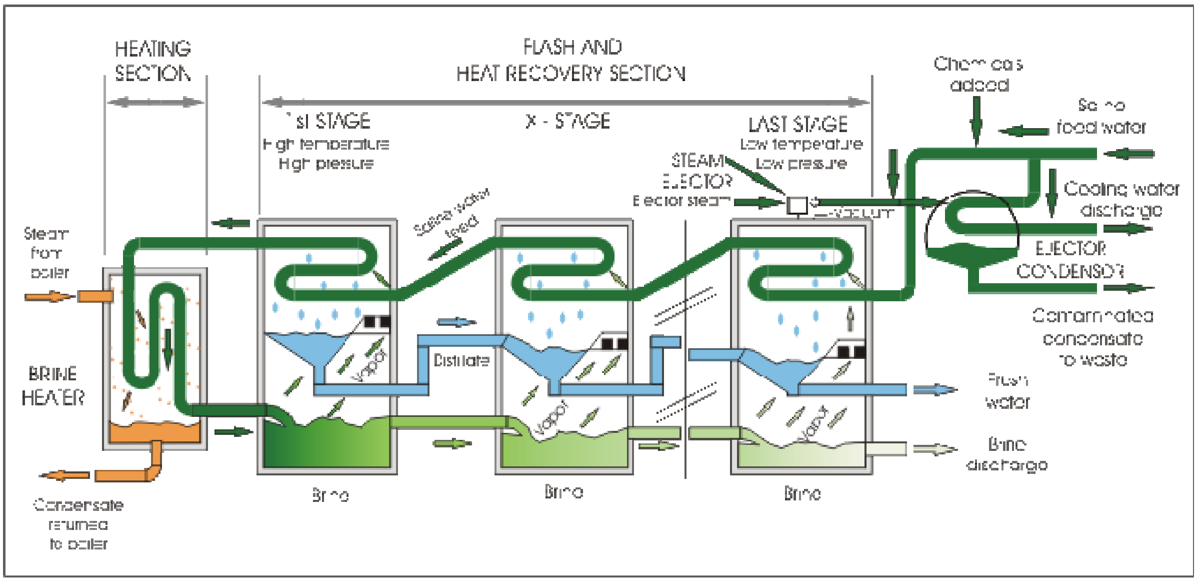


Fig. 8: Diagram of a Multi-Stage Flash Plant

In the MSF process (Fig. 8), seawater is heated in a vessel called the brine heater. This is generally done by condensing steam on a bank of tubes that carry seawater which passes through the vessel. This heated seawater then flows into another vessel, called a stage, where the ambient pressure is lower, causing the water to immediately boil. The sudden introduction of the heated water into the chamber causes it to boil rapidly, almost exploding or flashing into steam. [3]

Generally, only a small percentage of this water is converted to steam (water vapor), depending on the pressure maintained in this stage, since boiling will continue only until the water cools (furnishing the heat of vaporization) to the boiling point. The concept of distilling water with a vessel operating at a reduced pressure is not new and has been used for well over a century. In the 1950s, an MSF unit that used a series of stages set at increasingly lower atmospheric pressures was developed. In this unit, the feed water could pass from one stage to another and be boiled repeatedly without adding more heat. Typically, an MSF plant can contain from 15 to 25 stages. Adding stages increases the total surface area, thus increases the capital cost in addition to the complexity of operation. [3]

The vapor steam generated by flashing is converted to fresh water by being condensed on tubes of heat exchangers that run through each stage. The tubes are cooled by the incoming feed water going to the brine heater. This, in turn, warms up the feed water so that the amount of thermal energy needed in the brine heater to raise the temperature of the seawater is reduced. Multi-stage flash plants have been built commercially since the 1950s. They are generally built in units of about 4,000 to 57,000 m3/d. The MSF plants usually operate at the top brine temperatures after the brine heater of 90 -110 °C. [3]

One of the factors that affects the thermal efficiency of the plant is the difference between the temperature of the brine heater exit and the temperature in the last stage on the cold end of the plant. Operating a plant at the higher temperature limits of 110 °C increases the efficiency, but it also increases the potential for detrimental scale formation and accelerated corrosion of metal surfaces. [3]

The most significant progress that has been made over the past 10 years is the increase in the reliability of operation. This reliability has been brought about by improvements in scale control, attention to daily operation, automation and controls, and materials of construction. In addition, increases in the size of the basic unit have produced economies of scale in capital costs. Many countries on the Arabian Peninsula, such as Saudi Arabia, the United Arab Emirates, and Kuwait are highly dependent on MSF facilities to supply water to their urban areas. This dependence, combined with a large installed capacity, has encouraged them to take measures to protect this investment. [3]

4.2.2. Multi-Effect Distillation (MED)

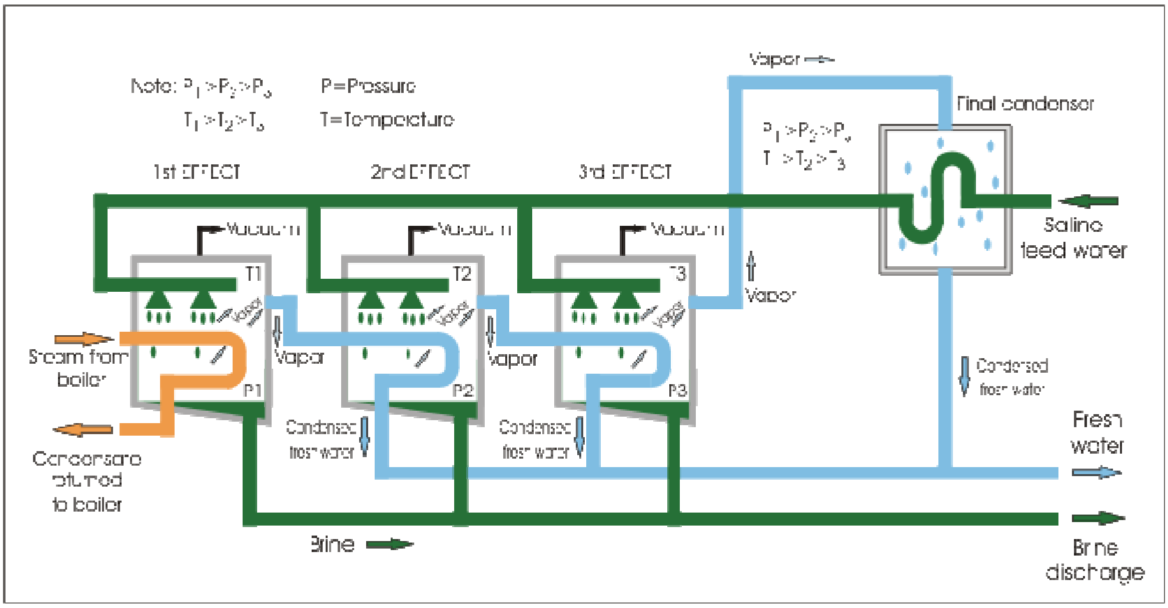


Fig. 9: Diagram of a Multi-Effect plant with horizontal tubes.

The Multi-Effect Distillation (MED) process (Fig. 9) has been used for industrial distillation for a long time. Traditional uses for this process are the evaporation of juice from sugar cane in the production of sugar and the production of salt with the evaporative process. Some of the early water distillation plants used the MED process, but MSF units, because of a better resistance against scaling, displaced this process. However, starting in the 1980s, interest in the MED process was revived, and a number of new designs have been built around the concept of operating on lower temperatures, thus minimizing corrosion and scaling. [3]

MED takes place in a series of vessels (effects) and uses the principles of condensation and evaporation at reduced ambient pressure in the various effects. This permits the seawater feed to undergo boiling without the need to supply additional heat after the first effect. In general, an effect consists of a vessel, a heat exchanger, and devices for transporting the various fluids between the effects. Diverse designs have been or are being used for the heat exchanger area, such as vertical tubes with falling brine film or rising liquids, horizontal tubes with falling film, or plates with a falling brine film. By far the most common heat exchanger consists of horizontal tubes with a falling film. [3]

Fig. 10: MED plant 48.000 m^3/d (4 units) at Jamnagar, Gujarat, India 2002

There are several methods of adding the feed water to the system. Adding feed water in equal portions to the various effects is the most common. The feed water is sprayed or otherwise distributed onto the surface of the evaporator surface (usually tubes) in a thin film to promote rapid boiling and evaporation after it has been preheated to the boiling temperature on the upper section. [3]

The surfaces in the first effect are heated by Steam from Steam turbines of the power plants or a boiler. The steam is then condensed on the colder heat transfer surface inside the effect causing it to heat. The condensate is recycled to the boiler for reuse. The surfaces of all the other effects are heated by the steam produced in each preceding effect. The vapor produced in the last effect is condensed in a separate heat exchanger called the final condenser, which is cooled by the incoming sea water, thus pre-heating the feed water. Only a portion of the seawater applied to the heat transfer surfaces is evaporated. The remaining feed water, of each effect, now concentrated and called brine, is often fed to the brine pool of the next effect, where some of it flashes into vapor. This vapor is also part of the heating process. All vapor condensed inside the effects is the source of the fresh water product. The ambient pressure in the various effects in the MED process is maintained by a separate vacuum system. [3]

The thermal efficiency of the process depends on the number of effects with 8 to 16 effects being found in a typical plant. MED plants are typically built in units of 2,000 to 20,000 m3/d. Some of the more recent plants have been built to operate with a top temperature (in the first effect app. 70 °C), which reduces the potential for scaling of seawater within the plant. This in turn increases the need for additional heat transfer areas that add to the physical size of the plants. [3]

Most of the more recent applications for the MED plants have been in India, the Caribbean, the Canary Islands and the United Arab Emirates. [3]

A new highly efficient MED plant with a capacity of 2400 m^3d was built 2004 in Kachchh, Gujarat. The client for this plant is the Gujarat Mineral Development Corporation Ltd. Planning was done by VA-Tech WABAG. At this plant, waste steam from the electric production gets used for running the thermal desalination process.

Highly efficient MED plants need a considerable number of effects and large heat transfer areas and are therefore used in cases where energy costs are high. In cases where low cost steam is available the MED capital costs are significantly reduced. In other MED applications, a vapor thermal compression cycle is usually added to the system. This considerably reduces the number of effects and surface area required for the same capacity. [3]

4.2.3. Vapor Compression Distillation (VC), mechanical and thermal

The Vapor Compression Distillation (VC) distillation process (Figs. 11 and 12) is generally used in combination with other processes (like the MED described above) and by itself for small and medium scale seawater desalting applications. The heat for evaporating the water comes from the compression of vapor rather than the direct exchange of heat from steam produced in a boiler. [3]

The plants that use this process are also designed to take advantage of the principle of reducing the boiling point temperature by reducing the pressure. Two methods of steam ejectors are common and used in the compression cycle to run the process. [3]

a) Mechanical Vapor Compression MVC

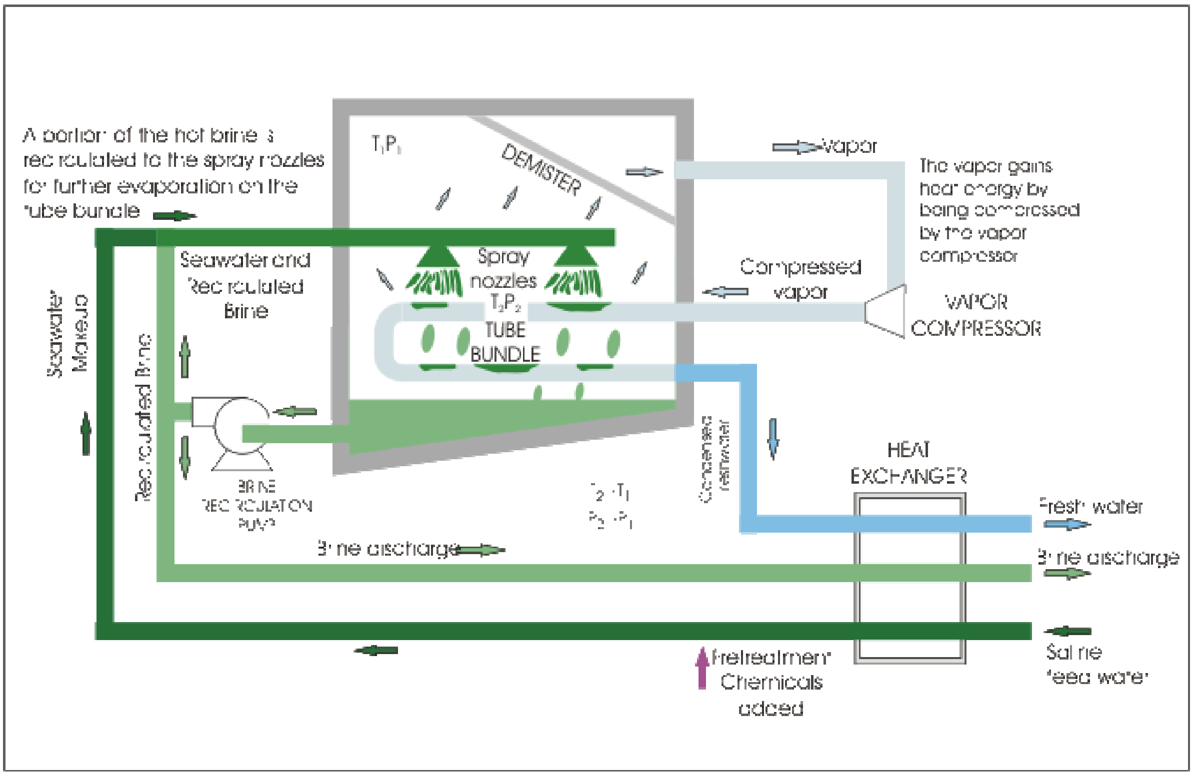


Fig. 11: Diagram of a mechanical vapor compression MVC Multi-Effect plant

The mechanical compressor is usually driven electrically, by diesel or by biofuel, allowing the sole use of electrical or mechanical energy to produce water by distillation.

MVC units have been built in a variety of configurations to promote the exchange of heat to evaporate the seawater. Fig. 11 shows a simplified method in which a mechanical compressor is used to generate the heat for evaporation. All steam is removed by a mechanical compressor from the last effect and introduced as heating steam into the first effect after compression where it condenses on the cold side of the heat transfer surface. Seawater is sprayed or otherwise distributed on the other side of the heat transfer surface where it boils and partially evaporates, producing more vapor. [3]

In order to use low cost compressors, the pressure increase is limited, and therefore, most smaller plants only have one stage. In newer and larger plants, several stages are used. The MVC units are produced in capacities ranging from a few liters up to 3,000 m3/d. They generally have an energy consumption of about 7 to 12 kWh/m3. [3]

b) Thermal Vapor Compression TVC

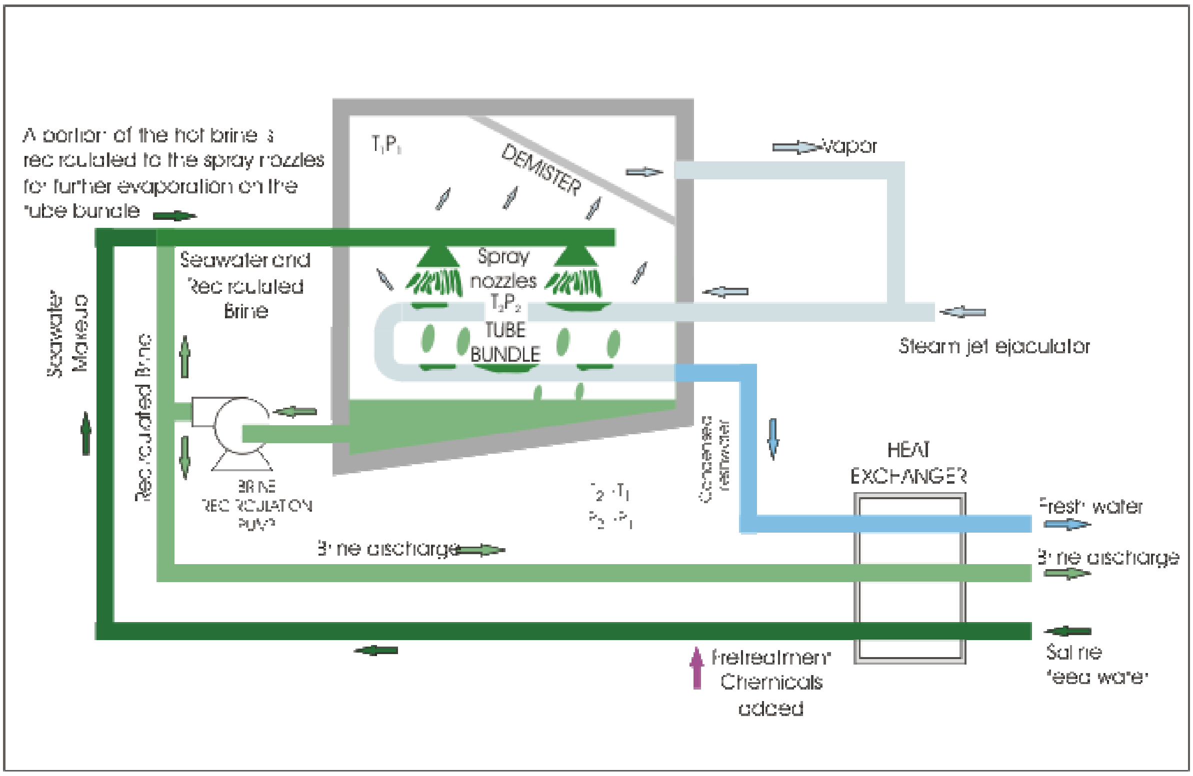


Fig. 12: Diagram of a thermal vapor compression TVC Multi-Effect plant

With the steam-jet type TVC unit, also called a thermo compressor, an ejector operated using 3 to 20 bar motive steam removes part of the water vapor (steam) from the vessel (Fig. 12). In the ejector, the removed vapor is compressed to the necessary heating steam pressure to be introduced into the first effect. On average, one part of motive steam removes one part vapor from the last effect, thus producing two parts of heating steam. Thermal vapor compression plants are usually built in the 500 to 20,000 m^3/d range. [3]

TVC units are often used for resorts, industries, and drilling sites where fresh water is not readily available. Their simplicity and reliability of operation make them an attractive unit for small installations where these factors are desired. The average energy consumption is only 1 KWh/m^3 if steam is provided. [3]

4.3. Membrane Processes

In nature, membranes play an important role in the separation of salts, including both the process of dialysis and of osmosis, occurring in the body. Membranes are used in two commercially important desalting processes: **Electro Dialysis (ED, Fig. 14)** and **Reverse Osmosis (RO, Fig.15)**. Each process uses the ability of the membranes to differentiate and selectively separate salts and water. [3]

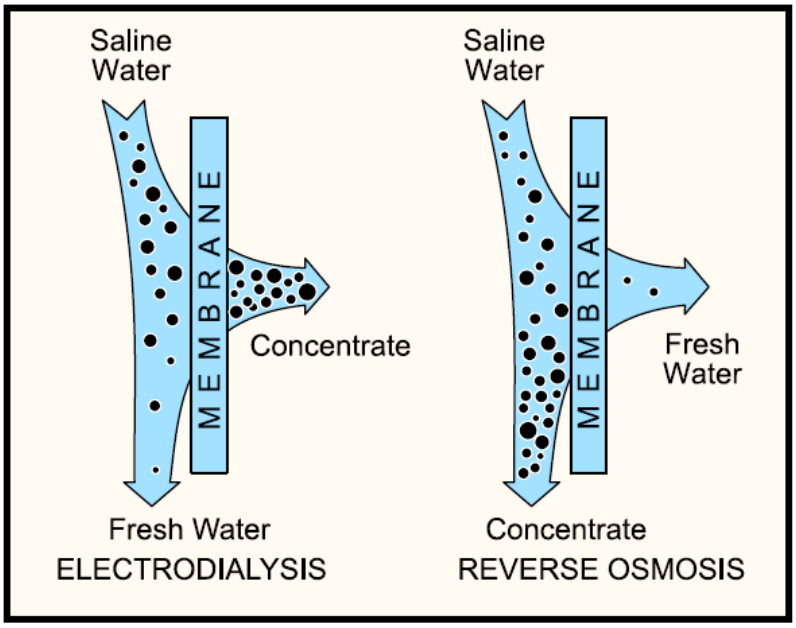


Fig. 13: Principle of **Electro Dialysis (ED)** and **Reverse Osmosis (RO) processes**

4.3.1. Electro Dialysis (ED)

ED is a voltage driven process and uses an electrical potential to move salts selectively through a membrane, leaving fresh water behind as product water. Fig. 14 shows the principle flow. Electro Dialysis ED was commercially introduced in the early 1960s, about 10 years before RO. The development of ED provided a cost-effective way to desalt brackish water and spurred considerable interest in the whole field of using desalting technologies for producing potable water for municipal use. ED depends on the following general principles: [3]

- Most salts dissolved in water are ionic, being positively (cationic) or negatively (an-ionic) charged.
- These ions migrate toward the electrodes with an opposite electric charge.
- Membranes can be constructed to permit selective passage of either anions or cat-ions.

- The dissolved ionic constituents in a saline solution, such as chloride (-) sodium (+), calcium (++), and carbonate (–), are dispersed in water, effectively neutralizing their individual charges.

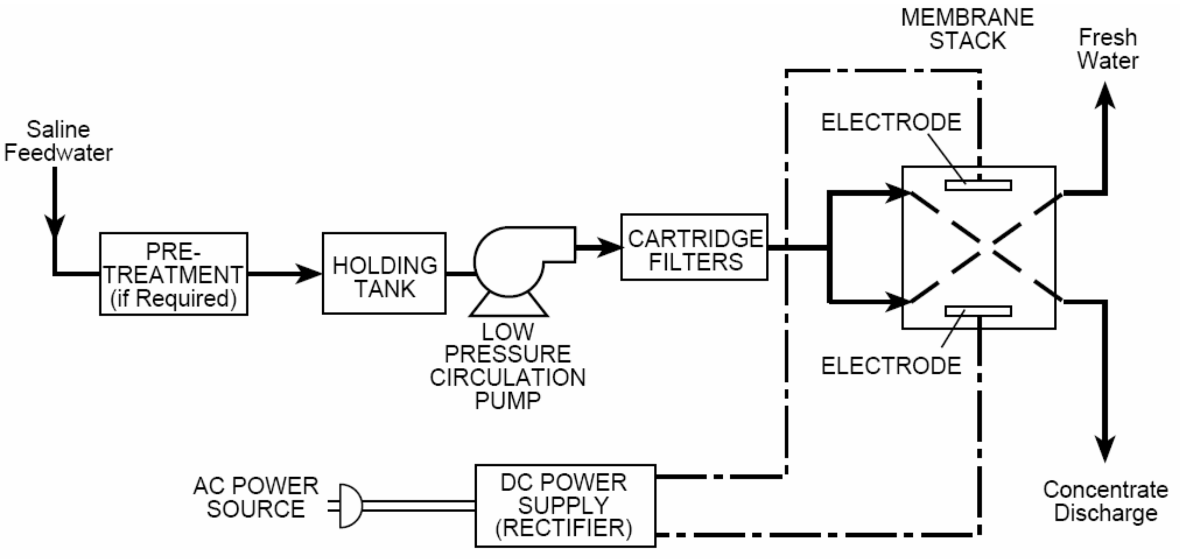


Fig. 14: Principle Flow Diagram in an **Electro Dialysis (ED) process**

When electrodes are connected to an outside source of direct current like a battery and placed in a container of saline water, electrical current is carried through the solution, with the ions tending to migrate to the electrode with the opposite charge. To use these phenomena to desalinate water, individual membranes that will allow either cat ions or anions (but not both) to pass are placed between a pair of electrodes. These membranes are arranged alternately, with an anion-selective membrane followed by a cat ion-selective membrane. [3]

A spacer sheet that permits water to flow along the face of the membrane is placed between each pair of membranes. One spacer provides a channel that carries feed (and product) water, while the next carries brine. As the electrodes are charged and saline feed water flows along the product water spacer at right angles to the electrodes, the anions (such as sodium and calcium) in the water are attracted and diverted through the membrane towards the positive electrode. This dilutes the salt content of the water in the product water channel. [3]

The an-ions pass through the an-ion-selective membrane, but cannot pass any farther than the cat ion-selective membrane, which blocks their path and traps the an-ions in the brine stream. Similarly, cat ions (such as chloride or carbonate) under the influence of the negative electrode move in the opposite direction through the cat ion-selective membrane to the concentrate channel on the other side. Here, the cat ions are trapped because the next membrane is anion-selective and prevents further movement towards the electrode. [3]

By this arrangement, concentrated and diluted solutions are created in the spaces between the alternating membranes. These spaces, bounded by two membranes (one anionic and the other cationic) are called cells. The cell pair consists of two cells, one from which the ions migrated (the dilute cell for the product water) and the other in which the ions concentrate (the concentrate cell for the brine stream). [3]

The basic ED unit consists of several hundred-cell pairs bound together with electrodes on the outside and is referred to as a membrane stack. Feed water passes simultaneously in parallel paths through all the cells to provide a continuous flow of desalted water and concentrate (or brine) from the stack. Depending on the design of the system, chemicals may be added to the streams in the stack to reduce the potential for scaling. An ED unit is made up of the following basic components: [3]

- Pretreatment train
- Membrane stack
- Low-pressure circulating pump
- Power supply for direct current (a rectifier)
- Post-treatment

The raw feed water must be pretreated to prevent materials that could harm the membranes or clog the narrow channels in the cells from entering the membrane stack. The feed water is circulated through the stack with a low pressure pump with enough power to overcome the resistance of the water as it passes through the narrow passages. A rectifier is used to transform alternating current to the direct current supplied to the electrodes on the outside of the membrane stacks. Post-treatment consists of stabilizing the water and preparing it for distribution. This post-treatment might consist of removing gases such as hydrogen sulfide and adjusting the pH. [3]

In the early 1970s, an American company commercially introduced the electro dialysis reversal (EDR) process. An EDR unit operates on the same general principle as a standard Electro Dialysis plant except that both the product and the brine channels are identical in construction. At intervals of several times an hour, the polarity of the electrodes is reversed, and the flows are simultaneously switched so that the brine channel becomes the product water channel, and the product water channel becomes the brine channel. [3]

The result is that the ions are attracted in the opposite direction across the membrane stack. Immediately following the reversal of polarity and flow, the product water is dumped until the stack and lines are flushed out and the desired water quality is restored. This flush takes only 1 or 2 minutes, and then the unit can resume producing water. The reversal process is useful in breaking up and flushing out scales, slimes, and other deposits in the cells before they can build up and create a problem. Flushing allows the unit to operate with fewer pretreatment chemicals and minimizes membrane fouling. [3]

ED has the following characteristics that make it suitable for a number of applications:

- Capability for high recovery (more product and less brine)
- Energy usage that is proportional to the salts removed
- Ability to treat feed water with a higher level of suspended solids than RO
- Unaffected by non-ionic substances such as silica
- Low chemical usage for pretreatment

ED units are normally used to desalinate brackish water.

4.3.2. Reverse Osmosis (RO)

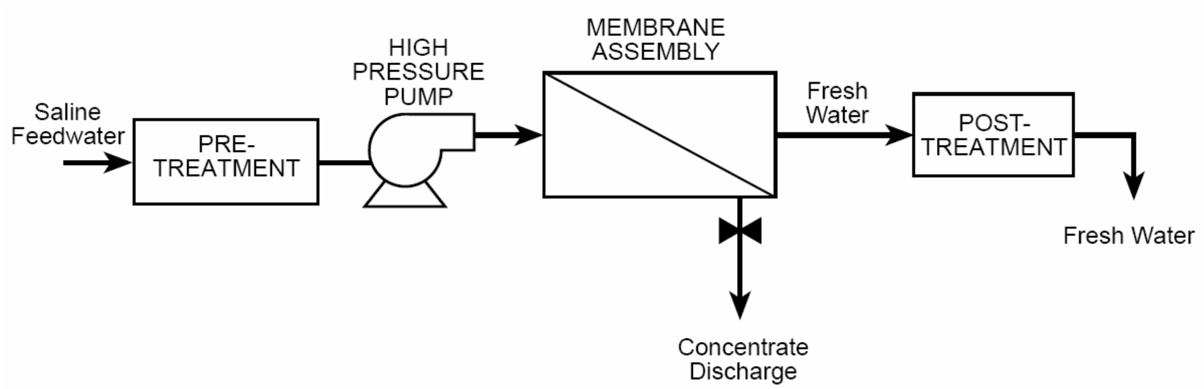


Fig. 15: Principle Flow Diagram in a **Reverse Osmosis (RO) process**

Reverse Osmosis (RO), in comparison to distillation and Electro Dialysis, is relatively new, with successful commercialization occurring in the early 1970s. It is a pressure-driven process, with the pressure used for separation by allowing fresh water to move through a membrane, leaving the salts behind (Fig. 15). Scientists have explored these concepts since the turn of the century, but their commercialization for desalting water for municipal purposes has occurred in only the last 30 to 40 years. [3]

RO is a membrane separation process in which the water from a pressurized saline solution is separated from the solutes (the dissolved material) by flowing through a membrane. No heating or phase change is necessary for this separation. The major energy required for desalting is for pressurizing the feed water. [3]

In practice, the saline feed water is pumped into a closed vessel where it is pressurized against the membrane. As a portion of the water passes through the membrane, the remaining feed water increases in salt content. At the same time, a portion of this feed water is discharged without passing through the membrane. [3]

Without this controlled discharge, the pressurized feed water would continue to increase in salt concentration, creating problems such as precipitation of super-saturated salts and increased osmotic pressure across the membranes. The amount of the feed water discharged to waste in the brine stream varies from 20 to 70 percent of the feed flow, depending on the salt content of the feed water, pressure, and type of membrane. An RO system is made up of the following basic components: [3]

- Pretreatment
- High-pressure pump
- Membrane assembly
- Post-treatment

Pretreatment is important in RO because the membrane surfaces must remain clean. Therefore, suspended solids must be removed and the water pretreated so that salt precipitation or microbial growth does not occur on the membranes. Usually, the pretreatment consists of fine filtration and the addition of acid or other chemicals to inhibit precipitation and the growth of microorganisms. [3]

The high-pressure pump supplies the pressure needed to enable the water to pass through the membrane and have the salts rejected. This pressure ranges from 15 to 25 bar for brackish water and from 54 to 80 bar for sea water. The membrane assembly consists of a pressure vessel and a membrane that permits the feed water to be pressurized against the membrane. The membrane must be able to withstand the entire pressure drop across it. After passing the membrane a post-treatment follows. Post-treatment consists of stabilizing and mineralization of the water and preparing it for distribution. This post-treatment might consist of the removing gases such as hydrogen sulfide and adjusting the pH. [3]

Two developments have helped to reduce the operating cost of RO plants during the past decade: the development of more efficient membranes and the use of energy recovery devices. The membranes now have higher water flux (passage per unit area), improved rejection of salts, lower prices, and longer service lives. It is common now to use energy recovery devices connected to the concentrate stream as it leaves the pressure vessel at about 1 to 4 bar less than the applied pressure from the high-pressure pump. These energy recovery devices are mechanical and generally consist of work or pressure exchangers, turbines, or pumps of some type that can convert the pressure difference to rotating or other types of energy that can be used to reduce the energy needs in the overall process. These can have a significant impact on the economics of operating large plants. They increase in value as the cost of energy increases. [3]

For new development of Energy Recovering (ERI) devices reducing the cost per m^3 freshwater, see chap. 3.5.3

The world's largest Reverse Osmosis plant is running in Yuma, USA. It is used to reduce the salinity of the Colorado River, 270.000 m3/d!

4.3.3. Nanofiltration Membranes (NF)

The other important event in the RO membrane area has been the use of membranes called nanofiltration (NF). These membranes are more porous to the passage of dissolved solids. This process is used to soften water by removing mostly divalent ions (e.g., Ca+2and Mg+2). The rejection by NF membranes of monovalent ions like Cl- is much lower than with RO membranes. They are used even where the feed water is essentially fresh, although it still contains dissolved solids that cause hardness. Whether the use of NF membranes to perform membrane softening (MS) is considered a desalting process is a matter of how one defines desalting. [3]

However, the development and use of NF membranes are a direct outgrowth from the RO industry. The MS process and NF membranes have revolutionized the water softening industry, and they are moving it from a chemical- based to a largely membrane-based process. Recently NF membranes found an application to effectively soften seawater. The NF softened seawater as a feed to distillation and RO processes offers the potential of significant improvement in seawater desalination costs. This, in turn, has furthered interest in all types of membranes for municipal potable water treatment. [3]

The past ten years have been significant ones for the RO process. Although the process has not fundamentally changed in concept, there have been steady and continuous improvements in the efficiency of the membranes, energy recovery, energy reduction, membrane life, control of operations and operational experience. The result has been an overall reduction in the cost of water produced by the RO process, especially in the desalting of seawater. [3]

4.4. Other Processes

A number of other processes have been used to desalt saline waters. These processes have not achieved the level of commercial success that distillation, ED, and RO have, but they may prove valuable under special circumstances or with further development. [3]

4.4.1. Freezing Desalination

Extensive work was done in the 1950s and 1960s to develop freezing desalination. During the process of freezing, dissolved salts are naturally excluded during the initial formation of ice crystals. Cooling saline water to form ice crystals under controlled conditions can desalinate seawater. Before the entire mass of water has been frozen, the mixture is usually washed and rinsed to remove the salts in the remaining water or adhering to the ice crystals. The ice is then melted to produce fresh water. [3]

Theoretically, freezing has some advantages over distillation, which was the predominant desalting process at the time the freezing process was developed. These advantages include a lower theoretical energy requirement for single stage operation, a reduced potential for corrosion, and few scaling or precipitation problems. The disadvantage is that it involves handling ice and water mixtures that are mechanically complex to move and process. [3]

There are several different processes that use freezing to desalt seawater, and a few plants have been built over the past 50 years. However, the process has not been a commercial success in the production of fresh water for municipal purposes. At this stage, freeze-desalting technology probably has better application in the treatment of industrial wastes than in the production of municipal drinking water. [3]

4.4.2. Membrane Distillation

Membrane distillation was introduced commercially on a small scale during the 1980s, but it has had demonstrated no commercial success. As the name implies, the process combines both the use of distillation and membranes. In the process, saline water is warmed to enhance vapor production, and this vapor is exposed to a membrane that can pass water vapor but not liquid water. After the vapor passes through the membrane, it is condensed on a cooler surface to produce fresh water. In the liquid form, the fresh water cannot pass back through the membrane, so it is trapped and collected as the output of the plant. [3]

The main advantages of membrane distillation lie in its simplicity and the need for only small temperature differentials to operate. This has resulted in the use of membrane distillation in experimental solar desalting units. [3]

However, the temperature differential and the recovery rate, similar to the MSF and MED processes, determine the overall thermal efficiency for the membrane distillation process. Thus, when it is run with low temperature differentials, large amounts of water must be used, which affects its overall energy efficiency. [3]

4.4.3. Solar Humidification

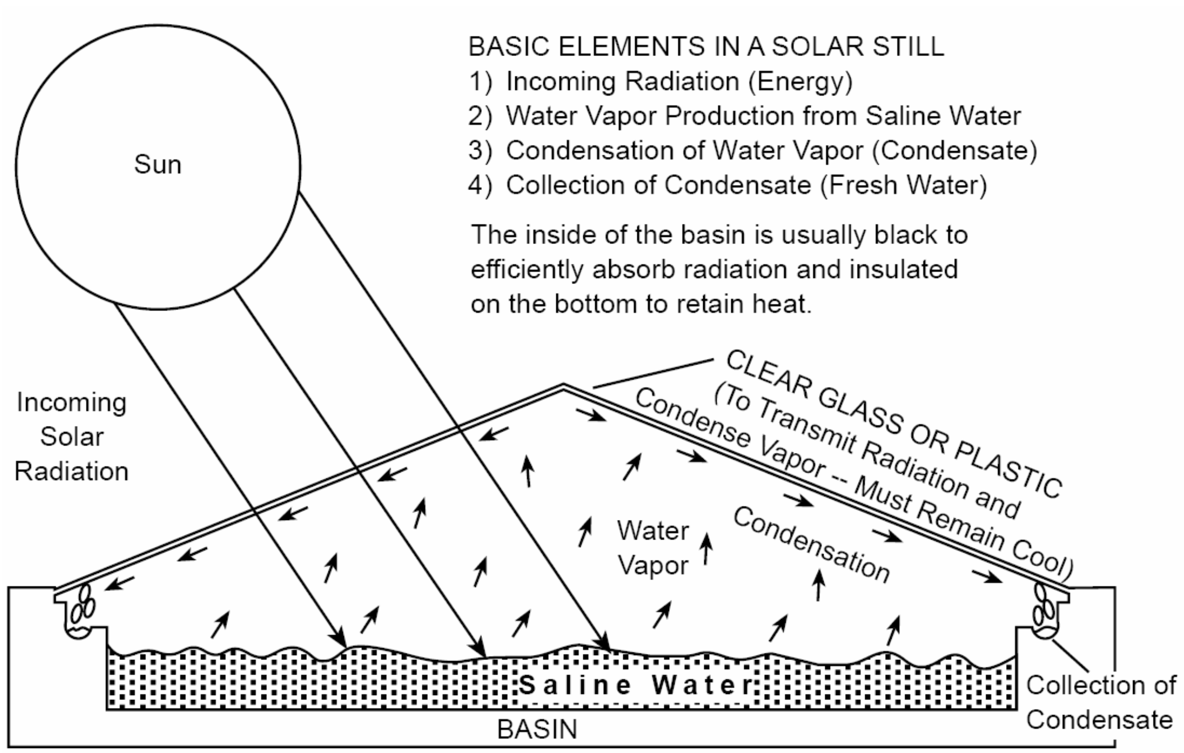


Fig. 16: Principle of Solar Humidification processes

The use of direct solar energy for desalting saline water has been investigated and used for some time (Fig. 16). During World War II, considerable work went into designing small solar stills for use on life rafts. This work continued after the war, with a variety of devices being made and tested. [3]

These devices generally imitate a part of the natural hydrologic cycle in that the sun's rays heat the saline water so that the production of water vapor (humidification) increases. The water vapor is then condensed on a cool surface, and the condensate collected as fresh water product. An example of this type of process is the greenhouse solar still, in which the saline water is heated in a basin on the floor, and the water vapor condenses on the sloping glass roof that covers the basin. [3]

Variations of this type of solar still have been made in an effort to increase efficiency, but they all share the following difficulties, which restrict the use of this technique for large-scale production:

- Large solar collection area requirements

- High capital cost
- Vulnerability to weather-related damage

A general rule of thumb for solar stills is that a solar collection area of about one square meter is needed to produce 4 liters of water per day. Thus, for a 4,000-m3/d facility, a minimum land area of 100 hectares (250 acres) would be needed. This operation would take up a tremendous area and could thus create difficulties if located near a city where land is scarce and expensive. [3]

The stills themselves are expensive to construct, and although the thermal energy may be free, additional energy is needed to pump the water to and from the facility. In addition, reasonable attention to operation and routine maintenance is needed to keep the structure repaired, prevent scale formation caused by the basins drying out, and repair glass or vapor leaks in the stills. An application for these types of solar humidification units has been for desalting saline water on a small scale for families or small villages where solar energy and low-cost or donated labor is abundant, but electricity is not. A properly constructed still can be quite robust, and solar stills have been reported to operate successfully for 20 years or more. [3]

The key is to have users who have a real involvement in its success and have been adequately trained in its construction, operation, and repair. Installing a solar still as a gift for others and then leaving it to its fate will probably result in failure of the operation. Efforts have been made by various researchers to increase the efficiency of solar stills by changing the design, using additional effects, adding wicking material, etc. In many cases, these modifications have increased production per unit area, but some of these have also increased the complications in operating and maintaining the devices for applications like remote villages. As with any village water supply, technology is only one part of the solution. The successful system will also take into account culture, tradition, and local conditions. One economic threat to these stills can surface when the local economy has developed to the point where the land area being used for the still becomes too valuable to remain as a water producing area or the value of labor increases. The locals may then consider that it is more economical to replace it with a small RO or VC unit that uses only a fraction of the space and their time. [3]

Dr. Alan Williams, UK ,is working on a large scale solar desalination using Multi Effect Humidification. Following is a summary of Dr. Alan Williams work:

Summary [24]:

"A theoretical proposal is outlined for large scale solar desalination using multi effect humidification. It involves the use of a large area solar collector, multi effect distillation and boiling at reduced pressure. The configuration devised is a circular tank of one kilometer diameter

containing water to a depth of 10 meter with a sealed double glazed dome, operating at 0.1 atmosphere pressure with a working temperature below 50° C. A solar absorber placed just above the water level, abundantly perforated but covering the entire area, sets up convection currents that evaporate the sea water and condense the vapor. Incoming seawater recovers energy from outgoing clean water and brine in a counter current heat exchanger. Water flow is driven by solar distillation and hydrostatic pressure. It is estimated that the structure would have 95% energy efficiency and a gained output ratio of 20. In sunbelt countries with average isolation of 6kwh/m^2/day the desalination plant would produce 100,000 m^3/d distilled water at a speculative cost of \$0.28/m^3. "

Dr Alan Williams, November 2004, http://www.globalwarmingsolutions.co.uk

4.4.4. Solar and Wind-Driven Desalters

Desalting units that use solar collectors or wind energy devices to provide heat or electrical energy also have been built to operate standard desalting processes like RO, ED, or distillation. The economics of operating these plants tend to be related to the cost of producing energy with these alternative energy devices. Costs tends to be high, but are expected to improve as development of these energy devices continues. [3]

Currently, using conventional energy to drive desalting devices is generally more cost-effective than using solar and wind-driven devices, although appropriate applications for solar and wind-driven Desalters do exist. The International Desalination Association (IDA) counted in 1998 about 100 known wind- and solar powered desalting plants scattered over 25 countries. Most of these installations had capacities of less than 20 m^3/d. [3]

4.4.4.1.Promising Pilot projects "CREST" and "IIT Chennai"

CREST is the centre for renewable energy at the **Loughborough University in the UK.** The University runs a battery less Photovoltaic RO Desalination System which was built in 2001. In the summary the executives of CREST came to the conclusion that the battery less photovoltaic-powered seawater desalination system will be commercially viable. They recommend that a pilot scheme based on their design should be implemented. [5]. However, the author does not know if this concept was followed up on a larger scale.

IIT Chennai has also started a pilot project with combined PV and RO desalination. The author will follow up the test phases.

4.4.5. New developments in Low Temperature Thermal Desalination plants using "Deep Water Technology"

Fig. 17: Low Temperature Thermal Desalination Plant at Kavaratti/ Chennai

The temperature difference which exists between the surface layer (28~30 C) and deep sea layer (7~15C) of the ocean could be effectively utilized to produce potable water apart from power generation, air conditioning and aquaculture. This technology is known as Low Temperature Thermal Desalination. In Low Temperature Thermal Desalination relatively warm water is flashed inside a vacuum flash chamber and the resultant vapor is condensed in a condenser using cold water. This technology has been utilized in the first ever low temperature thermal desalination plant which has been commissioned in April 2006 at Kavaratti/ Chennai. [18]

The plant is housed in a structure on the shore. The bathymetry at the island is such that 400m water depth is available around 400m from the shore. Due to this special feature a long pipe about 600m long to draw cold water has been deployed with one end at about 350m water depth. [18]

4.4.5.1. Advantages of this kind of technology:

+ No pre treatment of feed water is required
+ Consistent quality of water as per BIS/ WHO standards can be assured
+ Simple maintenance and operational

+ Environmental friendly technology, no chemicals are required
+ Highly nutrient cold water enhances marine life

− At present high investment costs

4.4.5.2.Operation Parameters:

Fresh water generation:	100,000 m^3/d
Warm water Temperature:	28ºC
Cold water Temperature:	10 ºC
Number of units:	2
Warm water flow rate:	569 kg/s and unit
Cold water flow rate:	500 kg/s and unit
Vacuum level:	23 mbar
Saturation Temperature:	20 ºC
Cold water pipe length and Diameter:	DN 1000, 850 m
Total Power requirement:	220 kW

4.5. Important additional aspects of Desalination

4.5.1. Concentrate disposal (brine) and environmental impact, use of chemicals

The common element in all of these desalination processes is the production of a concentrate brine, reject, or waste stream. This brine contains the salts removed from the saline feed to produce the fresh water product, as well as some of the chemicals that have been added during the process. It also contains corrosion by-products. The stream varies in volume, depending on the process, but will almost always be a significant quantity of water. [3]. Fig. 18 and 19 show the main chemicals used in different desalination processes.

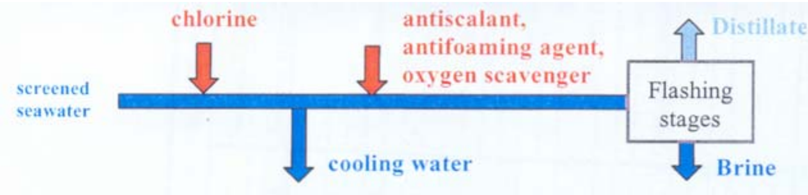


Fig. 18: Adding stages of the needed chemicals in thermal processes

Scaling: Sulfuric acid & anti scalant,
Bacteria and algae: chlorine
Foaming: polyglycol blends, antifoaming agent
Corrosion: de-aeration, oxygen scavengers, corrosion inhibitors

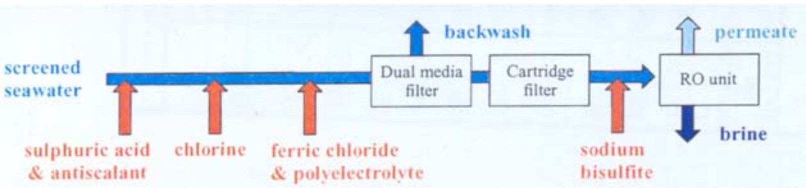


Fig. 19: Adding stages of the needed chemicals in membrane processes

Scaling: Sulfuric acid & antiscalant,
Bacteria and algae: chlorine
Oxidation by chlorine: de-chlorination with sodium bisulphate
Suspended material: coagulation and filtration

The disposal of this wastewater in an environmentally appropriate manner is an important part of the feasibility and operation of a desalting facility. If the desalting plant is located near the sea, the potential for a problem will be considerably less. The major solute in the concentrate brine is salt, and disposing of salt in the sea is generally not a problem. [3] **But** the chemical by products together with water temperature etc. create more and more difficulties for the marine life. Fig. 20 gives an overview of the environmental and marine impacts through chemicals used in Desalination processes. The potential for a more significant problem comes when a desalting facility is constructed inland, away from a natural salt-water body, such as is common for brackish water plants. Care must then be taken so as not to pollute any existing ground or surface water with the salts contained in the concentrate brine. Disposal may involve dilution, injection of the concentrate into a saline aquifer, evaporation, or transport by pipeline to a suitable disposal point. [3]

All of these methods add to the cost of the process. The means of properly disposing of the concentrate flow should be one of the items investigated early in any study of the feasibility of a desalination facility. The cost of disposal could be significant and could adversely affect the economics of desalination. In countries like the USA, with very stringent discharge regulations, the disposal of the concentrate stream has drastically affected the ability to use desalination as a treatment process. [3]

Fig. 20 shows the chemical impact in different Regions in the Middle East. [7]

Chemical loads in the Middle East Area				
Location	**Plant Capacity**	**Chlorine**	**Copper**	**Antiscalants**
	m^3/d	kg/d	kg/d	kg/d
Gulf	7 Million	15000	200	40200
Red Sea	1,6 Million	2700	36	9500
Mediterranean Sea	1,7 Million	1920	26	10250

Fig. 20: Chemical Loads in the Middle East

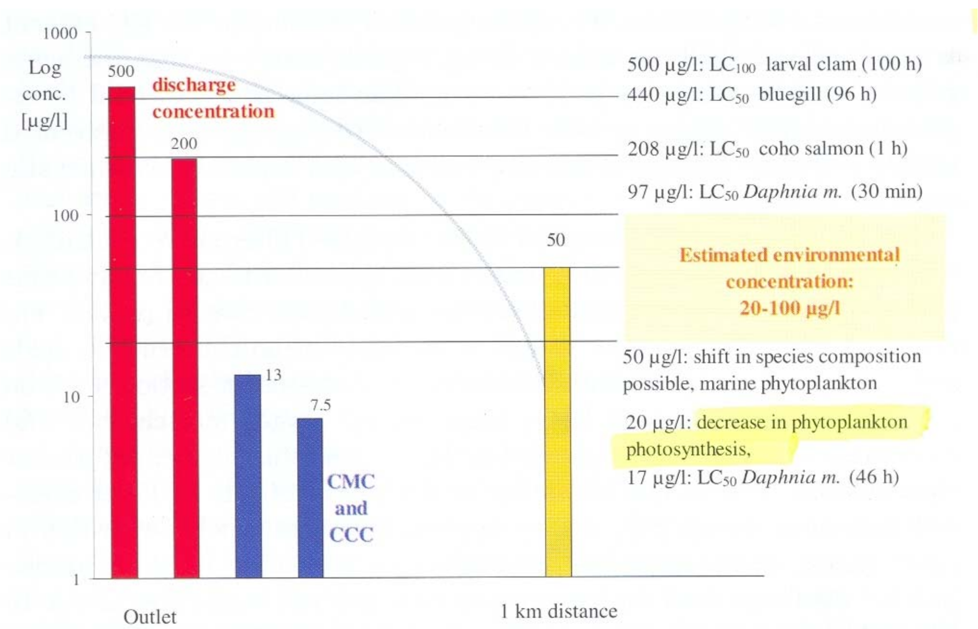


Fig. 21: Impact of chlorine discharge to marine life [16], LC = Log Concentration in µg/l

Chlorine is one of the hazardous chemicals mainly used for disinfection of the raw water. Fig. 21 shows the impact of Chlorine contained in the brine and the discharge into the sea. Even at one km distance, an impact on phytoplankton is possible.

Chemical Impacts on Marine Environment and Life through disposal of Brine

Chemicals	Used for	Impact on Marine Environment
Chlorine and byproducts * Halogenated hydrocarbons * Chloramine	Desinfection	decrease of phytoplankton photosynthesis
Coagulants * Ferric chloride * Ferric chlorate sulfate	backwash, filter cleaning, removal of phosphate	possibile of discoloration, decrease of light penetration, impairing of photosynthesis or increased sedimentaion impact on sessile Organismus, especially corals
Polyelectrolytes * polyacrylamide * polyyacrylate * polyphosphate	Scale control adiditives	increase of turbidity
Antifoaming agents * polyethylene glycol * polypropylene glycol	Antifoaming	slight increase of natural background concentrations of dissolved organic carbon, very low impact because of biodegradability.
Metals and Heavy Metals * copper * nickel	By-product by cleaning MSF in combination with acid	Heavy metal, effects on more sensitive species, reaches over the food chain the humans
Benzotriazole * benzotriazole * benzotriazole derivates	Corrosion inhibitors	The potential for bio concentration in aquatic organisms is low, yet the substances are classified as harmful to aquatic organisms according to the environmental data provided by ICSC which may be due to their longevity and possible chronic effects.
Formaldehyde * Formaldehyd * Glutaraldehyde	Membrane cleaning	prohibited for discharge in the US, toxic to very toxic to aquatic organisms (International chemical safety cards, ICSC 2000.
Isothiazole	Membrane cleaning	very toxic to aquatic organisms (International chemical safety cards, ICSC 2000.
Sodium dodecylbenzone sulfonate	Membrane cleaning, waste product	low toxic
Ethylenenediamine tetraacetic acid * EDTA	RO cleaning solution, removing of inorganic coloids and biofouling	problematic in coastel water body, slow biodegration. EDTA can contain heavy metal.
Sodium perborate * $NaBO_3$	Cleaning agent for oxidizing organic deposits on the membrane	non hazardous, decomposes to sodium borate and H_2O_3, Sodium Borate is harmful to brackish water organisms when exceeding 250 mg/l

Fig. 22: Impact of Brine and Chemical disposal on the Marine Environment and Aquatic life

4.5.2. Co-generation of Energy

In some situations, it is possible to use energy so that more than one use can be obtained from it as the energy moves from a high level to an ambient level. This occurs with co-generation where a single energy source can perform several different functions. Certain types of desalination processes, especially the distillation process, can be structured to take advantage of a co-generation situation. [3]

Most of the distillation plants installed in the Middle East and North Africa have operated under this principle since the 1960s and are known in the field as dual purpose plants (water plus power). These units are built as part of a facility that produces both electric power and fresh water out of seawater. [3]

Wind-turbine systems for example produce electricity that is in turn used to drive the mechanical VC unit (see chap. 3.2.3). [3]

Fossil (coal) power stations produce heat and high pressure steam out of which the turbines turn into electricity. In a typical case, boilers produce high-pressure steam at about 540ºC. As this steam expands in the turbine, its temperature and energy level is reduced. Distillation plants need steam whose temperature is about 120ºC or below, and this can be obtained by extracting the lower temperature steam at the low pressure end of the turbine after much of its energy has been used to generate electricity. This steam is then run through the distillation plant's brine heater, thereby increasing the temperature of the incoming seawater. The condensate from the steam is then returned to the boiler to be reheated for use in the turbine. [3]

The main advantage of a co-generation system is that it can significantly reduce the consumption of fuel when compared to the fuel needed for two separate plants. Since energy is a major operating cost in any desalination process, this can be an important economic benefit. [3]

One of the disadvantages is that the units are permanently connected together and, for the desalination plant to operate efficiently, the steam turbine must be operating. This permanent coupling can create a problem with water production when the demand for electricity is reduced or when the turbine or generator is down for repairs. This type of power and water production installation is commonly referred to as a dual-purpose plant. [3]

Since many of the oil producing countries of the Middle East and North Africa were engaged in building up their total infrastructure, these types of installations fit in well with the overall development program in these countries. The dual purpose plant has had a pronounced positive impact on reducing the cost of power and water. Other types of co-generation facilities benefiting desalination can derive lower-cost steam from heat recovery systems on gas turbine exhausts, heat pumps, or various industrial processes including burning solid wastes in an incinerator. [3]

Chap. 5 will follow up on options for alternative power supply for a desalination plant.

4.5.3. Energy recovering systems, new developments

At the Seawater Desalination test facility of the US Navy in Port Hueneme, California, a union of specialists in Energy recovering systems (ERI) and RO manufactures have demonstrated that water can be produced at 1.7 kWh/m^3. This is a major breakthrough. The energy recovering device is a pressure exchange device developed by ERI (Energy Recovering, Inc.). The efficiency of the energy recovering is 96 %! Fig. 23 shows the flow diagram from the test plant with a capacity of 10.000 m^3/d. The Device is marked in yellow. [8]

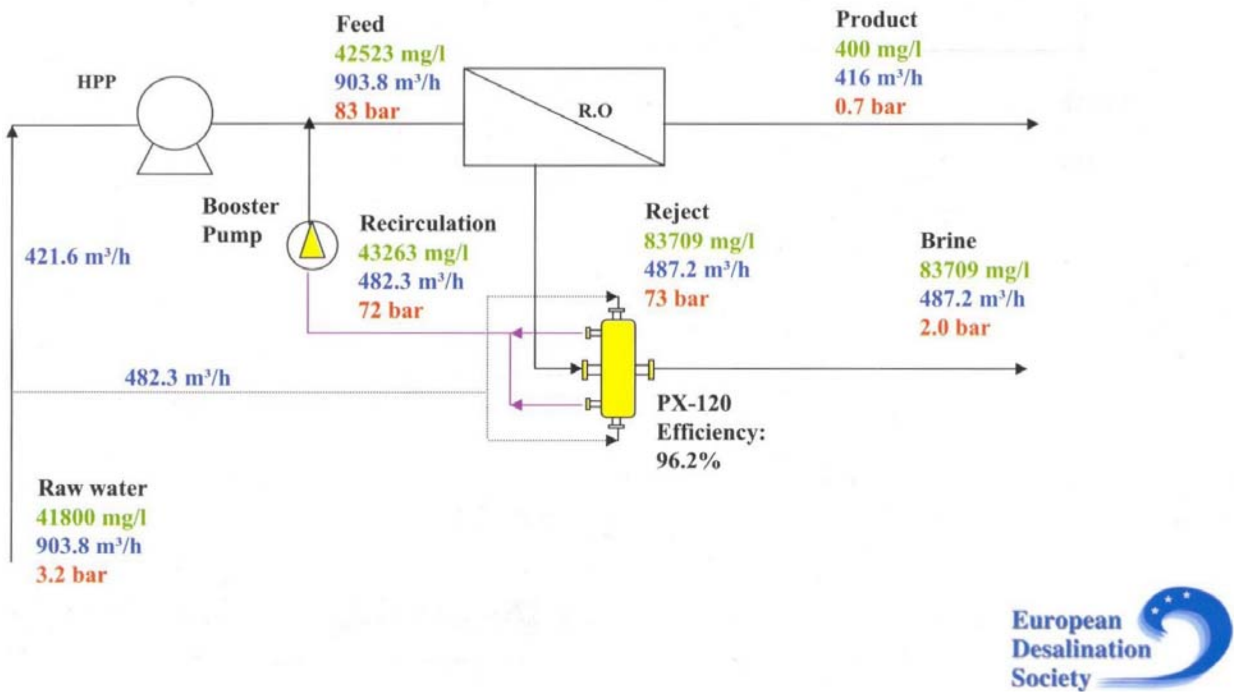


Fig. 23: Principle of ERI PX 120 device in a RO system, Flow Process [8]

Under normal conditions and for further calculations in this study, the assumption for the energy consumption of RO systems was 2.3 to 2.5 kWh/m^3 for SEA-WATER application.

4.5.4. Hybrid Facilities

Another method of reducing the overall costs of desalting can be the use of hybrid systems. Such hybrid systems are not applicable to most desalination installations, but can prove to be an economic benefit in some cases. A hybrid system is a treatment configuration made up of two or more desalination processes. [3]

An example is using both distillation and RO processes to desalt seawater at one facility and to combine the different characteristics of each process productively. Hybrid systems provide a better match between power and water development needs. An example of a hybrid system could be the use of steam in a dual-purpose plant (electricity and water). The steam is used in a distillation plant to desalt seawater. [3]

The product water from the distillation unit has a low level of total dissolved solids, perhaps 20 mg/l. Alongside the distillation plant could be a seawater RO plant that would be run only in off-peak power periods. This would help to stabilize the load on the generator and therefore use lower cost electricity. The RO plant could be designed to produce water with a higher level of total dissolved solids and, thus, also lower its production costs. [3]

Thermal and membrane processes can be linked in more complex manners to increase both efficiency and improve operations. The water from the two processes could then be combined to produce water that has a reasonable level of total dissolved solids, while reducing the overall unit cost of water. [3]

4.5.5. Operation and cost comparison of different desalination techniques

Desalination technique	MSF	MED	ME-TVC	MVC	RO- Brackish	RO- Seawater
Operation Temperature	< 120° C	< 65° C	< 65° C	< 65° C	< 45° C	< 45° C
Form of energy	Steam >2 bar	Steam >0.3 bar	Steam >3.5 bar	Electrical	Electrical	Electrical
Energy / m³ (Average)	3.5 kWh/m³	1.5 kWh/m³ *	1.0 kWh/m³ *	9.0 kWh/m³	3,0 - 3,5 kWh/m³ standard ERD**	3,5 - 4,0 kWh/m³ standard ERD**
Product water quality (TDS)	< 10 ppm	< 10 ppm	< 10 ppm	< 10 ppm	< 500 ppm (single stage)	< 500 ppm (single stage)
Single unit sizes/ Production in m³/d	5.000-50.000	500-20.000	500-20.000	50-3.000	10-10.000	10-10.000
Price for 1 m³ fresh water (Average)	~ no data Rs/m³	~ 55 Rs/m³	~ no data Rs/m³	~ no data Rs/m³	~ 40 Rs/m³	~ 50 Rs/m³
* without Steam Production			**1.7 kWh/m³ using ERI PX 120 Energy re-covering devices			

Fig. 24: Overview of Desalination techniques and operation costs based on the Indian market

Many factors enter into the capital and operating costs for desalination: capacity and type of plants, plant location, feed water, labor, energy, financing, concentrate disposal, and plant reliability. In general, the cost of desalted seawater is about 3 to 5 times the cost of desalting brackish water from the same size plant. [3]

Fig. 24 gives some idea of the range of costs involved based on the Indian market. In other countries the site- and country-specific factors will affect the actual costs. In any country or region, the economics of using desalination is not just the number of Dollars, Pesos, or Dinars per cubic meter, but the cost of desalted water versus the other alternatives. In many water-short areas, the cost of alternative sources of water is already very high and often above the cost of desalting. Any economic evaluation of the total cost of water delivered to a customer must include all the costs involved. This includes the costs for environmental protection (such as brine or concentrate disposal), distribution and losses in the storage and distribution system. [3]

4.5.6. BOO or BOOT

At the end of the 1990s a number of significant contracts were awarded to developers to fund, design, Build, Operate and either Own (BOO) or eventually Transfer (BOOT) large seawater desalting facilities. [3]

To give an example:

- A MSF facility in Abu Dhabi delivers water, at about $0.70 to $0.75/m3
- A 40,000 m3/d seawater RO facility in Cyprus delivers water at about $0.80 to $0.85/m3
- a 100,000 m3/d seawater RO facility near Tampa, USA produce water for $0.45 to $0.55/m3

All these BOO/BOOT prices that are based on paying for delivered water are influenced by many cost factors which make direct comparisons to each other difficult. These costs include factors such as fuel and electricity cost, as well as financial mechanisms, taxes, labor costs, period of the contract, existing facilities, penalty clauses, location, and contract terms. [3]

Although these costs cannot be directly compared, they do show that there are possible cost advantages that are possible for water utility when developers are permitted to do their own financing, design, and construction and are paid to essentially deliver water to a customer. It is anticipated that many more design, build, own and operate or variations of the same can be expected for major desalting facilities in the future. [3]

4.6. Summary

Desalination technology has been extensively developed over the past 50 years to the point where it is routinely considered and reliably used to produce fresh water from saline sources. This has effectively made the use of saline waters for water resource development possible. The cost for desalination can be significant variable because of its intensive use of energy. However, in many areas of the world, the cost to desalinate saline water is less than other alternatives that may exist or may be considered for the future. IDA conferences attract professionals from all over the world to exchange ideas on improving desalting technology. [3]

Desalinated water is used as a main source of municipal supply in many areas of the Caribbean, Mediterranean, and Middle East. Desalting is also being used or considered for many coastal urban areas in the USA, Asia, and other areas and where it is proving more economical than available conventional sources. [3]

There is no “best” method of desalination. Generally, distillation and RO are used for seawater desalting, while RO and Electro Dialysis are used to desalt brackish water. However, the selection of a process should depend on a careful study of site conditions and the application at hand. Local circumstances will always play a significant role in determining the most appropriate process for an area. The “best” desalination system should be more than economically reasonable in the study stage. It should work when it is installed and continue to work and deliver suitable amounts of fresh water at the expected quantity, quality, and cost for the life of a project. [3]

5. Alternative Energy source: "Solar Concentration"

"Mindful also of its responsibility toward future generations, the state shall protect the natural bases of life ..." German Basic Law, Article 20 A.

It is not only the Article 20A of the German Basic Law, but also the founder of Auroville, THE MOTHER, who wanted for the future energy supply of the city of Auroville (Chap. 16) an alternative electricity and power supply, too.

5.1. Introduction

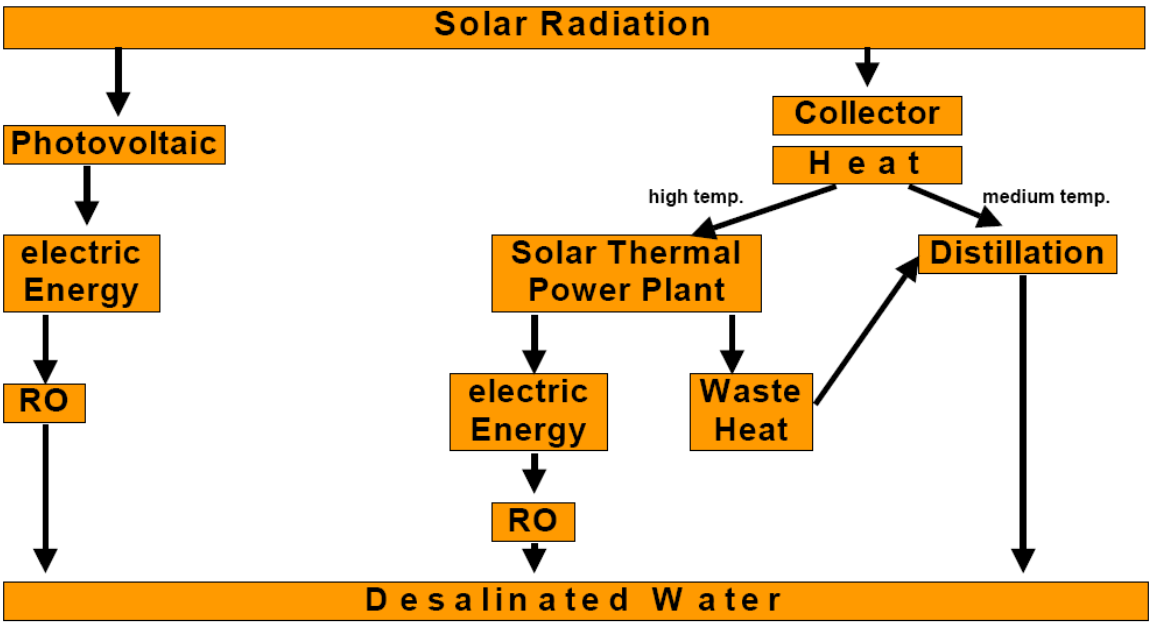


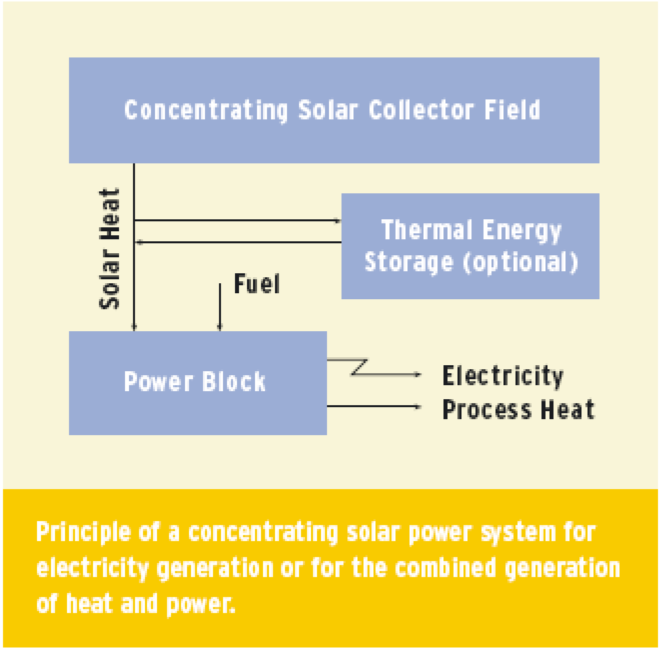
Fig. 25: Use of Solar Radiation for desalination [11]

Figure 25 explains the possible use of the Solar Radiation for desalination processes. In the following discussion the author explains the solar thermal technique which would be an option to solve the energy problem in Auroville and its Bioregion. The "waste steam" from such a plant can be used e.g. in MED or MED-VC processes. The alternative, wind, is explained in chap. 6.

Solar thermal power stations use mirrors to concentrate sunlight. Electricity is generated from the resulting heat. For the operation of these plants to be economically viable, they are best located in the Earth's hot, dry zones south of the 40th latitude (the so-called sun-belt). In theory, the desert regions of North Africa alone could cover the energy needs of the planet. [10]

Solar Concentration techniques are also not new in Auroville. In chap. 4.4, the Author describes the System build in 1996 on top of the "Solar kitchen".

5.2. Principles of a Thermal Solar Power Plant



Principle of a concentrating solar power system for electricity generation or for the combined generation of heat and power.

Fig. 26: Principle of a concentrating solar power plant

There are different technologies of Concentrating Solar Power (CSP), but all systems must concentrate the solar radiation for the production of heat, Fig. 26. The solar heat is then used to operate a conventional power cycle, such as a steam or gas turbine, or a Stirling engine. Solar heat collected during daytime can be stored in concrete, molten salt, ceramics or phase-change media. At night, it can be extracted from the storage to run the power block. Combined generation of heat and power by CSP is particularly interesting, as the high value solar input energy is used with the best possible efficiency, exceeding 85 %. **Process heat from combined generation can be used for industrial applications or sea water desalination**. [10]

CSP is one of the best suited technologies to help, in an affordable way, mitigate climate change as well as to reduce the consumption of fossil fuels. Therefore, CSP has a large potential to contribute to the sustainable generation of power. [10]

5.3. Concentrating Technologies

Parabolic Trough Power Plants as well as Solar Power Towers and Parabolic Dish Engines are the current CSP technologies. Parabolic trough plants (see Fig. 27) with 354 MW of presently installed capacity worldwide have been in commercial operation for many years. Power Towers and Dish Engines have been tested successfully in a series of demonstration projects. [10]

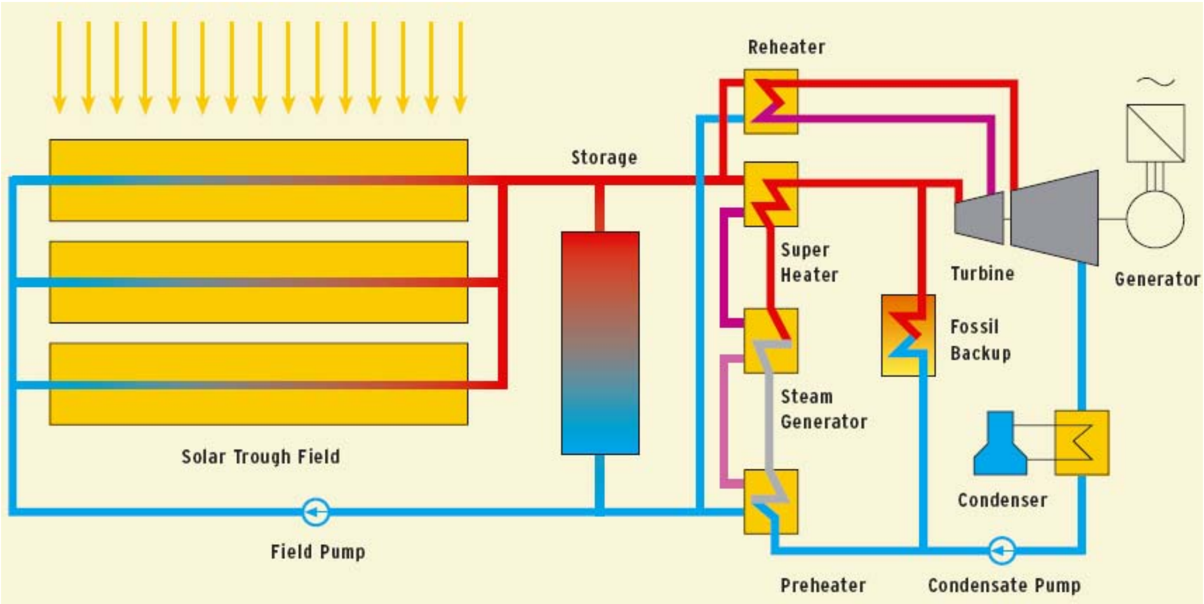


Fig. 27: Principle of a parabolic trough steam cycle plant.

5.3.1. Parabolic Trough Systems

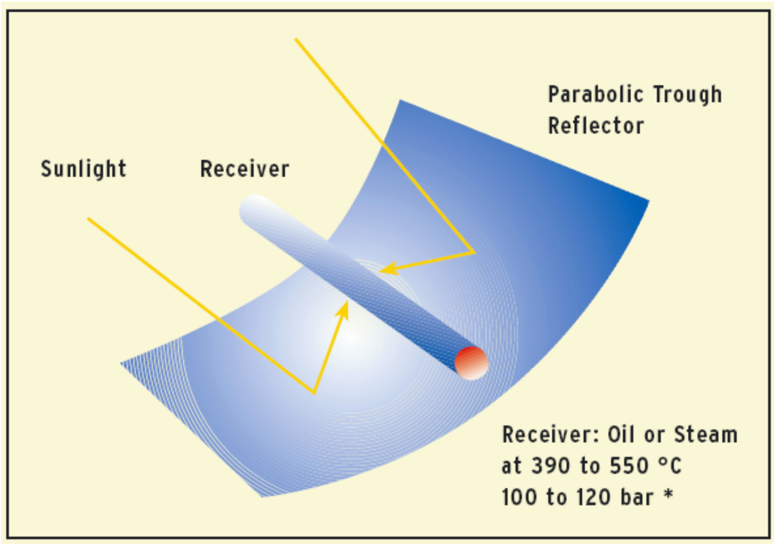


Fig. 28: Parabolic Trough Reflector

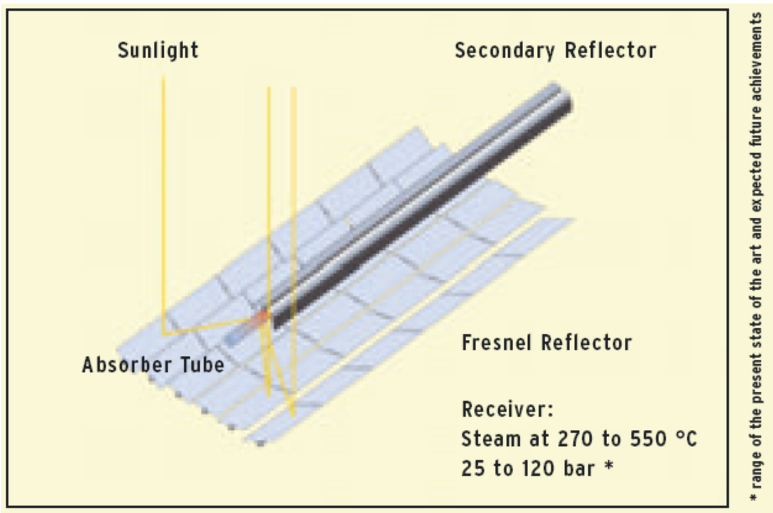


Fig. 29: Fresnel Reflector

Steam cycle power plants with up to 80 MW capacity using parabolic trough collectors have been in commercial operation for more than fifteen years. Nine plants are feeding the Californian electric grid with 800 million kWh/year at a cost (converted) of about 4 to 6 Rs/kWh. The plants have proven a maximum efficiency of 21 % for the conversion of direct solar radiation into grid electricity. [10]

A European consortium has developed the next collector generation, the EUROTROUGH, which aims to achieve better performance and cost by enhancing the trough structure. The new collector is in a test phase since 2003 under real operating conditions in the Californian solar thermal power plants within the PARASOL project funded by the German Federal Ministry for the Environment.

While the plants in California use synthetic oil as heat transfer fluid in the collectors, efforts to achieve direct steam generation within the absorber tubes are under way in the projects DISS and INDITEP sponsored by the European Commission, in order to reduce the costs further. [10]

Another option under investigation is the approximation of the parabolic troughs by segmented mirrors according to the principle of Fresnel (Fig. 29). Although this will reduce the efficiency, it shows a considerable potential for cost reduction. The close arrangement of the mirrors requires less land and provides a partially shaded, useful space below. [10]

5.3.2. Solar Tower Systems

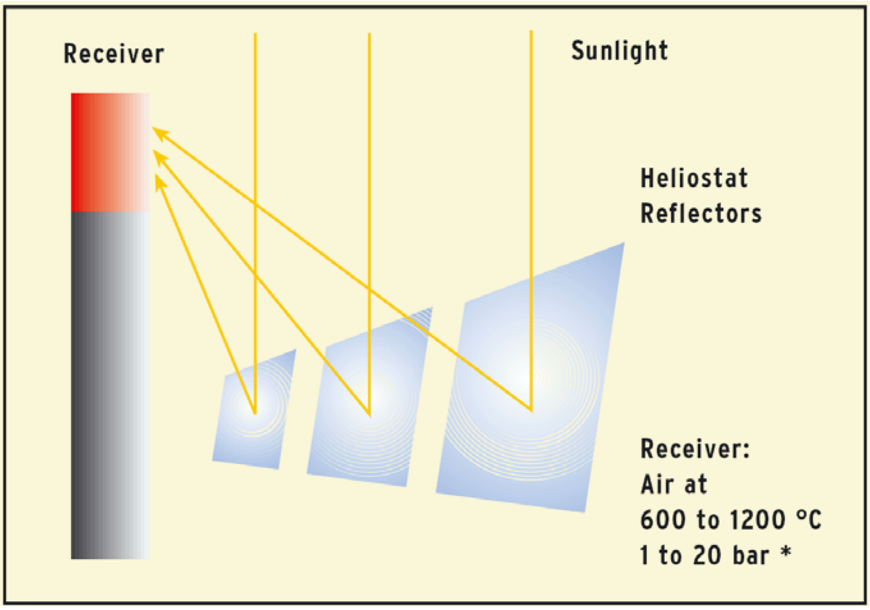


Fig. 30: Principle of a Solar Tower System

Concentrating the sunlight by up to 600 times, solar towers are capable of heating air or other media to 1200 °C and higher. The hot air may be used for steam generation or – making use of the full potential of this high-temperature technology in the future – to drive gas turbines. [10]

The PS10 project in Sanlucar, Spain aims to build a first European steam cycle pilot plant with 10 MW of power. For gas turbine operation, the air to be heated must pass through a pressurized solar receiver with a solar window. Combined cycle power plants using this method will require 30 % less collector area than equivalent steam cycles. At present, a first prototype to demonstrate this concept is built within the European SOLGATE project with three receiver units coupled to a 250 kW gas turbine. [10]

Fig. 31: Solar Tower Power Plant in Spain

5.3.3. Parabolic Dish Engines

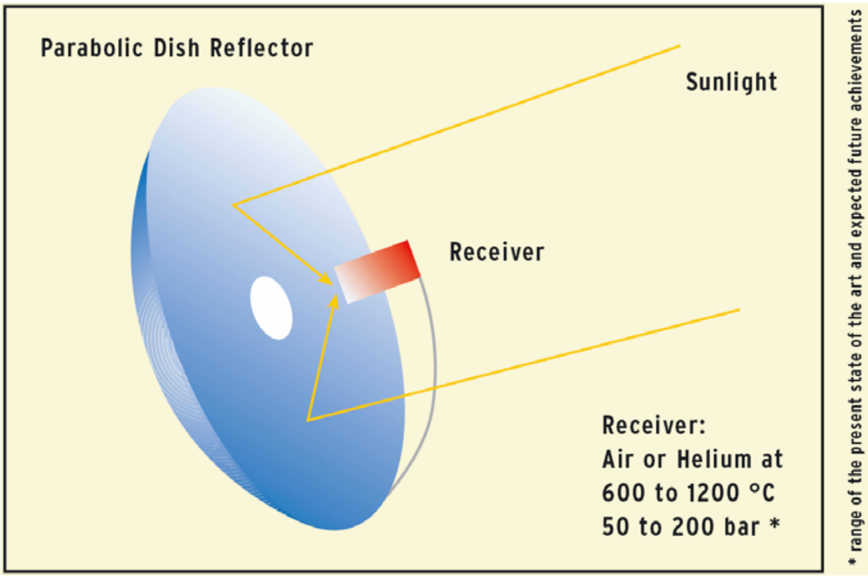


Fig. 32 Principle of a Parabolic Dish Engine

Parabolic dish concentrators are relatively small units that have a motor-generator in the focal point of the reflector. The motor-generator unit may be based on a Stirling engine or a small gas turbine. Their size typically ranges from 5 to 15 m of diameter or 5 to 25 kW of power, respectively. Like all concentrating systems, they can additionally be powered by fossil fuel or biomass, providing firm capacity at any time. Because of their size, **they are particularly well suited for decentralized power supply and remote, stand-alone power systems**.

Within the European project EURODISH, a cost effective 10 kW Dish-Stirling engine for decentralized electric power generation is being developed by a European consortium with partners from industry and research. [10]

Fig. 33: European project EURODISH, 10 kW Dish engine for decentralized power generation

5.4. Solar Concentrator in Auroville, India

Fig. 34: Solar Concentrator at Solar kitchen, Auroville, India

The technique of thermal solar plants is not new for Auroville. A spherical solar concentrator with a diameter of 15 m is installed on top of the Solar kitchen (Fig. 33)

This type of concentrator, with an aperture area of 176 m^2 has a fixed mirror and a sun-tracking receiver coil. Water is pumped through the receiver coil and turned to steam as it is heated by the sun. The system can produce on sunny days between 9 am and 3 pm app. 400 kg of steam at 3 bars pressure. A peak thermal power at noon of 60 kW-thermal has been recorded.

A concentrating system like this built on the Solar kitchen is just one type of concentrating system. It has the advantage over flat plate collectors that it can reach a significantly higher temperature and thus generate steam directly. It has the disadvantage, that it uses only the “direct radiation” of the sunlight, and does not use the diffuse component, which can be a significant percentage on hazy days. Thus the flat plate collector and the photoelectric panel can harvest some solar energy even on cloudy days, whereas the concentrators cannot.

The solar collector at the solar kitchen has no storage system, because it is very difficult to store steam. Storage can be achieved if the system is used to heat thermal fluid in the receiver coil instead of water. Such a thermal fluid, which has reached 250 º C in early tests in the Solar kitchen concentrator, may be stored in an insulated tank and used whenever needed. Higher Temperatures are theoretically possible but have not been experimented with in Auroville.

There are drawbacks to such an approach, such as the very high cost of the oil, the difficulties of keeping the hot-oil plumbing system leak free and the loss of efficiency due to the introduction of a secondary heat loop (assuming one wants to produce only 130° C steam at the end.)

Fig. 35: World’s largest Solar Concentrator at Tirupati, Andhra Pradesh/ India

Fig. 35 shows another solar steam cooking system designed to generate 4000 kg of steam per day, enough to cook meals for 70,000 people! This system has been installed at Tirupati app. 200 km north-west of Chennai in Andhra Pradesh at 500 m above Sea level. It is the world's biggest solar kitchen. The structure, called a SCHEFFLER cooker, produces temperatures of 650 degrees C, which help cook rice and vegetables in massive industrial pots of 200 and 400 liters.

5.5. Important Aspects of Thermal Solar Power Plants

5.5.1. Economic Sustainability and Cost Calculation

The history of the Solar Electricity Generating Systems (SEGS) in California shows impressive cost reductions achieved up to now, with electricity costs (converted) ranging today between 5 and 8 Rs/kWh. However, most of the learning curve is still ahead. Advanced technologies, mass production, economies of scale and improved operation will allow reducing of the solar electricity cost to a competitive level within the next 10 to 15 years. This will reduce the dependency on fossil fuels and thus, the risk of future electricity cost escalation. Hybrid solar-and-fuel plants, at favorable sites, making use of special schemes of finance, can already deliver competitively priced electricity today. [10]

PARAMETERS FOR ELECTRICITY COST CALCULATION:

General calculation parameters:

Hybrid 200 MW parabolic trough steam cycle power plant in medium load, solar share 45 %, annual electricity 1000 GWh/year, investment 425 million Euro, real discount rate 3.5 %, economic life 25 years, fuel cost 12 Euro/MWh, avoided CO_2 310,000 t/year. [10]

Parameters for conventional financing and (in brackets) ideal parameters for preferential start-up financing (PF):

Sample for Europe (Germany):

Debt interest rate 8 %/year (4 %/year), internal rate of return of equity 20 %/year (8 %/year), insurance rate 1 % (0.5 %) of inv./year, property tax 1.5 % (0 %) of inv./year, income tax 38 % (0 %) of income/year, custom duty 5 % (0 %) of direct investment, production overhead 10 % (5 %), grant 0 million Euro (50 million Euro), CO2-credit 0 Euro/t (5 Euro/t), risk management private (private & public). [10]

Calculations for India can vary from the above according to the laws and regulations of India.

5.5.2. Environmental Impact

In many regions of the world, every square kilometer of land can produce as much as 200 to 300 GWh/year of solar electricity using CSP technology (top). This is equivalent to the annual production of a conventional coal or gas fired 50 MW power plants or – over the total life cycle of a CSP system – to the energy contained in 16 million barrels of oil. The exploitation of less than 1 % of the total CSP potential would suffice to meet the recommendations of the Intergovernmental Panel on Climate Change (IPCC) for a long-term stabilization of the climate. At the same time, concentrating solar power will become economically competitive with fossil fuels. [10]

This large solar power potential will only be used to a small extent, if it is restricted by the regional demand and by the local technological and financial resources. But if solar electricity is exported to regions with a higher demand and less solar energy resources, a much greater part of the potential of the Sunbelt countries could be harvested for the protection of the global climate. Some countries like Germany already consider the perspective of solar electricity imports from North Africa and Southern Europe as a contribution to the long-term sustainable development of their power sector. [10]

5.5.3. Environmental Sustainability

Life cycle assessment of emissions and of land surface impacts of the concentrating solar power systems shows that they are best suited for the reduction of greenhouse gases and other pollutants, without creating other environmental risks or contamination. **For example, each square meter of collector surface can avoid 250 to 400 kg of CO_2- emissions per year**. [10]

The energy payback time of the concentrating solar power systems is in the order of only 5 months. This compares very favorably with their life span of approximately 25 to 30 years. Most of the collector materials can be recycled and used again for further plants. [10]

5.5.4. Social Sustainability

CSP systems supply electricity and process heat like any conventional power plant. Their integration into the grid does not require any measures for stabilization or backup capacity. On the contrary, they can be used for these purposes, allowing for a smooth transition from today's fossil fuel based power schemes to a future renewable energy economy. [10]

Large electricity grids such as a Euro-Mediterranean Power Pool via High Voltage Direct Current Transmission will in the medium term allow for an intercontinental transport of renewable electricity. The existing power line from Spain to Morocco could already be used for this purpose. This concept will help to stabilize the political and economic relations between the countries of the

North and the South. [10]

In Sunbelt countries, CSP will reduce the consumption of fossil energy resources and the need for energy imports. The power supply will be diversified with a resource that is distributed in a fair way and accessible by many countries. **Process heat from combined generation can be used for seawater desalination** and help, together with a more rational use of water, to address the challenge of growing water scarcity in many arid regions. Thus, CSP will not only create thousands of jobs and boost economy, but will also effectively reduce the risks of conflicts related to energy, water and climate change. One can envision a Euro-Mediterranean grid interconnecting sites with large renewable electricity resources. [10]

These concepts provide also a potential alternative for the energy management of the Subcontinent of Mother India.

5.5.5. Advantages and disadvantages of CSP

+ Solar Energy drives conventional Power Plants: *Concentrating solar collectors produce high temperature heat to operate steam and gas turbines, combined cycles or stand alone engines for electricity or for combined heat and power.*

+ Day and night Power supply: *Thermal storage systems allow for night-time solar power generation. Fuels like oil, gas, coal or biomass can additionally be used to deliver electricity whenever required.*

+ Low cost Solar Electricity: *Concentrating solar power still requires support, but co-firing and special schemes of finance yield affordable power already today.*

+ Solutions for Power and water: *Process heat from combined generation can be used for seawater desalination, thus helping to reduce the threat of freshwater scarcity in many arid countries.*

+ Large potential for sustainable development: *The concentrating solar power potential exceeds the world electricity demand by more than 100 times.*

– Problem during Monsoon time: *Low Energy production during the Monsoon time. A hybrid facility is necessary.*

– Problem with Dust: *Dust on the surface can reduce the performance of the system.*

– Huge Area is required: *Land is costly*

5.6. Realization Steps of a Thermal Solar Plant

5.6.1. Step 1: Basic Project Information

The initial step of a CSP project is to identify the basic investment opportunities. First evaluation can be started e.g. by regional authorities with eventual support from CSP experts to assess general information on the market chances, capacity requirement, cost level, revenues, availability of finance, national policies, the level of political risks, the solar irradiation level, possible project implementation structures and the general availability of sites. If the outcome is promising, partners for a project company and sources of finance for project development must be agreed. [10]

5.6.2. Step 2: Project Assessment

A pre-feasibility study will include solar energy resource assessment, a preliminary conceptual design of the plant and technical and economic performance modelling for several project alternatives. It will yield a first estimate of the levelised electricity cost and of the economic perspectives of the project. The study will give the general project outlines like administrative requirements, expected environmental impacts, viable schemes of finance and a project implementation structure. This phase will yield a pre-selection and recommendation for the most promising sites. The study will be the basis for the decision about the continuation of the project. [10]

5.6.3. Step 3: Project Definition

A feasibility study will analyze the most promising project configuration identified in the pre-feasibility phase, going into detail in resource assessment, thermodynamic and economic performance calculations, and specifying major equipment and investment estimates based on budgetary quotes. Usually, an environmental impact study is included. As a result, the project site will be selected and the necessary land will be reserved or purchased by the project company. The study will be the basis for a construction bid and for the related Engineering, Procurement and Construction (EPC) contract, as well as for all the legal and administrative requirements to start the project. [10]

5.6.4. Step 4: Engineering-Consortium

Consortium bidding for the EPC contract should consist of the construction company, power block supplier, solar plant supplier and an engineering company, all of whom will be experienced in CSP technology. The basis for this phase is a reliable scheme of finance that allows for electricity costs equivalent to the expected revenues. Due to the fact that fuel is substituted by capital goods, a long term power purchase agreement is a major pre-requisite for the realization of CSP plants. The final activity of this phase is the grid connection and commissioning of the plant. [10]

5.6.5. Step 5: Operation

Operation of the CSP plants is expected to last over an economic life cycle of 25 to 30 years. Financing Solar collectors increases the initial investment and the related capital cost in comparison to fuel-fired power plants. Interests for extra debt and equity, insurance costs, taxes and custom duties have to be paid, extra land has to be purchased and extra staff has to be employed. [10]

In contrast to that, fuels are purchased without any interest or insurance rates, and are often free of custom duties and taxes or even subsidized by the government. Therefore, CSP requires start-up finance to enter the market and to follow the learning curve. This can be achieved by an instrument such as the Renewable Energy Act of the country. [10]

For developing countries, a grant by the Global Environmental Facility (GEF) of approximately 50 million Euros per plant is expected to be applied to projects in Mexico, Morocco, **India** and Egypt. In order to achieve affordable costs today, a combination of financial mechanisms including public/ private risk sharing must reduce the capital cost. [10]

In addition to the GEF-grant and to CO_2-Credits from the Clean Development Mechanism, all stakeholders of a CSP project including host countries, banks, investors, insurers and suppliers are encouraged to contribute to start-up financing by adapting their profit expectations to the learning curve. Private participation in start-up finance will require an international public-private-partnership over the whole phase of market introduction in order to reduce the project related risks for all stakeholders to a minimum. [10]

During an executive conference on CSP organized by BMU, KfW and GEF in Berlin in June 2002, the “Berlin Declaration” was issued by an international group of stakeholders that agreed to jointly develop a long term strategy for the market introduction, and to discuss different innovative models of finance in order to start a series of CSP projects. (http://www.en-consulting.com/csp) [10]

5.7. Résumé and Out view for Solar Concentration technology

One of the most environmentally friendly technologies to produce energy is to concentrate solar radiation. Solar Concentrating Plants can be built as:

- Tower concentrators
- Parabolic Trough systems
- Parabolic Dish Engines

ESTIA, the European Solar Thermal Power Industry Association, is one of the leaders in the field of Solar Thermal Power Plants, with financial support from the German Federal Ministry for Economic Cooperation and Development (BMZ) and the GEF. The government of India is promoting renewable energy on a large scale. **India has plans to build its first big concentrating solar power plant in Mathania, in the State of Rajasthan.** [10]

The project is still pending because only 35% of the energy is produced by the Solarcollector. The world bank is at present not satisfied with the costs and performance of the designed system. The Author will follow up the development.

At present the world's largest Solar Desalination plant is built in the United Arabic Emirates. This plant produces 100 m^3/d by a Tube Collector surface of 1860 m^2. The yield is app. 5,4 l fresh water per m^2/d. [1]

The technology of solar concentration has been used in Auroville/ India for 10 years (see Fig. 33). A bigger plant could produce enough energy for the whole area. Auroville could have its own energy production and supply. The steam could be used to drive a Desalination plant which provides fresh and clean drinking water for Auroville and its Bioregion. For the realization of such a project, Auroville's Planning and Development Council together with the local authorities and Governments, would have to take action and further studies are necessary. The project should be accompanied by participation from a university, too.

Last, but not least, it must be mentioned that sweet water is needed and used for conventional energy production: [2]

- **Coal Power Station: 1,2 l/kWh (through flow cooling) to 2,6 l/kWh (Tower cooling)**
- **Oil and Gas Power Station: 1,1 l/kWh (through flow cooling) to 2,6 l/kWh (Tower cooling)**
- **Atom Power Station (Light water Reactor): 3,2 l/kWh**

5.8. Pros and cons for a desalination plant powered by concentrated solar energy

+ No pollution through energy generation

+ No use of water for energy production

+ Per m^2 CSP, 250 to 400 kg of CO_2- reduction per year

– At present high Investment costs

6. Alternative Energy source: "Photovoltaic"

The PA solar cell, or photovoltaic cell, is a semiconductor device consisting of a large-area p-n junction diode, which in the presence of sunlight is capable of generating usable electrical energy. This conversion is called the photovoltaic effect. The photovoltaic effect was discovered in 1839 by French experimental physicist Alexander-Edmond Becquerel, who observed that certain materials would produce a small current when exposed to light. The field of research related to solar cells is known as photovoltaic, Fig. 36. [25]

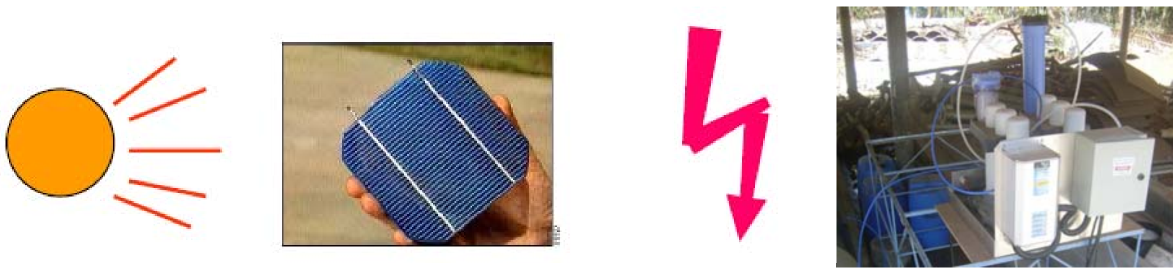


Fig. 36: Photovoltaic combined with RO

Solar cells have many applications. They are particularly well suited to, and historically used in, situations where electrical power from the grid is unavailable, such as in remote area power systems, Earth orbiting satellites, handheld calculators, remote radiotelephones and water pumping applications. Solar cells (in the form of modules or solar panels) on building roofs can be connected through an inverter to the electricity grid in a net metering arrangement. [25]

6.1. Photovoltaic powered Desalination plant for Tsunami relief projects in Auroville's bioregion

Within the scope of the Tsunami relief in Auroville, GENERAL ELECTRIC, US donated 14 small stand-alone RO desalination plants powered by Photovoltaic (600W) to be set-up in Auroville's Bioregion (Fig. 37). These plants can be used for the desalination of brackish water, only. The maximum TDS load is 2000mg/l which is equal to app. 3000 µs.

Fig. 37: Photovoltaic driven RO system for Tsunami relief

The systems works without battery back-up. Monitoring is done by CARE (Auroville Center for Applied Renewable Energy). The Author will follow up on this project.

6.2. Pros and cons for a desalination plant powered by Photovoltaic's

\+ No pollution through energy generation

\+ No use of water for energy production

\+ Per m^2 CSP, 250 to 400 kg of CO_2- reduction per year

− At present high Investment costs

7. Alternative Energy source: "Wind"

Electricity produced out of wind is up to now the most efficient and cheapest way to produce "clean energy".

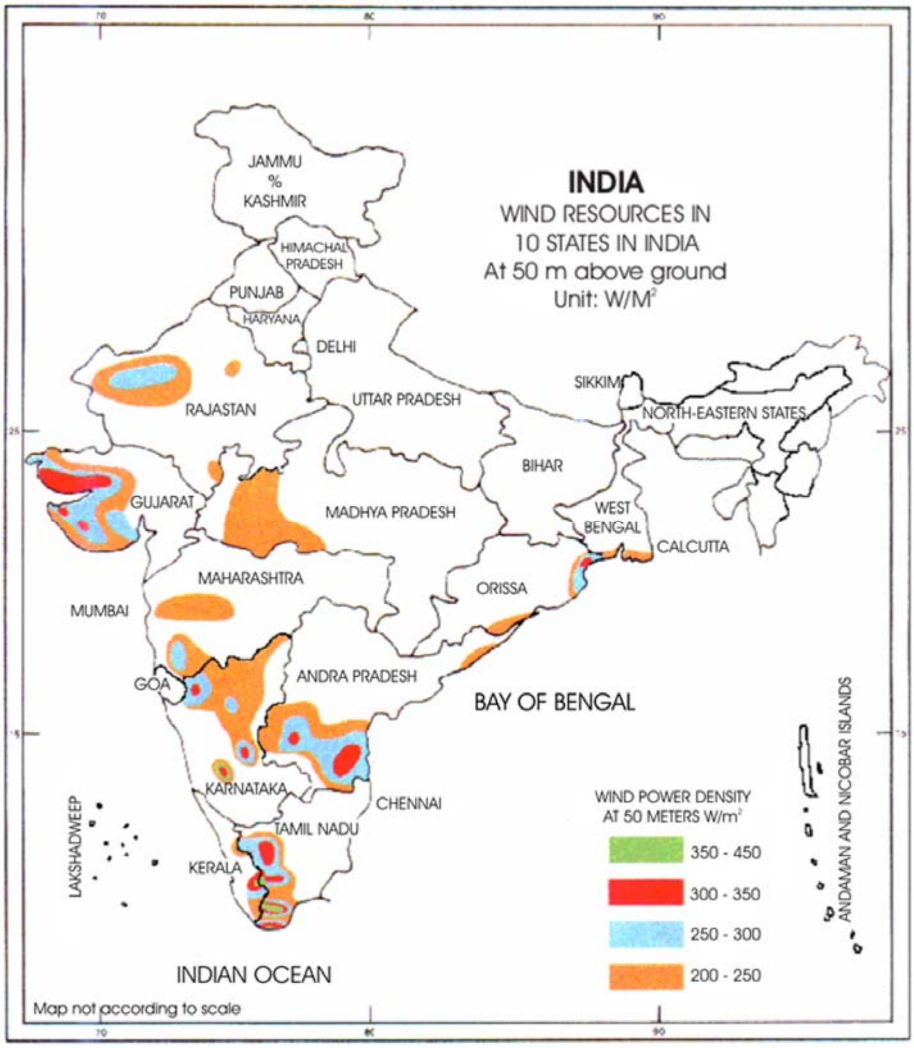


Fig. 38: Wind resources in India [13]

The potential wind power density of India is displayed in a basic map in Fig. 38. One can see that on the Border between Kerala and Tamil Nadu are promising good site conditions for generation of electricity by wind turbines.

The proposal to build a 1MW wind turbine engine near Coimbatore is not new in Auroville. The produced electricity would be channeled into the Tamil Nadu Electrical Board (TNEB) network and should be taken out of the grid in Auroville. This is possible and the Tamil Nadu Government supports this energy in and output by private companies/ investors.

According to Dr. Anil Kane, President of the World Wind Energy Association (WWEA) and

Chairman of Indian Wind Energy Association (In WEA), the yield from a wind turbine with installed capacity of 1.25 MW in Tamil Nadu is $24x10^5$ to $35x10^5$ kWh per year. The exact amount depends sensitively on the site of the set-up.

Fig. 39: Wind farm

For this type of wind turbine the costs including erection, land and grid connection are approximately 6 to 6.5 crore Rs. If the energy is fed to the grid in it can also be wheeled anywhere in Tamil Nadu. For this service a payment of 5 % of the energy has to be made. On the other hand, surplus energy can be sold to TNEB at a price of 2.70 RS/kWh.

The proposal to build a windmill for Auroville has not been realized because of the problem with the electrical network of TNEB. “It is not possible to guarantee that the power will be available for 24 h” say the officials of the Auroville Electrical Service. A deeper study and further clarifications are necessary.

7.1. Pros and cons for desalination plant powered by Wind Energy

+ No pollution through energy generation

+ Low place requirement

+ No use of water for energy production

+ No CO_2- emission

– At present high Investment costs

– Grid is not reliable; a generator would always have to be installed as an on site backup.

7.2. Case study Perth, Australia [8]

BIG BREAKTHROUGH TECHNOLOGY

REDUCING ENERGY AND OVERALL COSTS

The Industry Standard Solution

The efficiency and lifecycle costs of a plant's energy recovery technology is critical to both winning big SWRO projects and achieving maximum plant profitably through the lowest operating costs. Leading international OEM's such as GE Infrastructure, Suez Degrémont, CH2MHill, Befesa, GEIDA, INIMA, Beijing CNC, Fisia Italim Pianti, Aqua Engineering, Sadyt, Cobra Tedagua, and Metito have selected the ERI® PX® modular technology for their recent projects because it consistently achieves real energy transfer efficiencies—up to 98%, making it the most efficient energy recovery device available today. At the core of the PX device is a single moving rotor made of tough engineered ceramic that is unaffected by chemicals, will not corrode, and requires no periodic maintenance. Over 80 OEMs have standardized installations using PX technology in some of the world's largest desalination plants, such as Hamma, Skikda, Perth, Yuhuan, and Alicante.

Perth Project Facts - At a Glance

• Total 1st Pass Capacity (PX's installed)	160,000 m³/day
Permeate Capacity	144,000 m³/day
• SWRO Train Capacity	13,500 m³/day
• Number of SWRO Trains	12
• Membrane Water Recovery Rate	43%
• SWRO Energy Consumption*	2.5 kWh/m³*
• Total Plant Energy Consumption	Less than 4.2 kWh/m³*
• Energy Recovery Device Efficiency (at ERD)	96.8%
• Total SWRO Plant Cost	USD 290 million
• Power Generation	Wind Farm Offset

Includes 0.25 kWh/m³ lost on high pressure pump control valve (reducing pressure 8-10 bar).

ENERGY RECOVERY INC
Making Desalination Affordable™

Perth, Australia SWRO Desalination Project

Perth SWRO Plant, Kwinana, Western Australia

Perth, Western Australia Water Corporation

In November 2006, the 144,000 m³/day SWRO Plant in Western Australia began delivering desalinated water from the ocean into Perth's municipal water supply system. The vision of utilizing a combination of clean wind power and the highest efficiency ERD available for one of the most efficient and environmentally friendly desalination plants in the world became a reality.

A Thirsty Nation

The ongoing population growth in Australia's coastal communities combined with the worst drought in a century have unhappily converged, creating the necessity for the Australian government to find water sources that are located at or near large coastal communities in need. Most importantly, Australia needs a water source that is not subject to the whims of changing weather patterns.

A Proven Solution

Back in April 2005, facing impending water shortages, Western Australia's Water Corporation decided to form a public-private partnership with global water treatment company Degrémont. The two entities collaborated to build and operate Perth's first seawater desalination plant using reverse osmosis technology, the largest such plant in the southern hemisphere. The 144,000 m³/day (35 million U.S. gallons per day) plant, built at Kwinana, 25 kilometers south of Perth, will become the largest single source of water for Perth, supplying 17% of the city's needs.

To reduce energy and overall costs, ERI's industry-standard PX technology was selected by the Degrémont Multiplex Joint Venture as the advanced energy recovery solution for the project. The first of 12 trains of the Perth SWRO Plant started producing fresh water in November 2006.

Fig. 40: Perth Australia, Page 1 [8]

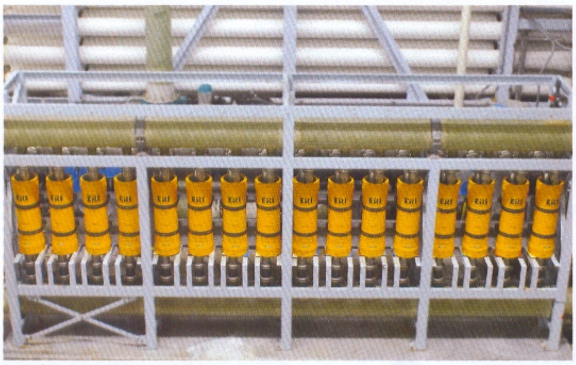
CASE STUDY

An Environmentally Green Plant Design

As part of Water Corporation's and WA's commitment to promote energy efficiency and reduce greenhouse gas emissions, the Perth SWRO Plant is the largest facility of its kind in the world to be powered by renewable energy. The plant buys its power needs from electricity generated by the Emu Downs Wind Farm, located 200 kms. north of Perth. The 83 MW wind farm consists of 48 wind turbines and contributes over 272 GWhr per year into the grid, fully offsetting the Perth SWRO Plant's estimated electrical requirement of 180 GWhr per year. In addition, instruments that continuously monitor plant discharges automatically shut down the process in the event of an exceedance.

The plant, with 12 SWRO trains with a first-pass capacity of 160,000 m³/day and six BWRO trains delivering a final product flow rate of 144,000 m³/day, will have one of the world's lowest specific energy consumption rates, due in part to the use of Energy Recovery, Inc.'s (ERI's) PX Pressure Exchanger® energy recovery devices (ERDs). The PX is an isobaric-chamber ERD that recovers pressure energy from the brine reject stream and delivers it to fresh seawater water going to the SWRO membrane feed at a net transfer efficiency of up to 98%, making it the world's most efficient ERD.

The combination of unheralded environmental protection and monitoring, low specific energy consumption and the use of a renewable energy make the Perth SWRO Plant a world model for providing water in an environmentally sound and sustainable manner, almost magically converting wind to fresh water. The Water Corporation has demonstrated that a well-planned alliance approach can produce a desalination plant that is environmentally responsible, well designed, and very cost effective all at once.



SWRO train of 16 PX-220 PX Pressure Exchangers.

Environmental protection and monitoring is a real concern.

Fig. 41: Perth Australia, Page 2 [8]

BIG BREAKTHROUGH TECHNOLOGY

REDUCING ENERGY AND OVERALL COSTS

Perth, Australia SWRO Desalination Project

Why the ERI PX?

Simply put, ERI's PX Technology offers the highest available net energy transfer efficiency and the lowest lifecycle costs of any ERD as well as maximum design flexibility, reduced high-pressure pump costs and operational flexibility.

Among the commercially available isobaric ERDs, the PX Pressure Exchanger isobaric ERD also provides the following added advantages:

- Highest available Net Transfer Efficiency – up to 98%
- No bearings, seals, valves - maintenance free operation
- No wetted metal parts that are subject to corrosion
- No required complicated computer controls
- No vibration, lateral loads, or pulsation
- Installed redundancy for maximum on-line time
- Only 80 kg per PX-220 and no special skid or foundation requirements
- Smallest footprint by a factor of 6 or more
- Local support and service in Europe, Australia, Asia Pacific, Middle East and North Africa, and the Americas

Guaranteed.

Membrane racks tower over the small footprint of the PX array train racks.

Gary Crisp stands by the first of 12 SWRO train of 16—PX-220 Pressure Exchangers.

Inside view of the Perth SWRO Desalination Plant.

"I sincerely believe that the MDJV (Multiplex Degrémont Joint Venture) Alliance and consequently the PRO Alliance have produced a design that is unmatched and will result in the most sophisticated seawater desalination plant in the world, the Perth Seawater Desalination Plant. It will no doubt be the world's model desalination plant incorporating some of the most advanced components including the highly efficient - simple to operate - with low maintenance isobaric energy recovery devices from ERI."

Gary Crisp,
Principal Engineer, Desalination
Water Corporation of Western Australia

Fig. 42: Perth Australia, Page 3 [8]

BIG BREAKTHROUGH TECHNOLOGY

REDUCING ENERGY AND OVERALL COSTS

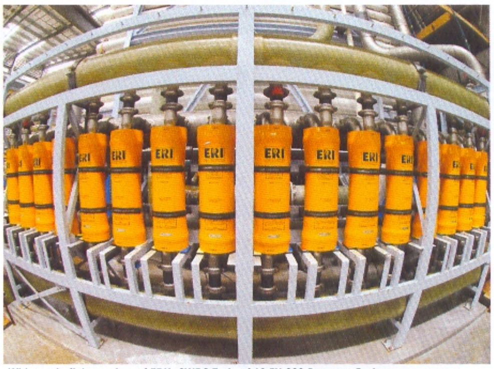
Perth, Australia SWRO Desalination Project

Energy Recovery, Inc. (ERI) is the leader in manufacturing highest efficiency, energy recovery products and technology. Our PX Pressure Exchanger (PX) is driving the rapid growth in the seawater reverse osmosis (SWRO) industry, and making desalination affordable worldwide. The PX is based on a rotary positive displacement pump that recovers energy from the high-pressure waste stream of SWRO desalination systems at up to 98% efficiency—with no downtime or scheduled maintenance. Since its introduction in 1997, the PX technology has emerged as the industry standard solution for seawater desalination. There are currently over 2,500 PX's installed/contracted in SWRO plants worldwide, significantly reducing the cost to produce over 1.8 million m³/day of fresh water, and saving customers an estimated 230 MW of energy or $162 million a year in operating costs and reducing CO^2 emissions by nearly 4 million tons over a 20 year life of a plant the size of Perth.

Contact us today to find out how you can start saving, or to learn more about ERI and the PX solution, visit us at:

www.energyrecovery.com

Aerial view of the Perth Desalination Plant in Kwinana, Western Australia.



Wide angle fisheye view of ERI's SWRO Train of 16 PX-220 Pressure Exchangers

A perspective view of ERI's SWRO Train of PX-220 Pressure Exchangers

Making Desalination Affordable™

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Design and specifications subject to change without prior notice.
Doc. No. ERI-CS109EB 2007-01

Fig. 43: Perth Australia, Page 4 [8]

8. Basic calculations & comparison of different renewable energy devices for desalination

The author has discussed different renewable energy devices (see chap. 4, 5 and 6) for the following plant sizes:

- 500 m^3/d, 1000 m^3/d, 5000 m^3/d, 10000 m^3/d

Fig. 44 shows several combinations of renewable energy systems and desalination processes that were considered in the cost calculation. The **red** stream indicates the electrical power requirement. For RO it includes an Energy Recovering Device (see chap. 4.5.3).

The **green** stream indicates the thermal power. The GOR (Gained Output Ratio) of 9 was assumed for the MED. This means that with 1kg of steam 9 kg of distillate can be produced. App. 2600 kJ are required to produce 1kg steam. 1 kJ = 0.0002778 kWh. 2600 kJ x 0,000278 kWh = 0,72 kWh/kg steam. With GOR 9 => 0,72 / 9 = 0,08 kWh/kg = 80 kWh/m^3 distillate.

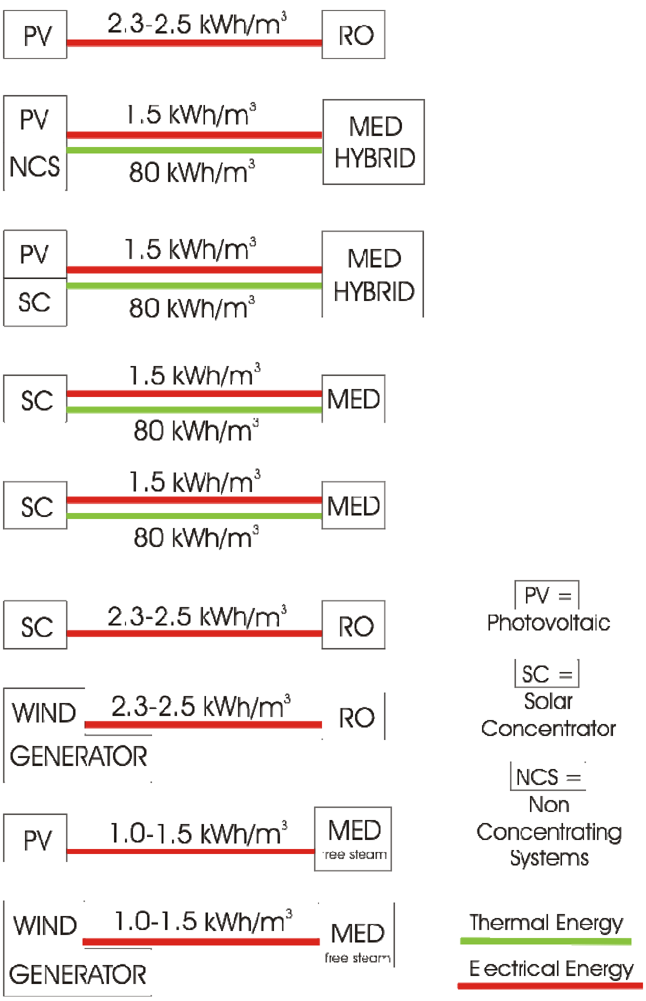

Fig. 44: Combinations of renewable energy devices and desalination processes

8.1. Basic data on solar radiation for Pondicherry

Data on solar radiation were given by Prof. Dr. Chamanlal Gupta, Solar Energy Unit, Sri Aurobindo Ashram, Pondicherry. The evaluated data cover global radiation on a horizontal surface for 5 successive years of measurements (1981 to 1985 for Pondicherry). Mean daily global radiation for each month is presented in Fig 45. This accounts for 5.4 kWh/(m²*d) as mean global radiation calculated over the time frame 1981 to 1985. Diminishing of radiation happens during the summer monsoon June to July and the winter monsoon October to December.

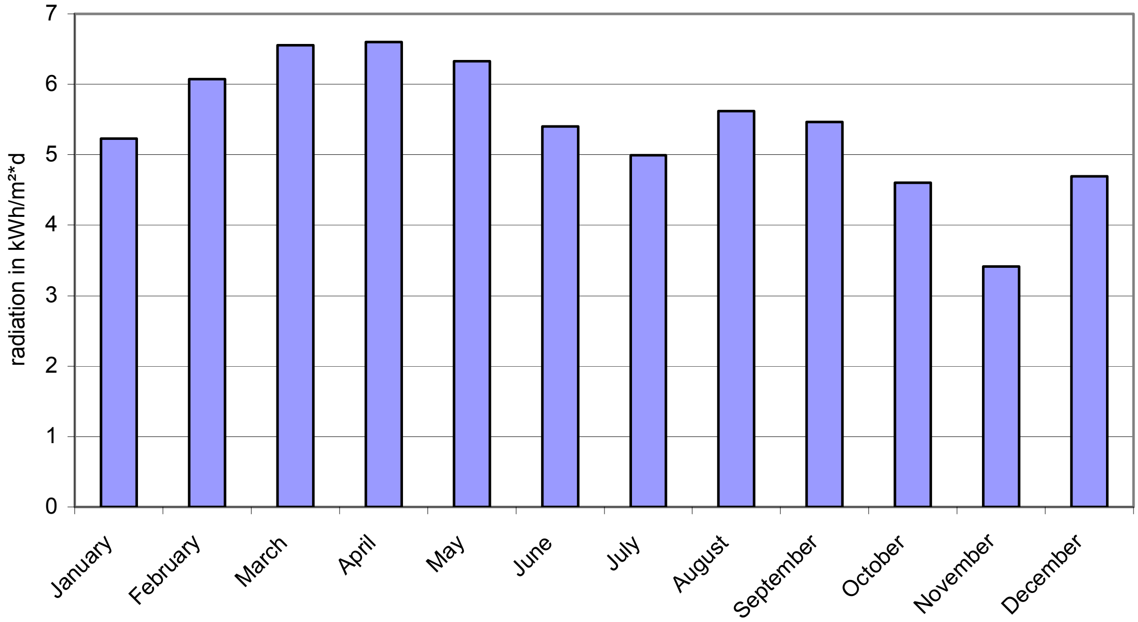

Fig. 45: Mean daily global horizontal radiation for Pondicherry

For maximum irradiation of the collector its surface has to be tilted towards the sun. For non-tracking systems a tilt corresponding to the latitude guarantees the highest yield. The panels should be kept clean to “extract” the maximum of solar radiation.

8.2. Calculation of irradiation on tilted surfaces

Based on the date, Solar Time ST, longitude λ (79.83 E) and latitude φ (11.94 N) of the site, declination δ, azimuth α_S and altitude of the sun γ_S can be calculated. For the calculations various equations can be found in the literature.

A summary of the equations used can be seen below:

The hour angle ω changes by 15° per hour and is 0° when the sun is in its zenith:

$$\omega = (12:00h - ST) \cdot 15^o / h \quad \text{(I)} \qquad [20]$$

During the year the declination δ of the sun moves between –23.27° and +23.27°. An approximation for calculation of the declination δ is given in equation (II) with n being the number of the day.

$$\delta = 23.27 \cdot \sin\left(\frac{360}{365.25} \cdot (n - 80)\right) \quad \text{(II)} \qquad [21]$$

The zenith angle θ_Z is the angle between the vertical and the actual vector to the sun and the altitude γ_S is its complementary:

$$\cos\theta_Z = \cos\varphi \cdot \cos\delta \cdot \cos\omega + \sin\varphi \cdot \sin\delta \quad \text{(III)} \qquad [21]$$

$$\gamma_S = 90^o - \theta_Z \quad \text{(IV)} \qquad [21]$$

Then it is possible to calculate the azimuth angle α_S:

$$\text{For } ST \leq 12:00: \alpha_S = 180^o - \arccos \cdot \left(\frac{\sin\gamma_S \cdot \sin\varphi - \sin\delta}{\cos\gamma_S \cdot \cos\varphi}\right) \quad \text{(V)} \qquad [20]$$

$$\text{For } ST > 12:00: \alpha_S = 180^o + \arccos \cdot \left(\frac{\sin\gamma_S \cdot \sin\varphi - \sin\delta}{\cos\gamma_S \cdot \cos\varphi}\right) \quad \text{(VI)} \qquad [20]$$

For the calculation of solar energy impinging on any tilted surface global radiation has to be divided into its diffuse and direct components. Direct radiation is the fraction that travels straight from the sun whereas diffuse radiation is distributed over the entire sky. It is scattered by water vapor and other particles on its way through the atmosphere.

The clearness index k is an indicator for the splitting of the global radiation into its diffuse and direct partition. It is calculated by equation (VII):

$$k = \frac{E_{G,hor}}{E_0 \cdot \sin \gamma_S} \qquad \text{(VII)} \qquad [20]$$

with $E_{G,hor}$ being the measured global radiation on the horizontal, E_0 the solar constant (1367 W/m²) and γ_s the altitude of the sun. The mean values of the clearness index for each month can be seen in Fig. 46. Low clearness of the sky can be observed at monsoon time.

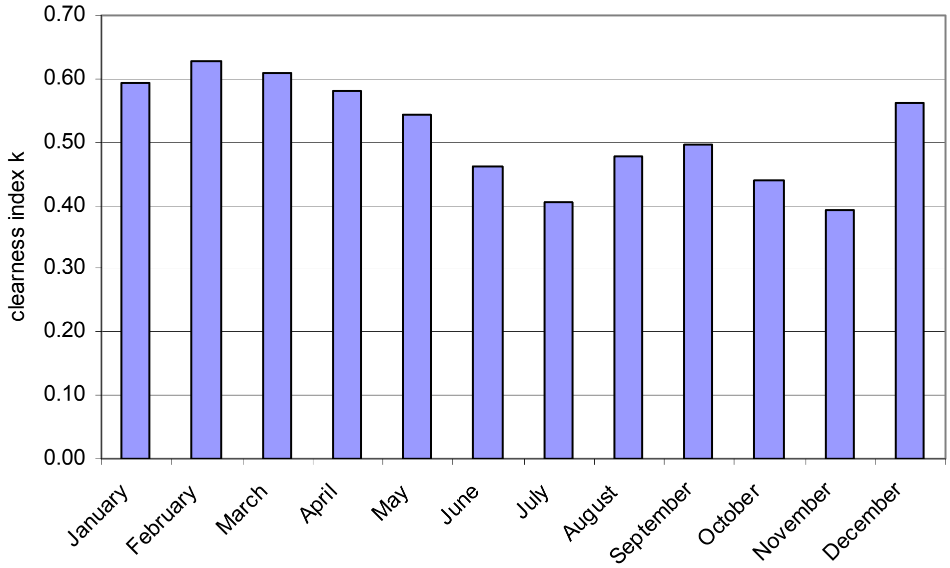

Fig. 46: Clearness index k, <u>monthly</u>

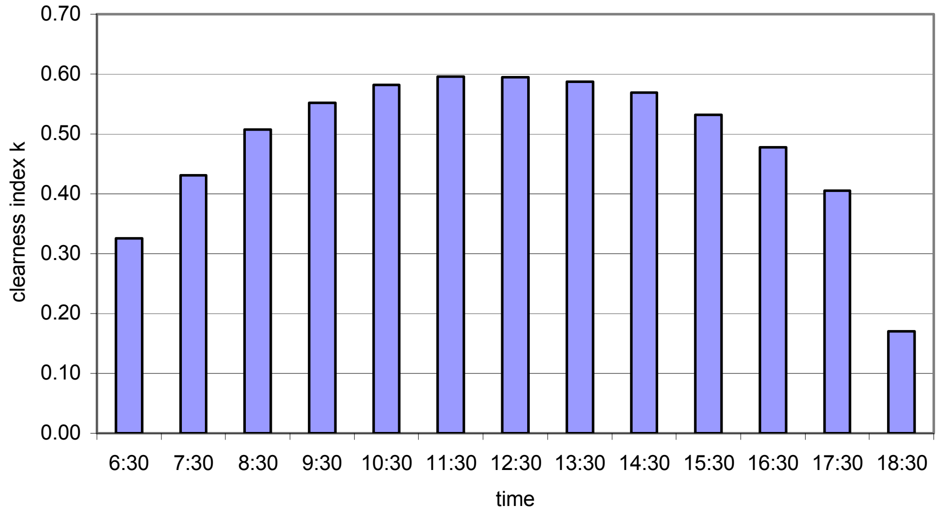

Fig. 47: Clearness index k, <u>daily</u>

During the day clearness is highest at noon and very low in the morning and evening, Fig. 47.

Statistical correlations are used for the break-down of global radiation into the diffuse and direct partition each on a horizontal surface.

For $k \leq 0,3$ $\quad E_{diff,hor} = E_{G,hor} \cdot (1,020 - 0,254 \cdot k + 0,0123 \cdot \sin\gamma_S)$ (VIII) [20]

For $0,3 < k < 0,78$: $\quad E_{diff,hor} = E_{G,hor} \cdot (1,400 - 1,749 \cdot k + 0,177 \cdot \sin\gamma_S)$ (IX) [20]

For $k \geq 0,78$: $\quad E_{diff,hor} = E_{G,hor} \cdot (0,486 \cdot k - 0,182 \cdot \sin\gamma_S)$ (X) [20]

The global radiation impinging on the tilted surface $E_{G,tilt}$ is calculated as follows:

$$E_{G,tilt} = E_{dir,tilt} + E_{diff,tilt} + E_{refl,tilt} \quad \text{(XI)}$$ [20]

$E_{dir,tilt}$ is the direct radiation and $E_{diff,tilt}$ the diffuse radiation both on the tilted surface. Radiation that is reflected by the ground and environment around the collector is $E_{refl,tilt}$.

$$E_{dir,tilt} = E_{dir,hor} \cdot \frac{\cos\Theta_{tilt}}{\sin\gamma_S} \quad \text{(XII)}$$ [20]

Θ_{tilt} being the incidence angle for sun-beams on a tilted surface:

$$\Theta_{tilt} = \arccos(-\cos\gamma_S \cdot \sin\beta \cdot \cos(\alpha_S - \alpha_S) + \sin\gamma_S \cdot \cos\beta) \quad \text{(XIII)}$$ [20]

β is the tilt of the surface. α_E is the angle between an orientation to the south (northern hemisphere) and the actual orientation of the receiving surface. If the surface rotated towards west α_E is positive. For the calculation of $E_{diff,tilt}$. Klucher's Model was used:

$$E_{diff,tilt} = E_{diff,hor} \cdot 0.5 \cdot (1 + \cos\beta) \cdot \left(1 + F \cdot \sin^3 \frac{\beta}{2}\right) \cdot \left(1 + F \cdot \cos^2 \Theta_{tilt} \cdot \cos^3 \beta\right) \quad \text{(XVI)}$$ [20]

$$\text{with } F = 1 - \left(\frac{E_{diff,hor}}{E_{G,hor}}\right)^2 \quad \text{(XV)}$$ [20]

To determine the reflected radiation $E_{refl,tilt}$ the Albedo Index A has to be defined. A depends on the surrounding environment. For no specifications given it is usually assumed as 0,2 which is also the value used in this calculation.

$$E_{refl,tilt} = E_{G,hor} \cdot A \cdot 0.5 \cdot (1 - \cos\beta) \quad \text{(XVI)}$$ [20]

8.3. Irradiation on a non-concentrating Solar Power Plant (e.g. Photovoltaic)

For the dimensioning of the PV-plant as well as for the flat plate and evacuated tube collectors it was assumed that no tracking of the system would be used. Two dimensional tracking systems optimize the yield of PV-plants. However, many disadvantages go along with these systems. The sophisticated technical equipment leads to a higher cost for the system. If tracking fails the solar system may stay in a position that accounts for even less energy production than the non-tracking alternative.

The yield by higher irradiation of the surfaces is lessened by the energy consumption of the motor for tracking the panels. In reality the most commonly used panels allow fixation in summer and winter position. For the calculations a tilt of the surface towards south of 23,5^{o} was assumed for winter months (October to March). For April to September the radiation on the horizontal was used for calculations. A comparison of global horizontal radiation with irradiation of a tilted surface in winter can be seen in Fig 48.

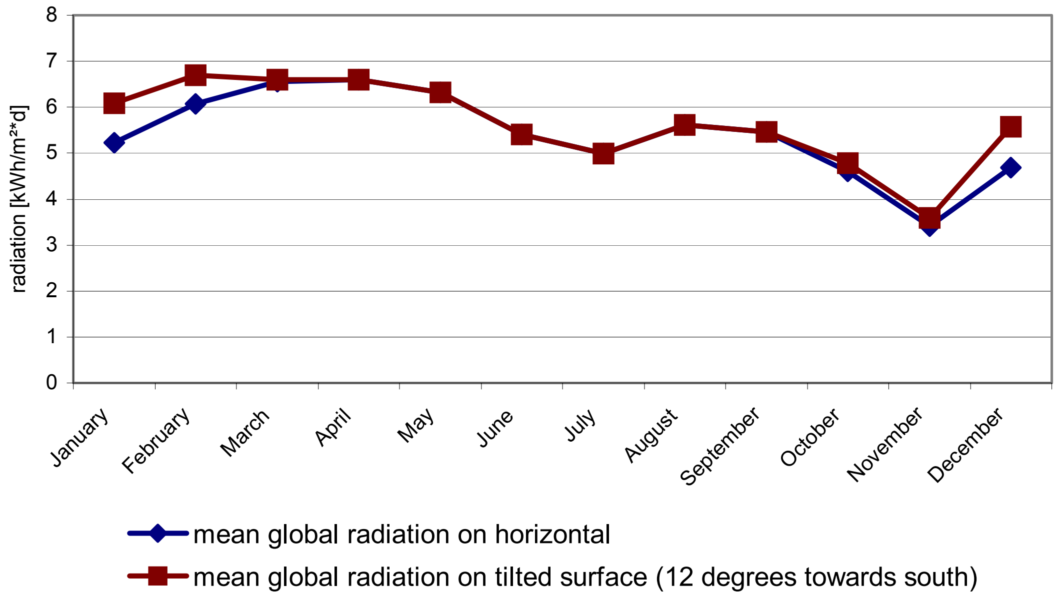

Fig. 48: Comparison between radiation on tilted surface and global horizontal radiation

Over the year the incident radiation on the tilted surface was calculated to be 5.6 kWh/(m²*d).

For PV systems, battery back-up was not included in calculations for several reasons. Batteries have an efficiency of 70 to 80%. This means that by running the plant from a battery system about one forth of the energy would be lost and therefore the PV plant would have to be dimensioned accordingly. Secondly, batteries have to be exchanged every 5 to 10 years, the waste disposal of them having great environmental impact. The most ecological solution would be to channel the excess current into the grid system (TNEB). In this case the grid could be used as a buffer.

8.4. Irradiation of Solar Concentrating Systems (e.g. parabolic trough concentrators)

For a concentrating system, only direct radiation can be reflected to the absorber. The radiation has to be directed to the comparatively small absorber so that for these systems tracking is crucial. For the calculations it was assumed that the axis of the parabolic trough would be oriented North to South and the collector would track the sun East to West. The optimum tilt β of the tracking system can then be calculated by:

$$\tan\beta = \tan\Theta_Z \cdot |\sin\gamma_S| \qquad \text{(XVII)} \qquad [21]$$

The incident radiation on the parabolic trough concentrator $E_{dir,coll}$ can be calculated by equation (XIII) by applying the tilt of the collector (see equation (XVII)) and inserting α_E (-90° in the morning and +90° in the afternoon). Another option which leads to the same result is to determine the direct radiation on the normal $E_{dir,norm}$ (XVIII). Due to the fact that the radiation does not impinge at an angle of 90° but at the actual angle χ, the cosine effect has to be included by multiplying it with $E_{dir,norm}$.

$$E_{dir,norm} = \frac{E_{dir,hor}}{\sin\gamma_S}. \qquad \text{(XVIII)} \qquad [20]$$

$$E_{dir,coll} = E_{dir,norm} \cdot \cos\chi \qquad \text{(XIX)} \qquad [20]$$

$$\chi = \arccos\left(\sqrt{1-\cos^2\gamma_S \cdot \cos^2\alpha_S}\right) \qquad \text{(XX)} \qquad [20]$$

Fig. 49 shows a comparison between direct radiation impinging on the tracking parabolic trough reactor and global radiation for example on a tilted PV plant. The mean direct radiation on the parabolic trough was calculated to be 3,4kWh/(m²*d)

Losses can also be caused by the parabolic troughs shading each other. The amount of the losses depends on the distance between the rows of parabolic concentrators. As a rule, this distance should be about 3 times the aperture width. Losses at the end of the parabolic trough collectors were not included in the calculations as in huge plants they are usually very low (less than 1%). For the same reason the Incident Angle Modifier IAM was not considered at this stage.

The dimensioning of the solar systems is based on the calculated mean values for solar radiation. The equivalent of the needed energy should be produced by solar.

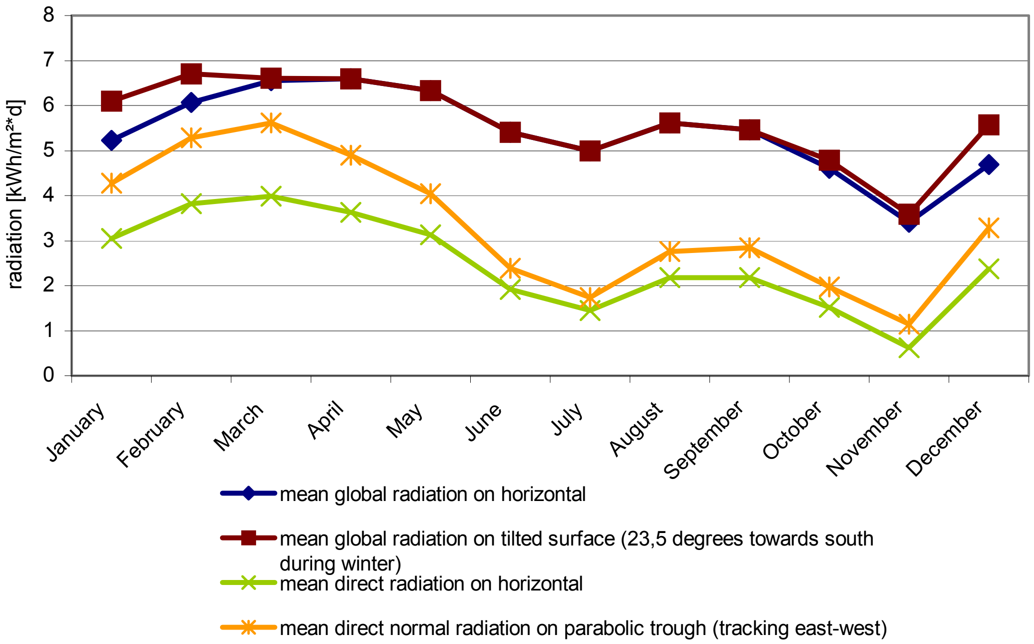

Fig. 49: Comparison between radiations that can be used by various solar systems

8.5. Cost calculation for Solar Systems

To calculate the total capital investment of a solar system, one has to consider the "Balance of system costs" or additional costs like AC/DC Converter, Materials and Installation charges. Fig. 50 shows the percentage of Balance of system costs.

Splitting of total capital costs			
electricity production		steam production	
PV power plant	**Solar Concentrator**	**Solar Concentrator**	**Non Concentrating System**
55% solar panels	45% solar field	60% solar field	40% evacuated tubes
14% AC\DC converter	30% gadgets for solar system	40% gatgets for solar system [18]	60% self/made collector frames, set-up
31% engineering, installation and materials [19] [12]	25% fossil plant [18]		

Fig. 50: Balance of System costs in % of the total capital costs

The Total Capital costs for different plant sizes driven with different Solar Power plants are calculated in Fig. 51. A safety factor of 20% was assumed for all the calculations.

The cost calculation of the non-concentrating system is based on the fact that evacuated tubes can be obtained from China for 300 INR each (1.5 m long, 0.05 m diameter). With a distance of 0.05 m between the tubes this gives to 2000 INR/m². With a self-made frame and set-up the costs were assumed to be 5000 INR/m².

Not calculated was the Fresnel Reflector (see Fig. 28). The company "Solarmundo", which has developed the Fresnel Reflector, claims that this collector could reduce the total capital investment costs to about 50% compared to a Parabolic Trough Collector. The running costs seem to be lower as well.

In a pilot plant of Solarmudo, it was shown by the company that the efficiency was app. 30% below that of the Parabolic Trough Collector. A full documentation can be downloaded as PDF-file from: Http://www.solarmundo.de.

The Author will follow up the promising alternative Fresnel Reflector development.

Investment calculation for Solar Power Plant							
		generation of electricity				generation of steam	
		for RO		for MED (steam is available)		for MED	
		by PV	by SC	by PV	by SC	by SC	by NCS*
Assumptions:	**Dimension**						
Energy consumption	kWh/m³	2,3 - 2,5	2,3 - 2,5	1.5	1.5	80 (GOR 9)	80 (GOR 9)
Usable radiation	kWh/d	5.6	3.4	5.6	3.4	3.4	5.6
Efficiency of system	%	11%	14% [18]	11%	14% [18]	48% [18]	35%
Costs of solar collector/panels	INR/ m²	13,200	10,000 - 12,000	13,200	10,000 - 12,000	10,000 - 12,000	5,000
Production of distillate 500 m³/d							
Aperture Area	m²	2,552	3,283	1,531	1,970	29,618	24,680
Total Capital Costs of plant*	lakhs INR	613	875	368	525	5,875	494
Production of distillate 1,000 m³/d							
Aperture Area	m²	5,105	6,565	3,063	3,939	59,237	49,359
Total Capital Costs of plant*	lakhs INR	1,225	1,748	735	1,049	11,657	987
Production of distillate 5,000 m³/d							
Aperture Area	m²	22,971	29,543	15,314	19,695	296,184	246,796
Total Capital Costs of plant*	lakhs INR	5,513	7,820	3,675	5,226	54,913	4,936
Production of distillate 10,000 m³/d							
Aperture Area	m²	45,942	59,086	30,628	39,391	592,368	493,592
Total Capital Costs of plant*	lakhs INR	11,026	15,527	7,351	10,401	103,305	9,872
* calculation: Area x costs/m² / part in % x 100% / 100,000			* exsample: 2,552 x 13,200 / 55% x 100% / 100,000 = 613 lakh INR				

Fig. 51: Total Capital Costs for different plant sizes powered by Solar Energy devices

The capital cost for Solar Energy devices for different types of Desalination plants can be seen in Fig. 51 which is also the basis for the economical cost calculation following in chap. 8.

The assumed energy consumption covers only the desalination process itself (especially RO) with no peripheral (pumping seawater from sea to the plant) and no pretreatment. For the RO plant the implementation of pressure exchangers was assumed (see chap. 3.5.3)

Example:

A **Photovoltaic** power plant for a **5,000 m³/d** freshwater **RO** plant costs **5,513 lakh Rs**. In case steam is available and the **5,000 m³/d** freshwater are produced via **MED**, and the energy would be produced through Solar Concentration, the capital costs are 5226 Rs lakh. In comparison, the investment would be slightly lower than the Photovoltaic power plant.

The picture changes extremely if one has to produce the steam first via a Solar Concentrator for the MED. The capital cost raises up to **54,913 lakh Rs**. This is 10 times as much as for the other technologies. Therefore a combination between Photovoltaic and Solar concentrator was discussed, only. The study of a pure SC driven MED plant was taken out by the authors because of the foreseen inefficiency of this option.

9. Economical cost calculation for combined Desalination and renewable energy devices

Economical cost calculations for 5,000 m³ RO plant powered by PV

S E A W A T E R - O P E N I N T A K E

Assumptions of costs:

Capital costs for 5,000 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
RO-plant	1,750 lakh	PV-maintenance	55 lakh	discounted Investment +operation cost	Lakh Rs.
PV-plant	5,513 lakh	Chemicals	16 lakh		11,473
wells / seawater extraction plant (see pretreatment)	0 lakh	Spare parts (mft)	69 lakh		
land costs	200 lakh	Labour (15 employees)	14 lakh	discounted water production assuming an inflation-indexed price	m³
pretreatment & disposal	875 lakh	membrane replacement (every 3 to 5 years)	20-50 lakh		23,509,023
generator	55 lakh	operational costs per year	154 lakh		
capital nominally invested	8,393 lakh	nominal operational costs	4,575 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capita	9,501 lakh	present value of operational costs	1,972 lakh		48.80

availability of plant	95%	
water production	1,734,938	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 25 years

Disc.Factor for Water assuming the water-price rises with inflation

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	6.00% %/a	discounted water prod. m³/a
	1	122%	839.3			1,019.99			
	2	110%	7,553.70			8,327.20			
Start	3	100%		153.6		153.63	1,734,938	100.0%	1,734,938
	4	90.7%		159.8		144.93	1,734,938	94.3%	1,636,733
	5	82.3%		166.2		136.73	1,734,938	89.0%	1,544,088
	6	74.6%		172.8		128.99	1,734,938	84.0%	1,456,687
	7	67.7%		179.7	20	135.23	1,734,938	79.2%	1,374,233
	8	61.4%		186.9		114.80	1,734,938	74.7%	1,296,446
	9	55.7%		194.4		108.30	1,734,938	70.5%	1,223,062
	10	50.5%		202.2		102.17	1,734,938	66.5%	1,153,833
	11	45.8%		210.2		96.39	1,734,938	62.7%	1,088,521
	12	41.6%		218.7	30	103.41	1,734,938	59.2%	1,026,907
	13	37.7%		227.4		85.78	1,734,938	55.8%	968,780
	14	34.2%		236.5		80.93	1,734,938	52.7%	913,943
	15	31.0%		246.0		76.35	1,734,938	49.7%	862,211
	16	28.2%		255.8		72.03	1,734,938	46.9%	813,406
	17	25.5%		266.0	40	78.17	1,734,938	44.2%	767,365
	18	23.2%		276.7		64.10	1,734,938	41.7%	723,929
	19	21.0%		287.7		60.47	1,734,938	39.4%	682,952
	20	19.1%		299.2		57.05	1,734,938	37.1%	644,294
	21	17.3%		311.2		53.82	1,734,938	35.0%	607,825
	22	15.7%		323.7	50	58.62	1,734,938	33.1%	573,419
	23	14.2%		336.6		47.90	1,734,938	31.2%	540,962
	24	12.9%		350.1		45.19	1,734,938	29.4%	510,341
	25	11.7%		364.1		42.63	1,734,938	27.8%	481,454
	26	10.6%		378.6		40.22	1,734,938	26.2%	454,202
	27	9.6%		393.8		37.94	1,734,938	24.7%	428,492

Fig. 52: Economical Cost Calculation: 5,000 m3/d Sea water intake on PV

The basis for the economic cost calculation (see Fig. 52) is the listing of the capital costs as well as the operational costs for the plant. The listed costs reflect only the production of drinking water. Not considered are storage tanks for drinking water and distribution systems.

The capital nominally invested is simply the sum of capital costs, whereas the present value of the capital considers also the discounting of the capital by the efficient discount factor. This means that the value of capital is referred to the starting time of the plant. The efficient discount factor is influenced by the discount factor due to the consideration of interest rates and by inflation. It is calculated by:

$$\text{Effective Discount Factor} = (1 + \text{discount factor}) \times (1 + \text{Inflation factor}) - 1$$

Starting with the planning and construction of the plant, the costs as well as the profits/yields are allocated to each year. The costs are then multiplied with the efficient discount factor referring to each year, which is calculated by:

$$(1 + \text{eff. Dis. factor})^{\Delta t}$$

The sum of all the discounted investment and operation costs can be seen in the right column as one of the results of the calculation.

The water production for each year is only weighted in respect of the inflation instead of the efficient discount factor. In the column of the results the sum of the discounted water production assuming an inflation-indexed price can be seen.

The water costs can then be calculated by dividing the discounted investment and operation costs by the discounted water production.

Fig. 52 shows the economical cost calculation for a 5,000 m^3/d **RO** powered **Photovoltaic** System. The cost per m^3 fresh water is **48.80 Rs** for Seawater Open Intake.

In annexure chap. 14.2 the different calculation sheets for various combinations of Desalination and renewable energy devices are listed. Fig. 53 shows the economical cost comparison according to the calculations sheets in chap. 14.2. Not displayed is the option MED_{hybrid} powered by SC/PV because the costs range between 301 Rs/m^3 for the 10,000 m^3/d plant and 363 Rs/m^3 for the 500 m^3/d plant.

One reason is that no “free steam” e.g. from a coal power plant etc. is available. Secondly, the location seems not to be suitable for the Solar concentrating technique. As described in chap. 8.2, Fig. 46, 47 and 49 the useable direct radiation is low in the Pondicherry region.

In other places of India or the world, the picture can be totally different because of other site

conditions. Here it might be possible to reach lower costs per m³ fresh water.

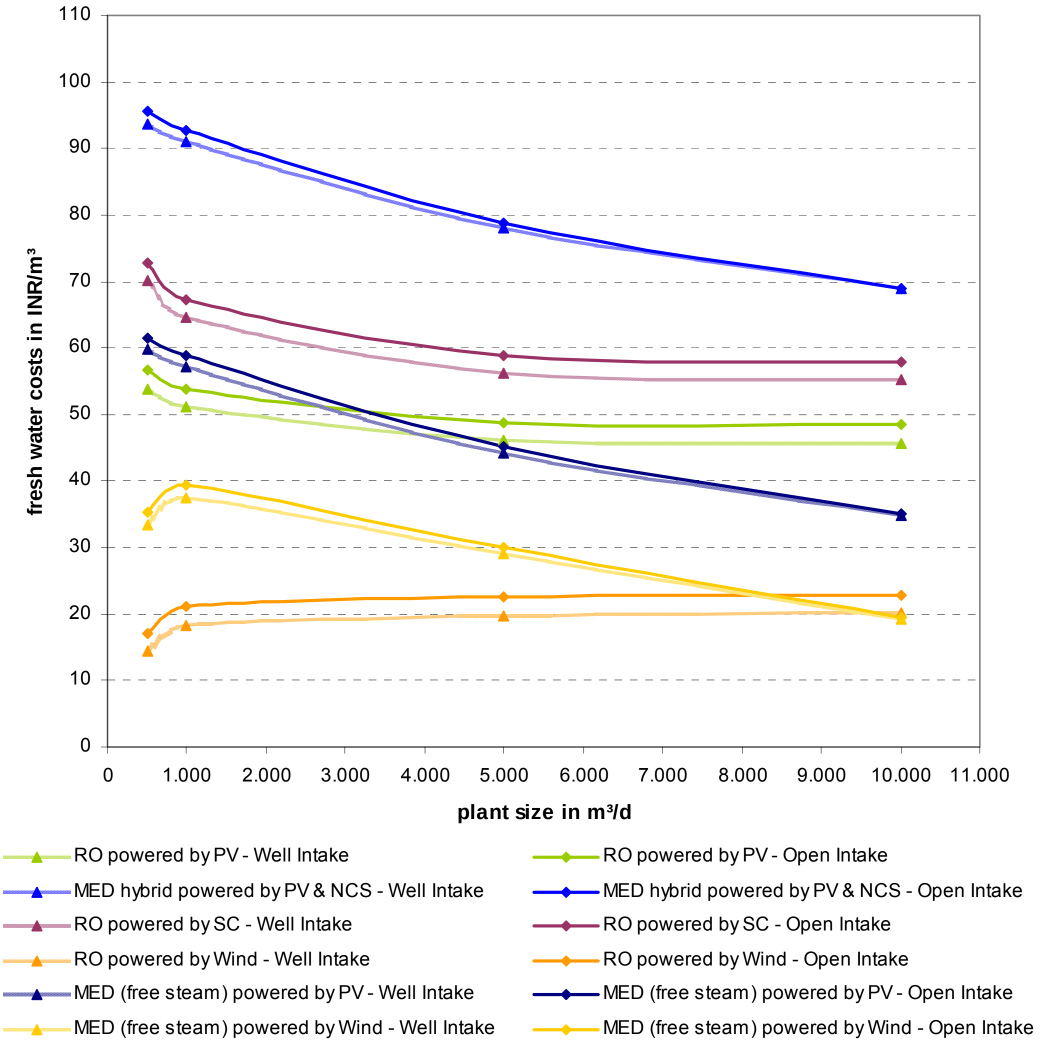

Fig. 53: Comparison of economical cost for Seawater desalination powered by renewable energy

The same problem of low useable direct radiation causes the high costs, 48 to 58 Rs/m³, for fresh water produced through **RO and Solar Concentration**. The cost per m³ produced via **RO and Photovoltaic** is between 46 to 53 Rs/m3, slightly lower.

Desalination using wind energy seems to be the cheapest option. The m³ cost ranges from 15 to 25 Rs. **However, the economical cost calculation for this scenario assumes that surplus energy produced by the wind turbine is sold for 2,7 Rs/kWh.**

There are several other combinations and technical optimization possible e.g. co generation power plants etc. They have not been considered in this economical cost calculation because much more research work would have been necessary and technical difficulties have to be discussed. Therefore the displayed scenarios give only an indication for the price tendency.

10. Important site aspects for implementation of a desalination plant in the Study Area

10.1. Location in the Region

For the location of the Desalination plant some conditions have to be fulfilled:

- The desalination plant should be located on the coast line
- There should be no development or village nearby
- The plant should be located in the study area or nearby (see Fig. 1)
- The beach or seashore on the side should allow the open extraction of seawater as well as the intake from well gallery (in view of space, see Fig. 54 and 55)
- The brine should be channeled after treatment back to the sea without disturbing the environment.

  Important: Brine disposal has a major environmental impact which has to be discussed in the feasibility study as a main point!
- The location should be Tsunami protected
- The delivering distance of raw water should be less than 1000 m.
- The chosen location should allow for the growth (extension) of the plant.

10.2. Extraction

10.2.1. Seawater extraction

The extraction point of raw water should be placed app. 300 till 400 m out from the seashore, because of pollution near the shore and the undercurrent and sediments. Raw seawater extraction requires a pre-treatment facility.

Furthermore, an impact study is necessary to clarify the following points:

- Government Permission
- Environmental and Social impact studies “Fishermen and fisher net”, brine disposal, etc.
- Construction of the extraction facilities such as pipes, foundations, buildings, etc
- Construction of Pre-Treatment facilities.

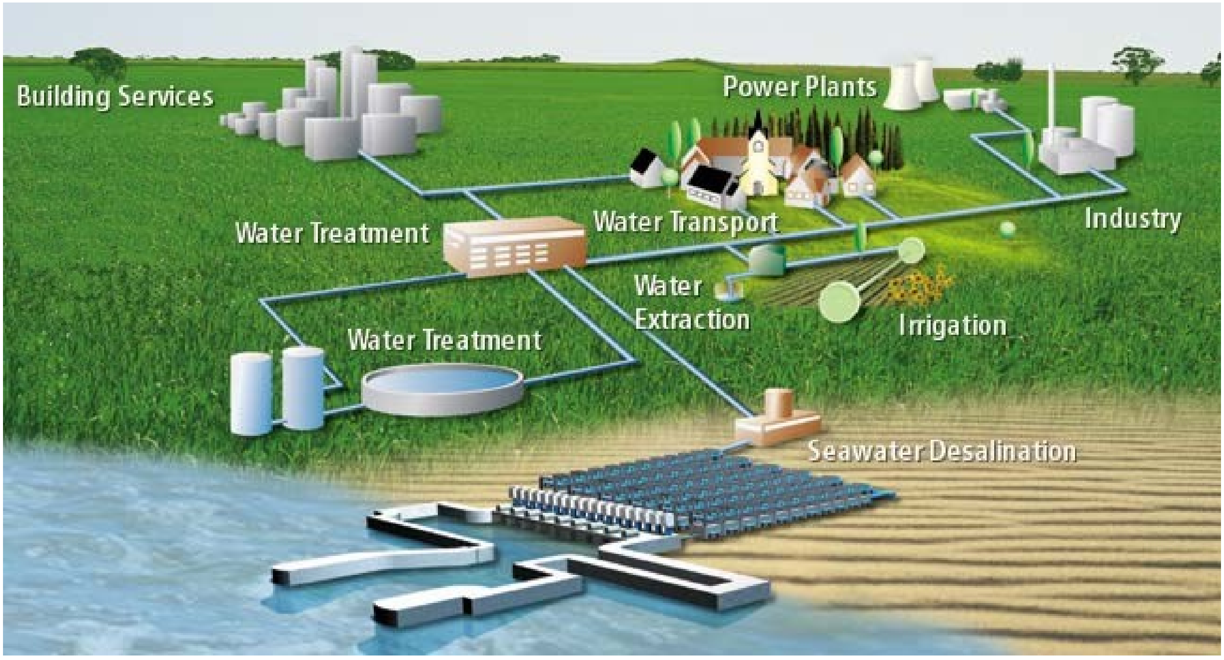

Fig. 54: Sketch of Seawater Extraction, Treatment and Supply

10.2.2. Well intake of Seawater

Well intake water extraction is another method to feed the Desalination plant. In this method, water is drawn not directly from the sea, but from a series of bore wells drilled near the shore. This water is pre-filtered because of the natural sand-seashore. A pre-treatment facility is not required.

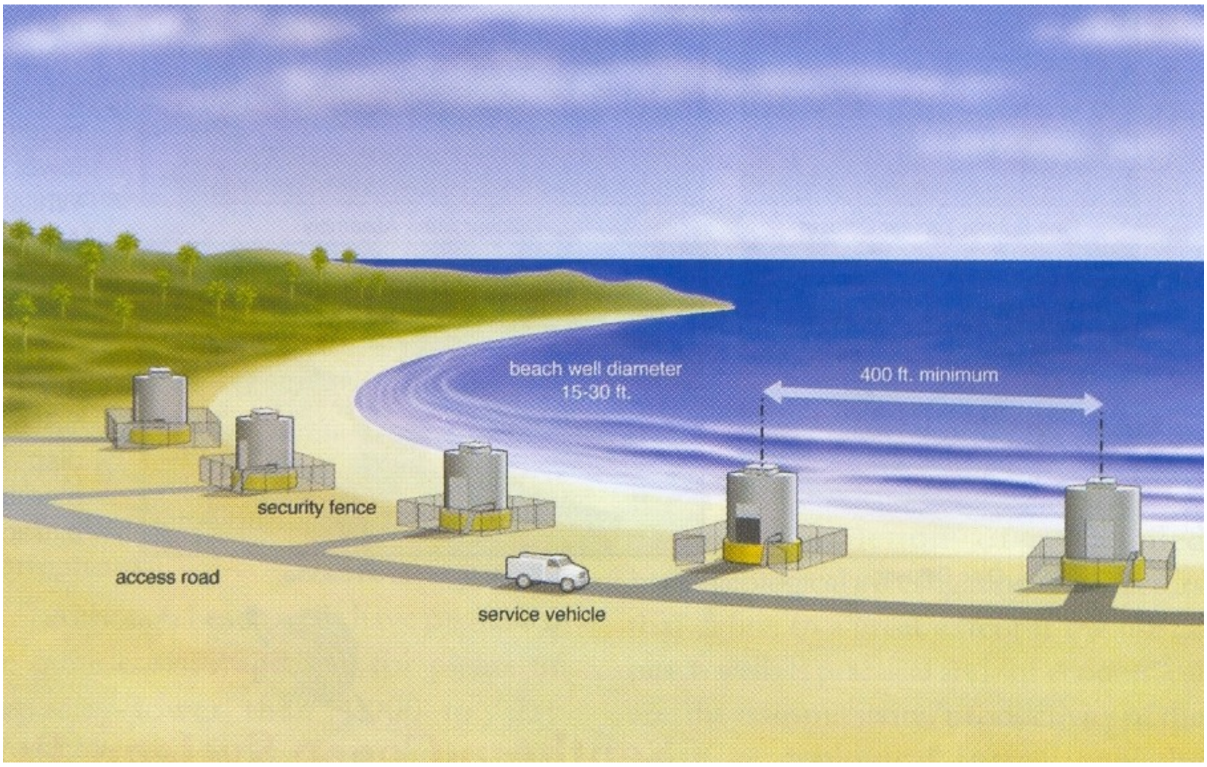

Fig. 55: Sketch of Well Gallery Extraction bore well gallery

To finalize a well gallery extraction it is necessary to clarify the following points:

- Government Permission
- Environmental Social impact studies “Fishermen”
- Well tests (groundwater flow and permeability)
- Construction of the extraction facilities such as pipes, foundations, buildings

The above necessary clarifications must be made in an earlier stage of the feasibility phase. The well test especially should be made over at least one whole year to demonstrate the functioning under all circumstances like monsoon, the hot summer period etc.

10.3. Government Permission

For water extraction out of the sea and for the necessary constructions and infrastructures at the seashore permission is necessary.

The responsible person in Tamil Nadu/ Villupuram district is the Executive Engineer, Public Works Department Villupuram (PWD- WRO). Furthermore the state Government of Tamil Nadu, Chennai, has to grant the permission.

In Pondicherry it is the Superintendent Engineer PWD-Pondicherry. The approval has to be given by the Pondicherry Government.

In the planning phase the local Panchayats have to be included as well.

10.4. Social and environmental impact study

A social- and environmental impact study is necessary in general and strongly recommended for the Bioregion of Auroville. The social impact study should be done in cooperation with the local Panchayats, Social workers and Auroville officials. The study must be positive, so that the people in the area benefit from it for example, employment at the plant, delivering of water against a small fee etc.

The environmental impact study should show that there is no pollution coming from the plant (especially for the fishermen) e.g. through brine disposal into the sea etc. A separate study on the brine disposal and cost calculation is necessary as well and has to be considered in the feasibility phase of the project.

10.5. Power supply

Since the power supply is the major key factor independent of what kind of Desalination plant will be built, a hybrid system must be developed. To produce water 24 hours a day, a constant power supply must be secured. This could be achieved e.g. by adding a biofuel or biogas driven generator. Another hybrid system could produce electricity via solar concentrators and use the “waste steam” for the distillation process.

In Nov. 2004 the President of India, Dr. Abdul Kalam had visited Pondicherry and Auroville. He presented Pondicherry a list of ten points related to environmental development and water issues (see chap. 17). One of these points was the waste land cultivation with oil trees plantings such as Pongamia and Jatropha. Biofuel can be extracted from the seeds of these trees, which could be used, in turn, to maintain the power supply of the plant.

10.6. Underground storage for fresh water

It is necessary to build fresh water underground storage tanks at the plant itself as well as in the distribution area. Those storage tanks should have a reserve capacity for a minimum of three days. The tanks must be sealed 100%, so that no pollution from outside can take place. The material shall be concrete. The tanks should be lined inside with HDPE (High Density Poly Ethylene) sheets, because this material is resistant to the growth of algae on its surface.

These storage facilities allow a certain amount of flexibility in the system itself, e.g. in times of maintenance, repair work or in case of weather problems, cyclones, storms, etc.:

10.7. Supply and distribution to the Study Area (basics)

The water supply from the Desalination plant to the different districts is a separate study. The main aspect for the distribution system is that all beneficiaries work together and not against each other. Basic ideas shall only be raised as topics in this report.

- Need of water, for coastal regions, Tsunami effected areas, existing villages, Auroville Township planning, industry and industrial areas etc.
- The area concerned should be split according to the technical parameters. Panchayat limits or districts boundaries etc. shall play a minor role.
- Panchayats must guarantee the safety of the water line during the crossing of village and paramboke land.
- Controlling of different sectors allows repairs and improvement in one sector without affecting the others.
- Material for the piping network must be HDPE 100 with a minimum strength of PN 10. PVC is according to WHO (World Health Organization), not suitable for drinking water supply because of Pollution through softener.
- The existing facilities inside the village or communities of Auroville like overhead tanks, storage places, pipe lines etc. can be used only after a general improvement of the piping network and storage tank system.

A detailed report on the water supply is part of the study “A sustainable Water Management Concept for Auroville and its Bioregion.”

11. What would be the right choice of a desalination plant for Auroville and its Bioregion?

This is the central question and not easy to answer. There are several more studies to be done before coming to a final decision or conclusion. At this point the Authors try to find a "direction".

In chapter 3.6 it is mentioned that there is no overall best method for the choice of a desalination plant. To find the best solution for the Auroville and its Bioregion at this point, the Author has defined important criteria which should be fulfilled as far as possible. After explanation of those aims, an evaluation follows by a matrix comparison of 4 kinds of plant sizes using RO and MED techniques, powered by alternative Energy devices.

- 500 m^3/d; 1,000 m^3/d; 5,000 m^3/d; 10,000 m^3/d

11.1. Aims

11.1.1. Easy handling, maintenance by a minimum of personnel

Operation and maintenance of the plant itself should be as easy as possible. That means a computerized system is required. The plant should be run by a minimum of highly qualified personnel.

The plant should be highly reliable, so that the maintenance costs are minimized. This guarantees not only an equal fresh water quality it reduces also the total production cost.

For the plant itself, jobs for maintenance should be created by employing people from the nearby villages; for example, mechanics, gardeners, watchmen, cleaning staff, etc. The surrounding area should always be kept 100% clean to avoid any possibility of pollution.

If one considers an alternative solar power plant, the requirement of workers will increase especially for maintenance work.

11.1.2. Economical Investment in combination with a long lifetime

The aim is to get the best and most economical system for Auroville and its Bioregion. The lifetime of the system should be at least 25 years.

The plant investment should be amortized as fast as possible.

11.1.3. Flexibility and easy extendibility

The plant has to have the possibility to be extended easily in the future to a higher capacity. One reason is the growth and the development of Auroville and its Bioregion. Another reason is the future need of water for the Matrimandir Lake. Furthermore, the deteriorating situation of the groundwater requires a flexibility of the plant in the future.

A detailed report on the groundwater situation is part of the study "A sustainable Water Management Concept for Auroville and its Bioregion."

11.1.4. Maximum efficiency in energy consumption, 24 h production

India has very limited oil resources of her own. Most oil has to be imported and the world market at present is very tight. The energy consumption of the proposed plant should be as low as possible; it doesn't matter whether the plant is connected to TNEB (Tamil Nadu Electricity Board) or to an alternative Energy Source. The fact is that the prices for commercial energy will increase and the price for alternative energy, such as photovoltaic, biofuel, wind or concentrated solar energy will decrease. As a result of this plants powered by conventional energy will have higher freshwater costs in the future.

A lower consumption of energy makes a combination with alternative energy easier. The CO_2 emission resulting from energy production and its impact on the world climate are undeniable. It is clear that with every liter of freshwater produced with conventional energy; the CO_2 emission has a negative impact on the world climate.

Furthermore, the system should produce 24 h water, because the utility factor is better than in a plant which runs only for 16 h. Under the circumstances, e.g. that TNEB current is not usually available for 24h, a hybrid facility is required. This facility will be designed according to the energy consumption. If the plant consumes a lot of energy, the price for the hybrid power will also increase.

11.1.5. Minimum use of chemicals, environmental impact

It is important to choose a desalination plant technology which has the lowest negative impact on the environment. Up to now it has been impossible to run a desalination plant without added chemicals. The aim must be to use a system which uses the least amount of chemicals. The chemicals which are used with the different desalting processes are mentioned in chap. 4.5.1.

If these chemicals remain untreated in the brine they will have a negative impact on the marine environment and therefore a negative impact on the income and life of the fishermen. A treatment plant has to be provided to extract the chemicals mentioned above from the brine before its disposal.

The occupational health and safety must be guaranteed for the employees at the plant (protection from chemicals etc.)

11.1.6. Multi Type Plant (brackish/ seawater)

It is possible in the future that the feed water quantity and quality change, so that it would be necessary to switch the plant to another resource e.g. from brackish water to pure seawater. The pump-able brackish water available today is a limited source, while seawater is endless. All these factors play major roles in the pros and cons of the different desalination techniques. For the above reasons the plant should be adjustable to varying concentrations of TDS.

11.1.7. Optimal use of the land

The area required by the plant should be as small as possible, because all the land has to be purchased first. Further more, land is not easily available.

11.2. Rating of the Aims

The Aims are clearly defined in chap. 11.1. The rating of the aims (in %, on the right below), was chosen according to the priorities.

1.	Easy handling, maintenance and minimum of personnel	10 %
2.	Economical investment in combination with a long lifetime	20 %
3.	Flexibility and easy extendibility	10 %
4.	Maximum efficiency in energy consumption, 24 h production	25 %
5.	Minimum use of chemicals, Environmental impact	20 %
6.	Multi Type Plant (brackish/ seawater)	10 %
7.	Optimal use of the land	5 %

The highest %, 25%, was set on Maximum efficiency in energy consumption, 24 h production, because efficiency is the key parameter in designing of any system.

The author considers economical investment as important as the clean environment. Therefore the aims Economical Investment in combination with a long lifetime and Minimum use of chemicals, Environmental impact, were weighted equally at 20%.

All three aims, easy handling, maintenance and minimum of personnel, flexibility and easy extendibility and Multi Type Plant (brackish/ seawater) are on the same level of importance. These aims are not crucial factors for the feasibility of the plant. Therefore the rating 10% was less than the previous aims.

Optimal use of the land, this aim got the lowest weight, 5%, because it was found that the land issue does not create such a strong pressure as, for example, the aim Investment..

To come finally to a conclusion the help of an assessment Matrix is necessary.

11.3. Assessment Matrix

For the Matrix (Fig. 56) the appraisal factor is fixed through the following scale.

0 = ***none***

1 = ***very poor***

2 = ***poor***

3 = ***acceptable***

4 = ***good***

5 = ***very good***

6 = ***best***

For the Evaluation of the proposals, the Authors compared the different Aims with the help of a Matrix.

			Combinations												Steam is available	
			RO / PV		MED_{hybrid} PV / NCS		MED_{hybrid} PV / SC		MED / SC		RO / SC		RO / Wind		MED_{hybrid} PV	
AIMS		rating in %	Appraisal	Evaluation	Appraisal	Evaluation	Appraisal	Evaluation	Appraisal	Evaluation	Appraisal	Evaluation	Appraisal	Evaluation	Appraisal	Evaluation
			I		II		III		IV		V		VI		II	
Aim 1	Easy handling, maintenance and minimum of personal	10	5	50	3	30	3	30	1	10	2	20	6	60	3	30
Aim 2	Economical Investment in combination with a long lifetime	20	4	80	2	40	0	0	0	0	3	60	6	120	4 **	80
Aim 3	Flexibility and easy extendibility	10	5	50	3	30	3	30	3	30	4	40	5	50	3	30
Aim 4	Maximum efficiency in energy consumption, 24 h production	25	4	100	0 *	0	0 *	0	0 *	0	4 *	100	4	100	6 **	150
Aim 5	Minimum use of chemicals, Environmental impact	20	2	40	4	80	4	80	4	80	2	40	2	40	4	80
Aim 6	Multi Type Plant (brackish/ seawater)	10	2	20	6	60	6	60	6	60	2	20	2	20	6	60
Aim 7	Optimal use of the land	5	3	15	0	0	0	0	0	0	3	15	6	30	4 **	20
	Result:	100		**355**		**240**		**200**		**180**		**295**		**420**		**450**
	Rank:			**2**		**4**		**5**		**6**		**3**		**1**		**1 ****
	Explanation:	Rating in %, Sum = 100; Appraisal (from 0 - 6) - 0 = none, 6 = best realisation of the Aim; Evaluation = valency (Rating in % x Appraisal)														
		* Steam has to be produced							** Steam is available							

Fig. 56: Evaluation Matrix

11.4. Explanation of the Evaluation of the Aims

11.4.1. Aim 1: Easy handling, maintenance and minimum of personnel

The handling of a RO plant is very simple, smaller sizes are pre-built in containers including all instruments and controlling systems, Fig. 57. The system is computerized and the plant can be run by two people only. Maintenance is also very easy, because of the design and accessibility of membranes and other components. Bigger systems are built as parallel connected "trains" or systems in industrial halls.

Wind turbines run practically without major maintenance requirements. The assessment for the combination of Wind energy and RO must therefore be “best”, 6 points.

As PV needs a lot of attention, frequent cleaning/ washing of the panels etc. the maintenance will be more,. This work can be easily done by unqualified personnel. The total work which has to be done is still acceptable and uncomplicated; therefore the assessment for the combination RO and Photovoltaic is 5 points.

Fig. 57: Small scale Desalination plant in pre fabricated containers

RO in combination with a Solar Concentrating Power Plant needs a lot of attention. Highly qualified personnel are needed to launch and run the Power Plant. Cleaning work of the solar trough system is as easy as cleaning of PV. The overall assessment for this aim is “poor”, 2 points.

MED as such needs more attention for maintenance in small scale desalination plants. Fig. 58, left and right, shows the sizes of small MED plants. In comparison to the RO Unit, the MED plant is big and the requirement of personnel is more. The handling and the maintenance in small scale thermal desalination plants, in relation to the fresh water production, is quite high. Above 5,000 m^3/d fresh water production the revenue and expenses are equal to that of RO plants.

2,000 m^3/d (0.5-mgd) vertically stacked MED plant in Japan

This MED unit in the United Arab Emirates has operated since 1985. The evacuated tube solar collectors in the foreground provide heated water input for the unit. Its design output is 80-m^3/d (0.02 mgd).

Fig. 58: 2000 m^3/d MED in Japan left, and 80 m^3/d solar MED in the Emirates

Solar Concentration only for steam production needs less maintenance than for electricity production, because no care has to be taken of the operating of turbines. The assessment for MED_{hybrid} combined with PV & SC or PV & NCS is therefore "acceptable", 3 points.

Three low-temperature MED plants on St. Thomas (V.I). Each plant has a capacity of about 5,000 m^3/d

Fig. 59: 15,000 m^3/d MED plant in St. Thomas, US

As mentioned above, the large MED plants require the same maintenance expenses as RO plants. The combination of MED + SC requires more attention because SC is producing steam as well as electricity so that the maintenance and handling of the bigger plant is "very poor", 1 point.

11.4.2. Aim 2: Economical Investment in combination with a long lifetime

The appraisal for the Economical Investment is based on the Economic Cost Calculation that was discussed in chap. 8. Graduations were made according to calculated costs for water. Because of the enormous water costs obtained by MED plants in combination with SC for steam supply the appraisal factor was set to 0.

The most economic scenario was found to be RO powered by wind turbines. The assessment therefore is "best", 6 points.

At 2^{nd} and 3^{rd} places follow the combinations RO & PV, "good", 4 points, and RO & SC, "acceptable", 3 points.

The combination MED_{hybrid} combined system PV & NCS was found to be "poor", 2 points.

11.4.3. Aim 3: Flexibility and easy extendibility

As mentioned above and discussed in chap. 3.3.2, RO plants can be built in modules, thus making a extendibility very easy. An extension of the wind park is also simple as well as the extension of the PV power plant. Therefore the appraisal for the RO & PV and RO & Wind combined systems is "very good", 5 points.

More work has to be done to increase the SC power field systems. The assessment for RO combined with SC is "acceptable", 3 points.

The MED units (see Fig. 59) are larger than the RO systems, thus an extension is more complicated. The extension of the electricity supply is, as mentioned above, easy for PV and more complicated for SC systems. To extend the steam supply from NCS or SC systems is indeed easier. Therefore the average appraisal for the thermal systems is "acceptable", 3 points.

11.4.4. Aim 4: Maximum efficiency in energy consumption, 24 h production

24 hours production is only possible if energy/steam is provided. The alternative energy devices work only periodically. All systems need a generator as back up.

In chap. 8 the power requirement for different desalination methods is displayed (Fig. 44). RO including an energy recovering device (4.5.3) requires app. 2.5 kWh/m^3, which can be assessed as "good", 4 points.

Thermal processes need app. 70 to 80 kWh/m^3. If free steam is available for the thermal desalination process, the electric power requirement for MED would only be 1.0 to 1.5 kW/h per m^3 (chap. 4.5.5). This is so far the optimal possible efficiency in a desalination process and the assessment is "best", 6 points. The assessment for the MED process is "none", 0 points, if steam has to be produced first.

11.4.5. Aim 5: Minimum use of chemicals, Environmental impact

As discussed in chap. 4.5.1 the pretreatment for RO requires high amounts of chemicals. These chemicals get disposed of with the brine and need further treatment. Therefore this aim reaches only "poor", 2 points.

The amount of chemicals used for the MED process is much lower but still the brine has an undeniable impact on marine environment and therefore the appraisal factor is "good", 4 points.

11.4.6. Aim 6: Multi Type Plant (brackish / seawater)

To change the intake for a RO plant from brackish water into sea water requires a full change of the membranes, pumps etc. Furthermore the power requirement will be higher for sea water intake, so that the electricity device would have to be extended, too. Therefore the assessment for the RO system is "poor", 2 points

A thermal desalination plant can handle brackish water as well as sea water, this is a big advantage! There is no need to change the power supply, too. The appraisal for thermal systems is "best" 6 points.

11.4.7. Aim 7: Optimal use of the land

If steam had to be produced for the MED plant by solar energy, huge areas would have to be covered to gain enough energy (see chap. 8.5.). The assessment factor is therefore "none", 0 points. Again with "free steam" being available the appraisal factor would rise to "good" with 4 points.

The land requirement for RO plants driven by PV or SC is still "acceptable", 3 points. The optimal use of land is reached with a RO combined wind energy system, "best", 6 points.

12. Conclusion

The question, "what would be the right desalination plant for Auroville and its Bioregion", was difficult to answer. Different proposals were made and different possible renewable energy devices assessed. After all one can say that with today's technical knowledge a RO system combined with a wind energy system is the best option. This proposal had reached a total of 420 points.

On rank 2 following with 355 points is the RO & PV system. The main difference between the two systems is the better performance of the wind energy device. This can change in the future if Photovoltaic cells could achieve a higher efficiency, e.g. 20 % or 25 % with lower investment prices.

The proposed MED systems combined with SC or NCS power supplies are playing a minor role because steam has to be produced first and this is economically a high investment. There is so far no power plant located in the Bioregion from where one could extract the steam, but it might be possible that Pondicherry or Auroville erect for example a waste incinerating plant. Then the MED_{hybrid} with PV or Wind would even be better than the RO & Wind System with 450 points.

Still, the desalination and renewable energy technologies are very young. What is the best today will be improved tomorrow. A fast change in these technologies can be guarantied during the century. Special attention should be given to Hydrogen Power systems or Low Temperature Desalination Processes (chap. 4.4.5)

Last but not least it shall be mentioned that Sri Aurobindo and the Mother have considered Solar Energy as the energy for the future, see chap. 16.

13. Thanks and greetings

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14. Annexure

14.1. Solar radiation time series for Pondicherry

Mean values data 1981 to 1985, Page 1

Mean global radiation on horizontal in W/m²

	6:30	7:30	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30
January	8	120	314	485	617	746	787	735	624	459	262	77	0
February	9	149	374	570	737	844	868	820	715	537	335	116	2
March	22	192	417	641	815	899	886	855	747	564	367	145	3
April	57	246	528	666	799	876	879	831	723	536	334	122	3
May	72	266	471	660	791	837	851	789	673	508	289	111	5
June	62	217	391	552	680	743	742	676	570	422	251	92	6
July	38	160	249	456	592	698	715	681	574	431	276	112	8
August	39	190	376	560	704	787	797	725	595	450	284	105	7
September	41	194	382	553	694	775	779	705	584	433	250	74	5
October	39	180	336	497	627	662	653	603	487	327	170	27	0
November	28	184	276	367	442	468	475	438	353	239	120	24	0
December	15	144	334	489	615	686	677	632	524	356	180	41	0

clearness index k

	6:30	7:30	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30
January		0.42	0.54	0.59	0.61	0.67	0.69	0.68	0.66	0.62	0.56	0.49	
February		0.51	0.62	0.65	0.69	0.70	0.70	0.69	0.68	0.63	0.58	0.45	
March	0.38	0.48	0.58	0.65	0.69	0.69	0.67	0.68	0.67	0.64	0.62	0.55	
April	0.34	0.49	0.65	0.63	0.64	0.65	0.65	0.65	0.64	0.60	0.56	0.45	
May	0.32	0.49	0.56	0.61	0.63	0.62	0.63	0.62	0.60	0.57	0.48	0.38	
June	0.23	0.38	0.46	0.51	0.55	0.56	0.56	0.54	0.52	0.49	0.43	0.33	
July	0.24	0.34	0.32	0.45	0.49	0.53	0.53	0.53	0.50	0.46	0.41	0.30	0.17
August	0.23	0.38	0.47	0.53	0.57	0.58	0.58	0.56	0.52	0.50	0.46	0.36	
September	0.26	0.39	0.48	0.53	0.56	0.58	0.58	0.56	0.54	0.51	0.46	0.35	
October	0.28	0.38	0.44	0.49	0.53	0.53	0.52	0.52	0.49	0.44	0.39	0.26	
November	0.39	0.47	0.41	0.40	0.41	0.40	0.41	0.41	0.39	0.35	0.31	0.34	
December	0.54	0.42	0.54	0.57	0.61	0.62	0.61	0.61	0.60	0.55	0.48	0.58	

Mean direct radiation on horizontal in W/m²

	6:30	7:30	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30
January		36	148	252	330	461	513	472	392	274	137	33	
February		68	227	360	486	568	575	531	462	322	182	41	1
March	6	74	219	394	536	580	532	535	473	341	221	76	1
April	10	95	336	373	448	492	487	470	419	288	165	42	
May	10	102	226	353	433	433	449	410	344	247	103	26	
June	2	40	113	194	268	300	299	260	212	144	68	13	
July	2	20	16	113	178	247	252	242	184	119	61	9	0
August	1	37	117	218	302	352	356	302	221	159	92	20	
September	2	44	127	213	295	348	347	298	235	168	83	14	
October	2	38	90	167	240	237	228	216	164	91	38	1	
November	8	69	64	70	81	74	80	78	58	32	11	4	
December	8	42	155	242	324	373	354	340	279	167	69	25	

Fig. 60: Solar radiation, mean values data 1981 to 1985 for Pondicherry, Page 1

Mean values data 1981 to 1985, Page 2													
Mean direct radiation on parabolic trough (tracking east-west) in W/m²													
	6:30	**7:30**	**8:30**	**9:30**	**10:30**	**11:30**	**12:30**	**13:30**	**14:30**	**15:30**	**16:30**	**17:30**	**18:30**
January	21	158	311	362	380	474	514	502	487	448	361	264	
February	19	308	486	527	568	588	575	555	549	485	411	209	1
March	132	252	414	539	605	594	533	564	570	519	504	387	1
April	77	256	568	480	492	499	489	500	510	442	375	212	
May	57	249	362	443	470	438	452	436	417	373	226	117	7
June	11	90	174	238	288	303	301	278	258	219	151	60	9
July	13	55	28	148	198	253	253	252	213	167	119	30	5
August	11	98	197	280	332	358	357	320	266	239	201	91	12
September	16	122	216	274	323	352	350	320	293	272	209	91	1
October	19	106	154	213	261	239	231	238	215	161	115	15	
November	139	223	116	92	89	75	81	86	77	57	34	79	
December	50	152	295	329	361	378	357	372	367	302	221	100	
Mean global radiation on tilted surface (23,5 degrees towards south in winter, horizontal in summer) in W/m²													
	6:30	**7:30**	**8:30**	**9:30**	**10:30**	**11:30**	**12:30**	**13:30**	**14:30**	**15:30**	**16:30**	**17:30**	**18:30**
January	11	146	374	565	701	843	890	839	727	550	327	119	0
February	11	178	430	639	808	911	931	884	786	601	382	135	
March	21	192	425	653	822	898	882	856	757	576	372	144	3
April	57	246	528	666	799	876	879	831	723	536	334	122	3
May	72	266	471	660	791	837	851	789	673	508	289	111	5
June	62	217	391	552	680	743	742	676	570	422	251	92	6
July	38	160	249	456	592	698	715	681	574	431	276	112	8
August	39	190	376	560	704	787	797	725	595	450	284	105	7
September	41	194	382	553	694	775	779	705	584	433	250	74	5
October	39	187	353	522	650	677	667	624	512	344	178	27	
November	47	219	298	385	457	476	484	452	367	247	123	35	
December	80	172	401	571	705	776	762	724	615	426	223	118	

Fig. 61: Solar radiation, mean values data 1981 to 1985 for Pondicherry, Page 2

	Comparision of Mean values data 1981 to 1985				
	daily total global Radiation	**clearness index k**	**mean direct Radiation on horizontal**	**mean direct Radiation on parabolic trough**	**tilt surface: 23,5° in winter, 0° in summer**
month	in kWh/m²*d	-	in kWh/m²*d	in kWh/m²*d	in kWh/m²*d
January	5.23	0.59	3.05	4.28	6.09
February	6.08	0.63	3.82	5.28	6.70
March	6.55	0.61	3.99	5.61	6.60
April	6.60	0.58	3.63	4.90	6.60
May	6.33	0.54	3.14	4.05	6.33
June	5.40	0.46	1.91	2.38	5.40
July	4.99	0.40	1.44	1.73	4.99
August	5.62	0.48	2.18	2.76	5.62
September	5.47	0.48	2.17	2.84	5.47
October	4.61	0.44	1.51	1.97	4.78
November	3.41	0.39	0.63	1.15	3.59
December	4.69	0.56	2.38	3.28	5.57
Mean	**5.41**	**0.51**	**2.49**	**3.35**	**5.64**

Fig. 62: Comparison of Solar radiation 1981 to 1985 for Pondicherry

14.2. Economical cost calculation sheets

Economical cost calculations for 500 m³ RO plant powered by PV

S E A WATER - O P E N INTAKE

Assumptions of costs:

Capital costs for 500 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
RO-plant	175 lakh	PV-maintenance	6 lakh	discounted Investment	Lakh Rs.
PV-plant	613 lakh	Chemicals	2 lakh	+operation cost	1,330
wells / seawater extraction plant (see pretreatment)	0 lakh	Spare parts (mft)	7 lakh		
land costs	20 lakh	Labour (10 employees)	9 lakh	discounted water production assuming an inflation-indexed price	m³
pretreatment & disposal	88 lakh	membrane replacement (every 3 to 5 years)	2-5 lakh		2,350,902
generator	6 lakh	operational costs per year	24 lakh		
capital nominally invested	902 lakh	nominal operational costs	707 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capita	1,028 lakh	present value of operational costs	302 lakh		56.58

availability of plant	95%	
water production	173,494	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 25 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	90.15			109.56			
	2	110%	811.35			894.43			
Start	3	100%		23.7		23.74	173,494	100.0%	173,494
	4	90.7%		24.7		22.40	173,494	94.3%	163,673
	5	82.3%		25.7		21.13	173,494	89.0%	154,409
	6	74.6%		26.7		19.93	173,494	84.0%	145,669
	7	67.7%		27.8	2	20.16	173,494	79.2%	137,423
	8	61.4%		28.9		17.74	173,494	74.7%	129,645
	9	55.7%		30.0		16.74	173,494	70.5%	122,306
	10	50.5%		31.2		15.79	173,494	66.5%	115,383
	11	45.8%		32.5		14.90	173,494	62.7%	108,852
	12	41.6%		33.8	3	15.30	173,494	59.2%	102,691
	13	37.7%		35.1		13.26	173,494	55.8%	96,878
	14	34.2%		36.5		12.51	173,494	52.7%	91,394
	15	31.0%		38.0		11.80	173,494	49.7%	86,221
	16	28.2%		39.5		11.13	173,494	46.9%	81,341
	17	25.5%		41.1	4	11.52	173,494	44.2%	76,736
	18	23.2%		42.8		9.91	173,494	41.7%	72,393
	19	21.0%		44.5		9.35	173,494	39.4%	68,295
	20	19.1%		46.2		8.82	173,494	37.1%	64,429
	21	17.3%		48.1		8.32	173,494	35.0%	60,782
	22	15.7%		50.0	5	8.63	173,494	33.1%	57,342
	23	14.2%		52.0		7.40	173,494	31.2%	54,096
	24	12.9%		54.1		6.98	173,494	29.4%	51,034
	25	11.7%		56.3		6.59	173,494	27.8%	48,145
	26	10.6%		58.5		6.22	173,494	26.2%	45,420
	27	9.6%		60.9		5.86	173,494	24.7%	42,849

Fig. 63: Economical Cost calculation: **RO 500 m³/d -- PV, Seawater Open Intake**

Economical cost calculations for 500 m^3 RO plant powered by PV

S E A WA T E R - W E L L   I N T A K E

Assumptions of costs:

Capital costs for 500 m^3/d in Lakh		**Operational costs in Lakh/a**		**Results of Calculation**	
RO-plant	175 lakh	PV-maintenance	6 lakh	discounted Investment +operation cost	Lakh Rs. 1,265
PV-plant	613 lakh	Chemicals	2 lakh		
wells / seawater extraction plant (see pretreatment)	20 lakh	Spare parts (mft)	7 lakh		
land costs	20 lakh	Labour (15 employees)	9 lakh	discounted water production assuming an inflation-indexed price	m^3 2,350,902
pretreatment & disposal	9 lakh	membrane replacement (every 3 to 5 years)	2-5 lakh		
generator	6 lakh	operational costs per year	24 lakh		
capital nominally invested	843 lakh	nominal operational costs	989 lakh	water price in first year of production, which grows annually with inflation	Rs/m^3 53.80
present value of capita	962 lakh	present value of operational costs	302 lakh		

availability of plant	95%	
water production	173,494	m^3/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 25 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m^3/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m^3/a
	1	122%	84.275			102.42			
	2	110%	758.475			836.14			
Start	3	100%		23.7		23.74	173,494	100.0%	173,494
	4	90.7%		24.7		22.40	173,494	94.3%	163,673
	5	82.3%		25.7		21.13	173,494	89.0%	154,409
	6	74.6%		26.7		19.93	173,494	84.0%	145,669
	7	67.7%		27.8	2	20.16	173,494	79.2%	137,423
	8	61.4%		28.9		17.74	173,494	74.7%	129,645
	9	55.7%		30.0		16.74	173,494	70.5%	122,306
	10	50.5%		31.2		15.79	173,494	66.5%	115,383
	11	45.8%		32.5		14.90	173,494	62.7%	108,852
	12	41.6%		33.8	3	15.30	173,494	59.2%	102,691
	13	37.7%		35.1		13.26	173,494	55.8%	96,878
	14	34.2%		36.5		12.51	173,494	52.7%	91,394
	15	31.0%		38.0		11.80	173,494	49.7%	86,221
	16	28.2%		39.5		11.13	173,494	46.9%	81,341
	17	25.5%		41.1	4	11.52	173,494	44.2%	76,736
	18	23.2%		42.8		9.91	173,494	41.7%	72,393
	19	21.0%		44.5		9.35	173,494	39.4%	68,295
	20	19.1%		46.2		8.82	173,494	37.1%	64,429
	21	17.3%		48.1		8.32	173,494	35.0%	60,782
	22	15.7%		50.0	5	8.63	173,494	33.1%	57,342
	23	14.2%		52.0		7.40	173,494	31.2%	54,096
	24	12.9%		54.1		6.98	173,494	29.4%	51,034
	25	11.7%		56.3		6.59	173,494	27.8%	48,145
	26	10.6%		58.5		6.22	173,494	26.2%	45,420
	27	9.6%		60.9		5.86	173,494	24.7%	42,849

Fig. 64: Economical Cost calculation: **RO 500 m^3/d -- PV, Well Intake**

Economical cost calculations for 1,000 m³ RO plant powered by PV

S E A WA T E R - O P E N   I N T A K E

Assumptions of costs:

Capital costs for 1,000 m³/d in Lakh		**Operational costs in Lakh/a**		**Results of Calculation**	
RO-plant	350 lakh	PV-maintenance	12 lakh	discounted Investment +operation cost	Lakh Rs. 2,531
PV-plant	1,225 lakh	Chemicals	3 lakh		
wells / seawater extraction plant (see pretreatment)	0 lakh	Spare parts (mft)	14 lakh		
land costs	40 lakh	Labour (20 employees)	9 lakh	discounted water production assuming an inflation-indexed price	m³ 4,701,805
pretreatment & disposal	175 lakh	membrane replacement (every 3 to 5 years)	4-10 lakh		
generator	8 lakh	operational costs per year	38 lakh		
capital nominally invested	1,798 lakh	nominal operational costs	1,597 lakh	water price in first year of production, which grows annually with inflation	Rs/m³ 53.83
present value of capita	2,041 lakh	present value of operational costs	490 lakh		

availability of plant	95%	
water production	346,988	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 25 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	179.8			218.51			
	2	110%	1,618.20			1,783.90			
Start	3	100%		38.3		38.34	346,988	100.0%	346,988
	4	90.7%		39.9		36.17	346,988	94.3%	327,347
	5	82.3%		41.5		34.12	346,988	89.0%	308,818
	6	74.6%		43.1		32.19	346,988	84.0%	291,337
	7	67.7%		44.9	4	33.08	346,988	79.2%	274,847
	8	61.4%		46.6		28.65	346,988	74.7%	259,289
	9	55.7%		48.5		27.03	346,988	70.5%	244,612
	10	50.5%		50.5		25.50	346,988	66.5%	230,767
	11	45.8%		52.5		24.06	346,988	62.7%	217,704
	12	41.6%		54.6	6	25.19	346,988	59.2%	205,381
	13	37.7%		56.8		21.41	346,988	55.8%	193,756
	14	34.2%		59.0		20.20	346,988	52.7%	182,789
	15	31.0%		61.4		19.05	346,988	49.7%	172,442
	16	28.2%		63.8		17.98	346,988	46.9%	162,681
	17	25.5%		66.4	8	19.00	346,988	44.2%	153,473
	18	23.2%		69.1		16.00	346,988	41.7%	144,786
	19	21.0%		71.8		15.09	346,988	39.4%	136,590
	20	19.1%		74.7		14.24	346,988	37.1%	128,859
	21	17.3%		77.7		13.43	346,988	35.0%	121,565
	22	15.7%		80.8	10	14.24	346,988	33.1%	114,684
	23	14.2%		84.0		11.95	346,988	31.2%	108,192
	24	12.9%		87.4		11.28	346,988	29.4%	102,068
	25	11.7%		90.9		10.64	346,988	27.8%	96,291
	26	10.6%		94.5		10.04	346,988	26.2%	90,840
	27	9.6%		98.3		9.47	346,988	24.7%	85,698

Fig. 65: Economical Cost calculation: **RO 1,000 m³/d -- PV**, **Seawater Open Intake**

Economical cost calculations for 1,000 m³ RO plant powered by PV

S E A W A T E R - W E L L I N T A K E

Assumptions of costs:

Capital costs for 1,000 m³/d in Lakh		**Operational costs in Lakh/a**		**Results of Calculation**	
RO-plant	350 lakh	PV-maintenance	12 lakh	discounted Investment	Lakh Rs.
PV-plant	1,225 lakh	Chemicals	3 lakh	+operation cost	2,400
wells / seawater extraction plant (see pretreatment)	40 lakh	Spare parts (mft)	14 lakh		
land costs	40 lakh	Labour (20 employees)	9 lakh	discounted water production assuming an inflation-indexed price	m³
pretreatment & disposal	18 lakh	membrane replacement (every 3 to 5 years)	4-10 lakh		4,701,805
generator	8 lakh	operational costs per year	38 lakh		
capital nominally invested	1,681 lakh	nominal operational costs	1,142 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capita	1,910 lakh	present value of operational costs	490 lakh		51.04

availability of plant	95%	
water production	346,988	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 25 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	168.05			204.23			
	2	110%	1,512.45			1,667.32			
Start	3	100%		38.3		38.34	346,988	100.0%	346,988
	4	90.7%		39.9		36.17	346,988	94.3%	327,347
	5	82.3%		41.5		34.12	346,988	89.0%	308,818
	6	74.6%		43.1		32.19	346,988	84.0%	291,337
	7	67.7%		44.9	4	33.08	346,988	79.2%	274,847
	8	61.4%		46.6		28.65	346,988	74.7%	259,289
	9	55.7%		48.5		27.03	346,988	70.5%	244,612
	10	50.5%		50.5		25.50	346,988	66.5%	230,767
	11	45.8%		52.5		24.06	346,988	62.7%	217,704
	12	41.6%		54.6	6	25.19	346,988	59.2%	205,381
	13	37.7%		56.8		21.41	346,988	55.8%	193,756
	14	34.2%		59.0		20.20	346,988	52.7%	182,789
	15	31.0%		61.4		19.05	346,988	49.7%	172,442
	16	28.2%		63.8		17.98	346,988	46.9%	162,681
	17	25.5%		66.4	8	19.00	346,988	44.2%	153,473
	18	23.2%		69.1		16.00	346,988	41.7%	144,786
	19	21.0%		71.8		15.09	346,988	39.4%	136,590
	20	19.1%		74.7		14.24	346,988	37.1%	128,859
	21	17.3%		77.7		13.43	346,988	35.0%	121,565
	22	15.7%		80.8	10	14.24	346,988	33.1%	114,684
	23	14.2%		84.0		11.95	346,988	31.2%	108,192
	24	12.9%		87.4		11.28	346,988	29.4%	102,068
	25	11.7%		90.9		10.64	346,988	27.8%	96,291
	26	10.6%		94.5		10.04	346,988	26.2%	90,840
	27	9.6%		98.3		9.47	346,988	24.7%	85,698

Fig. 66: Economical Cost calculation: **RO 1,000 m³/d -- PV, Well Intake**

Economical cost calculations for 5,000 m³ RO plant powered by PV

S E A WA T E R - O P E N I N T A K E

Assumptions of costs:

Capital costs for 5,000 m³/d in Lakh		**Operational costs in Lakh/a**		**Results of Calculation**	
RO-plant	1,750 lakh	PV-maintenance	55 lakh	discounted Investment	Lakh Rs.
PV-plant	5,513 lakh	Chemicals	16 lakh	+operation cost	11,473
wells / seawater extraction plant (see pretreatment)	0 lakh	Spare parts (mft)	69 lakh		
land costs	200 lakh	Labour (15 employees)	14 lakh	discounted water production assuming an inflation-indexed price	m³
pretreatment & disposal	875 lakh	membrane replacement (every 3 to 5 years)	20-50 lakh		23,509,023
generator	55 lakh	operational costs per year	154 lakh		
capital nominally invested	8,393 lakh	nominal operational costs	4,575 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capita	9,501 lakh	present value of operational costs	1,972 lakh		48.80

availability of plant	95%	
water production	1,734,938	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 25 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	839.3			1,019.99			
	2	110%	7,553.70			8,327.20			
Start	3	100%		153.6		153.63	1,734,938	100.0%	1,734,938
	4	90.7%		159.8		144.93	1,734,938	94.3%	1,636,733
	5	82.3%		166.2		136.73	1,734,938	89.0%	1,544,088
	6	74.6%		172.8		128.99	1,734,938	84.0%	1,456,687
	7	67.7%		179.7	20	135.23	1,734,938	79.2%	1,374,233
	8	61.4%		186.9		114.80	1,734,938	74.7%	1,296,446
	9	55.7%		194.4		108.30	1,734,938	70.5%	1,223,062
	10	50.5%		202.2		102.17	1,734,938	66.5%	1,153,833
	11	45.8%		210.2		96.39	1,734,938	62.7%	1,088,521
	12	41.6%		218.7	30	103.41	1,734,938	59.2%	1,026,907
	13	37.7%		227.4		85.78	1,734,938	55.8%	968,780
	14	34.2%		236.5		80.93	1,734,938	52.7%	913,943
	15	31.0%		246.0		76.35	1,734,938	49.7%	862,211
	16	28.2%		255.8		72.03	1,734,938	46.9%	813,406
	17	25.5%		266.0	40	78.17	1,734,938	44.2%	767,365
	18	23.2%		276.7		64.10	1,734,938	41.7%	723,929
	19	21.0%		287.7		60.47	1,734,938	39.4%	682,952
	20	19.1%		299.2		57.05	1,734,938	37.1%	644,294
	21	17.3%		311.2		53.82	1,734,938	35.0%	607,825
	22	15.7%		323.7	50	58.62	1,734,938	33.1%	573,419
	23	14.2%		336.6		47.90	1,734,938	31.2%	540,962
	24	12.9%		350.1		45.19	1,734,938	29.4%	510,341
	25	11.7%		364.1		42.63	1,734,938	27.8%	481,454
	26	10.6%		378.6		40.22	1,734,938	26.2%	454,202
	27	9.6%		393.8		37.94	1,734,938	24.7%	428,492

Fig. 67: Economical Cost calculation: **RO 5,000 m³/d -- PV, Seawater Open Intake**

Economical cost calculations for 5,000 m³ RO plant powered by PV

S E A WA T E R - W E L L I N T A K E

Assumptions of costs:

Capital costs for 5,000 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
RO-plant	1,750 lakh	PV-maintenance	55 lakh	discounted Investment	Lakh Rs.
PV-plant	5,513 lakh	Chemicals	16 lakh	+operation cost	10,819
wells / seawater extraction plant (see pretreatment)	200 lakh	Spare parts (mft)	69 lakh		
land costs	200 lakh	Labour (15 employees)	14 lakh	discounted water production assuming an inflation-indexed price	m³
pretreatment & disposal	88 lakh	membrane replacement (every 3 to 5 years)	20-50 lakh		23,509,023
generator	55 lakh	operational costs per year	154 lakh		
capital nominally invested	7,806 lakh	nominal operational costs	6,398 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capita	8,847 lakh	present value of operational costs	1,972 lakh		46.02

availability of plant	95%	
water production	1,734,938	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 25 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	780.55			948.59			
	2	110%	7,024.95			7,744.30			
Start	3	100%		153.6		153.63	1,734,938	100.0%	1,734,938
	4	90.7%		159.8		144.93	1,734,938	94.3%	1,636,733
	5	82.3%		166.2		136.73	1,734,938	89.0%	1,544,088
	6	74.6%		172.8		128.99	1,734,938	84.0%	1,456,687
	7	67.7%		179.7	20	135.23	1,734,938	79.2%	1,374,233
	8	61.4%		186.9		114.80	1,734,938	74.7%	1,296,446
	9	55.7%		194.4		108.30	1,734,938	70.5%	1,223,062
	10	50.5%		202.2		102.17	1,734,938	66.5%	1,153,833
	11	45.8%		210.2		96.39	1,734,938	62.7%	1,088,521
	12	41.6%		218.7	30	103.41	1,734,938	59.2%	1,026,907
	13	37.7%		227.4		85.78	1,734,938	55.8%	968,780
	14	34.2%		236.5		80.93	1,734,938	52.7%	913,943
	15	31.0%		246.0		76.35	1,734,938	49.7%	862,211
	16	28.2%		255.8		72.03	1,734,938	46.9%	813,406
	17	25.5%		266.0	40	78.17	1,734,938	44.2%	767,365
	18	23.2%		276.7		64.10	1,734,938	41.7%	723,929
	19	21.0%		287.7		60.47	1,734,938	39.4%	682,952
	20	19.1%		299.2		57.05	1,734,938	37.1%	644,294
	21	17.3%		311.2		53.82	1,734,938	35.0%	607,825
	22	15.7%		323.7	50	58.62	1,734,938	33.1%	573,419
	23	14.2%		336.6		47.90	1,734,938	31.2%	540,962
	24	12.9%		350.1		45.19	1,734,938	29.4%	510,341
	25	11.7%		364.1		42.63	1,734,938	27.8%	481,454
	26	10.6%		378.6		40.22	1,734,938	26.2%	454,202
	27	9.6%		393.8		37.94	1,734,938	24.7%	428,492

Fig. 68: Economical Cost calculation: **RO 5,000 m³/d -- PV, Well Intake**

Economical cost calculations for 10,000 m³ RO plant powered by PV

S E A WA T E R - O P E N I N T A K E

Assumptions of costs:

Capital costs for 10,000 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
RO-plant	3,500 lakh	PV-maintenance	110 lakh	discounted Investment	Lakh Rs.
PV-plant	11,026 lakh	Chemicals	32 lakh	+operation cost	22,778
wells / seawater extraction plant (see pretreatment)	0 lakh	Spare parts (mft)	138 lakh		
land costs	400 lakh	Labour (20 employees)	18 lakh	discounted water production assuming an inflation-indexed price	m³
pretreatment & disposal	1,750 lakh	membrane replacement (every 3 to 5 years)	40-100 lakh		47,018,047
generator	70 lakh	operational costs per year	298 lakh		
capital nominally invested	16,746 lakh	nominal operational costs	8,878 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capita	18,948 lakh	present value of operational costs	3,830 lakh		48.44

availability of plant	95%	
water production	3,469,875	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 25 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	1,674.60			2,035.12			
	2	110%	15,071.40			16,614.71			
Start	3	100%		298.1		298.12	3,469,875	100.0%	3,469,875
	4	90.7%		310.0		281.25	3,469,875	94.3%	3,273,467
	5	82.3%		322.4		265.33	3,469,875	89.0%	3,088,176
	6	74.6%		335.3		250.31	3,469,875	84.0%	2,913,374
	7	67.7%		348.8	40	263.22	3,469,875	79.2%	2,748,466
	8	61.4%		362.7		222.77	3,469,875	74.7%	2,592,892
	9	55.7%		377.2		210.16	3,469,875	70.5%	2,446,125
	10	50.5%		392.3		198.27	3,469,875	66.5%	2,307,665
	11	45.8%		408.0		187.05	3,469,875	62.7%	2,177,043
	12	41.6%		424.3	60	201.41	3,469,875	59.2%	2,053,814
	13	37.7%		441.3		166.47	3,469,875	55.8%	1,937,560
	14	34.2%		458.9		157.05	3,469,875	52.7%	1,827,887
	15	31.0%		477.3		148.16	3,469,875	49.7%	1,724,422
	16	28.2%		496.4		139.77	3,469,875	46.9%	1,626,813
	17	25.5%		516.3	80	152.29	3,469,875	44.2%	1,534,729
	18	23.2%		536.9		124.40	3,469,875	41.7%	1,447,858
	19	21.0%		558.4		117.35	3,469,875	39.4%	1,365,903
	20	19.1%		580.7		110.71	3,469,875	37.1%	1,288,588
	21	17.3%		603.9		104.45	3,469,875	35.0%	1,215,649
	22	15.7%		628.1	100	114.22	3,469,875	33.1%	1,146,839
	23	14.2%		653.2		92.96	3,469,875	31.2%	1,081,923
	24	12.9%		679.4		87.69	3,469,875	29.4%	1,020,682
	25	11.7%		706.5		82.73	3,469,875	27.8%	962,908
	26	10.6%		734.8		78.05	3,469,875	26.2%	908,404
	27	9.6%		764.2		73.63	3,469,875	24.7%	856,985

Fig. 69: Economical Cost calculation: **RO 10,000 m^3/d -- PV, Seawater Open Intake**

Economical cost calculations for 10,000 m³ RO plant powered by PV

SEA WATER-WELL INTAKE

Assumptions of costs:

Capital costs for 10,000 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
RO-plant	3,500 lakh	PV-maintenance	110 lakh	discounted Investment	Lakh Rs.
PV-plant	11,026 lakh	Chemicals	32 lakh	+operation cost	21,469
wells / seawater extraction plant (see pretreatment)	400 lakh	Spare parts (mft)	138 lakh		
land costs	400 lakh	Labour (20 employees)	18 lakh	discounted water	m³
pretreatment & disposal	175 lakh	membrane replacement (every 3 to 5 years)	40-100 lakh	production assuming an inflation-indexed price	47,018,047
generator	70 lakh	operational costs per year	298 lakh		
capital nominally invested	15,571 lakh	nominal operational costs	8,878 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capita	17,639 lakh	present value of operational costs	3,830 lakh		45.66

availability of plant	95%	
water production	3,469,875	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 25 year

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	1,557.10			1,892.32			
	2	110%	14,013.90			15,448.92			
Start	3	100%		298.1		298.12	3,469,875	100.0%	3,469,875
	4	90.7%		310.0		281.25	3,469,875	94.3%	3,273,467
	5	82.3%		322.4		265.33	3,469,875	89.0%	3,088,176
	6	74.6%		335.3		250.31	3,469,875	84.0%	2,913,374
	7	67.7%		348.8	40	263.22	3,469,875	79.2%	2,748,466
	8	61.4%		362.7		222.77	3,469,875	74.7%	2,592,892
	9	55.7%		377.2		210.16	3,469,875	70.5%	2,446,125
	10	50.5%		392.3		198.27	3,469,875	66.5%	2,307,665
	11	45.8%		408.0		187.05	3,469,875	62.7%	2,177,043
	12	41.6%		424.3	60	201.41	3,469,875	59.2%	2,053,814
	13	37.7%		441.3		166.47	3,469,875	55.8%	1,937,560
	14	34.2%		458.9		157.05	3,469,875	52.7%	1,827,887
	15	31.0%		477.3		148.16	3,469,875	49.7%	1,724,422
	16	28.2%		496.4		139.77	3,469,875	46.9%	1,626,813
	17	25.5%		516.3	80	152.29	3,469,875	44.2%	1,534,729
	18	23.2%		536.9		124.40	3,469,875	41.7%	1,447,858
	19	21.0%		558.4		117.35	3,469,875	39.4%	1,365,903
	20	19.1%		580.7		110.71	3,469,875	37.1%	1,288,588
	21	17.3%		603.9		104.45	3,469,875	35.0%	1,215,649
	22	15.7%		628.1	100	114.22	3,469,875	33.1%	1,146,839
	23	14.2%		653.2		92.96	3,469,875	31.2%	1,081,923
	24	12.9%		679.4		87.69	3,469,875	29.4%	1,020,682
	25	11.7%		706.5		82.73	3,469,875	27.8%	962,908
	26	10.6%		734.8		78.05	3,469,875	26.2%	908,404
	27	9.6%		764.2		73.63	3,469,875	24.7%	856,985

Fig. 70: Economical Cost calculation: **RO 10,000 m³/d -- PV, Well Intake**

Economical cost calculations for 500 m^3 MED plant pow. by NCS/PV

S E A W A T E R - O P E N   I N T A K E

Assumptions of costs:

Capital costs for 500 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
MED-plant	660 lakh	PV & NCS maintenance	9 lakh	discounted Investment	Lakh Rs.
PV & NCS plant	862 lakh	Chemicals	1 lakh	+operation cost	2,415
wells / seawater extraction plant (see pretreatment)	0 lakh	Spare parts	7 lakh		
land costs	200 lakh	Labour (10 employees)	9 lakh	discounted water	m³
pretreatment & disposal	66 lakh	membrane replacement (every 3 to 5 years)	0 lakh	production assuming an inflation-indexed price	2,528,532
generator	15 lakh	operational costs per year	25 lakh		
capital nominally invested	1,803 lakh	nominal operational costs	1,410 lakh	water price in first year of	Rs/m³
present value of capita	2,033 lakh	present value of operational costs	382 lakh	production, which grows annually with inflation	95.50

availability of plant	95%	
water production	173,494	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	180.3			219.12			
	2	110%	1,622.7			1,788.86			
Start	3	100%		25.1		25.15	173,494	100.0%	173,494
	4	90.7%		26.2		23.72	173,494	94.3%	163,673
	5	82.3%		27.2		22.38	173,494	89.0%	154,409
	6	74.6%		28.3		21.11	173,494	84.0%	145,669
	7	67.7%		29.4		19.92	173,494	79.2%	137,423
	8	61.4%		30.6		18.79	173,494	74.7%	129,645
	9	55.7%		31.8		17.73	173,494	70.5%	122,306
	10	50.5%		33.1		16.72	173,494	66.5%	115,383
	11	45.8%		34.4		15.78	173,494	62.7%	108,852
	12	41.6%		35.8		14.88	173,494	59.2%	102,691
	13	37.7%		37.2		14.04	173,494	55.8%	96,878
	14	34.2%		38.7		13.25	173,494	52.7%	91,394
	15	31.0%		40.3		12.50	173,494	49.7%	86,221
	16	28.2%		41.9		11.79	173,494	46.9%	81,341
	17	25.5%		43.5		11.12	173,494	44.2%	76,736
	18	23.2%		45.3		10.49	173,494	41.7%	72,393
	19	21.0%		47.1		9.90	173,494	39.4%	68,295
	20	19.1%		49.0		9.34	173,494	37.1%	64,429
	21	17.3%		50.9		8.81	173,494	35.0%	60,782
	22	15.7%		53.0	254	48.09	164,819	33.1%	54,475
	23	14.2%		55.1		7.84	173,494	31.2%	54,096
	24	12.9%		57.3		7.40	173,494	29.4%	51,034
	25	11.7%		59.6		6.98	173,494	27.8%	48,145
	26	10.6%		62.0		6.58	173,494	26.2%	45,420
	27	9.6%		64.5		6.21	173,494	24.7%	42,849
	28	8.7%		67.0		5.86	173,494	23.3%	40,424
	29	7.9%		69.7		5.53	173,494	22.0%	38,136
	30	7.2%		72.5		5.21	173,494	20.7%	35,977
	31	6.5%		75.4		4.92	173,494	19.6%	33,941
	32	5.9%		78.4		4.64	173,494	18.5%	32,019

Fig. 71: Economical. Cost calculation: **MED_{hybrid} 500 m^3/d -- NCS/PV**, **Seawater Open Intake**

Economical cost calculations for 500 m³ MED plant pow. by NCS/PV

S E A WA T E R - W E L L INTAKE

Assumptions of costs:

Capital costs for 500 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
MED-plant	660 lakh	PV & NCS maintenance	9 lakh	discounted Investment +operation cost	Lakh Rs. 2,371
PV & NCS plant	862 lakh	Chemicals	1 lakh		
wells / seawater extraction plant (see pretreatment)	20 lakh	Spare parts	7 lakh		
land costs	200 lakh	Labour (10 employees)	9 lakh	discounted water production assuming an inflation-indexed price	m³ 2,528,532
pretreatment & disposal	7 lakh	membrane replacement (every 3 to 5 years)	0 lakh		
generator	15 lakh	operational costs per year	25 lakh		
capital nominally invested	1,764 lakh	nominal operational costs	1,410 lakh	water price in first year of production, which grows annually with inflation	Rs/m³ 93.76
present value of capita	1,989 lakh	present value of operational costs	382 lakh		

availability of plant	95%	
water production	173,494	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	176.4			214.33			
	2	110%	1,587.2			1,749.77			
Start	3	100%		25.1		25.15	173,494	100.0%	173,494
	4	90.7%		26.2		23.72	173,494	94.3%	163,673
	5	82.3%		27.2		22.38	173,494	89.0%	154,409
	6	74.6%		28.3		21.11	173,494	84.0%	145,669
	7	67.7%		29.4		19.92	173,494	79.2%	137,423
	8	61.4%		30.6		18.79	173,494	74.7%	129,645
	9	55.7%		31.8		17.73	173,494	70.5%	122,306
	10	50.5%		33.1		16.72	173,494	66.5%	115,383
	11	45.8%		34.4		15.78	173,494	62.7%	108,852
	12	41.6%		35.8		14.88	173,494	59.2%	102,691
	13	37.7%		37.2		14.04	173,494	55.8%	96,878
	14	34.2%		38.7		13.25	173,494	52.7%	91,394
	15	31.0%		40.3		12.50	173,494	49.7%	86,221
	16	28.2%		41.9		11.79	173,494	46.9%	81,341
	17	25.5%		43.5		11.12	173,494	44.2%	76,736
	18	23.2%		45.3		10.49	173,494	41.7%	72,393
	19	21.0%		47.1		9.90	173,494	39.4%	68,295
	20	19.1%		49.0		9.34	173,494	37.1%	64,429
	21	17.3%		50.9		8.81	173,494	35.0%	60,782
	22	15.7%		53.0	254	48.09	164,819	33.1%	54,475
	23	14.2%		55.1		7.84	173,494	31.2%	54,096
	24	12.9%		57.3		7.40	173,494	29.4%	51,034
	25	11.7%		59.6		6.98	173,494	27.8%	48,145
	26	10.6%		62.0		6.58	173,494	26.2%	45,420
	27	9.6%		64.5		6.21	173,494	24.7%	42,849
	28	8.7%		67.0		5.86	173,494	23.3%	40,424
	29	7.9%		69.7		5.53	173,494	22.0%	38,136
	30	7.2%		72.5		5.21	173,494	20.7%	35,977
	31	6.5%		75.4		4.92	173,494	19.6%	33,941
	32	5.9%		78.4		4.64	173,494	18.5%	32,019

Fig. 72: Economical Cost calculation: **MED_{hybrid} 500 m³/d -- NSC/PV, Well Intake**

Economical cost calculations for 1,000 m³ MED plant pow. by NCS/PV

S E A W A T E R - O P E N I N T A K E

Assumptions of costs:

Capital costs for 1,000 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
MED-plant	1,320 lakh	PV & NCS maintenance	17 lakh	discounted Investment +operation cost	Lakh Rs.
PV & NCS plant	1,722 lakh	Chemicals	2 lakh		4,694
wells / seawater extraction plant (see pretreatment)	0 lakh	Spare parts	13 lakh		
land costs	400 lakh	Labour (10 employees)	9 lakh	discounted water production assuming an inflation-indexed price	m³
pretreatment & disposal	132 lakh	membrane replacement (every 3 to 5 years)	0 lakh		5,057,064
generator	30 lakh	operational costs per year	41 lakh		
capital nominally invested	3,604 lakh	nominal operational costs	2,307 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capita	4,055 lakh	present value of operational costs	639 lakh		92.81

availability of plant	95%	
water production	346,988	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 30 years

Disc.Factor for Water assuming the water-price rises with inflation

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	6.00% %/a	discounted water prod. m³/a
	1	122%	360.4			437.99			
	2	110%	3,243.6			3,575.74			
Start	3	100%		41.1		41.14	346,988	100.0%	346,988
	4	90.7%		42.8		38.81	346,988	94.3%	327,347
	5	82.3%		44.5		36.62	346,988	89.0%	308,818
	6	74.6%		46.3		34.54	346,988	84.0%	291,337
	7	67.7%		48.1		32.59	346,988	79.2%	274,847
	8	61.4%		50.1		30.74	346,988	74.7%	259,289
	9	55.7%		52.1		29.00	346,988	70.5%	244,612
	10	50.5%		54.1		27.36	346,988	66.5%	230,767
	11	45.8%		56.3		25.81	346,988	62.7%	217,704
	12	41.6%		58.6		24.35	346,988	59.2%	205,381
	13	37.7%		60.9		22.97	346,988	55.8%	193,756
	14	34.2%		63.3		21.67	346,988	52.7%	182,789
	15	31.0%		65.9		20.45	346,988	49.7%	172,442
	16	28.2%		68.5		19.29	346,988	46.9%	162,681
	17	25.5%		71.2		18.20	346,988	44.2%	153,473
	18	23.2%		74.1		17.17	346,988	41.7%	144,786
	19	21.0%		77.1		16.20	346,988	39.4%	136,590
	20	19.1%		80.1		15.28	346,988	37.1%	128,859
	21	17.3%		83.3		14.41	346,988	35.0%	121,565
	22	15.7%		86.7	507	93.09	329,638	33.1%	108,950
	23	14.2%		90.1		12.83	346,988	31.2%	108,192
	24	12.9%		93.8		12.10	346,988	29.4%	102,068
	25	11.7%		97.5		11.42	346,988	27.8%	96,291
	26	10.6%		101.4		10.77	346,988	26.2%	90,840
	27	9.6%		105.5		10.16	346,988	24.7%	85,698
	28	8.7%		109.7		9.59	346,988	23.3%	80,848
	29	7.9%		114.1		9.04	346,988	22.0%	76,271
	30	7.2%		118.6		8.53	346,988	20.7%	71,954
	31	6.5%		123.4		8.05	346,988	19.6%	67,881
	32	5.9%		128.3		7.59	346,988	18.5%	64,039

Fig. 73: Economical Cost calculation: **MED_{hybrid} 1,000 m³/d -- NCS/PV, Seawater Open Intake**

Economical cost calculations for 1,000 m³ MED plant pow. by NCS/PV

S E A W A T E R - W E L L   I N T A K E

Assumptions of costs:

Capital costs for 1,000 m³/d in Lakh		**Operational costs in Lakh/a**		**Results of Calculation**	
MED-plant	1,320 lakh	PV & NCS maintenance	17 lakh	discounted Investment +operation cost	Lakh Rs.
PV & NCS plant	1,722 lakh	Chemicals	2 lakh		4,606
wells / seawater extraction plant (see pretreatment)	40 lakh	Spare parts	13 lakh		
land costs	400 lakh	Labour (10 employees)	9 lakh	discounted water production assuming an inflation-indexed price	m³
pretreatment & disposal	13 lakh	membrane replacement (every 3 to 5 years)	0 lakh		5,057,064
generator	30 lakh	operational costs per year	41 lakh		
capital nominally invested	3,525 lakh	nominal operational costs	2,307 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capita	3,967 lakh	present value of operational costs	639 lakh		91.08

availability of plant	95%	
water production	346,988	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	352.5			428.41			
	2	110%	3,172.7			3,497.56			
Start	3	100%		41.1		41.14	346,988	100.0%	346,988
	4	90.7%		42.8		38.81	346,988	94.3%	327,347
	5	82.3%		44.5		36.62	346,988	89.0%	308,818
	6	74.6%		46.3		34.54	346,988	84.0%	291,337
	7	67.7%		48.1		32.59	346,988	79.2%	274,847
	8	61.4%		50.1		30.74	346,988	74.7%	259,289
	9	55.7%		52.1		29.00	346,988	70.5%	244,612
	10	50.5%		54.1		27.36	346,988	66.5%	230,767
	11	45.8%		56.3		25.81	346,988	62.7%	217,704
	12	41.6%		58.6		24.35	346,988	59.2%	205,381
	13	37.7%		60.9		22.97	346,988	55.8%	193,756
	14	34.2%		63.3		21.67	346,988	52.7%	182,789
	15	31.0%		65.9		20.45	346,988	49.7%	172,442
	16	28.2%		68.5		19.29	346,988	46.9%	162,681
	17	25.5%		71.2		18.20	346,988	44.2%	153,473
	18	23.2%		74.1		17.17	346,988	41.7%	144,786
	19	21.0%		77.1		16.20	346,988	39.4%	136,590
	20	19.1%		80.1		15.28	346,988	37.1%	128,859
	21	17.3%		83.3		14.41	346,988	35.0%	121,565
	22	15.7%		86.7	507	93.09	329,638	33.1%	108,950
	23	14.2%		90.1		12.83	346,988	31.2%	108,192
	24	12.9%		93.8		12.10	346,988	29.4%	102,068
	25	11.7%		97.5		11.42	346,988	27.8%	96,291
	26	10.6%		101.4		10.77	346,988	26.2%	90,840
	27	9.6%		105.5		10.16	346,988	24.7%	85,698
	28	8.7%		109.7		9.59	346,988	23.3%	80,848
	29	7.9%		114.1		9.04	346,988	22.0%	76,271
	30	7.2%		118.6		8.53	346,988	20.7%	71,954
	31	6.5%		123.4		8.05	346,988	19.6%	67,881
	32	5.9%		128.3		7.59	346,988	18.5%	64,039

Fig. 74: Economical Cost calculation: **MED_{hybrid} 1,000 m^3/d -- NCS/PV, Well Intake**

Economical cost calculations for 5,000 m³ MED plant pow. by NCS/PV

S E A W A T E R - O P E N I N T A K E

Assumptions of costs:

Capital costs for 5,000 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
MED-plant	4,400 lakh	PV & NCS maintenance	86 lakh	discounted Investment +operation cost	Lakh Rs.
PV & NCS plant	8,611 lakh	Chemicals	8 lakh		19,927
wells / seawater extraction plant (see pretreatment)	0 lakh	Spare parts	44 lakh		
land costs	2,000 lakh	Labour (15 employees)	14 lakh	discounted water production assuming an inflation-indexed price	m³
pretreatment & disposal	440 lakh	membrane replacement (every 3 to 5 years)	0 lakh		25,285,318
generator	100 lakh	operational costs per year	152 lakh		
capital nominally invested	15,551 lakh	nominal operational costs	8,511 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capita	17,471 lakh	present value of operational costs	2,457 lakh		78.81

availability of plant	95%	
water production	1,734,938	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	1,555.1			1,889.89			
	2	110%	13,995.9			15,429.08			
Start	3	100%		151.8		151.76	1,734,938	100.0%	1,734,938
	4	90.7%		157.8		143.17	1,734,938	94.3%	1,636,733
	5	82.3%		164.1		135.06	1,734,938	89.0%	1,544,088
	6	74.6%		170.7		127.42	1,734,938	84.0%	1,456,687
	7	67.7%		177.5		120.21	1,734,938	79.2%	1,374,233
	8	61.4%		184.6		113.40	1,734,938	74.7%	1,296,446
	9	55.7%		192.0		106.98	1,734,938	70.5%	1,223,062
	10	50.5%		199.7		100.93	1,734,938	66.5%	1,153,833
	11	45.8%		207.7		95.21	1,734,938	62.7%	1,088,521
	12	41.6%		216.0		89.82	1,734,938	59.2%	1,026,907
	13	37.7%		224.6		84.74	1,734,938	55.8%	968,780
	14	34.2%		233.6		79.94	1,734,938	52.7%	913,943
	15	31.0%		243.0		75.42	1,734,938	49.7%	862,211
	16	28.2%		252.7		71.15	1,734,938	46.9%	813,406
	17	25.5%		262.8		67.12	1,734,938	44.2%	767,365
	18	23.2%		273.3		63.32	1,734,938	41.7%	723,929
	19	21.0%		284.2		59.74	1,734,938	39.4%	682,952
	20	19.1%		295.6		56.36	1,734,938	37.1%	644,294
	21	17.3%		307.4		53.17	1,734,938	35.0%	607,825
	22	15.7%		319.7	2,512	444.23	1,648,191	33.1%	544,748
	23	14.2%		332.5		47.32	1,734,938	31.2%	540,962
	24	12.9%		345.8		44.64	1,734,938	29.4%	510,341
	25	11.7%		359.7		42.11	1,734,938	27.8%	481,454
	26	10.6%		374.0		39.73	1,734,938	26.2%	454,202
	27	9.6%		389.0		37.48	1,734,938	24.7%	428,492
	28	8.7%		404.6		35.36	1,734,938	23.3%	404,238
	29	7.9%		420.7		33.36	1,734,938	22.0%	381,357
	30	7.2%		437.6		31.47	1,734,938	20.7%	359,770
	31	6.5%		455.1		29.69	1,734,938	19.6%	339,406
	32	5.9%		473.3		28.01	1,734,938	18.5%	320,194

Fig. 75: Economical Cost calculation: **MED_{hybrid} 5,000 m^3/d -- NCS/PV, Seawater Open Intake**

Economical cost calculations for 5,000 m³ MED plant pow. by NCS/PV

S E A W A T E R - W E L L I N T A K E

Assumptions of costs:

Capital costs for 5,000 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
MED-plant	4,400 lakh	PV & NCS maintenance	86 lakh	discounted Investment +operation cost	Lakh Rs.
PV & NCS plant	8,611 lakh	Chemicals	8 lakh		19,709
wells / seawater extraction plant (see pretreatment)	200 lakh	Spare parts	44 lakh		
land costs	2,000 lakh	Labour (15 employees)	14 lakh	discounted water production assuming an inflation-indexed price	m³
pretreatment & disposal	44 lakh	membrane replacement (every 3 to 5 years)	0 lakh		25,285,318
generator	100 lakh	operational costs per year	152 lakh		
capital nominally invested	15,355 lakh	nominal operational costs	8,511 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capita	17,252 lakh	present value of operational costs	2,457 lakh		77.95

availability of plant	95%	
water production	1,734,938	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	1,535.5			1,866.07			
	2	110%	13,819.5			15,234.62			
Start	3	100%		151.8		151.76	1,734,938	100.0%	1,734,938
	4	90.7%		157.8		143.17	1,734,938	94.3%	1,636,733
	5	82.3%		164.1		135.06	1,734,938	89.0%	1,544,088
	6	74.6%		170.7		127.42	1,734,938	84.0%	1,456,687
	7	67.7%		177.5		120.21	1,734,938	79.2%	1,374,233
	8	61.4%		184.6		113.40	1,734,938	74.7%	1,296,446
	9	55.7%		192.0		106.98	1,734,938	70.5%	1,223,062
	10	50.5%		199.7		100.93	1,734,938	66.5%	1,153,833
	11	45.8%		207.7		95.21	1,734,938	62.7%	1,088,521
	12	41.6%		216.0		89.82	1,734,938	59.2%	1,026,907
	13	37.7%		224.6		84.74	1,734,938	55.8%	968,780
	14	34.2%		233.6		79.94	1,734,938	52.7%	913,943
	15	31.0%		243.0		75.42	1,734,938	49.7%	862,211
	16	28.2%		252.7		71.15	1,734,938	46.9%	813,406
	17	25.5%		262.8		67.12	1,734,938	44.2%	767,365
	18	23.2%		273.3		63.32	1,734,938	41.7%	723,929
	19	21.0%		284.2		59.74	1,734,938	39.4%	682,952
	20	19.1%		295.6		56.36	1,734,938	37.1%	644,294
	21	17.3%		307.4		53.17	1,734,938	35.0%	607,825
	22	15.7%		319.7	2,512	444.23	1,648,191	33.1%	544,748
	23	14.2%		332.5		47.32	1,734,938	31.2%	540,962
	24	12.9%		345.8		44.64	1,734,938	29.4%	510,341
	25	11.7%		359.7		42.11	1,734,938	27.8%	481,454
	26	10.6%		374.0		39.73	1,734,938	26.2%	454,202
	27	9.6%		389.0		37.48	1,734,938	24.7%	428,492
	28	8.7%		404.6		35.36	1,734,938	23.3%	404,238
	29	7.9%		420.7		33.36	1,734,938	22.0%	381,357
	30	7.2%		437.6		31.47	1,734,938	20.7%	359,770
	31	6.5%		455.1		29.69	1,734,938	19.6%	339,406
	32	5.9%		473.3		28.01	1,734,938	18.5%	320,194

Fig. 76: Economical Cost calculation: **MED_{hybrid} 5,000 m³/d -- NCS/PV, Well Intake**

Economical cost calculations for 10,000 m³ MED plant pow. by NCS/PV

SEA WATER-OPEN INTAKE

Assumptions of costs:

Capital costs for 10,000 m³/d in Lakh		**Operational costs in Lakh/a**		**Results of Calculation**	
MED-plant	5,280 lakh	PV & NCS maintenance	172 lakh	discounted Investment +operation cost	Lakh Rs. 34,891
PV & NCS plant	17,223 lakh	Chemicals	16 lakh		
wells / seawater extraction plant (see pretreatment)	0 lakh	Spare parts	53 lakh		
land costs	4,000 lakh	Labour (20 employees)	18 lakh	discounted water production assuming an inflation-indexed price	m³ 50,570,636
pretreatment & disposal	528 lakh	membrane replacement (every 3 to 5 years)	0 lakh		
generator	200 lakh	operational costs per year	259 lakh		
capital nominally invested	27,231 lakh	nominal operational costs	14,537 lakh	water price in first year of production, which grows annually with inflation	Rs/m³ 69.00
present value of capita	30,586 lakh	present value of operational costs	4,305 lakh		

availability of plant	95%	
water production	3,469,875	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	2,723.1			3,309.34			
	2	110%	24,507.9			27,017.51			
Start	3	100%		259.2		259.19	3,469,875	100.0%	3,469,875
	4	90.7%		269.6		244.52	3,469,875	94.3%	3,273,467
	5	82.3%		280.3		230.68	3,469,875	89.0%	3,088,176
	6	74.6%		291.6		217.62	3,469,875	84.0%	2,913,374
	7	67.7%		303.2		205.30	3,469,875	79.2%	2,748,466
	8	61.4%		315.3		193.68	3,469,875	74.7%	2,592,892
	9	55.7%		328.0		182.72	3,469,875	70.5%	2,446,125
	10	50.5%		341.1		172.38	3,469,875	66.5%	2,307,665
	11	45.8%		354.7		162.62	3,469,875	62.7%	2,177,043
	12	41.6%		368.9		153.42	3,469,875	59.2%	2,053,814
	13	37.7%		383.7		144.73	3,469,875	55.8%	1,937,560
	14	34.2%		399.0		136.54	3,469,875	52.7%	1,827,887
	15	31.0%		415.0		128.81	3,469,875	49.7%	1,724,422
	16	28.2%		431.6		121.52	3,469,875	46.9%	1,626,813
	17	25.5%		448.8		114.64	3,469,875	44.2%	1,534,729
	18	23.2%		466.8		108.15	3,469,875	41.7%	1,447,858
	19	21.0%		485.5		102.03	3,469,875	39.4%	1,365,903
	20	19.1%		504.9		96.25	3,469,875	37.1%	1,288,588
	21	17.3%		525.1		90.81	3,469,875	35.0%	1,215,649
	22	15.7%		546.1	4,989	868.29	3,296,381	33.1%	1,089,497
	23	14.2%		567.9		80.82	3,469,875	31.2%	1,081,923
	24	12.9%		590.6		76.24	3,469,875	29.4%	1,020,682
	25	11.7%		614.3		71.93	3,469,875	27.8%	962,908
	26	10.6%		638.8		67.86	3,469,875	26.2%	908,404
	27	9.6%		664.4		64.01	3,469,875	24.7%	856,985
	28	8.7%		691.0		60.39	3,469,875	23.3%	808,476
	29	7.9%		718.6		56.97	3,469,875	22.0%	762,713
	30	7.2%		747.3		53.75	3,469,875	20.7%	719,541
	31	6.5%		777.2		50.71	3,469,875	19.6%	678,812
	32	5.9%		808.3		47.84	3,469,875	18.5%	640,389

Fig. 77: Economical Cost calculation: **MED_{hybrid} 10,000 m³/d -- NCS/PV, Seawater Open Intake**

Economical cost calculations for 10,000 m³ MED plant pow. by NCS/PV

S E A WA T E R - W E L L   I N T A K E

Assumptions of costs:

Capital costs for 10,000 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
MED-plant	5,280 lakh	PV & NCS maintenance	172 lakh	discounted Investment +operation cost	Lakh Rs. 34,808
PV & NCS plant	17,223 lakh	Chemicals	16 lakh		
wells / seawater extraction plant (see pretreatment)	400 lakh	Spare parts	53 lakh		
land costs	4,000 lakh	Labour (20 employees)	18 lakh	discounted water production assuming an inflation-indexed price	m³ 50,570,636
pretreatment & disposal	53 lakh	membrane replacement (every 3 to 5 years)	0 lakh		
generator	200 lakh	operational costs per year	259 lakh		
capital nominally invested	27,156 lakh	nominal operational costs	14,537 lakh	water price in first year of production, which grows annually with inflation	Rs/m³ 68.83
present value of capita	30,502 lakh	present value of operational costs	4,305 lakh		

availability of plant	95%	
water production	3,469,875	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	6.00% %/a	discounted water prod. m³/a
								Disc.Factor for Water assuming the water-price rises with inflation	
	1	122%	2,715.6			3,300.21			
	2	110%	24,440.2			26,942.90			
Start	3	100%		259.2		259.19	3,469,875	100.0%	3,469,875
	4	90.7%		269.6		244.52	3,469,875	94.3%	3,273,467
	5	82.3%		280.3		230.68	3,469,875	89.0%	3,088,176
	6	74.6%		291.6		217.62	3,469,875	84.0%	2,913,374
	7	67.7%		303.2		205.30	3,469,875	79.2%	2,748,466
	8	61.4%		315.3		193.68	3,469,875	74.7%	2,592,892
	9	55.7%		328.0		182.72	3,469,875	70.5%	2,446,125
	10	50.5%		341.1		172.38	3,469,875	66.5%	2,307,665
	11	45.8%		354.7		162.62	3,469,875	62.7%	2,177,043
	12	41.6%		368.9		153.42	3,469,875	59.2%	2,053,814
	13	37.7%		383.7		144.73	3,469,875	55.8%	1,937,560
	14	34.2%		399.0		136.54	3,469,875	52.7%	1,827,887
	15	31.0%		415.0		128.81	3,469,875	49.7%	1,724,422
	16	28.2%		431.6		121.52	3,469,875	46.9%	1,626,813
	17	25.5%		448.8		114.64	3,469,875	44.2%	1,534,729
	18	23.2%		466.8		108.15	3,469,875	41.7%	1,447,858
	19	21.0%		485.5		102.03	3,469,875	39.4%	1,365,903
	20	19.1%		504.9		96.25	3,469,875	37.1%	1,288,588
	21	17.3%		525.1		90.81	3,469,875	35.0%	1,215,649
	22	15.7%		546.1	4,989	868.29	3,296,381	33.1%	1,089,497
	23	14.2%		567.9		80.82	3,469,875	31.2%	1,081,923
	24	12.9%		590.6		76.24	3,469,875	29.4%	1,020,682
	25	11.7%		614.3		71.93	3,469,875	27.8%	962,908
	26	10.6%		638.8		67.86	3,469,875	26.2%	908,404
	27	9.6%		664.4		64.01	3,469,875	24.7%	856,985
	28	8.7%		691.0		60.39	3,469,875	23.3%	808,476
	29	7.9%		718.6		56.97	3,469,875	22.0%	762,713
	30	7.2%		747.3		53.75	3,469,875	20.7%	719,541
	31	6.5%		777.2		50.71	3,469,875	19.6%	678,812
	32	5.9%		808.3		47.84	3,469,875	18.5%	640,389

Fig. 78: Economical Cost calculation: **MED_{hybrid} 10,000 m^3/d -- NCS/PV, Well Intake**

Economical cost calculations for 500 m³ MED plant powered by SC/PV

S E A WA T E R - O P E N I N T A K E

Assumptions of costs:

Capital costs for 500 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
MED-plant	660 lakh	SC & PV maintenance	62 lakh	discounted Investment +operation cost	Lakh Rs.
SC & PV plant	6,243 lakh	Chemicals	1 lakh		9,183
wells / seawater extraction plant (see pretreatment)	0 lakh	Spare parts	7 lakh		
land costs	200 lakh	Labour (10 employees)	9 lakh	discounted water production assuming an inflation-indexed price	m³
pretreatment & disposal	66 lakh	membrane replacement (every 3 to 5 years)	0 lakh		2,528,532
generator	15 lakh	operational costs per year	79 lakh		
capital nominally invested	7,184 lakh	nominal operational costs	2,351 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capital	8,080 lakh	present value of operational costs	1,103 lakh		363.16

availability of plant	95%	
water production	173,494	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	718.4			873.06			
	2	110%	6,465.6			7,127.68			
Start	3	100%		79.0		78.96	173,494	100.0%	173,494
	4	90.7%		82.1		74.49	173,494	94.3%	163,673
	5	82.3%		85.4		70.27	173,494	89.0%	154,409
	6	74.6%		88.8		66.29	173,494	84.0%	145,669
	7	67.7%		92.4		62.54	173,494	79.2%	137,423
	8	61.4%		96.1		59.00	173,494	74.7%	129,645
	9	55.7%		99.9		55.66	173,494	70.5%	122,306
	10	50.5%		103.9		52.51	173,494	66.5%	115,383
	11	45.8%		108.1		49.54	173,494	62.7%	108,852
	12	41.6%		112.4		46.73	173,494	59.2%	102,691
	13	37.7%		116.9		44.09	173,494	55.8%	96,878
	14	34.2%		121.5		41.59	173,494	52.7%	91,394
	15	31.0%		126.4		39.24	173,494	49.7%	86,221
	16	28.2%		131.5		37.02	173,494	46.9%	81,341
	17	25.5%		136.7		34.92	173,494	44.2%	76,736
	18	23.2%		142.2		32.95	173,494	41.7%	72,393
	19	21.0%		147.9		31.08	173,494	39.4%	68,295
	20	19.1%		153.8		29.32	173,494	37.1%	64,429
	21	17.3%		160.0		27.66	173,494	35.0%	60,782
	22	15.7%		166.3	191	56.00	164,819	33.1%	54,475
	23	14.2%		173.0		24.62	173,494	31.2%	54,096
	24	12.9%		179.9		23.23	173,494	29.4%	51,034
	25	11.7%		187.1		21.91	173,494	27.8%	48,145
	26	10.6%		194.6		20.67	173,494	26.2%	45,420
	27	9.6%		202.4		19.50	173,494	24.7%	42,849
	28	8.7%		210.5		18.40	173,494	23.3%	40,424
	29	7.9%		218.9		17.36	173,494	22.0%	38,136
	30	7.2%		227.7		16.37	173,494	20.7%	35,977
	31	6.5%		236.8		15.45	173,494	19.6%	33,941
	32	5.9%		246.2		14.57	173,494	18.5%	32,019

Fig. 79: Economical. Cost calculation: **MED_{hybrid} 500 m^3/d -- SC/PV, Seawater Open Intake**

Economical cost calculations for 500 m³ MED plant powered by SC/PV

S E A W A T E R - W E L L I N T A K E

Assumptions of costs:

Capital costs for 500 m³/d in Lakh		**Operational costs in Lakh/a**		**Results of Calculation**	
MED-plant	660 lakh	SC & PV maintenance	62 lakh	discounted Investment +operation cost	Lakh Rs.
SC & PV plant	6,243 lakh	Chemicals	1 lakh		9,139
wells / seawater extraction plant (see pretreatment)	20 lakh	Spare parts	7 lakh		
land costs	200 lakh	Labour (10 employees)	9 lakh	discounted water production assuming an inflation-indexed price	m³
pretreatment & disposal	7 lakh	membrane replacement (every 3 to 5 years)	0 lakh		2,528,532
generator	15 lakh	operational costs per year	79 lakh		
capital nominally invested	7,145 lakh	nominal operational costs	4,428 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capita	8,036 lakh	present value of operational costs	1,103 lakh		361.43

availability of plant	95%	
water production	173,494	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	714.5			868.27			
	2	110%	6,430.1			7,088.59			
Start	3	100%		79.0		78.96	173,494	100.0%	173,494
	4	90.7%		82.1		74.49	173,494	94.3%	163,673
	5	82.3%		85.4		70.27	173,494	89.0%	154,409
	6	74.6%		88.8		66.29	173,494	84.0%	145,669
	7	67.7%		92.4		62.54	173,494	79.2%	137,423
	8	61.4%		96.1		59.00	173,494	74.7%	129,645
	9	55.7%		99.9		55.66	173,494	70.5%	122,306
	10	50.5%		103.9		52.51	173,494	66.5%	115,383
	11	45.8%		108.1		49.54	173,494	62.7%	108,852
	12	41.6%		112.4		46.73	173,494	59.2%	102,691
	13	37.7%		116.9		44.09	173,494	55.8%	96,878
	14	34.2%		121.5		41.59	173,494	52.7%	91,394
	15	31.0%		126.4		39.24	173,494	49.7%	86,221
	16	28.2%		131.5		37.02	173,494	46.9%	81,341
	17	25.5%		136.7		34.92	173,494	44.2%	76,736
	18	23.2%		142.2		32.95	173,494	41.7%	72,393
	19	21.0%		147.9		31.08	173,494	39.4%	68,295
	20	19.1%		153.8		29.32	173,494	37.1%	64,429
	21	17.3%		160.0		27.66	173,494	35.0%	60,782
	22	15.7%		166.3	191	56.00	164,819	33.1%	54,475
	23	14.2%		173.0		24.62	173,494	31.2%	54,096
	24	12.9%		179.9		23.23	173,494	29.4%	51,034
	25	11.7%		187.1		21.91	173,494	27.8%	48,145
	26	10.6%		194.6		20.67	173,494	26.2%	45,420
	27	9.6%		202.4		19.50	173,494	24.7%	42,849
	28	8.7%		210.5		18.40	173,494	23.3%	40,424
	29	7.9%		218.9		17.36	173,494	22.0%	38,136
	30	7.2%		227.7		16.37	173,494	20.7%	35,977
	31	6.5%		236.8		15.45	173,494	19.6%	33,941
	32	5.9%		246.2		14.57	173,494	18.5%	32,019

Fig. 80: Economical Cost calculation: **MED_{hybrid} 500 m^3/d -- SC /PV, Well Intake**

Economical cost calculations for 1,000 m³ MED plant pow. by SC/PV

S E A W A T E R - O P E N I N T A K E

Assumptions of costs:

Capital costs for 1,000 m³/d in Lakh		**Operational costs in Lakh/a**		**Results of Calculation**	
MED-plant	1,320 lakh	SC & PV maintenance	124 lakh	discounted Investment +operation cost	Lakh Rs. 18,114
SC & PV plant	12,392 lakh	Chemicals	2 lakh		
wells / seawater extraction plant (see pretreatment)	0 lakh	Spare parts	13 lakh		
land costs	400 lakh	Labour (10 employees)	9 lakh	discounted water production assuming an inflation-indexed price	m³ 5,057,064
pretreatment & disposal	132 lakh	membrane replacement (every 3 to 5 years)	0 lakh		
generator	30 lakh	operational costs per year	148 lakh		
capital nominally invested	14,274 lakh	nominal operational costs	8,292 lakh	water price in first year of production, which grows annually with inflation	Rs/m³ 358.18
present value of capita	16,045 lakh	present value of operational costs	2,069 lakh		

availability of plant	95%	
water production	346,988	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	6.00% %/a	discounted water prod. m³/a
	1	122%	1,427.4			1,734.70			
	2	110%	12,846.6			14,162.09			
Start	3	100%		147.8		147.84	346,988	100.0%	346,988
	4	90.7%		153.8		139.47	346,988	94.3%	327,347
	5	82.3%		159.9		131.58	346,988	89.0%	308,818
	6	74.6%		166.3		124.13	346,988	84.0%	291,337
	7	67.7%		173.0		117.10	346,988	79.2%	274,847
	8	61.4%		179.9		110.48	346,988	74.7%	259,289
	9	55.7%		187.1		104.22	346,988	70.5%	244,612
	10	50.5%		194.5		98.32	346,988	66.5%	230,767
	11	45.8%		202.3		92.76	346,988	62.7%	217,704
	12	41.6%		210.4		87.51	346,988	59.2%	205,381
	13	37.7%		218.8		82.55	346,988	55.8%	193,756
	14	34.2%		227.6		77.88	346,988	52.7%	182,789
	15	31.0%		236.7		73.47	346,988	49.7%	172,442
	16	28.2%		246.2		69.31	346,988	46.9%	162,681
	17	25.5%		256.0		65.39	346,988	44.2%	153,473
	18	23.2%		266.3		61.69	346,988	41.7%	144,786
	19	21.0%		276.9		58.20	346,988	39.4%	136,590
	20	19.1%		288.0		54.90	346,988	37.1%	128,859
	21	17.3%		299.5		51.80	346,988	35.0%	121,565
	22	15.7%		311.5	381	108.59	329,638	33.1%	108,950
	23	14.2%		323.9		46.10	346,988	31.2%	108,192
	24	12.9%		336.9		43.49	346,988	29.4%	102,068
	25	11.7%		350.4		41.03	346,988	27.8%	96,291
	26	10.6%		364.4		38.70	346,988	26.2%	90,840
	27	9.6%		379.0		36.51	346,988	24.7%	85,698
	28	8.7%		394.1		34.45	346,988	23.3%	80,848
	29	7.9%		409.9		32.50	346,988	22.0%	76,271
	30	7.2%		426.3		30.66	346,988	20.7%	71,954
	31	6.5%		443.3		28.92	346,988	19.6%	67,881
	32	5.9%		461.1		27.29	346,988	18.5%	64,039

Disc.Factor for Water assuming the water-price rises with inflation

Fig. 81: Economical Cost calculation: **MED$_{hybrid}$ 1,000 m^3/d -- SC /PV, Seawater Open Intake**

Economical cost calculations for 1,000 m³ MED plant pow. by SC/PV

S E A WA T E R - W E L L I N T A K E

Assumptions of costs:

Capital costs for 1,000 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
MED-plant	1,320 lakh	SC & PV maintenance	124 lakh	discounted Investment +operation cost	Lakh Rs.
SC & PV plant	12,392 lakh	Chemicals	2 lakh		18,026
wells / seawater extraction plant (see pretreatment)	40 lakh	Spare parts	13 lakh		
land costs	400 lakh	Labour (10 employees)	9 lakh	discounted water production assuming an inflation-indexed price	m³
pretreatment & disposal	13 lakh	membrane replacement (every 3 to 5 years)	0 lakh		5,057,064
generator	30 lakh	operational costs per year	148 lakh		
capital nominally invested	14,195 lakh	nominal operational costs	8,292 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capita	15,957 lakh	present value of operational costs	2,069 lakh		356.45

availability of plant	95%	
water production	346,988	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	1,419.5			1,725.12			
	2	110%	12,775.7			14,083.91			
Start	3	100%		147.8		147.84	346,988	100.0%	346,988
	4	90.7%		153.8		139.47	346,988	94.3%	327,347
	5	82.3%		159.9		131.58	346,988	89.0%	308,818
	6	74.6%		166.3		124.13	346,988	84.0%	291,337
	7	67.7%		173.0		117.10	346,988	79.2%	274,847
	8	61.4%		179.9		110.48	346,988	74.7%	259,289
	9	55.7%		187.1		104.22	346,988	70.5%	244,612
	10	50.5%		194.5		98.32	346,988	66.5%	230,767
	11	45.8%		202.3		92.76	346,988	62.7%	217,704
	12	41.6%		210.4		87.51	346,988	59.2%	205,381
	13	37.7%		218.8		82.55	346,988	55.8%	193,756
	14	34.2%		227.6		77.88	346,988	52.7%	182,789
	15	31.0%		236.7		73.47	346,988	49.7%	172,442
	16	28.2%		246.2		69.31	346,988	46.9%	162,681
	17	25.5%		256.0		65.39	346,988	44.2%	153,473
	18	23.2%		266.3		61.69	346,988	41.7%	144,786
	19	21.0%		276.9		58.20	346,988	39.4%	136,590
	20	19.1%		288.0		54.90	346,988	37.1%	128,859
	21	17.3%		299.5		51.80	346,988	35.0%	121,565
	22	15.7%		311.5	381	108.59	329,638	33.1%	108,950
	23	14.2%		323.9		46.10	346,988	31.2%	108,192
	24	12.9%		336.9		43.49	346,988	29.4%	102,068
	25	11.7%		350.4		41.03	346,988	27.8%	96,291
	26	10.6%		364.4		38.70	346,988	26.2%	90,840
	27	9.6%		379.0		36.51	346,988	24.7%	85,698
	28	8.7%		394.1		34.45	346,988	23.3%	80,848
	29	7.9%		409.9		32.50	346,988	22.0%	76,271
	30	7.2%		426.3		30.66	346,988	20.7%	71,954
	31	6.5%		443.3		28.92	346,988	19.6%	67,881
	32	5.9%		461.1		27.29	346,988	18.5%	64,039

Fig. 82: Economical Cost calculation: **MED$_{hybrid}$ 1,000 m^3/d -- SC /PV, Well Intake**

Economical cost calculations for 5,000 m³ MED plant pow by SC/PV

S E A W A T E R - O P E N I N T A K E

Assumptions of costs:

Capital costs for 5,000 m³/d in Lakh		**Operational costs in Lakh/a**		**Results of Calculation**	
MED-plant	4,400 lakh	SC & PV maintenance	586 lakh	discounted Investment +operation cost	Lakh Rs. 82,779
SC & PV plant	58,588 lakh	Chemicals	8 lakh		
wells / seawater extraction plant (see pretreatment)	0 lakh	Spare parts	44 lakh		
land costs	2,000 lakh	Labour (15 employees)	14 lakh	discounted water production assuming an inflation-indexed price	m³ 25,285,318
pretreatment & disposal	440 lakh	membrane replacement (every 3 to 5 years)	0 lakh		
generator	100 lakh	operational costs per year	652 lakh		
capital nominally invested	65,528 lakh	nominal operational costs	36,541 lakh	water price in first year of production, which grows annually with inflation	Rs/m³ 327.38
present value of capita	73,629 lakh	present value of operational costs	9,150 lakh		

availability of plant	95%	
water production	1,734,938	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	6,552.8			7,963.52			
	2	110%	58,975.2			65,014.26			
Start	3	100%		651.5		651.53	1,734,938	100.0%	1,734,938
	4	90.7%		677.6		614.65	1,734,938	94.3%	1,636,733
	5	82.3%		704.7		579.86	1,734,938	89.0%	1,544,088
	6	74.6%		732.9		547.03	1,734,938	84.0%	1,456,687
	7	67.7%		762.2		516.07	1,734,938	79.2%	1,374,233
	8	61.4%		792.7		486.86	1,734,938	74.7%	1,296,446
	9	55.7%		824.4		459.30	1,734,938	70.5%	1,223,062
	10	50.5%		857.4		433.30	1,734,938	66.5%	1,153,833
	11	45.8%		891.7		408.78	1,734,938	62.7%	1,088,521
	12	41.6%		927.3		385.64	1,734,938	59.2%	1,026,907
	13	37.7%		964.4		363.81	1,734,938	55.8%	968,780
	14	34.2%		1,003.0		343.22	1,734,938	52.7%	913,943
	15	31.0%		1,043.1		323.79	1,734,938	49.7%	862,211
	16	28.2%		1,084.8		305.46	1,734,938	46.9%	813,406
	17	25.5%		1,128.2		288.17	1,734,938	44.2%	767,365
	18	23.2%		1,173.4		271.86	1,734,938	41.7%	723,929
	19	21.0%		1,220.3		256.47	1,734,938	39.4%	682,952
	20	19.1%		1,269.1		241.95	1,734,938	37.1%	644,294
	21	17.3%		1,319.9		228.26	1,734,938	35.0%	607,825
	22	15.7%		1,372.7	1,882	510.50	1,648,191	33.1%	544,748
	23	14.2%		1,427.6		203.15	1,734,938	31.2%	540,962
	24	12.9%		1,484.7		191.65	1,734,938	29.4%	510,341
	25	11.7%		1,544.1		180.80	1,734,938	27.8%	481,454
	26	10.6%		1,605.8		170.57	1,734,938	26.2%	454,202
	27	9.6%		1,670.1		160.91	1,734,938	24.7%	428,492
	28	8.7%		1,736.9		151.80	1,734,938	23.3%	404,238
	29	7.9%		1,806.3		143.21	1,734,938	22.0%	381,357
	30	7.2%		1,878.6		135.11	1,734,938	20.7%	359,770
	31	6.5%		1,953.7		127.46	1,734,938	19.6%	339,406
	32	5.9%		2,031.9		120.24	1,734,938	18.5%	320,194

Fig. 83: Economical Cost calculation: **MED_{hybrid} 5,000 m³/d -- SC /PV, Seawater Open Intake**

Economical cost calculations for 5,000 m³ MED plant pow. by SC/PV

SEA WATER-WELL INTAKE

Assumptions of costs:

Capital costs for 5,000 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
MED-plant	4,400 lakh	SC & PV maintenance	586 lakh	discounted Investment +operation cost	Lakh Rs.
SC & PV plant	58,588 lakh	Chemicals	8 lakh		82,561
wells / seawater extraction plant (see pretreatment)	200 lakh	Spare parts	44 lakh		
land costs	2,000 lakh	Labour (15 employees)	14 lakh	discounted water production assuming an inflation-indexed price	m³
pretreatment & disposal	44 lakh	membrane replacement (every 3 to 5 years)	0 lakh		25,285,318
generator	100 lakh	operational costs per year	652 lakh		
capital nominally invested	65,332 lakh	nominal operational costs	36,541 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capita	73,411 lakh	present value of operational costs	9,150 lakh		326.52

availability of plant	95%	
water production	1,734,938	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	6,533.2			7,939.70			
	2	110%	58,798.8			64,819.80			
Start	3	100%		651.5		651.53	1,734,938	100.0%	1,734,938
	4	90.7%		677.6		614.65	1,734,938	94.3%	1,636,733
	5	82.3%		704.7		579.86	1,734,938	89.0%	1,544,088
	6	74.6%		732.9		547.03	1,734,938	84.0%	1,456,687
	7	67.7%		762.2		516.07	1,734,938	79.2%	1,374,233
	8	61.4%		792.7		486.86	1,734,938	74.7%	1,296,446
	9	55.7%		824.4		459.30	1,734,938	70.5%	1,223,062
	10	50.5%		857.4		433.30	1,734,938	66.5%	1,153,833
	11	45.8%		891.7		408.78	1,734,938	62.7%	1,088,521
	12	41.6%		927.3		385.64	1,734,938	59.2%	1,026,907
	13	37.7%		964.4		363.81	1,734,938	55.8%	968,780
	14	34.2%		1,003.0		343.22	1,734,938	52.7%	913,943
	15	31.0%		1,043.1		323.79	1,734,938	49.7%	862,211
	16	28.2%		1,084.8		305.46	1,734,938	46.9%	813,406
	17	25.5%		1,128.2		288.17	1,734,938	44.2%	767,365
	18	23.2%		1,173.4		271.86	1,734,938	41.7%	723,929
	19	21.0%		1,220.3		256.47	1,734,938	39.4%	682,952
	20	19.1%		1,269.1		241.95	1,734,938	37.1%	644,294
	21	17.3%		1,319.9		228.26	1,734,938	35.0%	607,825
	22	15.7%		1,372.7	1,882	510.50	1,648,191	33.1%	544,748
	23	14.2%		1,427.6		203.15	1,734,938	31.2%	540,962
	24	12.9%		1,484.7		191.65	1,734,938	29.4%	510,341
	25	11.7%		1,544.1		180.80	1,734,938	27.8%	481,454
	26	10.6%		1,605.8		170.57	1,734,938	26.2%	454,202
	27	9.6%		1,670.1		160.91	1,734,938	24.7%	428,492
	28	8.7%		1,736.9		151.80	1,734,938	23.3%	404,238
	29	7.9%		1,806.3		143.21	1,734,938	22.0%	381,357
	30	7.2%		1,878.6		135.11	1,734,938	20.7%	359,770
	31	6.5%		1,953.7		127.46	1,734,938	19.6%	339,406
	32	5.9%		2,031.9		120.24	1,734,938	18.5%	320,194

Fig. 84: Economical Cost calculation: **MED$_{hybrid}$ 5,000 m³/d -- SC /PV, Well Intake**

Economical cost calculations for 10,000 m³ MED plant pow. by SC/PV

S E A W A T E R - O P E N I N T A K E

Assumptions of costs:

Capital costs for 10,000 m³/d in Lakh		**Operational costs in Lakh/a**		**Results of Calculation**	
MED-plant	5,280 lakh	SC & PV maintenance	1,107 lakh	discounted Investment +operation cost	Lakh Rs. 152,381
SC & PV plant	110,656 lakh	Chemicals	16 lakh		
wells / seawater extraction plant (see pretreatment)	0 lakh	Spare parts	53 lakh		
land costs	4,000 lakh	Labour (20 employees)	18 lakh	discounted water production assuming an inflation-indexed price	m³ 50,570,636
pretreatment & disposal	528 lakh	membrane replacement (every 3 to 5 years)	0 lakh		
generator	200 lakh	operational costs per year	1,194 lakh		
capital nominally invested	120,664 lakh	nominal operational costs	66,939 lakh	water price in first year of production, which grows annually with inflation	Rs/m³ 301.32
present value of capita	135,576 lakh	present value of operational costs	16,806 lakh		

availability of plant	95%	
water production	3,469,875	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	12,066.4			14,664.12			
	2	110%	108,597.6			119,717.99			
Start	3	100%		1,193.5		1,193.52	3,469,875	100.0%	3,469,875
	4	90.7%		1,241.3		1,125.96	3,469,875	94.3%	3,273,467
	5	82.3%		1,290.9		1,062.23	3,469,875	89.0%	3,088,176
	6	74.6%		1,342.6		1,002.10	3,469,875	84.0%	2,913,374
	7	67.7%		1,396.3		945.38	3,469,875	79.2%	2,748,466
	8	61.4%		1,452.1		891.87	3,469,875	74.7%	2,592,892
	9	55.7%		1,510.2		841.39	3,469,875	70.5%	2,446,125
	10	50.5%		1,570.6		793.76	3,469,875	66.5%	2,307,665
	11	45.8%		1,633.4		748.83	3,469,875	62.7%	2,177,043
	12	41.6%		1,698.8		706.44	3,469,875	59.2%	2,053,814
	13	37.7%		1,766.7		666.46	3,469,875	55.8%	1,937,560
	14	34.2%		1,837.4		628.73	3,469,875	52.7%	1,827,887
	15	31.0%		1,910.9		593.14	3,469,875	49.7%	1,724,422
	16	28.2%		1,987.3		559.57	3,469,875	46.9%	1,626,813
	17	25.5%		2,066.8		527.90	3,469,875	44.2%	1,534,729
	18	23.2%		2,149.5		498.02	3,469,875	41.7%	1,447,858
	19	21.0%		2,235.4		469.83	3,469,875	39.4%	1,365,903
	20	19.1%		2,324.9		443.23	3,469,875	37.1%	1,288,588
	21	17.3%		2,417.9		418.14	3,469,875	35.0%	1,215,649
	22	15.7%		2,514.6	3,728	979.35	3,296,381	33.1%	1,089,497
	23	14.2%		2,615.2		372.15	3,469,875	31.2%	1,081,923
	24	12.9%		2,719.8		351.08	3,469,875	29.4%	1,020,682
	25	11.7%		2,828.6		331.21	3,469,875	27.8%	962,908
	26	10.6%		2,941.7		312.46	3,469,875	26.2%	908,404
	27	9.6%		3,059.4		294.77	3,469,875	24.7%	856,985
	28	8.7%		3,181.7		278.09	3,469,875	23.3%	808,476
	29	7.9%		3,309.0		262.35	3,469,875	22.0%	762,713
	30	7.2%		3,441.4		247.50	3,469,875	20.7%	719,541
	31	6.5%		3,579.0		233.49	3,469,875	19.6%	678,812
	32	5.9%		3,722.2		220.27	3,469,875	18.5%	640,389

Fig. 85: Economical Cost calculation: **MED$_{hybrid}$ 10,000 m^3/d -- SC /PV, Seawater Open Intake**

Economical cost calculations for 10,000 m³ MED plant pow. by SC/PV

S E A WA T E R - W E L L I N T A K E

Assumptions of costs:

Capital costs for 10,000 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
MED-plant	5,280 lakh	SC & PV maintenance	1,107 lakh	discounted Investment +operation cost	Lakh Rs. 152,298
SC & PV plant	110,656 lakh	Chemicals	16 lakh		
wells / seawater extraction plant (see pretreatment)	400 lakh	Spare parts	53 lakh		
land costs	4,000 lakh	Labour (20 employees)	18 lakh	discounted water production assuming an inflation-indexed price	m³ 50,570,636
pretreatment & disposal	53 lakh	membrane replacement (every 3 to 5 years)	0 lakh		
generator	200 lakh	operational costs per year	1,194 lakh		
capital nominally invested	120,589 lakh	nominal operational costs	66,939 lakh	water price in first year of production, which grows annually with inflation	Rs/m³ 301.16
present value of capita	135,492 lakh	present value of operational costs	16,806 lakh		

availability of plant	95%	
water production	3,469,875	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	12,058.9			14,654.99			
	2	110%	108,529.9			119,643.38			
Start	3	100%		1,193.5		1,193.52	3,469,875	100.0%	3,469,875
	4	90.7%		1,241.3		1,125.96	3,469,875	94.3%	3,273,467
	5	82.3%		1,290.9		1,062.23	3,469,875	89.0%	3,088,176
	6	74.6%		1,342.6		1,002.10	3,469,875	84.0%	2,913,374
	7	67.7%		1,396.3		945.38	3,469,875	79.2%	2,748,466
	8	61.4%		1,452.1		891.87	3,469,875	74.7%	2,592,892
	9	55.7%		1,510.2		841.39	3,469,875	70.5%	2,446,125
	10	50.5%		1,570.6		793.76	3,469,875	66.5%	2,307,665
	11	45.8%		1,633.4		748.83	3,469,875	62.7%	2,177,043
	12	41.6%		1,698.8		706.44	3,469,875	59.2%	2,053,814
	13	37.7%		1,766.7		666.46	3,469,875	55.8%	1,937,560
	14	34.2%		1,837.4		628.73	3,469,875	52.7%	1,827,887
	15	31.0%		1,910.9		593.14	3,469,875	49.7%	1,724,422
	16	28.2%		1,987.3		559.57	3,469,875	46.9%	1,626,813
	17	25.5%		2,066.8		527.90	3,469,875	44.2%	1,534,729
	18	23.2%		2,149.5		498.02	3,469,875	41.7%	1,447,858
	19	21.0%		2,235.4		469.83	3,469,875	39.4%	1,365,903
	20	19.1%		2,324.9		443.23	3,469,875	37.1%	1,288,588
	21	17.3%		2,417.9		418.14	3,469,875	35.0%	1,215,649
	22	15.7%		2,514.6	3,728	979.35	3,296,381	33.1%	1,089,497
	23	14.2%		2,615.2		372.15	3,469,875	31.2%	1,081,923
	24	12.9%		2,719.8		351.08	3,469,875	29.4%	1,020,682
	25	11.7%		2,828.6		331.21	3,469,875	27.8%	962,908
	26	10.6%		2,941.7		312.46	3,469,875	26.2%	908,404
	27	9.6%		3,059.4		294.77	3,469,875	24.7%	856,985
	28	8.7%		3,181.7		278.09	3,469,875	23.3%	808,476
	29	7.9%		3,309.0		262.35	3,469,875	22.0%	762,713
	30	7.2%		3,441.4		247.50	3,469,875	20.7%	719,541
	31	6.5%		3,579.0		233.49	3,469,875	19.6%	678,812
	32	5.9%		3,722.2		220.27	3,469,875	18.5%	640,389

Fig. 86: Economical Cost calculation: **MED_{hybrid} 10,000 m^3/d -- SC /PV, Well Intake**

Economical cost calculations for 500 m³ RO plant powered by SC

S E A W A T E R - W E L L I N T A K E

Assumptions of costs:

Capital costs for 500 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
RO-plant	175 lakh	SC-maintenance	9 lakh	discounted Investment +operation cost	Lakh Rs.
SC-plant	875 lakh	Chemicals	2 lakh		1,772
wells / seawater extraction plant (see pretreatment)	20 lakh	Spare parts (mft)	7 lakh		
land costs	25 lakh	Labour (20 employees)	18 lakh	discounted water production assuming an inflation-indexed price	m³
pretreatment & disposal	9 lakh	membrane replacement (every 3 to 5 years)	2-6 lakh		2,528,532
generator	6 lakh	operational costs per year	35 lakh		
capital nominally invested	1,110 lakh	nominal operational costs	1,991 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capita	1,271 lakh	present value of operational costs	500 lakh		70.07

availability of plant	95%	
water production	173,494	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	110.975			134.87			
	2	110%	998.775			1,101.05			
Start	3	100%		35.5		35.49	173,494	100.0%	173,494
	4	90.7%		36.9		33.48	173,494	94.3%	163,673
	5	82.3%		38.4		31.59	173,494	89.0%	154,409
	6	74.6%		39.9		29.80	173,494	84.0%	145,669
	7	67.7%		41.5	2	29.47	173,494	79.2%	137,423
	8	61.4%		43.2		26.52	173,494	74.7%	129,645
	9	55.7%		44.9		25.02	173,494	70.5%	122,306
	10	50.5%		46.7		23.60	173,494	66.5%	115,383
	11	45.8%		48.6		22.27	173,494	62.7%	108,852
	12	41.6%		50.5	3	22.26	173,494	59.2%	102,691
	13	37.7%		52.5		19.82	173,494	55.8%	96,878
	14	34.2%		54.6		18.70	173,494	52.7%	91,394
	15	31.0%		56.8		17.64	173,494	49.7%	86,221
	16	28.2%		59.1		16.64	173,494	46.9%	81,341
	17	25.5%		61.5	4	16.72	173,494	44.2%	76,736
	18	23.2%		63.9		14.81	173,494	41.7%	72,393
	19	21.0%		66.5		13.97	173,494	39.4%	68,295
	20	19.1%		69.1		13.18	173,494	37.1%	64,429
	21	17.3%		71.9		12.43	173,494	35.0%	60,782
	22	15.7%		74.8	88	25.46	164,819	33.1%	54,475
	23	14.2%		77.8		11.07	173,494	31.2%	54,096
	24	12.9%		80.9		10.44	173,494	29.4%	51,034
	25	11.7%		84.1		9.85	173,494	27.8%	48,145
	26	10.6%		87.5		9.29	173,494	26.2%	45,420
	27	9.6%		91.0	6	9.34	173,494	24.7%	42,849
	28	8.7%		94.6		8.27	173,494	23.3%	40,424
	29	7.9%		98.4		7.80	173,494	22.0%	38,136
	30	7.2%		102.3		7.36	173,494	20.7%	35,977
	31	6.5%		106.4		6.94	173,494	19.6%	33,941
	32	5.9%		110.7		6.55	173,494	18.5%	32,019

Fig. 87: Economical Cost calculation: **RO 500 m³/d -- SC, Seawater Open Intake**

Economical cost calculations for 500 m³ RO plant powered by SC

S E A WA T E R - O P E N I N T A K E

Assumptions of costs:

Capital costs for 500 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
RO-plant	175 lakh	SC-maintenance	9 lakh	discounted Investment	Lakh Rs.
SC-plant	875 lakh	Chemicals	2 lakh	+operation cost	1,837
wells / seawater extraction plant (see pretreatment)	0 lakh	Spare parts (mft)	7 lakh		
land costs	25 lakh	Labour (20 employees)	18 lakh	discounted water production assuming an inflation-indexed price	m³
pretreatment & disposal	88 lakh	membrane replacement (every 3 to 5 years)	2-6 lakh		2,528,532
generator	6 lakh	operational costs per year	35 lakh		
capital nominally invested	1,169 lakh	nominal operational costs	1,991 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capita	1,337 lakh	present value of operational costs	500 lakh		72.66

availability of plant	95%	
water production	173,494	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	116.85			142.01			
	2	110%	1,051.65			1,159.34			
Start	3	100%		35.5		35.49	173,494	100.0%	173,494
	4	90.7%		36.9		33.48	173,494	94.3%	163,673
	5	82.3%		38.4		31.59	173,494	89.0%	154,409
	6	74.6%		39.9		29.80	173,494	84.0%	145,669
	7	67.7%		41.5	2	29.47	173,494	79.2%	137,423
	8	61.4%		43.2		26.52	173,494	74.7%	129,645
	9	55.7%		44.9		25.02	173,494	70.5%	122,306
	10	50.5%		46.7		23.60	173,494	66.5%	115,383
	11	45.8%		48.6		22.27	173,494	62.7%	108,852
	12	41.6%		50.5	3	22.26	173,494	59.2%	102,691
	13	37.7%		52.5		19.82	173,494	55.8%	96,878
	14	34.2%		54.6		18.70	173,494	52.7%	91,394
	15	31.0%		56.8		17.64	173,494	49.7%	86,221
	16	28.2%		59.1		16.64	173,494	46.9%	81,341
	17	25.5%		61.5	4	16.72	173,494	44.2%	76,736
	18	23.2%		63.9		14.81	173,494	41.7%	72,393
	19	21.0%		66.5		13.97	173,494	39.4%	68,295
	20	19.1%		69.1		13.18	173,494	37.1%	64,429
	21	17.3%		71.9		12.43	173,494	35.0%	60,782
	22	15.7%		74.8	88	25.46	164,819	33.1%	54,475
	23	14.2%		77.8		11.07	173,494	31.2%	54,096
	24	12.9%		80.9		10.44	173,494	29.4%	51,034
	25	11.7%		84.1		9.85	173,494	27.8%	48,145
	26	10.6%		87.5		9.29	173,494	26.2%	45,420
	27	9.6%		91.0	6	9.34	173,494	24.7%	42,849
	28	8.7%		94.6		8.27	173,494	23.3%	40,424
	29	7.9%		98.4		7.80	173,494	22.0%	38,136
	30	7.2%		102.3		7.36	173,494	20.7%	35,977
	31	6.5%		106.4		6.94	173,494	19.6%	33,941
	32	5.9%		110.7		6.55	173,494	18.5%	32,019

Fig. 88: Economical Cost calculation: **RO 500 m³/d -- SC, Well Intake**

Economical cost calculations for 1,000 m³ RO plant powered by SC

S E A W A T E R - O P E N   I N T A K E

Assumptions of costs:

Capital costs for 1,000 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
RO-plant	350 lakh	SC-maintenance	17 lakh	discounted Investment +operation cost	Lakh Rs. 3,401
SC-plant	1,748 lakh	Chemicals	3 lakh		
wells / seawater extraction plant (see pretreatment)	0 lakh	Spare parts (mft)	14 lakh		
land costs	50 lakh	Labour (20 employees)	18 lakh	discounted water production assuming an inflation-indexed price	m³ 5,057,064
pretreatment & disposal	175 lakh	membrane replacement (every 3 to 5 years)	4-12 lakh		
generator	8 lakh	operational costs per year	53 lakh		
capital nominally invested	2,331 lakh	nominal operational costs	2,956 lakh	water price in first year of production, which grows annually with inflation	Rs/m³ 67.25
present value of capita	2,649 lakh	present value of operational costs	752 lakh		

availability of plant	95%	
water production	346,988	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	233.1			283.28			
	2	110%	2,097.9			2,312.72			
Start	3	100%		52.7		52.70	346,988	100.0%	346,988
	4	90.7%		54.8		49.72	346,988	94.3%	327,347
	5	82.3%		57.0		46.91	346,988	89.0%	308,818
	6	74.6%		59.3		44.25	346,988	84.0%	291,337
	7	67.7%		61.7	4	44.45	346,988	79.2%	274,847
	8	61.4%		64.1		39.38	346,988	74.7%	259,289
	9	55.7%		66.7		37.15	346,988	70.5%	244,612
	10	50.5%		69.4		35.05	346,988	66.5%	230,767
	11	45.8%		72.1		33.07	346,988	62.7%	217,704
	12	41.6%		75.0	6	33.69	346,988	59.2%	205,381
	13	37.7%		78.0		29.43	346,988	55.8%	193,756
	14	34.2%		81.1		27.76	346,988	52.7%	182,789
	15	31.0%		84.4		26.19	346,988	49.7%	172,442
	16	28.2%		87.8		24.71	346,988	46.9%	162,681
	17	25.5%		91.3	8	25.35	346,988	44.2%	153,473
	18	23.2%		94.9		21.99	346,988	41.7%	144,786
	19	21.0%		98.7		20.75	346,988	39.4%	136,590
	20	19.1%		102.7		19.57	346,988	37.1%	128,859
	21	17.3%		106.8		18.46	346,988	35.0%	121,565
	22	15.7%		111.0	175	44.87	329,638	33.1%	108,950
	23	14.2%		115.5		16.43	346,988	31.2%	108,192
	24	12.9%		120.1		15.50	346,988	29.4%	102,068
	25	11.7%		124.9		14.63	346,988	27.8%	96,291
	26	10.6%		129.9		13.80	346,988	26.2%	90,840
	27	9.6%		135.1	12	14.17	346,988	24.7%	85,698
	28	8.7%		140.5		12.28	346,988	23.3%	80,848
	29	7.9%		146.1		11.58	346,988	22.0%	76,271
	30	7.2%		152.0		10.93	346,988	20.7%	71,954
	31	6.5%		158.0		10.31	346,988	19.6%	67,881
	32	5.9%		164.4		9.73	346,988	18.5%	64,039

Fig. 89: Economical Cost calculation: **RO 1,000 m³/d -- SC,** Seawater Open Intake

Economical cost calculations for 1,000 m³ RO plant powered by SC

S E A W A T E R - W E L L   I N T A K E

Assumptions of costs:

Capital costs for 1,000 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
RO-plant	350 lakh	SC-maintenance	17 lakh	discounted Investment +operation cost	Lakh Rs.
SC-plant	1,748 lakh	Chemicals	3 lakh		3,270
wells / seawater extraction plant (see pretreatment)	40 lakh	Spare parts (mft)	14 lakh		
land costs	50 lakh	Labour (20 employees)	18 lakh	discounted water production assuming an inflation-indexed price	m³
pretreatment & disposal	18 lakh	membrane replacement (every 3 to 5 years)	4-12 lakh		5,057,064
generator	8 lakh	operational costs per year	53 lakh		
capital nominally invested	2,214 lakh	nominal operational costs	2,956 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capita	2,518 lakh	present value of operational costs	752 lakh		64.66

availability of plant	95%	
water production	346,988	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	221.35			269.00			
	2	110%	1,992.15			2,196.15			
Start	3	100%		52.7		52.70	346,988	100.0%	346,988
	4	90.7%		54.8		49.72	346,988	94.3%	327,347
	5	82.3%		57.0		46.91	346,988	89.0%	308,818
	6	74.6%		59.3		44.25	346,988	84.0%	291,337
	7	67.7%		61.7	4	44.45	346,988	79.2%	274,847
	8	61.4%		64.1		39.38	346,988	74.7%	259,289
	9	55.7%		66.7		37.15	346,988	70.5%	244,612
	10	50.5%		69.4		35.05	346,988	66.5%	230,767
	11	45.8%		72.1		33.07	346,988	62.7%	217,704
	12	41.6%		75.0	6	33.69	346,988	59.2%	205,381
	13	37.7%		78.0		29.43	346,988	55.8%	193,756
	14	34.2%		81.1		27.76	346,988	52.7%	182,789
	15	31.0%		84.4		26.19	346,988	49.7%	172,442
	16	28.2%		87.8		24.71	346,988	46.9%	162,681
	17	25.5%		91.3	8	25.35	346,988	44.2%	153,473
	18	23.2%		94.9		21.99	346,988	41.7%	144,786
	19	21.0%		98.7		20.75	346,988	39.4%	136,590
	20	19.1%		102.7		19.57	346,988	37.1%	128,859
	21	17.3%		106.8		18.46	346,988	35.0%	121,565
	22	15.7%		111.0	175	44.87	329,638	33.1%	108,950
	23	14.2%		115.5		16.43	346,988	31.2%	108,192
	24	12.9%		120.1		15.50	346,988	29.4%	102,068
	25	11.7%		124.9		14.63	346,988	27.8%	96,291
	26	10.6%		129.9		13.80	346,988	26.2%	90,840
	27	9.6%		135.1	12	14.17	346,988	24.7%	85,698
	28	8.7%		140.5		12.28	346,988	23.3%	80,848
	29	7.9%		146.1		11.58	346,988	22.0%	76,271
	30	7.2%		152.0		10.93	346,988	20.7%	71,954
	31	6.5%		158.0		10.31	346,988	19.6%	67,881
	32	5.9%		164.4		9.73	346,988	18.5%	64,039

Fig. 90: Economical Cost calculation: **RO 1,000 m³/d -- SC, Well Intake**

Economical cost calculations for 5,000 m³ RO plant powered by SC

S E A W A T E R - O P E N   I N T A K E

Assumptions of costs:

Capital costs for 5,000 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
RO-plant	1,750 lakh	SC-maintenance	78 lakh	discounted Investment +operation cost	Lakh Rs.
SC-plant	7,820 lakh	Chemicals	16 lakh		14,864
wells / seawater extraction plant (see pretreatment)	0 lakh	Spare parts (mft)	69 lakh		
land costs	250 lakh	Labour (25 employees)	23 lakh	discounted water production assuming an inflation-indexed price	m³
pretreatment & disposal	875 lakh	membrane replacement (every 3 to 5 years)	20-60 lakh		25,285,318
generator	55 lakh	operational costs per year	186 lakh		
capital nominally invested	10,750 lakh	nominal operational costs	10,428 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capita	12,158 lakh	present value of operational costs	2,706 lakh		58.79

availability of plant	95%	
water production	1,734,938	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	1,075.0			1,306.43			
	2	110%	9,675.0			10,665.72			
Start	3	100%		185.9		185.93	1,734,938	100.0%	1,734,938
	4	90.7%		193.4		175.40	1,734,938	94.3%	1,636,733
	5	82.3%		201.1		165.48	1,734,938	89.0%	1,544,088
	6	74.6%		209.1		156.11	1,734,938	84.0%	1,456,687
	7	67.7%		217.5	20	160.81	1,734,938	79.2%	1,374,233
	8	61.4%		226.2		138.94	1,734,938	74.7%	1,296,446
	9	55.7%		235.3		131.07	1,734,938	70.5%	1,223,062
	10	50.5%		244.7		123.65	1,734,938	66.5%	1,153,833
	11	45.8%		254.5		116.65	1,734,938	62.7%	1,088,521
	12	41.6%		264.6	30	122.53	1,734,938	59.2%	1,026,907
	13	37.7%		275.2		103.82	1,734,938	55.8%	968,780
	14	34.2%		286.2		97.94	1,734,938	52.7%	913,943
	15	31.0%		297.7		92.40	1,734,938	49.7%	862,211
	16	28.2%		309.6		87.17	1,734,938	46.9%	813,406
	17	25.5%		322.0	40	92.45	1,734,938	44.2%	767,365
	18	23.2%		334.8		77.58	1,734,938	41.7%	723,929
	19	21.0%		348.2		73.19	1,734,938	39.4%	682,952
	20	19.1%		362.2		69.05	1,734,938	37.1%	644,294
	21	17.3%		376.7		65.14	1,734,938	35.0%	607,825
	22	15.7%		391.7	875	198.72	1,648,191	33.1%	544,748
	23	14.2%		407.4		57.97	1,734,938	31.2%	540,962
	24	12.9%		423.7		54.69	1,734,938	29.4%	510,341
	25	11.7%		440.6		51.60	1,734,938	27.8%	481,454
	26	10.6%		458.3		48.68	1,734,938	26.2%	454,202
	27	9.6%		476.6	60	51.70	1,734,938	24.7%	428,492
	28	8.7%		495.7		43.32	1,734,938	23.3%	404,238
	29	7.9%		515.5		40.87	1,734,938	22.0%	381,357
	30	7.2%		536.1		38.56	1,734,938	20.7%	359,770
	31	6.5%		557.5		36.37	1,734,938	19.6%	339,406
	32	5.9%		579.8		34.31	1,734,938	18.5%	320,194

Fig. 91: Economical Cost calculation: **RO 5,000 m³/d -- SC,** **Seawater Open Intake**

Economical cost calculations for 5,000 m³ RO plant powered by SC

S E A W A T E R - W E L L I N T A K E

Assumptions of costs:

Capital costs for 5,000 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
RO-plant	1,750 lakh	SC-maintenance	78 lakh	discounted Investment +operation cost	Lakh Rs.
SC-plant	7,820 lakh	Chemicals	16 lakh		14,210
wells / seawater extraction plant (see pretreatment)	200 lakh	Spare parts (mft)	69 lakh		
land costs	250 lakh	Labour (25 employees)	23 lakh	discounted water production assuming an inflation-indexed price	m³
pretreatment & disposal	88 lakh	membrane replacement (every 3 to 5 years)	20-60 lakh		25,285,318
generator	55 lakh	operational costs per year	186 lakh		
capital nominally invested	10,163 lakh	nominal operational costs	###########	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capita	11,504 lakh	present value of operational costs	2,706 lakh		56.20

availability of plant	95%	
water production	1,734,938	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	1,016.3			1,235.03			
	2	110%	9,146.3			10,082.83			
Start	3	100%		185.9		185.93	1,734,938	100.0%	1,734,938
	4	90.7%		193.4		175.40	1,734,938	94.3%	1,636,733
	5	82.3%		201.1		165.48	1,734,938	89.0%	1,544,088
	6	74.6%		209.1		156.11	1,734,938	84.0%	1,456,687
	7	67.7%		217.5	20	160.81	1,734,938	79.2%	1,374,233
	8	61.4%		226.2		138.94	1,734,938	74.7%	1,296,446
	9	55.7%		235.3		131.07	1,734,938	70.5%	1,223,062
	10	50.5%		244.7		123.65	1,734,938	66.5%	1,153,833
	11	45.8%		254.5		116.65	1,734,938	62.7%	1,088,521
	12	41.6%		264.6	30	122.53	1,734,938	59.2%	1,026,907
	13	37.7%		275.2		103.82	1,734,938	55.8%	968,780
	14	34.2%		286.2		97.94	1,734,938	52.7%	913,943
	15	31.0%		297.7		92.40	1,734,938	49.7%	862,211
	16	28.2%		309.6		87.17	1,734,938	46.9%	813,406
	17	25.5%		322.0	40	92.45	1,734,938	44.2%	767,365
	18	23.2%		334.8		77.58	1,734,938	41.7%	723,929
	19	21.0%		348.2		73.19	1,734,938	39.4%	682,952
	20	19.1%		362.2		69.05	1,734,938	37.1%	644,294
	21	17.3%		376.7		65.14	1,734,938	35.0%	607,825
	22	15.7%		391.7	875	198.72	1,648,191	33.1%	544,748
	23	14.2%		407.4		57.97	1,734,938	31.2%	540,962
	24	12.9%		423.7		54.69	1,734,938	29.4%	510,341
	25	11.7%		440.6		51.60	1,734,938	27.8%	481,454
	26	10.6%		458.3		48.68	1,734,938	26.2%	454,202
	27	9.6%		476.6	60	51.70	1,734,938	24.7%	428,492
	28	8.7%		495.7		43.32	1,734,938	23.3%	404,238
	29	7.9%		515.5		40.87	1,734,938	22.0%	381,357
	30	7.2%		536.1		38.56	1,734,938	20.7%	359,770
	31	6.5%		557.5		36.37	1,734,938	19.6%	339,406
	32	5.9%		579.8		34.31	1,734,938	18.5%	320,194

Fig. 92: Economical Cost calculation: **RO 5,000 m³/d -- SC, Well Intake**

Economical cost calculations for 10,000 m³ RO plant powered by SC

S E A W A T E R - O P E N   I N T A K E

Assumptions of costs:

Capital costs for 10,000 m³/d in Lakh		**Operational costs in Lakh/a**		**Results of Calculation**	
RO-plant	3,500 lakh	SC-maintenance	155 lakh	discounted Investment +operation cost	Lakh Rs.
SC-plant	15,527 lakh	Chemicals	32 lakh		29,272
wells / seawater extraction plant (see pretreatment)	0 lakh	Spare parts (mft)	138 lakh		
land costs	500 lakh	Labour (30 employees)	27 lakh	discounted water production assuming an inflation-indexed price	m³
pretreatment & disposal	1,750 lakh	membrane replacement (every 3 to 5 years)	40-120 lakh		50,570,636
generator	70 lakh	operational costs per year	352 lakh		
capital nominally invested	21,347 lakh	nominal operational costs	19,757 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capita	24,126 lakh	present value of operational costs	5,146 lakh		57.88

availability of plant	95%	
water production	3,469,875	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	6.00% %/a	discounted water prod. m³/a
	1	122%	2,134.7			2,594.27			
	2	110%	19,212.3			21,179.64			
Start	3	100%		352.3		352.26	3,469,875	100.0%	3,469,875
	4	90.7%		366.4		332.32	3,469,875	94.3%	3,273,467
	5	82.3%		381.0		313.51	3,469,875	89.0%	3,088,176
	6	74.6%		396.2		295.77	3,469,875	84.0%	2,913,374
	7	67.7%		412.1	40	306.11	3,469,875	79.2%	2,748,466
	8	61.4%		428.6		263.23	3,469,875	74.7%	2,592,892
	9	55.7%		445.7		248.33	3,469,875	70.5%	2,446,125
	10	50.5%		463.6		234.28	3,469,875	66.5%	2,307,665
	11	45.8%		482.1		221.01	3,469,875	62.7%	2,177,043
	12	41.6%		501.4	60	233.46	3,469,875	59.2%	2,053,814
	13	37.7%		521.4		196.70	3,469,875	55.8%	1,937,560
	14	34.2%		542.3		185.57	3,469,875	52.7%	1,827,887
	15	31.0%		564.0		175.06	3,469,875	49.7%	1,724,422
	16	28.2%		586.5		165.15	3,469,875	46.9%	1,626,813
	17	25.5%		610.0	80	176.24	3,469,875	44.2%	1,534,729
	18	23.2%		634.4		146.99	3,469,875	41.7%	1,447,858
	19	21.0%		659.8		138.67	3,469,875	39.4%	1,365,903
	20	19.1%		686.2		130.82	3,469,875	37.1%	1,288,588
	21	17.3%		713.6		123.41	3,469,875	35.0%	1,215,649
	22	15.7%		742.2	1,750	390.96	3,296,381	33.1%	1,089,497
	23	14.2%		771.9		109.84	3,469,875	31.2%	1,081,923
	24	12.9%		802.7		103.62	3,469,875	29.4%	1,020,682
	25	11.7%		834.8		97.75	3,469,875	27.8%	962,908
	26	10.6%		868.2		92.22	3,469,875	26.2%	908,404
	27	9.6%		903.0	120	98.56	3,469,875	24.7%	856,985
	28	8.7%		939.1		82.08	3,469,875	23.3%	808,476
	29	7.9%		976.6		77.43	3,469,875	22.0%	762,713
	30	7.2%		1015.7		73.05	3,469,875	20.7%	719,541
	31	6.5%		1,056.3		68.91	3,469,875	19.6%	678,812
	32	5.9%		1,098.6		65.01	3,469,875	18.5%	640,389

Disc.Factor for Water assuming the water-price rises with inflation

Fig. 93: Economical Cost calculation: **RO 10,000 m³/d -- SC, Seawater Open Intake**

Economical cost calculations for 10,000 m³ RO plant powered by SC

S E A W A T E R - W E L L   I N T A K E

Assumptions of costs:

Capital costs for 10,000 m³/d in Lakh		**Operational costs in Lakh/a**		**Results of Calculation**	
RO-plant	3,500 lakh	SC-maintenance	155 lakh	discounted Investment +operation cost	Lakh Rs. 27,964
SC-plant	15,527 lakh	Chemicals	32 lakh		
wells / seawater extraction plant (see pretreatment)	400 lakh	Spare parts (mft)	138 lakh		
land costs	500 lakh	Labour (30 employees)	27 lakh	discounted water production assuming an inflation-indexed price	m³ 50,570,636
pretreatment & disposal	175 lakh	membrane replacement (every 3 to 5 years)	40-120 lakh		
generator	70 lakh	operational costs per year	352 lakh		
capital nominally invested	20,172 lakh	nominal operational costs	19,757 lakh	water price in first year of production, which grows annually with inflation	Rs/m³ 55.30
present value of capita	22,818 lakh	present value of operational costs	5,146 lakh		

availability of plant	95%	
water production	3,469,875	m³/a
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	2,017.2			2,451.47			
	2	110%	18,154.8			20,013.85			
Start	3	100%		352.3		352.26	3,469,875	100.0%	3,469,875
	4	90.7%		366.4		332.32	3,469,875	94.3%	3,273,467
	5	82.3%		381.0		313.51	3,469,875	89.0%	3,088,176
	6	74.6%		396.2		295.77	3,469,875	84.0%	2,913,374
	7	67.7%		412.1	40	306.11	3,469,875	79.2%	2,748,466
	8	61.4%		428.6		263.23	3,469,875	74.7%	2,592,892
	9	55.7%		445.7		248.33	3,469,875	70.5%	2,446,125
	10	50.5%		463.6		234.28	3,469,875	66.5%	2,307,665
	11	45.8%		482.1		221.01	3,469,875	62.7%	2,177,043
	12	41.6%		501.4	60	233.46	3,469,875	59.2%	2,053,814
	13	37.7%		521.4		196.70	3,469,875	55.8%	1,937,560
	14	34.2%		542.3		185.57	3,469,875	52.7%	1,827,887
	15	31.0%		564.0		175.06	3,469,875	49.7%	1,724,422
	16	28.2%		586.5		165.15	3,469,875	46.9%	1,626,813
	17	25.5%		610.0	80	176.24	3,469,875	44.2%	1,534,729
	18	23.2%		634.4		146.99	3,469,875	41.7%	1,447,858
	19	21.0%		659.8		138.67	3,469,875	39.4%	1,365,903
	20	19.1%		686.2		130.82	3,469,875	37.1%	1,288,588
	21	17.3%		713.6		123.41	3,469,875	35.0%	1,215,649
	22	15.7%		742.2	1,750	390.96	3,296,381	33.1%	1,089,497
	23	14.2%		771.9		109.84	3,469,875	31.2%	1,081,923
	24	12.9%		802.7		103.62	3,469,875	29.4%	1,020,682
	25	11.7%		834.8		97.75	3,469,875	27.8%	962,908
	26	10.6%		868.2		92.22	3,469,875	26.2%	908,404
	27	9.6%		903.0	120	98.56	3,469,875	24.7%	856,985
	28	8.7%		939.1		82.08	3,469,875	23.3%	808,476
	29	7.9%		976.6		77.43	3,469,875	22.0%	762,713
	30	7.2%		1015.7		73.05	3,469,875	20.7%	719,541
	31	6.5%		1,056.3		68.91	3,469,875	19.6%	678,812
	32	5.9%		1,098.6		65.01	3,469,875	18.5%	640,389

Fig. 94: Economical Cost calculation: **RO 10,000 m^3/d -- SC, Well Intake**

Economical cost calculations for 500 m^3 RO plant powered by Wind

S E A WA T E R - O P E N I N T A K E

Assumptions of costs:

Capital costs for 500 m^3/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
RO-plant	175 lakh	Wind turbine maintenance	6 lakh	discounted Investment	Lakh Rs. 402
Wind turbine	625 lakh	Chemicals	2 lakh		
wells / seawater extraction plant (see	0 lakh	Spare parts (RO)	7 lakh		
land costs	1 lakh	Labour (10 employees)	9 lakh	discounted water production assuming an inflation-indexed price	m^3 2,350,902
pretreatment & disposal	88 lakh	membrane replacement (every 3 to 5 years)	2-5 lakh		
generator	6 lakh	operational costs per year	24 lakh		
capital nominally invested	895 lakh	nominal operational costs	994 lakh	water price in first year of production, which grows annually with inflation	Rs/m^3 17.09
present value of capital	1,020 lakh	present value of operational costs	-618 lakh		

availability of plant	95%	
water production	173,494	m^3/a
surplus energy production	2,520,609	kWh/a
price for sold energy	2.7	Rs/kWh
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 20 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	disc. revenue for sold energy Rs lakh/a	discounted revenue Rs lakh/a	water prod. m^3/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m^3/a
	1	122%	89.45			108.71					
	2	110%	805 lakh			887.49					
Start	3	100%		23.9		23.86	68	-44	173,494	100.0%	173,494
	4	90.7%		24.8		22.51	64	-42	173,494	94.3%	163,673
	5	82.3%		25.8		21.24	61	-39	173,494	89.0%	154,409
	6	74.6%		26.8		20.03	57	-37	173,494	84.0%	145,669
	7	67.7%		27.9	2	20.25	54	-34	173,494	79.2%	137,423
	8	61.4%		29.0		17.83	51	-33	173,494	74.7%	129,645
	9	55.7%		30.2		16.82	48	-31	173,494	70.5%	122,306
	10	50.5%		31.4		15.87	45	-29	173,494	66.5%	115,383
	11	45.8%		32.7		14.97	43	-28	173,494	62.7%	108,852
	12	41.6%		34.0	3	15.37	40	-25	173,494	59.2%	102,691
	13	37.7%		35.3		13.32	38	-25	173,494	55.8%	96,878
	14	34.2%		36.7		12.57	36	-23	173,494	52.7%	91,394
	15	31.0%		38.2		11.86	34	-22	173,494	49.7%	86,221
	16	28.2%		39.7		11.19	32	-21	173,494	46.9%	81,341
	17	25.5%		41.3	4	11.58	30	-19	173,494	44.2%	76,736
	18	23.2%		43.0		9.96	28	-18	173,494	41.7%	72,393
	19	21.0%		44.7		9.39	27	-17	173,494	39.4%	68,295
	20	19.1%		46.5		8.86	25	-16	173,494	37.1%	64,429
	21	17.3%		48.3		8.36	24	-15	173,494	35.0%	60,782
	22	15.7%		50.3	5	8.67	22	-14	173,494	33.1%	57,342
	23	14.2%		52.3		7.44	21	-14	173,494	31.2%	54,096
	24	12.9%		54.4		7.02	20	-13	173,494	29.4%	51,034
	25	11.7%		56.5		6.62	19	-12	173,494	27.8%	48,145
	26	10.6%		58.8		6.25	18	-12	173,494	26.2%	45,420
	27	9.6%		61.2		5.89	17	-11	173,494	24.7%	42,849

Fig. 95: Economical Cost calculation: **RO 500 m^3/d -- Wind, Seawater Open Intake**

Economical cost calculations for 500 m³ RO plant powered by Wind

S E A WA T E R - W E L L I N T A K E

Assumptions of costs:

Capital costs for 500 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
RO-plant	175 lakh	Wind turbine maintenance	6 lakh	discounted	Lakh Rs.
Wind turbine	625 lakh	Chemicals	2 lakh	Investment	336
wells / seawater extraction plant (see	20 lakh	Spare parts (RO)	7 lakh		
land costs	1 lakh	Labour (10 employees)	9 lakh	discounted water production assuming an inflation-indexed price	m³
pretreatment & disposal	9 lakh	membrane replacement (every 3 to 5 years)	2-5 lakh		2,350,902
generator	6 lakh	operational costs per year	24 lakh		
capital nominally invested	836 lakh	nominal operational costs	994 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capital	955 lakh	present value of operational costs	-618 lakh		14.31

availability of plant	95%	
water production	173,494	m³/a
surplus energy production	2,520,609	kWh/a
price for sold ener(	2.7	Rs/kWh
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 20 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	disc. revenue for sold energy	discounted revenue	water prod.	Disc.Factor for Water assuming the water-price rises with inflation 6.00%	discounted water prod.
	1	122%	83.575			101.57					
	2	110%	752 lakh			829.20	Rs lakh/a	Rs lakh/a	m³/a	%/a	m³/a
Start	3	100%		23.9		23.86	68	-44	173,494	100.0%	173,494
	4	90.7%		24.8		22.51	64	-42	173,494	94.3%	163,673
	5	82.3%		25.8		21.24	61	-39	173,494	89.0%	154,409
	6	74.6%		26.8		20.03	57	-37	173,494	84.0%	145,669
	7	67.7%		27.9	2	20.25	54	-34	173,494	79.2%	137,423
	8	61.4%		29.0		17.83	51	-33	173,494	74.7%	129,645
	9	55.7%		30.2		16.82	48	-31	173,494	70.5%	122,306
	10	50.5%		31.4		15.87	45	-29	173,494	66.5%	115,383
	11	45.8%		32.7		14.97	43	-28	173,494	62.7%	108,852
	12	41.6%		34.0	3	15.37	40	-25	173,494	59.2%	102,691
	13	37.7%		35.3		13.32	38	-25	173,494	55.8%	96,878
	14	34.2%		36.7		12.57	36	-23	173,494	52.7%	91,394
	15	31.0%		38.2		11.86	34	-22	173,494	49.7%	86,221
	16	28.2%		39.7		11.19	32	-21	173,494	46.9%	81,341
	17	25.5%		41.3	4	11.58	30	-19	173,494	44.2%	76,736
	18	23.2%		43.0		9.96	28	-18	173,494	41.7%	72,393
	19	21.0%		44.7		9.39	27	-17	173,494	39.4%	68,295
	20	19.1%		46.5		8.86	25	-16	173,494	37.1%	64,429
	21	17.3%		48.3		8.36	24	-15	173,494	35.0%	60,782
	22	15.7%		50.3	5	8.67	22	-14	173,494	33.1%	57,342
	23	14.2%		52.3		7.44	21	-14	173,494	31.2%	54,096
	24	12.9%		54.4		7.02	20	-13	173,494	29.4%	51,034
	25	11.7%		56.5		6.62	19	-12	173,494	27.8%	48,145
	26	10.6%		58.8		6.25	18	-12	173,494	26.2%	45,420
	27	9.6%		61.2		5.89	17	-11	173,494	24.7%	42,849

Fig. 96: Economical Cost calculation: **RO 500 m³/d -- Wind, Well Intake**

Economical cost calculations for 1,000 m³ RO plant powered by Wind

S E A WA T E R - O P E N I N T A K E

Assumptions of costs:

Capital costs for 1,000 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
RO-plant	350 lakh	Wind turbine maintenance	6 lakh	discounted Investment	Lakh Rs. 991
Wind turbine	625 lakh	Chemicals	3 lakh		
wells / seawater extraction plant (see	0 lakh	Spare parts (RO)	14 lakh		
land costs	1 lakh	Labour (10 employees)	9 lakh	discounted water production assuming an inflation-indexed price	m³ 4,701,805
pretreatment & disposal	175 lakh	membrane replacement (every 3 to 5 years)	4-10 lakh		
generator	8 lakh	operational costs per year	32 lakh		
capital nominally invested	1,159 lakh	nominal operational costs	1,347 lakh	water price in first year of production, which grows annually with inflation	Rs/m³ 21.08
present value of capital	1,323 lakh	present value of operational costs	-332 lakh		

availability of plant	95%	
water production	346,988	m³/a
surplus energy production	2,041,219	kWh/a
price for sold energy	2.7	Rs/kWh
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 20 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	disc. revenue for sold Rs lakh/a	discounted revenue Rs lakh/a	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	115.9			140.85					
	2	110%	#########			1,150					
Start	3	100%		32.3		32.34	55	-23	346,988	100.0%	346,988
	4	90.7%		33.6		30.51	52	-21	346,988	94.3%	327,347
	5	82.3%		35.0		28.78	49	-20	346,988	89.0%	308,818
	6	74.6%		36.4		27.15	46	-19	346,988	84.0%	291,337
	7	67.7%		37.8	4	28.33	44	-15	346,988	79.2%	274,847
	8	61.4%		39.3		24.17	41	-17	346,988	74.7%	259,289
	9	55.7%		40.9		22.80	39	-16	346,988	70.5%	244,612
	10	50.5%		42.6		21.51	37	-15	346,988	66.5%	230,767
	11	45.8%		44.3		20.29	35	-14	346,988	62.7%	217,704
	12	41.6%		46.0	6	21.64	33	-11	346,988	59.2%	205,381
	13	37.7%		47.9		18.06	31	-13	346,988	55.8%	193,756
	14	34.2%		49.8		17.04	29	-12	346,988	52.7%	182,789
	15	31.0%		51.8		16.07	27	-11	346,988	49.7%	172,442
	16	28.2%		53.9		15.16	26	-11	346,988	46.9%	162,681
	17	25.5%		56.0	8	16.35	24	-8	346,988	44.2%	153,473
	18	23.2%		58.2		13.49	23	-10	346,988	41.7%	144,786
	19	21.0%		60.6		12.73	22	-9	346,988	39.4%	136,590
	20	19.1%		63.0		12.01	20	-8	346,988	37.1%	128,859
	21	17.3%		65.5		11.33	19	-8	346,988	35.0%	121,565
	22	15.7%		68.1	10	12.26	18	-6	346,988	33.1%	114,684
	23	14.2%		70.9		10.08	17	-7	346,988	31.2%	108,192
	24	12.9%		73.7		9.51	16	-7	346,988	29.4%	102,068
	25	11.7%		76.6		8.97	15	-6	346,988	27.8%	96,291
	26	10.6%		79.7		8.47	14	-6	346,988	26.2%	90,840
	27	9.6%		82.9		7.99	14	-6	346,988	24.7%	85,698

Fig. 97: Economical Cost calculation: **RO 1,000 m³/d -- Wind, Seawater Open Intake**

Economical cost calculations for 1,000 m³ RO plant powered by Wind

S E A W A T E R - W E L L   I N T A K E

Assumptions of costs:

Capital costs for 1,000 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
RO-plant	350 lakh	Wind turbine maintenance	6 lakh	discounted Investment	Lakh Rs. 860
Wind turbine	625 lakh	Chemicals	3 lakh		
wells / seawater extraction plant (see	40 lakh	Spare parts (RO)	14 lakh		
land costs	1 lakh	Labour (10 employees)	9 lakh	discounted water production assuming an inflation-indexed price	m³ 4,701,805
pretreatment & disposal	18 lakh	membrane replacement (every 3 to 5 years)	4-10 lakh		
generator	8 lakh	operational costs per year	32 lakh		
capital nominally invested	1,042 lakh	nominal operational costs	1,347 lakh	water price in first year of production, which grows annually with inflation	Rs/m³ 18.29
present value of capital	1,192 lakh	present value of operational costs	-332 lakh		

availability of plant	95%	
water production	346,988	m³/a
surplus energy production	2,041,219	kWh/a
price for sold energy	2.7	Rs/kWh
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 20 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	disc. revenue for sold Rs lakh/a	discounted revenue Rs lakh/a	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	104.15			126.57					
	2	110%	937 lakh			1,033.33					
Start	3	100%		32.3		32.34	55	-23	346,988	100.0%	346,988
	4	90.7%		33.6		30.51	52	-21	346,988	94.3%	327,347
	5	82.3%		35.0		28.78	49	-20	346,988	89.0%	308,818
	6	74.6%		36.4		27.15	46	-19	346,988	84.0%	291,337
	7	67.7%		37.8	4	28.33	44	-15	346,988	79.2%	274,847
	8	61.4%		39.3		24.17	41	-17	346,988	74.7%	259,289
	9	55.7%		40.9		22.80	39	-16	346,988	70.5%	244,612
	10	50.5%		42.6		21.51	37	-15	346,988	66.5%	230,767
	11	45.8%		44.3		20.29	35	-14	346,988	62.7%	217,704
	12	41.6%		46.0	6	21.64	33	-11	346,988	59.2%	205,381
	13	37.7%		47.9		18.06	31	-13	346,988	55.8%	193,756
	14	34.2%		49.8		17.04	29	-12	346,988	52.7%	182,789
	15	31.0%		51.8		16.07	27	-11	346,988	49.7%	172,442
	16	28.2%		53.9		15.16	26	-11	346,988	46.9%	162,681
	17	25.5%		56.0	8	16.35	24	-8	346,988	44.2%	153,473
	18	23.2%		58.2		13.49	23	-10	346,988	41.7%	144,786
	19	21.0%		60.6		12.73	22	-9	346,988	39.4%	136,590
	20	19.1%		63.0		12.01	20	-8	346,988	37.1%	128,859
	21	17.3%		65.5		11.33	19	-8	346,988	35.0%	121,565
	22	15.7%		68.1	10	12.26	18	-6	346,988	33.1%	114,684
	23	14.2%		70.9		10.08	17	-7	346,988	31.2%	108,192
	24	12.9%		73.7		9.51	16	-7	346,988	29.4%	102,068
	25	11.7%		76.6		8.97	15	-6	346,988	27.8%	96,291
	26	10.6%		79.7		8.47	14	-6	346,988	26.2%	90,840
	27	9.6%		82.9		7.99	14	-6	346,988	24.7%	85,698

Fig. 98: Economical Cost calculation: **RO 1,000 m³/d -- Wind, Well Intake**

Economical cost calculations for 5,000 m³ RO plant powered by Wind

S E A WA T E R - O P E N I N T A K E

Assumptions of costs:

Capital costs for 5,000 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
RO-plant	1,750 lakh	Wind turbine maintenance	13 lakh	discounted Investment	Lakh Rs. 5,310
Wind turbine	1,250 lakh	Chemicals	16 lakh		
wells / seawater extraction plant (see	0 lakh	Spare parts (RO)	69 lakh		
land costs	2 lakh	Labour (15 employees)	14 lakh	discounted water production assuming an inflation-indexed price	m³ 23,509,023
pretreatment & disposal	875 lakh	membrane replacement (every 3 to 5 years)	20-50 lakh		
generator	55 lakh	operational costs per year	111 lakh		
capital nominally invested	3,932 lakh	nominal operational costs	4,623 lakh	water price in first year of production, which grows annually with inflation	Rs/m³ 22.59
present value of capital	4,490 lakh	present value of operational costs	820 lakh		

availability of plant	95%	
water production	1,734,938	m³/a
surplus energy production	1,685,484	kWh/a
price for sold energy	2.7	Rs/kWh
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 20 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	disc. revenue for sold Rs lakh/a	disc. revenue Rs lakh/a	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	393.2			477.85					
	2	110%	3,538.80			3,901.17					
Start	3	100%		111.0		111.00	46	65	1,734,938	100.0%	1,734,938
	4	90.7%		115.4		104.71	43	62	1,734,938	94.3%	1,636,733
	5	82.3%		120.1		98.79	41	58	1,734,938	89.0%	1,544,088
	6	74.6%		124.9		93.20	38	55	1,734,938	84.0%	1,456,687
	7	67.7%		129.9	20	101.46	36	65	1,734,938	79.2%	1,374,233
	8	61.4%		135.0		82.94	34	49	1,734,938	74.7%	1,296,446
	9	55.7%		140.4		78.25	32	46	1,734,938	70.5%	1,223,062
	10	50.5%		146.1		73.82	30	44	1,734,938	66.5%	1,153,833
	11	45.8%		151.9		69.64	29	41	1,734,938	62.7%	1,088,521
	12	41.6%		158.0	30	78.17	27	51	1,734,938	59.2%	1,026,907
	13	37.7%		164.3		61.98	25	37	1,734,938	55.8%	968,780
	14	34.2%		170.9		58.47	24	34	1,734,938	52.7%	913,943
	15	31.0%		177.7		55.16	23	33	1,734,938	49.7%	862,211
	16	28.2%		184.8		52.04	21	31	1,734,938	46.9%	813,406
	17	25.5%		192.2	40	59.31	20	39	1,734,938	44.2%	767,365
	18	23.2%		199.9		46.32	19	27	1,734,938	41.7%	723,929
	19	21.0%		207.9		43.69	18	26	1,734,938	39.4%	682,952
	20	19.1%		216.2		41.22	17	24	1,734,938	37.1%	644,294
	21	17.3%		224.9		38.89	16	23	1,734,938	35.0%	607,825
	22	15.7%		233.9	50	44.53	15	29	1,734,938	33.1%	573,419
	23	14.2%		243.2		34.61	14	20	1,734,938	31.2%	540,962
	24	12.9%		252.9		32.65	13	19	1,734,938	29.4%	510,341
	25	11.7%		263.1		30.80	13	18	1,734,938	27.8%	481,454
	26	10.6%		273.6		29.06	12	17	1,734,938	26.2%	454,202
	27	9.6%		284.5		27.41	11	16	1,734,938	24.7%	428,492

Fig. 99: Economical Cost calculation: **RO 5,000 m³/d -- Wind, Seawater Open Intake**

Economical cost calculations for 5,000 m³ RO plant powered by Wind

S E A WA T E R - W E L L   I N T A K E

Assumptions of costs:

Capital costs for 5,000 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
RO-plant	1,750 lakh	Wind turbine maintenance	13 lakh	discounted	Lakh Rs.
Wind turbine	1,250 lakh	Chemicals	16 lakh	Investment	4,656
wells / seawater extraction plant (see	200 lakh	Spare parts (RO)	69 lakh		
land costs	2 lakh	Labour (15 employees)	14 lakh	discounted water production assuming an inflation-indexed price	m³
pretreatment & disposal	88 lakh	membrane replacement (every 3 to 5 years)	20-50 lakh		23,509,023
generator	55 lakh	operational costs per year	111 lakh		
capital nominally invested	3,345 lakh	nominal operational costs	4,623 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capital	3,836 lakh	present value of operational costs	820 lakh		19.81

availability of plant	95%	
water production	1,734,938	m³/a
surplus energy production	1,685,484	kWh/a
price for sold energy	2.7	Rs/kWh
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 20 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	disc. revenue for sold Rs lakh/a	discounted revenue Rs lakh/a	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	334.45			406.45					
	2	110%	3,010.05			3,318.28					
Start	3	100%		111.0		111.00	46	65	1,734,938	100.0%	1,734,938
	4	90.7%		115.4		104.71	43	62	1,734,938	94.3%	1,636,733
	5	82.3%		120.1		98.79	41	58	1,734,938	89.0%	1,544,088
	6	74.6%		124.9		93.20	38	55	1,734,938	84.0%	1,456,687
	7	67.7%		129.9	20	101.46	36	65	1,734,938	79.2%	1,374,233
	8	61.4%		135.0		82.94	34	49	1,734,938	74.7%	1,296,446
	9	55.7%		140.4		78.25	32	46	1,734,938	70.5%	1,223,062
	10	50.5%		146.1		73.82	30	44	1,734,938	66.5%	1,153,833
	11	45.8%		151.9		69.64	29	41	1,734,938	62.7%	1,088,521
	12	41.6%		158.0	30	78.17	27	51	1,734,938	59.2%	1,026,907
	13	37.7%		164.3		61.98	25	37	1,734,938	55.8%	968,780
	14	34.2%		170.9		58.47	24	34	1,734,938	52.7%	913,943
	15	31.0%		177.7		55.16	23	33	1,734,938	49.7%	862,211
	16	28.2%		184.8		52.04	21	31	1,734,938	46.9%	813,406
	17	25.5%		192.2	40	59.31	20	39	1,734,938	44.2%	767,365
	18	23.2%		199.9		46.32	19	27	1,734,938	41.7%	723,929
	19	21.0%		207.9		43.69	18	26	1,734,938	39.4%	682,952
	20	19.1%		216.2		41.22	17	24	1,734,938	37.1%	644,294
	21	17.3%		224.9		38.89	16	23	1,734,938	35.0%	607,825
	22	15.7%		233.9	50	44.53	15	29	1,734,938	33.1%	573,419
	23	14.2%		243.2		34.61	14	20	1,734,938	31.2%	540,962
	24	12.9%		252.9		32.65	13	19	1,734,938	29.4%	510,341
	25	11.7%		263.1		30.80	13	18	1,734,938	27.8%	481,454
	26	10.6%		273.6		29.06	12	17	1,734,938	26.2%	454,202
	27	9.6%		284.5		27.41	11	16	1,734,938	24.7%	428,492

Fig. 100: Economical Cost calculation: **RO 5,000 m³/d -- Wind, Well Intake**

Economical cost calculations for 10,000 m^3 RO plant powered by Wind

S E A WA T E R - O P E N I N T A K E

Assumptions of costs:

Capital costs for 10,000 m^3/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
RO-plant	3,500 lakh	Wind turbine maintenance	19 lakh	discounted	Lakh Rs.
Wind turbine	1,875 lakh	Chemicals	32 lakh	Investment	10,768
wells / seawater extraction plant (see	0 lakh	Spare parts (RO)	138 lakh		
land costs	3 lakh	Labour (20 employees)	18 lakh	discounted water production assuming an inflation-indexed price	m^3
pretreatment & disposal	1,750 lakh	membrane replacement (every 3 to 5 years)	40-100 lakh		47,018,047
generator	70 lakh	operational costs per year	207 lakh		
capital nominally invested	7,198 lakh	nominal operational costs	8,605 lakh	water price in first year of production, which grows annually with inflation	Rs/m^3
present value of capital	8,223 lakh	present value of operational costs	2,545 lakh		22.90

availability of plant	95%	
water production	3,469,875	m^3/a
surplus energy production	370,969	kWh/a
price for sold energy	2.7	Rs/kWh
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 20 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	disc. revenue for sold Rs lakh/a	discounted revenue Rs lakh/a	water prod. m^3/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m^3/a
	1	122%	719.8			874.76					
	2	110%	6,478.2			7,141.57					
Start	3	100%		206.6		206.61	10	197	3,469,875	100.0%	3,469,875
	4	90.7%		214.9		194.92	9	185	3,469,875	94.3%	3,273,467
	5	82.3%		223.5		183.88	9	175	3,469,875	89.0%	3,088,176
	6	74.6%		232.4		173.48	8	165	3,469,875	84.0%	2,913,374
	7	67.7%		241.7	40	190.74	8	183	3,469,875	79.2%	2,748,466
	8	61.4%		251.4		154.39	7	147	3,469,875	74.7%	2,592,892
	9	55.7%		261.4		145.65	7	139	3,469,875	70.5%	2,446,125
	10	50.5%		271.9		137.41	7	131	3,469,875	66.5%	2,307,665
	11	45.8%		282.8		129.63	6	123	3,469,875	62.7%	2,177,043
	12	41.6%		294.1	60	147.25	6	141	3,469,875	59.2%	2,053,814
	13	37.7%		305.8		115.37	6	110	3,469,875	55.8%	1,937,560
	14	34.2%		318.1		108.84	5	104	3,469,875	52.7%	1,827,887
	15	31.0%		330.8		102.68	5	98	3,469,875	49.7%	1,724,422
	16	28.2%		344.0		96.87	5	92	3,469,875	46.9%	1,626,813
	17	25.5%		357.8	80	111.82	4	107	3,469,875	44.2%	1,534,729
	18	23.2%		372.1		86.21	4	82	3,469,875	41.7%	1,447,858
	19	21.0%		387.0		81.33	4	77	3,469,875	39.4%	1,365,903
	20	19.1%		402.5		76.73	4	73	3,469,875	37.1%	1,288,588
	21	17.3%		418.6		72.39	4	69	3,469,875	35.0%	1,215,649
	22	15.7%		435.3	100	83.98	3	81	3,469,875	33.1%	1,146,839
	23	14.2%		452.7		64.42	3	61	3,469,875	31.2%	1,081,923
	24	12.9%		470.8		60.78	3	58	3,469,875	29.4%	1,020,682
	25	11.7%		489.7		57.34	3	55	3,469,875	27.8%	962,908
	26	10.6%		509.2		54.09	3	51	3,469,875	26.2%	908,404
	27	9.6%		529.6		51.03	2	49	3,469,875	24.7%	856,985

Fig. 101: Economical Cost calculation: **RO 10,000 m^3/d -- Wind,** **Seawater Open Intake**

Economical cost calculations for 10,000 m³ RO plant powered by Wind

SEA WATER-WELL INTAKE

Assumptions of costs:

Capital costs for 10,000 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
RO-plant	3,500 lakh	Wind turbine maintenance	19 lakh	discounted Investment	Lakh Rs. 9,460
Wind turbine	1,875 lakh	Chemicals	32 lakh		
wells / seawater extraction plant (see	400 lakh	Spare parts (RO)	138 lakh		
land costs	3 lakh	Labour (20 employees)	18 lakh	discounted water production assuming an inflation-indexed price	m³ 47,018,047
pretreatment & disposal	175 lakh	membrane replacement (every 3 to 5 years)	40-100 lakh		
generator	70 lakh	operational costs per year	207 lakh		
capital nominally invested	6,023 lakh	nominal operational costs	8,605 lakh	water price in first year of production, which grows annually with inflation	Rs/m³ 20.12
present value of capital	6,914 lakh	present value of operational costs	2,545 lakh		

availability of plant	95%	
water production	3,469,875	m³/a
surplus energy production	370,969	kWh/a
price for sold energy	2.7	Rs/kWh
discount factor	6.00%	/a
inflation	4.00%	/a
eff. discount factor	10.24%	/a

assumed life time 20 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	disc. revenue for sold Rs lakh/a	discounted revenue Rs lakh/a	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6.00% %/a	discounted water prod. m³/a
	1	122%	602.3			731.97					
	2	110%	5,420.70			5,975.78					
Start	3	100%		206.6		206.61	10	197	3,469,875	100.0%	3,469,875
	4	90.7%		214.9		194.92	9	185	3,469,875	94.3%	3,273,467
	5	82.3%		223.5		183.88	9	175	3,469,875	89.0%	3,088,176
	6	74.6%		232.4		173.48	8	165	3,469,875	84.0%	2,913,374
	7	67.7%		241.7	40	190.74	8	183	3,469,875	79.2%	2,748,466
	8	61.4%		251.4		154.39	7	147	3,469,875	74.7%	2,592,892
	9	55.7%		261.4		145.65	7	139	3,469,875	70.5%	2,446,125
	10	50.5%		271.9		137.41	7	131	3,469,875	66.5%	2,307,665
	11	45.8%		282.8		129.63	6	123	3,469,875	62.7%	2,177,043
	12	41.6%		294.1	60	147.25	6	141	3,469,875	59.2%	2,053,814
	13	37.7%		305.8		115.37	6	110	3,469,875	55.8%	1,937,560
	14	34.2%		318.1		108.84	5	104	3,469,875	52.7%	1,827,887
	15	31.0%		330.8		102.68	5	98	3,469,875	49.7%	1,724,422
	16	28.2%		344.0		96.87	5	92	3,469,875	46.9%	1,626,813
	17	25.5%		357.8	80	111.82	4	107	3,469,875	44.2%	1,534,729
	18	23.2%		372.1		86.21	4	82	3,469,875	41.7%	1,447,858
	19	21.0%		387.0		81.33	4	77	3,469,875	39.4%	1,365,903
	20	19.1%		402.5		76.73	4	73	3,469,875	37.1%	1,288,588
	21	17.3%		418.6		72.39	4	69	3,469,875	35.0%	1,215,649
	22	15.7%		435.3	100	83.98	3	81	3,469,875	33.1%	1,146,839
	23	14.2%		452.7		64.42	3	61	3,469,875	31.2%	1,081,923
	24	12.9%		470.8		60.78	3	58	3,469,875	29.4%	1,020,682
	25	11.7%		489.7		57.34	3	55	3,469,875	27.8%	962,908
	26	10.6%		509.2		54.09	3	51	3,469,875	26.2%	908,404
	27	9.6%		529.6		51.03	2	49	3,469,875	24.7%	856,985

Fig. 102: Economical Cost calculation: **RO 10,000 m³/d -- Wind, Well Intake**

Economical cost cal. for 500 m³ MED plant pow. by PV, free steam

S E A W A T E R - W E L L I N T A K E

Assumptions of costs:

Capital costs for 500 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
MED-plant	660 lakh	PV maintenance	4 lakh	discounted Investment +operation cost	Lakh Rs. 1.512
PV plant	368 lakh	Chemicals	1 lakh		
wells / seawater extraction plant (see pretreatment)	20 lakh	Spare parts	7 lakh		
land costs	8 lakh	Labour (10 employees)	9 lakh	discounted water production assuming an inflation-indexed price	m³ 2.528.532
pretreatment & disposal	7 lakh	membrane replacement (every 3 to 5 years)	0 lakh		
generator	4 lakh	operational costs per year	20 lakh		
capital nominally invested	1.066 lakh	nominal operational costs	1.133 lakh	water price in first year of production, which grows annually with inflation	Rs/m³ 59,80
present value of capita	1.208 lakh	present value of operational costs	305 lakh		

availability of plant	95%	
water production	173.494	m³/a
discount factor	6,00%	/a
inflation	4,00%	/a
eff. discount factor	10,24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6,00% %/a	discounted water prod. m³/a
	1	122%	106,6			129,56			
	2	110%	959,5			1.057,74			
Start	3	100%		20,2		20,21	173.494	100,0%	173.494
	4	90,7%		21,0		19,06	173.494	94,3%	163.673
	5	82,3%		21,9		17,98	173.494	89,0%	154.409
	6	74,6%		22,7		16,97	173.494	84,0%	145.669
	7	67,7%		23,6		16,01	173.494	79,2%	137.423
	8	61,4%		24,6		15,10	173.494	74,7%	129.645
	9	55,7%		25,6		14,24	173.494	70,5%	122.306
	10	50,5%		26,6		13,44	173.494	66,5%	115.383
	11	45,8%		27,7		12,68	173.494	62,7%	108.852
	12	41,6%		28,8		11,96	173.494	59,2%	102.691
	13	37,7%		29,9		11,28	173.494	55,8%	96.878
	14	34,2%		31,1		10,64	173.494	52,7%	91.394
	15	31,0%		32,4		10,04	173.494	49,7%	86.221
	16	28,2%		33,6		9,47	173.494	46,9%	81.341
	17	25,5%		35,0		8,94	173.494	44,2%	76.736
	18	23,2%		36,4		8,43	173.494	41,7%	72.393
	19	21,0%		37,8		7,95	173.494	39,4%	68.295
	20	19,1%		39,4		7,50	173.494	37,1%	64.429
	21	17,3%		40,9		7,08	173.494	35,0%	60.782
	22	15,7%		42,6	191	36,58	164.819	33,1%	54.475
	23	14,2%		44,3		6,30	173.494	31,2%	54.096
	24	12,9%		46,0		5,94	173.494	29,4%	51.034
	25	11,7%		47,9		5,61	173.494	27,8%	48.145
	26	10,6%		49,8		5,29	173.494	26,2%	45.420
	27	9,6%		51,8		4,99	173.494	24,7%	42.849
	28	8,7%		53,9		4,71	173.494	23,3%	40.424
	29	7,9%		56,0		4,44	173.494	22,0%	38.136
	30	7,2%		58,3		4,19	173.494	20,7%	35.977
	31	6,5%		60,6		3,95	173.494	19,6%	33.941
	32	5,9%		63,0		3,73	173.494	18,5%	32.019

Fig. 103: Economical Cost calculation: **MED$_{free\ steam}$ 500 m^3/d -- PV, Seawater Open Intake**

Economical cost cal. for 500 m³ MED plant pow. by PV, free steam

SEA WATER-WELL INTAKE

Assumptions of costs:

Capital costs for 500 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
MED-plant	660 lakh	PV maintenance	4 lakh	discounted Investment +operation cost	Lakh Rs. 1.512
PV plant	368 lakh	Chemicals	1 lakh		
wells / seawater extraction plant (see pretreatment)	20 lakh	Spare parts	7 lakh		
land costs	8 lakh	Labour (10 employees)	9 lakh	discounted water production assuming an inflation-indexed price	m³ 2.528.532
pretreatment & disposal	7 lakh	membrane replacement (every 3 to 5 years)	0 lakh		
generator	4 lakh	operational costs per year	20 lakh		
capital nominally invested	1.066 lakh	nominal operational costs	1.133 lakh	water price in first year of production, which grows annually with inflation	Rs/m³ 59,80
present value of capita	1.208 lakh	present value of operational costs	305 lakh		

availability of plant	95%	
water production	173.494	m³/a
discount factor	6,00%	/a
inflation	4,00%	/a
eff. discount factor	10,24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6,00% %/a	discounted water prod. m³/a
	1	122%	106,6			129,56			
	2	110%	959,5			1.057,74			
Start	3	100%		20,2		20,21	173.494	100,0%	173.494
	4	90,7%		21,0		19,06	173.494	94,3%	163.673
	5	82,3%		21,9		17,98	173.494	89,0%	154.409
	6	74,6%		22,7		16,97	173.494	84,0%	145.669
	7	67,7%		23,6		16,01	173.494	79,2%	137.423
	8	61,4%		24,6		15,10	173.494	74,7%	129.645
	9	55,7%		25,6		14,24	173.494	70,5%	122.306
	10	50,5%		26,6		13,44	173.494	66,5%	115.383
	11	45,8%		27,7		12,68	173.494	62,7%	108.852
	12	41,6%		28,8		11,96	173.494	59,2%	102.691
	13	37,7%		29,9		11,28	173.494	55,8%	96.878
	14	34,2%		31,1		10,64	173.494	52,7%	91.394
	15	31,0%		32,4		10,04	173.494	49,7%	86.221
	16	28,2%		33,6		9,47	173.494	46,9%	81.341
	17	25,5%		35,0		8,94	173.494	44,2%	76.736
	18	23,2%		36,4		8,43	173.494	41,7%	72.393
	19	21,0%		37,8		7,95	173.494	39,4%	68.295
	20	19,1%		39,4		7,50	173.494	37,1%	64.429
	21	17,3%		40,9		7,08	173.494	35,0%	60.782
	22	15,7%		42,6	191	36,58	164.819	33,1%	54.475
	23	14,2%		44,3		6,30	173.494	31,2%	54.096
	24	12,9%		46,0		5,94	173.494	29,4%	51.034
	25	11,7%		47,9		5,61	173.494	27,8%	48.145
	26	10,6%		49,8		5,29	173.494	26,2%	45.420
	27	9,6%		51,8		4,99	173.494	24,7%	42.849
	28	8,7%		53,9		4,71	173.494	23,3%	40.424
	29	7,9%		56,0		4,44	173.494	22,0%	38.136
	30	7,2%		58,3		4,19	173.494	20,7%	35.977
	31	6,5%		60,6		3,95	173.494	19,6%	33.941
	32	5,9%		63,0		3,73	173.494	18,5%	32.019

Fig. 104: Economical Cost calculation: **MED$_{free\ steam}$ 500 m^3/d -- PV, Well Intake**

Economical cost cal. for 1,000 m³ MED plant pow. by PV, free steam

S E A WA T E R - O P E N I N T A K E

Assumptions of costs:

Capital costs for 1,000 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
MED-plant	1.320 lakh	PV maintenance	7 lakh	discounted Investment +operation cost	Lakh Rs. 2.977
PV plant	735 lakh	Chemicals	2 lakh		
wells / seawater extraction plant (see pretreatment)	0 lakh	Spare parts	13 lakh		
land costs	15 lakh	Labour (10 employees)	9 lakh	discounted water production assuming an inflation-indexed price	m³ 5.057.064
pretreatment & disposal	132 lakh	membrane replacement (every 3 to 5 years)	0 lakh		
generator	8 lakh	operational costs per year	31 lakh		
capital nominally invested	2.210 lakh	nominal operational costs	1.754 lakh	water price in first year of production, which grows annually with inflation	Rs/m³ 58,87
present value of capita	2.493 lakh	present value of operational costs	485 lakh		

availability of plant	95%	
water production	346.988	m³/a
discount factor	6,00%	/a
inflation	4,00%	/a
eff. discount factor	10,24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6,00% %/a	discounted water prod. m³/a
	1	122%	221,0			268,58			
	2	110%	1.989,0			2.192,67			
Start	3	100%		31,3		31,27	346.988	100,0%	346.988
	4	90,7%		32,5		29,50	346.988	94,3%	327.347
	5	82,3%		33,8		27,83	346.988	89,0%	308.818
	6	74,6%		35,2		26,26	346.988	84,0%	291.337
	7	67,7%		36,6		24,77	346.988	79,2%	274.847
	8	61,4%		38,0		23,37	346.988	74,7%	259.289
	9	55,7%		39,6		22,04	346.988	70,5%	244.612
	10	50,5%		41,2		20,80	346.988	66,5%	230.767
	11	45,8%		42,8		19,62	346.988	62,7%	217.704
	12	41,6%		44,5		18,51	346.988	59,2%	205.381
	13	37,7%		46,3		17,46	346.988	55,8%	193.756
	14	34,2%		48,1		16,47	346.988	52,7%	182.789
	15	31,0%		50,1		15,54	346.988	49,7%	172.442
	16	28,2%		52,1		14,66	346.988	46,9%	162.681
	17	25,5%		54,2		13,83	346.988	44,2%	153.473
	18	23,2%		56,3		13,05	346.988	41,7%	144.786
	19	21,0%		58,6		12,31	346.988	39,4%	136.590
	20	19,1%		60,9		11,61	346.988	37,1%	128.859
	21	17,3%		63,3		10,96	346.988	35,0%	121.565
	22	15,7%		65,9	381	70,06	329.638	33,1%	108.950
	23	14,2%		68,5		9,75	346.988	31,2%	108.192
	24	12,9%		71,3		9,20	346.988	29,4%	102.068
	25	11,7%		74,1		8,68	346.988	27,8%	96.291
	26	10,6%		77,1		8,19	346.988	26,2%	90.840
	27	9,6%		80,2		7,72	346.988	24,7%	85.698
	28	8,7%		83,4		7,29	346.988	23,3%	80.848
	29	7,9%		86,7		6,87	346.988	22,0%	76.271
	30	7,2%		90,2		6,48	346.988	20,7%	71.954
	31	6,5%		93,8		6,12	346.988	19,6%	67.881
	32	5,9%		97,5		5,77	346.988	18,5%	64.039

Fig. 105: Economical Cost calculation: **MED$_{free\ steam}$ 1,000 m^3/d -- PV,** **Seawater Open Intake**

Economical cost cal. for 1,000 m^3 MED plant pow. by PV, free steam

S E A WA T E R - W E L L   I N T A K E

Assumptions of costs:

Capital costs for 1,000 m^3/d in Lakh		**Operational costs in Lakh/a**		**Results of Calculation**	
MED-plant	1.320 lakh	PV maintenance	7 lakh	discounted Investment	Lakh Rs.
PV plant	735 lakh	Chemicals	2 lakh	+operation cost	2.889
wells / seawater extraction plant (see pretreatment)	40 lakh	Spare parts	13 lakh		
land costs	15 lakh	Labour (10 employees)	9 lakh	discounted water production assuming an inflation-indexed price	m^3
pretreatment & disposal	13 lakh	membrane replacement (every 3 to 5 years)	0 lakh		5.057.064
generator	8 lakh	operational costs per year	31 lakh		
capital nominally invested	2.131 lakh	nominal operational costs	1.754 lakh	water price in first year of production, which grows annually with inflation	Rs/m^3
present value of capita	2.405 lakh	present value of operational costs	485 lakh		57,14

availability of plant	95%	
water production	346.988	m^3/a
discount factor	6,00%	/a
inflation	4,00%	/a
eff. discount factor	10,24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m^3/a	Disc.Factor for Water assuming the water-price rises with inflation: 6,00% %/a	discounted water prod. m^3/a
	1	122%	213,1			259,00			
	2	110%	1.918,1			2.114,49			
Start	3	100%		31,3		31,27	346.988	100,0%	346.988
	4	90,7%		32,5		29,50	346.988	94,3%	327.347
	5	82,3%		33,8		27,83	346.988	89,0%	308.818
	6	74,6%		35,2		26,26	346.988	84,0%	291.337
	7	67,7%		36,6		24,77	346.988	79,2%	274.847
	8	61,4%		38,0		23,37	346.988	74,7%	259.289
	9	55,7%		39,6		22,04	346.988	70,5%	244.612
	10	50,5%		41,2		20,80	346.988	66,5%	230.767
	11	45,8%		42,8		19,62	346.988	62,7%	217.704
	12	41,6%		44,5		18,51	346.988	59,2%	205.381
	13	37,7%		46,3		17,46	346.988	55,8%	193.756
	14	34,2%		48,1		16,47	346.988	52,7%	182.789
	15	31,0%		50,1		15,54	346.988	49,7%	172.442
	16	28,2%		52,1		14,66	346.988	46,9%	162.681
	17	25,5%		54,2		13,83	346.988	44,2%	153.473
	18	23,2%		56,3		13,05	346.988	41,7%	144.786
	19	21,0%		58,6		12,31	346.988	39,4%	136.590
	20	19,1%		60,9		11,61	346.988	37,1%	128.859
	21	17,3%		63,3		10,96	346.988	35,0%	121.565
	22	15,7%		65,9	381	70,06	329.638	33,1%	108.950
	23	14,2%		68,5		9,75	346.988	31,2%	108.192
	24	12,9%		71,3		9,20	346.988	29,4%	102.068
	25	11,7%		74,1		8,68	346.988	27,8%	96.291
	26	10,6%		77,1		8,19	346.988	26,2%	90.840
	27	9,6%		80,2		7,72	346.988	24,7%	85.698
	28	8,7%		83,4		7,29	346.988	23,3%	80.848
	29	7,9%		86,7		6,87	346.988	22,0%	76.271
	30	7,2%		90,2		6,48	346.988	20,7%	71.954
	31	6,5%		93,8		6,12	346.988	19,6%	67.881
	32	5,9%		97,5		5,77	346.988	18,5%	64.039

Fig. 106: Economical Cost calculation: **$MED_{free\ steam}$ 1,000 m^3/d -- PV, Well Intake**

Economical cost cal. for 5,000 m³ MED plant pow. by PV, free steam

S E A W A T E R - O P E N I N T A K E

Assumptions of costs:

Capital costs for 5,000 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
MED-plant	4.400 lakh	PV maintenance	37 lakh	discounted Investment +operation cost	Lakh Rs.
PV plant	3.675 lakh	Chemicals	8 lakh		11.400
wells / seawater extraction plant (see pretreatment)	0 lakh	Spare parts	44 lakh		
land costs	75 lakh	Labour (15 employees)	14 lakh	discounted water production assuming an inflation-indexed price	m³
pretreatment & disposal	440 lakh	membrane replacement (every 3 to 5 years)	0 lakh		25.285.318
generator	40 lakh	operational costs per year	102 lakh		
capital nominally invested	8.630 lakh	nominal operational costs	5.743 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capita	9.714 lakh	present value of operational costs	1.687 lakh		45,09

availability of plant	95%	
water production	1.734.938	m³/a
discount factor	6,00%	/a
inflation	4,00%	/a
eff. discount factor	10,24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6,00% %/a	discounted water prod. m³/a
	1	122%	863,0			1.048,79			
	2	110%	7.767,0			8.562,34			
Start	3	100%		102,4		102,40	1.734.938	100,0%	1.734.938
	4	90,7%		106,5		96,60	1.734.938	94,3%	1.636.733
	5	82,3%		110,8		91,13	1.734.938	89,0%	1.544.088
	6	74,6%		115,2		85,97	1.734.938	84,0%	1.456.687
	7	67,7%		119,8		81,11	1.734.938	79,2%	1.374.233
	8	61,4%		124,6		76,52	1.734.938	74,7%	1.296.446
	9	55,7%		129,6		72,19	1.734.938	70,5%	1.223.062
	10	50,5%		134,7		68,10	1.734.938	66,5%	1.153.833
	11	45,8%		140,1		64,25	1.734.938	62,7%	1.088.521
	12	41,6%		145,7		60,61	1.734.938	59,2%	1.026.907
	13	37,7%		151,6		57,18	1.734.938	55,8%	968.780
	14	34,2%		157,6		53,94	1.734.938	52,7%	913.943
	15	31,0%		163,9		50,89	1.734.938	49,7%	862.211
	16	28,2%		170,5		48,01	1.734.938	46,9%	813.406
	17	25,5%		177,3		45,29	1.734.938	44,2%	767.365
	18	23,2%		184,4		42,73	1.734.938	41,7%	723.929
	19	21,0%		191,8		40,31	1.734.938	39,4%	682.952
	20	19,1%		199,5		38,03	1.734.938	37,1%	644.294
	21	17,3%		207,4		35,87	1.734.938	35,0%	607.825
	22	15,7%		215,7	1.882	329,00	1.648.191	33,1%	544.748
	23	14,2%		224,4		31,93	1.734.938	31,2%	540.962
	24	12,9%		233,3		30,12	1.734.938	29,4%	510.341
	25	11,7%		242,7		28,42	1.734.938	27,8%	481.454
	26	10,6%		252,4		26,81	1.734.938	26,2%	454.202
	27	9,6%		262,5		25,29	1.734.938	24,7%	428.492
	28	8,7%		273,0		23,86	1.734.938	23,3%	404.238
	29	7,9%		283,9		22,51	1.734.938	22,0%	381.357
	30	7,2%		295,2		21,23	1.734.938	20,7%	359.770
	31	6,5%		307,1		20,03	1.734.938	19,6%	339.406
	32	5,9%		319,3		18,90	1.734.938	18,5%	320.194

Fig. 107: Economical Cost calculation: **MED$_{free\ steam}$ 5,000 m^3/d -- PV, Seawater Open Intake**

Economical cost cal. for 5,000 m³ MED plant pow. by PV, free steam

SEA WATER-WELL INTAKE

Assumptions of costs:

Capital costs for 5,000 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
MED-plant	4.400 lakh	PV maintenance	37 lakh	discounted Investment +operation cost	Lakh Rs. 11.182
PV plant	3.675 lakh	Chemicals	8 lakh		
wells / seawater extraction plant (see pretreatment)	200 lakh	Spare parts	44 lakh		
land costs	75 lakh	Labour (15 employees)	14 lakh	discounted water production assuming an inflation-indexed price	m³ 25.285.318
pretreatment & disposal	44 lakh	membrane replacement (every 3 to 5 years)	0 lakh		
generator	40 lakh	operational costs per year	102 lakh		
capital nominally invested	8.434 lakh	nominal operational costs	5.743 lakh	water price in first year of production, which grows annually with inflation	Rs/m³ 44,22
present value of capita	9.495 lakh	present value of operational costs	1.687 lakh		

availability of plant	95%	
water production	1.734.938	m³/a
discount factor	6,00%	/a
inflation	4,00%	/a
eff. discount factor	10,24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6,00% %/a	discounted water prod. m³/a
	1	122%	843,4			1.024,97			
	2	110%	7.590,6			8.367,88			
Start	3	100%		102,4		102,40	1.734.938	100,0%	1.734.938
	4	90,7%		106,5		96,60	1.734.938	94,3%	1.636.733
	5	82,3%		110,8		91,13	1.734.938	89,0%	1.544.088
	6	74,6%		115,2		85,97	1.734.938	84,0%	1.456.687
	7	67,7%		119,8		81,11	1.734.938	79,2%	1.374.233
	8	61,4%		124,6		76,52	1.734.938	74,7%	1.296.446
	9	55,7%		129,6		72,19	1.734.938	70,5%	1.223.062
	10	50,5%		134,7		68,10	1.734.938	66,5%	1.153.833
	11	45,8%		140,1		64,25	1.734.938	62,7%	1.088.521
	12	41,6%		145,7		60,61	1.734.938	59,2%	1.026.907
	13	37,7%		151,6		57,18	1.734.938	55,8%	968.780
	14	34,2%		157,6		53,94	1.734.938	52,7%	913.943
	15	31,0%		163,9		50,89	1.734.938	49,7%	862.211
	16	28,2%		170,5		48,01	1.734.938	46,9%	813.406
	17	25,5%		177,3		45,29	1.734.938	44,2%	767.365
	18	23,2%		184,4		42,73	1.734.938	41,7%	723.929
	19	21,0%		191,8		40,31	1.734.938	39,4%	682.952
	20	19,1%		199,5		38,03	1.734.938	37,1%	644.294
	21	17,3%		207,4		35,87	1.734.938	35,0%	607.825
	22	15,7%		215,7	1.882	329,00	1.648.191	33,1%	544.748
	23	14,2%		224,4		31,93	1.734.938	31,2%	540.962
	24	12,9%		233,3		30,12	1.734.938	29,4%	510.341
	25	11,7%		242,7		28,42	1.734.938	27,8%	481.454
	26	10,6%		252,4		26,81	1.734.938	26,2%	454.202
	27	9,6%		262,5		25,29	1.734.938	24,7%	428.492
	28	8,7%		273,0		23,86	1.734.938	23,3%	404.238
	29	7,9%		283,9		22,51	1.734.938	22,0%	381.357
	30	7,2%		295,2		21,23	1.734.938	20,7%	359.770
	31	6,5%		307,1		20,03	1.734.938	19,6%	339.406
	32	5,9%		319,3		18,90	1.734.938	18,5%	320.194

Fig. 108: Economical Cost calculation: **MED$_{free\ steam}$ 5,000 m^3/d -- PV, Well Intake**

Economical cost cal. for 10,000 m³ MED plant pow. by PV, free steam

S E A WA T E R - O P E N I N T A K E

Assumptions of costs:

Capital costs for 10,000 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
MED-plant	5.280 lakh	PV maintenance	74 lakh	discounted Investment +operation cost	Lakh Rs. 17.737
PV plant	7.351 lakh	Chemicals	16 lakh		
wells / seawater extraction plant (see pretreatment)	0 lakh	Spare parts	53 lakh		
land costs	150 lakh	Labour (15 employees)	14 lakh	discounted water production assuming an inflation-indexed price	m³ 50.570.636
pretreatment & disposal	528 lakh	membrane replacement (every 3 to 5 years)	0 lakh		
generator	50 lakh	operational costs per year	156 lakh		
capital nominally invested	13.359 lakh	nominal operational costs	8.744 lakh	water price in first year of production, which grows annually with inflation	Rs/m³ 35,07
present value of capita	15.034 lakh	present value of operational costs	2.704 lakh		

availability of plant	95%	
water production	3.469.875	m³/a
discount factor	6,00%	/a
inflation	4,00%	/a
eff. discount factor	10,24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6,00% %/a	discounted water prod. m³/a
	1	122%	1.335,9			1.623,50			
	2	110%	12.023,1			13.254,27			
Start	3	100%		155,9		155,91	3.469.875	100,0%	3.469.875
	4	90,7%		162,1		147,08	3.469.875	94,3%	3.273.467
	5	82,3%		168,6		138,76	3.469.875	89,0%	3.088.176
	6	74,6%		175,4		130,90	3.469.875	84,0%	2.913.374
	7	67,7%		182,4		123,49	3.469.875	79,2%	2.748.466
	8	61,4%		189,7		116,50	3.469.875	74,7%	2.592.892
	9	55,7%		197,3		109,91	3.469.875	70,5%	2.446.125
	10	50,5%		205,2		103,69	3.469.875	66,5%	2.307.665
	11	45,8%		213,4		97,82	3.469.875	62,7%	2.177.043
	12	41,6%		221,9		92,28	3.469.875	59,2%	2.053.814
	13	37,7%		230,8		87,06	3.469.875	55,8%	1.937.560
	14	34,2%		240,0		82,13	3.469.875	52,7%	1.827.887
	15	31,0%		249,6		77,48	3.469.875	49,7%	1.724.422
	16	28,2%		259,6		73,10	3.469.875	46,9%	1.626.813
	17	25,5%		270,0		68,96	3.469.875	44,2%	1.534.729
	18	23,2%		280,8		65,05	3.469.875	41,7%	1.447.858
	19	21,0%		292,0		61,37	3.469.875	39,4%	1.365.903
	20	19,1%		303,7		57,90	3.469.875	37,1%	1.288.588
	21	17,3%		315,8		54,62	3.469.875	35,0%	1.215.649
	22	15,7%		328,5	3.728	636,41	3.296.381	33,1%	1.089.497
	23	14,2%		341,6		48,61	3.469.875	31,2%	1.081.923
	24	12,9%		355,3		45,86	3.469.875	29,4%	1.020.682
	25	11,7%		369,5		43,26	3.469.875	27,8%	962.908
	26	10,6%		384,3		40,82	3.469.875	26,2%	908.404
	27	9,6%		399,6		38,51	3.469.875	24,7%	856.985
	28	8,7%		415,6		36,33	3.469.875	23,3%	808.476
	29	7,9%		432,2		34,27	3.469.875	22,0%	762.713
	30	7,2%		449,5		32,33	3.469.875	20,7%	719.541
	31	6,5%		467,5		30,50	3.469.875	19,6%	678.812
	32	5,9%		486,2		28,77	3.469.875	18,5%	640.389

Fig. 109: Economical Cost calculation: **$MED_{free\ steam}$ 10,000 m³/d -- PV, Seawater Open Intake**

Economical cost cal. for 10,000 m³ MED plant pow. by PV, free steam

S E A WA T E R - W E L L I N T A K E

Assumptions of costs:

Capital costs for 10,000 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
MED-plant	5.280 lakh	PV maintenance	74 lakh	discounted Investment	Lakh Rs.
PV plant	7.351 lakh	Chemicals	16 lakh	+operation cost	17.654
wells / seawater extraction plant (see pretreatment)	400 lakh	Spare parts	53 lakh		
land costs	150 lakh	Labour (15 employees)	14 lakh	discounted water production assuming an inflation-indexed price	m³
pretreatment & disposal	53 lakh	membrane replacement (every 3 to 5 years)	0 lakh		50.570.636
generator	50 lakh	operational costs per year	156 lakh		
capital nominally invested	13.284 lakh	nominal operational costs	8.744 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capita	14.950 lakh	present value of operational costs	2.704 lakh		34,91

availability of plant	95%	
water production	3.469.875	m³/a
discount factor	6,00%	/a
inflation	4,00%	/a
eff. discount factor	10,24%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh		Disc.Factor for Water assuming the water-price rises with inflation	discounted
	1	122%	1.328,4			1.614,36	water prod.	6,00%	water prod.
	2	110%	11.955,4			13.179,66	m³/a	%/a	m³/a
Start	3	100%		155,9		155,91	3.469.875	100,0%	3.469.875
	4	90,7%		162,1		147,08	3.469.875	94,3%	3.273.467
	5	82,3%		168,6		138,76	3.469.875	89,0%	3.088.176
	6	74,6%		175,4		130,90	3.469.875	84,0%	2.913.374
	7	67,7%		182,4		123,49	3.469.875	79,2%	2.748.466
	8	61,4%		189,7		116,50	3.469.875	74,7%	2.592.892
	9	55,7%		197,3		109,91	3.469.875	70,5%	2.446.125
	10	50,5%		205,2		103,69	3.469.875	66,5%	2.307.665
	11	45,8%		213,4		97,82	3.469.875	62,7%	2.177.043
	12	41,6%		221,9		92,28	3.469.875	59,2%	2.053.814
	13	37,7%		230,8		87,06	3.469.875	55,8%	1.937.560
	14	34,2%		240,0		82,13	3.469.875	52,7%	1.827.887
	15	31,0%		249,6		77,48	3.469.875	49,7%	1.724.422
	16	28,2%		259,6		73,10	3.469.875	46,9%	1.626.813
	17	25,5%		270,0		68,96	3.469.875	44,2%	1.534.729
	18	23,2%		280,8		65,05	3.469.875	41,7%	1.447.858
	19	21,0%		292,0		61,37	3.469.875	39,4%	1.365.903
	20	19,1%		303,7		57,90	3.469.875	37,1%	1.288.588
	21	17,3%		315,8		54,62	3.469.875	35,0%	1.215.649
	22	15,7%		328,5	3.728	636,41	3.296.381	33,1%	1.089.497
	23	14,2%		341,6		48,61	3.469.875	31,2%	1.081.923
	24	12,9%		355,3		45,86	3.469.875	29,4%	1.020.682
	25	11,7%		369,5		43,26	3.469.875	27,8%	962.908
	26	10,6%		384,3		40,82	3.469.875	26,2%	908.404
	27	9,6%		399,6		38,51	3.469.875	24,7%	856.985
	28	8,7%		415,6		36,33	3.469.875	23,3%	808.476
	29	7,9%		432,2		34,27	3.469.875	22,0%	762.713
	30	7,2%		449,5		32,33	3.469.875	20,7%	719.541
	31	6,5%		467,5		30,50	3.469.875	19,6%	678.812
	32	5,9%		486,2		28,77	3.469.875	18,5%	640.389

Fig. 110: Economical Cost calculation: **MED$_{free\ steam}$ 10,000 m³/d -- PV, Well Intake**

Economical cost cal. for 500 m³ MED plant powered by Wind, free steam

SEA WATER-OPEN INTAKE

Assumptions of costs:

Capital costs for 500 m³/d in Lakh		**Operational costs in Lakh/a**		**Results of Calculation**	
MED-plant	660 lakh	Wind turbine maintenance	6 lakh	discounted Investment +operation cost	Lakh Rs. 829
Wind turbine	625 lakh	Chemicals	1 lakh		
wells / seawater extraction plant (see pretreatment)	0 lakh	Spare parts	7 lakh		
land costs	1 lakh	Labour (10 employees)	9 lakh	discounted water production assuming an inflation-indexed price	m³ 2.350.902
pretreatment & disposal	66 lakh	membrane replacement (every 3 to 5 years)	0 lakh		
generator	4 lakh	operational costs per year	23 lakh		
capital nominally invested	1.356 lakh	nominal operational costs	957 lakh	water price in first year of production, which grows annually with inflation	Rs/m³ 35,27
present value of capital	1.533 lakh	present value of operational costs	-704 lakh		

availability of plant	95%	
water production	173.494	m³/a
surplus energy production	2.712.366	kWh/a
price for sold energy	2,7	Rs/kWh
discount factor	6,00%	/a
inflation	4,00%	/a
eff. discount factor	10,24%	/a

assumed life time 25 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	disc. Cost Rs lakh	disc. revenue for sold energy	discounted revenue	water prod.	Disc.Factor for Water assuming the water-price rises with inflation 6,00%	discounted water prod.
	1	122%	135,6		164,79					
	2	110%	1.220 lakh		1345,37	Rs lakh/a	Rs lakh/a	m³/a	%/a	m³/a
Start	3	100%		23,0	22,98	73	-50	173.494	100,0%	173.494
	4	90,7%		23,9	21,68	69	-47	173.494	94,3%	163.673
	5	82,3%		24,9	20,45	65	-45	173.494	89,0%	154.409
	6	74,6%		25,9	19,30	61	-42	173.494	84,0%	145.669
	7	67,7%		26,9	18,20	58	-40	173.494	79,2%	137.423
	8	61,4%		28,0	17,17	55	-38	173.494	74,7%	129.645
	9	55,7%		29,1	16,20	52	-35	173.494	70,5%	122.306
	10	50,5%		30,2	15,28	49	-33	173.494	66,5%	115.383
	11	45,8%		31,5	14,42	46	-32	173.494	62,7%	108.852
	12	41,6%		32,7	13,60	43	-30	173.494	59,2%	102.691
	13	37,7%		34,0	12,83	41	-28	173.494	55,8%	96.878
	14	34,2%		35,4	12,11	39	-26	173.494	52,7%	91.394
	15	31,0%		36,8	11,42	36	-25	173.494	49,7%	86.221
	16	28,2%		38,3	10,77	34	-24	173.494	46,9%	81.341
	17	25,5%		39,8	10,16	32	-22	173.494	44,2%	76.736
	18	23,2%		41,4	9,59	31	-21	173.494	41,7%	72.393
	19	21,0%		43,0	9,05	29	-20	173.494	39,4%	68.295
	20	19,1%		44,8	8,53	27	-19	173.494	37,1%	64.429
	21	17,3%		46,6	8,05	26	-18	173.494	35,0%	60.782
	22	15,7%		48,4	7,60	24	-17	173.494	33,1%	57.342
	23	14,2%		50,4	7,17	23	-16	173.494	31,2%	54.096
	24	12,9%		52,4	6,76	22	-15	173.494	29,4%	51.034
	25	11,7%		54,5	6,38	20	-14	173.494	27,8%	48.145
	26	10,6%		56,6	6,02	19	-13	173.494	26,2%	45.420
	27	9,6%		58,9	5,68	18	-12	173.494	24,7%	42.849

Fig. 111: Economical Cost calculation: **MED$_{free\ steam}$ 500 m^3/d – Wind, Seawater Open Intake**

Economical cost cal. for 500 m³ MED plant powered by Wind, free steam

S E A WA T E R - W E L L I N T A K E

Assumptions of costs:

Capital costs for 500 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
MED-plant	660 lakh	Wind turbine maintenance	6 lakh	discounted Investment +operation cost	Lakh Rs. 785
Wind turbine	625 lakh	Chemicals	1 lakh		
wells / seawater extraction plant (see pretreatment)	20 lakh	Spare parts	7 lakh		
land costs	1 lakh	Labour (10 employees)	9 lakh	discounted water production assuming an inflation-indexed price	m³ 2.350.902
pretreatment & disposal	7 lakh	membrane replacement (every 3 to 5 years)	0 lakh		
generator	4 lakh	operational costs per year	23 lakh		
capital nominally invested	1.317 lakh	nominal operational costs	957 lakh	water price in first year of production, which grows annually with inflation	Rs/m³ 33,41
present value of capital	1.489 lakh	present value of operational costs	-704 lakh		

availability of plant	95%	
water production	173.494	m³/a
surplus energy production	2.712.366	kWh/a
price for sold energy	2,7	Rs/kWh
discount factor	6,00%	/a
inflation	4,00%	/a
eff. discount factor	10,24%	/a

assumed life time 25 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	disc. Cost Rs lakh	disc. revenue for sold energy Rs lakh/a	discounted revenue Rs lakh/a	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6,00% %/a	discounted water prod. m³/a
	1	122%	131,66		160,00					
	2	110%	1.185 lakh		1306,28					
Start	3	100%		23,0	22,98	73	-50	173.494	100,0%	173.494
	4	90,7%		23,9	21,68	69	-47	173.494	94,3%	163.673
	5	82,3%		24,9	20,45	65	-45	173.494	89,0%	154.409
	6	74,6%		25,9	19,30	61	-42	173.494	84,0%	145.669
	7	67,7%		26,9	18,20	58	-40	173.494	79,2%	137.423
	8	61,4%		28,0	17,17	55	-38	173.494	74,7%	129.645
	9	55,7%		29,1	16,20	52	-35	173.494	70,5%	122.306
	10	50,5%		30,2	15,28	49	-33	173.494	66,5%	115.383
	11	45,8%		31,5	14,42	46	-32	173.494	62,7%	108.852
	12	41,6%		32,7	13,60	43	-30	173.494	59,2%	102.691
	13	37,7%		34,0	12,83	41	-28	173.494	55,8%	96.878
	14	34,2%		35,4	12,11	39	-26	173.494	52,7%	91.394
	15	31,0%		36,8	11,42	36	-25	173.494	49,7%	86.221
	16	28,2%		38,3	10,77	34	-24	173.494	46,9%	81.341
	17	25,5%		39,8	10,16	32	-22	173.494	44,2%	76.736
	18	23,2%		41,4	9,59	31	-21	173.494	41,7%	72.393
	19	21,0%		43,0	9,05	29	-20	173.494	39,4%	68.295
	20	19,1%		44,8	8,53	27	-19	173.494	37,1%	64.429
	21	17,3%		46,6	8,05	26	-18	173.494	35,0%	60.782
	22	15,7%		48,4	7,60	24	-17	173.494	33,1%	57.342
	23	14,2%		50,4	7,17	23	-16	173.494	31,2%	54.096
	24	12,9%		52,4	6,76	22	-15	173.494	29,4%	51.034
	25	11,7%		54,5	6,38	20	-14	173.494	27,8%	48.145
	26	10,6%		56,6	6,02	19	-13	173.494	26,2%	45.420
	27	9,6%		58,9	5,68	18	-12	173.494	24,7%	42.849

Fig. 112: Economical Cost calculation: **$MED_{free\ steam}$ 500 m^3/d -- Wind, Well Intake**

Economical cost cal. for 1000 m³ MED plant pow. by Wind, free steam

S E A W A T E R - O P E N I N T A K E

Assumptions of costs:

Capital costs for 500 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
MED-plant	1.320 lakh	Wind turbine maintenance	6 lakh	discounted Investment +operation cost	Lakh Rs. 1850
Wind turbine	625 lakh	Chemicals	2 lakh		
wells / seawater extraction plant (see pretreatment)	0 lakh	Spare parts	13 lakh		
land costs	1 lakh	Labour (10 employees)	9 lakh	discounted water production assuming an inflation-indexed price	m³ 4.701.811
pretreatment & disposal	132 lakh	membrane replacement (every 3 to 5 years)	0 lakh		
generator	8 lakh	operational costs per year	31 lakh		
capital nominally invested	2.086 lakh	nominal operational costs	1.274 lakh	water price in first year of production, which grows annually with inflation	Rs/m³ 39,36
present value of capital	2.354 lakh	present value of operational costs	-503 lakh		

availability of plant	95%	
water production	346.988	m³/a
surplus energy production	2.424.731	kWh/a
price for sold energy	2,7	Rs/kWh
discount factor	6,00%	/a
inflation	4,00%	/a
eff. discount factor	10,24%	/a

assumed life time 25 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	disc. Cost Rs lakh	disc. revenue for sold energy Rs lakh/a	discounted revenue Rs lakh/a	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6,00% %/a	discounted water prod. m³/a
	1	122%	208,6		253,51					
	2	110%	1.877 lakh		2069,65					
Start	3	100%		30,6	30,58	65	-35	346.988	100,0%	346.988
	4	90,7%		31,8	28,85	62	-33	346.988	94,3%	327.347
	5	82,3%		33,1	27,22	58	-31	346.988	89,0%	308.818
	6	74,6%		34,4	25,68	55	-29	346.988	84,0%	291.338
	7	67,7%		35,8	24,22	52	-28	346.988	79,2%	274.847
	8	61,4%		37,2	22,85	49	-26	346.988	74,7%	259.290
	9	55,7%		38,7	21,56	46	-25	346.988	70,5%	244.613
	10	50,5%		40,2	20,34	44	-23	346.988	66,5%	230.767
	11	45,8%		41,9	19,19	41	-22	346.988	62,7%	217.705
	12	41,6%		43,5	18,10	39	-21	346.988	59,2%	205.382
	13	37,7%		45,3	17,08	37	-19	346.988	55,8%	193.756
	14	34,2%		47,1	16,11	34	-18	346.988	52,7%	182.789
	15	31,0%		49,0	15,20	33	-17	346.988	49,7%	172.442
	16	28,2%		50,9	14,34	31	-16	346.988	46,9%	162.682
	17	25,5%		53,0	13,53	29	-15	346.988	44,2%	153.473
	18	23,2%		55,1	12,76	27	-15	346.988	41,7%	144.786
	19	21,0%		57,3	12,04	26	-14	346.988	39,4%	136.591
	20	19,1%		59,6	11,36	24	-13	346.988	37,1%	128.859
	21	17,3%		62,0	10,71	23	-12	346.988	35,0%	121.565
	22	15,7%		64,4	10,11	22	-12	346.988	33,1%	114.684
	23	14,2%		67,0	9,54	20	-11	346.988	31,2%	108.192
	24	12,9%		69,7	9,00	19	-10	346.988	29,4%	102.068
	25	11,7%		72,5	8,49	18	-10	346.988	27,8%	96.291
	26	10,6%		75,4	8,01	17	-9	346.988	26,2%	90.841
	27	9,6%		78,4	7,55	16	-9	346.988	24,7%	85.699

Fig. 113: Economical Cost calculation: **MED$_{free\ steam}$ 1,000 m^3/d -- Wind, Seawater Open Intake**

Economical cost cal. for 1,000 m³ MED plant pow. by Wind, free steam

S E A WA T E R - W E L L I N T A K E

Assumptions of costs:

Capital costs for 500 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
MED-plant	1.320 lakh	Wind turbine maintenance	6 lakh	discounted Investment +operation cost	Lakh Rs. 1763
Wind turbine	625 lakh	Chemicals	2 lakh		
wells / seawater extraction plant (see pretreatment)	40 lakh	Spare parts	13 lakh		
land costs	1 lakh	Labour (10 employees)	9 lakh	discounted water production assuming an inflation-indexed price	m³ 4.701.811
pretreatment & disposal	13 lakh	membrane replacement (every 3 to 5 years)	0 lakh		
generator	8 lakh	operational costs per year	31 lakh		
capital nominally invested	2.007 lakh	nominal operational costs	1.274 lakh	water price in first year of production, which grows annually with inflation	Rs/m³ 37,49
present value of capital	2.266 lakh	present value of operational costs	-503 lakh		

availability of plant	95%	
water production	346.988	m³/a
surplus energy production	2.424.731	kWh/a
price for sold energy	2,7	Rs/kWh
discount factor	6,00%	/a
inflation	4,00%	/a
eff. discount factor	10,24%	/a

assumed life time 25 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	disc. Cost Rs lakh	disc. revenue for sold energy Rs lakh/a	discounted revenue Rs lakh/a	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6,00% %/a	discounted water prod. m³/a
	1	122%	200,72		243,93					
	2	110%	1.806 lakh		1991,46					
Start	3	100%		30,6	30,58	65	-35	346.988	100,0%	346.988
	4	90,7%		31,8	28,85	62	-33	346.988	94,3%	327.347
	5	82,3%		33,1	27,22	58	-31	346.988	89,0%	308.818
	6	74,6%		34,4	25,68	55	-29	346.988	84,0%	291.338
	7	67,7%		35,8	24,22	52	-28	346.988	79,2%	274.847
	8	61,4%		37,2	22,85	49	-26	346.988	74,7%	259.290
	9	55,7%		38,7	21,56	46	-25	346.988	70,5%	244.613
	10	50,5%		40,2	20,34	44	-23	346.988	66,5%	230.767
	11	45,8%		41,9	19,19	41	-22	346.988	62,7%	217.705
	12	41,6%		43,5	18,10	39	-21	346.988	59,2%	205.382
	13	37,7%		45,3	17,08	37	-19	346.988	55,8%	193.756
	14	34,2%		47,1	16,11	34	-18	346.988	52,7%	182.789
	15	31,0%		49,0	15,20	33	-17	346.988	49,7%	172.442
	16	28,2%		50,9	14,34	31	-16	346.988	46,9%	162.682
	17	25,5%		53,0	13,53	29	-15	346.988	44,2%	153.473
	18	23,2%		55,1	12,76	27	-15	346.988	41,7%	144.786
	19	21,0%		57,3	12,04	26	-14	346.988	39,4%	136.591
	20	19,1%		59,6	11,36	24	-13	346.988	37,1%	128.859
	21	17,3%		62,0	10,71	23	-12	346.988	35,0%	121.565
	22	15,7%		64,4	10,11	22	-12	346.988	33,1%	114.684
	23	14,2%		67,0	9,54	20	-11	346.988	31,2%	108.192
	24	12,9%		69,7	9,00	19	-10	346.988	29,4%	102.068
	25	11,7%		72,5	8,49	18	-10	346.988	27,8%	96.291
	26	10,6%		75,4	8,01	17	-9	346.988	26,2%	90.841
	27	9,6%		78,4	7,55	16	-9	346.988	24,7%	85.699

Fig. 114: Economical Cost calculation: **$MED_{free\ steam}$ 1,000 m^3/d -- Wind, Well Intake**

Economical cost cal. for 5,000 m³ MED plant pow. by Wind, free steam

S E A WA T E R - O P E N INTAKE

Assumptions of costs:

Capital costs for 500 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
MED-plant	4.400 lakh	Wind turbine maintenance	6 lakh	discounted Investment	Lakh Rs.
Wind turbine	625 lakh	Chemicals	8 lakh	+operation cost	7062
wells / seawater extraction plant (see pretreatment)	0 lakh	Spare parts	44 lakh		
land costs	1 lakh	Labour (10 employees)	14 lakh	discounted water production assuming an inflation-indexed price	m³
pretreatment & disposal	440 lakh	membrane replacement (every 3 to 5 years)	0 lakh		23.509.023
generator	40 lakh	operational costs per year	72 lakh		
capital nominally invested	5.506 lakh	nominal operational costs	2.996 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capital	6.204 lakh	present value of operational costs	858 lakh		30,04

availability of plant	95%	
water production	1.734.938	m³/a
surplus energy production	123.656	kWh/a
price for sold energy	2,7	Rs/kWh
discount factor	6,00%	/a
inflation	4,00%	/a
eff. discount factor	10,24%	/a

assumed life time 25 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	disc. Cost Rs lakh	disc. revenue for sold energy Rs lakh/a	discounted revenue Rs lakh/a	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6,00% %/a	discounted water prod. m³/a
	1	122%	550,6		669,14					
	2	110%	4.955 lakh		5462,83					
Start	3	100%		71,9	71,95	3	69	1.734.938	100,0%	1.734.938
	4	90,7%		74,8	67,87	3	65	1.734.938	94,3%	1.636.733
	5	82,3%		77,8	64,03	3	61	1.734.938	89,0%	1.544.088
	6	74,6%		80,9	60,41	3	58	1.734.938	84,0%	1.456.687
	7	67,7%		84,2	56,99	3	54	1.734.938	79,2%	1.374.233
	8	61,4%		87,5	53,76	2	51	1.734.938	74,7%	1.296.446
	9	55,7%		91,0	50,72	2	48	1.734.938	70,5%	1.223.062
	10	50,5%		94,7	47,85	2	46	1.734.938	66,5%	1.153.833
	11	45,8%		98,5	45,14	2	43	1.734.938	62,7%	1.088.521
	12	41,6%		102,4	42,59	2	41	1.734.938	59,2%	1.026.907
	13	37,7%		106,5	40,17	2	38	1.734.938	55,8%	968.780
	14	34,2%		110,8	37,90	2	36	1.734.938	52,7%	913.943
	15	31,0%		115,2	35,76	2	34	1.734.938	49,7%	862.211
	16	28,2%		119,8	33,73	2	32	1.734.938	46,9%	813.406
	17	25,5%		124,6	31,82	1	30	1.734.938	44,2%	767.365
	18	23,2%		129,6	30,02	1	29	1.734.938	41,7%	723.929
	19	21,0%		134,8	28,32	1	27	1.734.938	39,4%	682.952
	20	19,1%		140,1	26,72	1	25	1.734.938	37,1%	644.294
	21	17,3%		145,8	25,21	1	24	1.734.938	35,0%	607.825
	22	15,7%		151,6	23,78	1	23	1.734.938	33,1%	573.419
	23	14,2%		157,6	22,43	1	21	1.734.938	31,2%	540.962
	24	12,9%		164,0	21,16	1	20	1.734.938	29,4%	510.341
	25	11,7%		170,5	19,97	1	19	1.734.938	27,8%	481.454
	26	10,6%		177,3	18,84	1	18	1.734.938	26,2%	454.202
	27	9,6%		184,4	17,77	1	17	1.734.938	24,7%	428.492

Fig. 115: Economical Cost calculation: **MED$_{free\ steam}$ 5,000 m^3/d -- Wind,** **Seawater Open Intake**

Economical cost cal. for 5,000 m^3 MED plant pow. by Wind, free steam

S E A W A T E R - W E L L I N T A K E

Assumptions of costs:

Capital costs for 500 m^3/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
MED-plant	4.400 lakh	Wind turbine maintenance	6 lakh	discounted Investment	Lakh Rs.
Wind turbine	625 lakh	Chemicals	8 lakh	+operation cost	6843
wells / seawater extraction plant (see pretreatment)	200 lakh	Spare parts	44 lakh		
land costs	1 lakh	Labour (10 employees)	14 lakh	discounted water production assuming an inflation-indexed price	m^3
pretreatment & disposal	44 lakh	membrane replacement (every 3 to 5 years)	0 lakh		23.509.023
generator	40 lakh	operational costs per year	72 lakh		
capital nominally invested	5.310 lakh	nominal operational costs	2.996 lakh	water price in first year of production, which grows annually with inflation	Rs/m^3
present value of capital	5.986 lakh	present value of operational costs	858 lakh		29,11

availability of plant	95%	
water production	1.734.938	m^3/a
surplus energy production	123.656	kWh/a
price for sold energy	2,7	Rs/kWh
discount factor	6,00%	/a
inflation	4,00%	/a
eff. discount factor	10,24%	/a

assumed life time 25 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	disc. Cost Rs lakh	disc. revenue for sold energy Rs lakh/a	discounted revenue Rs lakh/a	water prod. m^3/a	Disc.Factor for Water assuming the water-price rises with inflation 6,00% %/a	discounted water prod. m^3/a
	1	122%	531		645,32					
	2	110%	4.779 lakh		5268,37					
Start	3	100%		71,9	71,95	3	69	1.734.938	100,0%	1.734.938
	4	90,7%		74,8	67,87	3	65	1.734.938	94,3%	1.636.733
	5	82,3%		77,8	64,03	3	61	1.734.938	89,0%	1.544.088
	6	74,6%		80,9	60,41	3	58	1.734.938	84,0%	1.456.687
	7	67,7%		84,2	56,99	3	54	1.734.938	79,2%	1.374.233
	8	61,4%		87,5	53,76	2	51	1.734.938	74,7%	1.296.446
	9	55,7%		91,0	50,72	2	48	1.734.938	70,5%	1.223.062
	10	50,5%		94,7	47,85	2	46	1.734.938	66,5%	1.153.833
	11	45,8%		98,5	45,14	2	43	1.734.938	62,7%	1.088.521
	12	41,6%		102,4	42,59	2	41	1.734.938	59,2%	1.026.907
	13	37,7%		106,5	40,17	2	38	1.734.938	55,8%	968.780
	14	34,2%		110,8	37,90	2	36	1.734.938	52,7%	913.943
	15	31,0%		115,2	35,76	2	34	1.734.938	49,7%	862.211
	16	28,2%		119,8	33,73	2	32	1.734.938	46,9%	813.406
	17	25,5%		124,6	31,82	1	30	1.734.938	44,2%	767.365
	18	23,2%		129,6	30,02	1	29	1.734.938	41,7%	723.929
	19	21,0%		134,8	28,32	1	27	1.734.938	39,4%	682.952
	20	19,1%		140,1	26,72	1	25	1.734.938	37,1%	644.294
	21	17,3%		145,8	25,21	1	24	1.734.938	35,0%	607.825
	22	15,7%		151,6	23,78	1	23	1.734.938	33,1%	573.419
	23	14,2%		157,6	22,43	1	21	1.734.938	31,2%	540.962
	24	12,9%		164,0	21,16	1	20	1.734.938	29,4%	510.341
	25	11,7%		170,5	19,97	1	19	1.734.938	27,8%	481.454
	26	10,6%		177,3	18,84	1	18	1.734.938	26,2%	454.202
	27	9,6%		184,4	17,77	1	17	1.734.938	24,7%	428.492

Fig. 116: Economical Cost calculation: **MED$_{free\ steam}$ 5,000 m^3/d -- Wind, Well Intake**

Economical cost cal. for 10,000 m³ MED plant pow. by Wind, free steam

S E A W A T E R - O P E N I N T A K E

Assumptions of costs:

Capital costs for 500 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
MED-plant	5.280 lakh	Wind turbine maintenance	13 lakh	discounted Investment	Lakh Rs.
Wind turbine	1.250 lakh	Chemicals	16 lakh	+operation cost	9115
wells / seawater extraction plant (see pretreatment)	0 lakh	Spare parts	53 lakh		
land costs	2 lakh	Labour (10 employees)	14 lakh	discounted water production assuming an inflation-indexed price	m³
pretreatment & disposal	528 lakh	membrane replacement (every 3 to 5 years)	0 lakh		47.018.047
generator	50 lakh	operational costs per year	95 lakh		
capital nominally invested	7.110 lakh	nominal operational costs	3.956 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capital	8.013 lakh	present value of operational costs	1.102 lakh		19,39

availability of plant	95%	
water production	3.469.875	m³/a
surplus energy production	247.313	kWh/a
price for sold energy	2,7	Rs/kWh
discount factor	6,00%	/a
inflation	4,00%	/a
eff. discount factor	10,24%	/a

assumed life time 25 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	disc. Cost Rs lakh	disc. revenue for sold energy Rs lakh/a	discounted revenue Rs lakh/a	water prod. m³/a	Disc.Factor for Water assuming the water-price rises with inflation 6,00% %/a	discounted water prod. m³/a
	1	122%	711		864,07					
	2	110%	6.399 lakh		7054,26					
Start	3	100%		95,0	95,00	7	88	3.469.875	100,0%	3.469.875
	4	90,7%		98,8	89,62	6	83	3.469.875	94,3%	3.273.467
	5	82,3%		102,7	84,55	6	79	3.469.875	89,0%	3.088.176
	6	74,6%		106,9	79,76	6	74	3.469.875	84,0%	2.913.374
	7	67,7%		111,1	75,25	5	70	3.469.875	79,2%	2.748.466
	8	61,4%		115,6	70,99	5	66	3.469.875	74,7%	2.592.892
	9	55,7%		120,2	66,97	5	62	3.469.875	70,5%	2.446.125
	10	50,5%		125,0	63,18	4	59	3.469.875	66,5%	2.307.665
	11	45,8%		130,0	59,60	4	55	3.469.875	62,7%	2.177.043
	12	41,6%		135,2	56,23	4	52	3.469.875	59,2%	2.053.814
	13	37,7%		140,6	53,05	4	49	3.469.875	55,8%	1.937.560
	14	34,2%		146,2	50,04	4	47	3.469.875	52,7%	1.827.887
	15	31,0%		152,1	47,21	3	44	3.469.875	49,7%	1.724.422
	16	28,2%		158,2	44,54	3	41	3.469.875	46,9%	1.626.813
	17	25,5%		164,5	42,02	3	39	3.469.875	44,2%	1.534.729
	18	23,2%		171,1	39,64	3	37	3.469.875	41,7%	1.447.858
	19	21,0%		177,9	37,40	3	35	3.469.875	39,4%	1.365.903
	20	19,1%		185,0	35,28	2	33	3.469.875	37,1%	1.288.588
	21	17,3%		192,4	33,28	2	31	3.469.875	35,0%	1.215.649
	22	15,7%		200,1	31,40	2	29	3.469.875	33,1%	1.146.839
	23	14,2%		208,1	29,62	2	28	3.469.875	31,2%	1.081.923
	24	12,9%		216,5	27,94	2	26	3.469.875	29,4%	1.020.682
	25	11,7%		225,1	26,36	2	25	3.469.875	27,8%	962.908
	26	10,6%		234,1	24,87	2	23	3.469.875	26,2%	908.404
	27	9,6%		243,5	23,46	2	22	3.469.875	24,7%	856.985

Fig. 117: Economical Cost calculation: **MED$_{free\ steam}$ 10,000 m^3/d -- Wind, Seawater Open Intake**

Economical cost cal. for 10,000 m^3 MED plant pow. by Wind, free steam

S E A W A T E R - W E L L   I N T A K E

Assumptions of costs:

Capital costs for 500 m^3/d in Lakh		**Operational costs in Lakh/a**		**Results of Calculation**	
MED-plant	5.280 lakh	Wind turbine maintenance	13 lakh	discounted Investment +operation cost	Lakh Rs. 9031
Wind turbine	1.250 lakh	Chemicals	16 lakh		
wells / seawater extraction plant (see pretreatment)	400 lakh	Spare parts	53 lakh		
land costs	2 lakh	Labour (10 employees)	14 lakh	discounted water production assuming an inflation-indexed price	m^3 47.018.047
pretreatment & disposal	53 lakh	membrane replacement (every 3 to 5 years)	0 lakh		
generator	50 lakh	operational costs per year	95 lakh		
capital nominally invested	7.035 lakh	nominal operational costs	3.956 lakh	water price in first year of production, which grows annually with inflation	Rs/m^3 19,21
present value of capital	7.930 lakh	present value of operational costs	1.102 lakh		

availability of plant	95%	
water production	3.469.875	m^3/a
surplus energy production	247.313	kWh/a
price for sold energy	2,7	Rs/kWh
discount factor	6,00%	/a
inflation	4,00%	/a
eff. discount factor	10,24%	/a

assumed life time 25 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	disc. Cost Rs lakh	disc. revenue for sold energy Rs lakh/a	discounted revenue Rs lakh/a	water prod. m^3/a	Disc.Factor for Water assuming the water-price rises with inflation 6,00% %/a	discounted water prod. m^3/a
	1	122%	703,48		854,93					
	2	110%	6.331 lakh		6979,65					
Start	3	100%		95,0	95,00	7	88	3.469.875	100,0%	3.469.875
	4	90,7%		98,8	89,62	6	83	3.469.875	94,3%	3.273.467
	5	82,3%		102,7	84,55	6	79	3.469.875	89,0%	3.088.176
	6	74,6%		106,9	79,76	6	74	3.469.875	84,0%	2.913.374
	7	67,7%		111,1	75,25	5	70	3.469.875	79,2%	2.748.466
	8	61,4%		115,6	70,99	5	66	3.469.875	74,7%	2.592.892
	9	55,7%		120,2	66,97	5	62	3.469.875	70,5%	2.446.125
	10	50,5%		125,0	63,18	4	59	3.469.875	66,5%	2.307.665
	11	45,8%		130,0	59,60	4	55	3.469.875	62,7%	2.177.043
	12	41,6%		135,2	56,23	4	52	3.469.875	59,2%	2.053.814
	13	37,7%		140,6	53,05	4	49	3.469.875	55,8%	1.937.560
	14	34,2%		146,2	50,04	4	47	3.469.875	52,7%	1.827.887
	15	31,0%		152,1	47,21	3	44	3.469.875	49,7%	1.724.422
	16	28,2%		158,2	44,54	3	41	3.469.875	46,9%	1.626.813
	17	25,5%		164,5	42,02	3	39	3.469.875	44,2%	1.534.729
	18	23,2%		171,1	39,64	3	37	3.469.875	41,7%	1.447.858
	19	21,0%		177,9	37,40	3	35	3.469.875	39,4%	1.365.903
	20	19,1%		185,0	35,28	2	33	3.469.875	37,1%	1.288.588
	21	17,3%		192,4	33,28	2	31	3.469.875	35,0%	1.215.649
	22	15,7%		200,1	31,40	2	29	3.469.875	33,1%	1.146.839
	23	14,2%		208,1	29,62	2	28	3.469.875	31,2%	1.081.923
	24	12,9%		216,5	27,94	2	26	3.469.875	29,4%	1.020.682
	25	11,7%		225,1	26,36	2	25	3.469.875	27,8%	962.908
	26	10,6%		234,1	24,87	2	23	3.469.875	26,2%	908.404
	27	9,6%		243,5	23,46	2	22	3.469.875	24,7%	856.985

Fig. 118: Economical Cost calculation: **MED$_{\text{free steam}}$ 10,000 m^3/d -- Wind, Well Intake**

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14.4. Nomenclature

α_E	angle between an orientation to the south (northern hemisphere) and the actual orientation of the receiving surface
α_S	azimuth
β	tilt of surface
δ	declination
E_0	solar constant (1367 W/m²)
$E_{diff,hor}$	diffuse radiation on horizontal
$E_{diff,tilt}$	diffuse radiation on tilted surface
$E_{dir,norm}$	direct radiation on normal
$E_{dir,tilt}$	direct radiation on tilted surface
$E_{G,hor}$	global horizontal radiation
$E_{refl,tilt}$	reflected radiation impinging on tilted surface
F	factor Klucher's model
γ_S	altitude of sun
λ	longitude
n	number of day starting with 1 on 01. January
Θ_{tilt}	incidence angle of sun-beams on tilted surface
θ_Z	zenith angle
k	clearness index
φ	latitude
ST	Solar Time
ω	hour angle
χ	angle of incidence

14.5. Internet links

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15. Mother's words on Desalination

Mother's Agenda, Vol. 10

August 30, 1969

….North of Pondicherry, there are places by the sea where nothing could ever be done (they're constantly flooded), but there's a way to make use of them, so I am trying to get the government's permission to occupy it all. If we can get all of it, then we can have a free port, a free airport, an airfield (but more inland), also cultivation based on the new methods of irrigation with sea water, and naturally the transformation of sea water – but they've found something to transform sea water into drinkable water (Mother takes a brochure by her side). It's French, I think, and an economical method; it's very interesting. It's under way, and if we wait for a few more years, they'll have perfected it quite well….

Mother's Agenda, Vol. 6, p. 140

"…From a practical point of view, it would be very good: at the edge, outside the park, we could build reservoirs that would provide water to the residents…."

Mother's Agenda, Vol. 6, p. 147

"…The biggest difficulty is water, because there is no nearby river up there; but they are already trying to harness rivers. There is even a project to divert water from the Himalayas and bring it across the whole of India (L. had made a plan and discussed it in Delhi; of course, they objected that it would be a little costly!). But anyway, without going into such grandiose things, something has to be done to bring water; that will be the biggest difficulty, that's what will take the longest time. As for the rest – light, power – it will be made on the spot in the industrial section – but you can't manufacture water! The Americans have given serious thought to a way of using sea water, because the earth no longer has enough drinking water for people (the water they call "fresh"[i] ... it's ironical); the amount of water is insufficient for people's use, so they have already started chemical experiments on a big scale to transform sea water and make it usable – obviously that would be the solution to the problem."

S.: "But it already exists."

"It exists, but not in a sufficient proportion."

S.: "Yes, in Israel."

"They do it in Israel? They use sea water? Obviously, that would be the solution – the sea is there. It has to be studied. Then the water would have to be sent uphill... "

[i]. "Fresh water" is eau douce in French, douce meaning "gentle" or "sweet."

Mother's Agenda, Vol. 10, p. 496

"…But of course, what is needed … There are material difficulties: for this islet, we need water – naturally, otherwise it's not an islet! To have the water, we must transform it – there isn't enough underground water."

S.: "Not enough water?"

"There is water, but it's enough for one or two houses, anyway not enough to create a permanent flow. We would need transformed sea water. In Israel they have found a way to do it economically (we even have brochures on this), but you understand, economical for a city, not economical for an individual! So then, we'd need to have water to make this islet, that's the difficulty."

16. Udar's write-ups from meetings with the Mother on Solar Energy

6. Sri Aurobindo's Action---August 1974

Solar Energy: New Views, New Hopes

There is now an increasing interest world wide in the search for a larger and more diverse utilization of the energy that comes from the sun. Up to now it has been largely of academic interest or a sort of a hobby with some enthusiasts; but now it is coming into greater prominence, being forced to attention by the pressure of circumstances. This, at least, is one view, the view generally considered in all who now approach the subject. There is another and more relevant view given by the Mother and this we shall discuss as it is not commonly realized and must therefore be presented as forcefully as possible.

Let us first examine the circumstances that appear on the surface to which all attention is now directed. It will be relevant to refer to the January 1974 edition of the *Unesco Courrier,* wholly devoted to this subject. UNESCO being an international organization, the views expressed in its official Journal may be taken as world view. The introduction to the subject matter of the first article, "Our Dwindling Energy Resources", gives a clear view of the situation as is seen by serious people all over the world:

Recent world events have focused attention on the grave energy crisis facing the world. With total energy demand growing at a rate of about 5% a year and conventional energy resources rapidly dwindling, the problem is urgent with serious implications not only for the developed but also for developing countries. World population is expected to have doubled by the year 2000 and merely to maintain this population, with no attempt to raise living standards, will require over three times the current rate of energy production. Power is the key to expanding food and industrial production and to many other vital problems of world development. For this reason world energy needs have for many years been a matter of grave concern to the United Nations and UNESCO. The following article presents a global energy "balance sheet" from which it becomes clear that our present problems and future requirements call for the speediest possible developments of power sources other than fossil fuels.

This then expresses clearly and forcefully the superficial reasons for the sudden spurt of interest in the uses of Solar Energy, which have to do with, as The Mother has said, the pressure of "crashing circumstances". But if we go behind the appearances we may find even the cause of these crashing circumstances and the true insistence which leads us to the sun.

We are now at a crisis in our evolution and at the point of the sudden turn to a new phase. This point, according to the plan of nature, is preceded by a great destruction, the *pralaya,* and then follows the long and painful period as we begin anew the upward curve in our progressive movement. It is to avoid this *pralaya* and to bring in the new phase of evolution, consciously and joyously, that Sri Aurobindo and The Mother undertook their great *tapasya* and evolved the system of the Integral Yoga. Through this they opened the way to the new world into which we have to evolve and to bring down the very power of that world, the force of that new consciousness itself to lead us there. This is the supramental plane and the force, the supramental Truth Conscious Force.

They succeeded in making a break-through in 1956 and since 1970 this force has become definitely active in all areas of our life and is forcing us, often in spite of ourselves, towards the transformation. Thus abound all about us the "crashing circumstances" as we approach "The Hour of God".

And we are being driven towards the sun, the physical symbol of the supramental, and away from the reliance on fossil fuels which belong to the long-dead past, as their very name signifies. The drive towards finding new and more effective ways of using Solar Energy has the Divine force itself behind it.

We must, however, sound a note of warning. In the drive towards new sources of energy and force, unless we consciously move towards the true future, we may be sidetracked into a source, a very powerful source of energy, also new, but one that is linked with the *pralaya* and not with the transformation. In particular we must be very alert to the danger of the forces released by nuclear fission or thermonuclear fusion. These are the forces that can lead to *pralaya,* and however much we imagine using them only for peaceful, progressive purposes, the forces of *pralaya* will create the conditions such that they be used for destruction.

So we should concentrate on the development of uses of **Solar Energy**, for not only is the sun the symbol of Truth, but also, in a practical way, its energy has such immense possibilities that it can more than meet the needs of the whole world.

In the Ashram and at Auroville we are doing much in this direction, as far as our means permit. There is already in use a Solar Still for distilled water and a Solar Cooker using steam for five people. A Solar Water Heater for domestic use is almost complete and will be a prototype for general use. A Solar Refrigerator project has been taken up. The most exciting is the project of a five horsepower Solar Pump, presently under study. Its development will signal a great achievement as it is what is most needed in the country by small farmers. The pump will work without electricity or oil and only by energy from the sun. It will not, of course, work on rainy days but then it will not be needed if it is used for irrigation.

There are many uses to which Solar Energy can be put but the most promising is in the conversion of the Sun's heat and light into electric energy. The photo voltaic cell is the most promising as it makes the conversion directly. It appears that already cells with 16% efficiency are in production but at prohibitive costs.

If these costs could be brought down and efficiency increased to at least 20% (23% is the maximum possible, theoretically) then this would be a positive solution.

In July, 1973, at Paris, Unesco sponsored a Congress of Scientists entitled:

"The Sun in the Service of Mankind".

From this has emerged a Working Group that will recommend programmes of research and development all over the world which can be sponsored and assisted by Unesco directly or through other world organizations or by Governments themselves.

I am trying to get the interest of this Working Group in our projects at the Ashram and Auroville but more particularly in the setting up here of a top level Institute of Research in Solar Energy with particular reference to photo voltaic cells. The reason for this is that I hope that in such an Institute of Research we may be able to use the true method of Scientific Research of which The Mother has spoken, that by the Yoga, the scientist may open to that plane of Consciousness where the knowledge he seeks already exists. Then he should, again by the power of Yoga, bring that knowledge down into the prepared field of the Laboratory. The knowledge may come in flashes of inspiration or in a steady stream of light.

In the United States, in 1972, I spoke of this process to many scientists, some of them Nobel Prize winners, and all showed great interest in this approach. In particular very much interest was shown at the N.A.S.A. Institute by a group of scientists working on the photo voltaic cell. It is there that the cells used in the American Spacecraft are made. They want very much to co-operate with us here and so an Institute working through yogic processes would be of immense value not only to us in India but to the whole world. Hence we here are working with all the means and the various contacts we have to see that such a proposal materializes. This is a magnificent opportunity to show to the world what India really is and how she can lead the world and not just follow in the footsteps of the so-called advanced and developed countries. The lead would be on new paths of knowledge and practical application, as steps towards the new world towards which Sri Aurobindo and The Mother are leading us.

UDAR PINTO

3. Sri Aurobindo's Action---June 1979,

Letter from the Secretary (Second topic only)

Solar Energy

There is, at present, quite some anxiety about resources of energy. All this disquietude arises from our narrow view that our energy requirements can only be met by coal and oil and both are becoming more difficult of access whether from our own resources or from other countries.

Let us examine this question with some spiritual vision and that is really the only true vision on any subject. For such spiritual vision we can know best by asking what The Mother has said on these points because, as Mother had Herself so often explained to me, whenever I asked Her a question, She answered from what She saw and not from what She thought. She repeated often that for over 40 years She had not thought but only 'seen'.

Regarding coal and oil, Mother said, both are fossil fuels and so, by their very nature, belong to a dead past. We should look for our energy requirements-from things of the present leading into the future. With regard to nuclear energy, as I have already written before, (December 1978), this energy is obtained by breaking up the nuclears of the atoms and so, in the very principle, is a destructive energy, the force selected by the Powers that try for the destruction of the world, the Pralaya. The Mother said that we should concentrate our research on Solar Energy. The sun, Mother said, is the physical sign of the supramental, the goal towards which we are moving in Their Yoga. The sun pours down a tremendous amount of energy and only a very little fraction of its is being used, almost all of it goes waste. Particularly in India, we are very fortunate in having so much of the glory and blessing of the sun that we should thank God constantly for it. But we do not realise this great boon and sometimes even complain of it. So I appeal to our scientists and research organisations to make the maximum possible efforts for solar energy research.

Udar

14. Sri Aurobindo's Action---December 1983, *Letter from the Secretary*

Nuclear and Solar Energy

The 12th World Energy Congress ended at Delhi on 23rd September 83 with the participation of 62 nations in the deliberations on the important question of energy. This reminds me of what I wrote earlier on the development of nuclear destructives and solar energy. I had stated that according to the vision of the Maharshis and Mahayogis our country should keep away from the dark path of nuclear competition.

Our Government now says that even if all the other countries in the world make the nuclear bomb India will not do it. This should have been said earlier and the Mother had tried to get the Government to say this before we had our nuclear explosion. To say it now is closing the stable door after the horse has run away.

The more important thing to state is something which physical science will not accept and that is that energy has characteristics. They maintain that energy is neutral and can be well used or ill used but the Mother has said very strongly that nuclear energy is evil in its very base. It comes from the destruction of the basis of matter, the nucleus of the atom and so its very characteristic is destructive. Even the so-called peaceful purpose is a blind. It can never be peaceful and, somehow or the other, will cause great damage. On the other hand the Mother has shown that the true spiritual energy in the physical comes from the sun. It is the physical symbol of the Supramental and it pours down on us enormous quantities of wonderful energy of which we now use only a very, very small fraction. So our whole attention must be concentrated on using solar energy, in all its forms.

The best form of solar energy is of course what the Mother had seen in an experience where enormous amounts of solar energy was being produced just by the sun shining on vast panels. This is a clear vision of the use of photo voltaic cells for producing electricity directly from the sun's light. Scientists all agree about this, but they say at present the cost of the solar cells is prohibitive for any widespread use. The answer to this is very simple. Let us do more and more research till we find a way of making these cells at quite a low cost. Even now, Japan is making them at one-fourth of the cost of production in the U.S.A. and Western countries. If we in India just stop copying what other countries are doing and do our own research I am sure we can produce the cells very, very cheaply. Instead of spending all that we do on nuclear energy research and even on maintaining the present nuclear research and the power stations we could do much more in photo voltaic research. We have both the scientific capacity and abundance of labour at low cost, so our productivity can be stupendous. I have a dream, and not such an empty one at that, of producing these cells here at Pondicherry with the Mother to guide us to a wonderful result.

But in the meantime there is another low cost method of producing electricity, the lowest cost that exists anywhere and one so highly suitable for our country and yet nothing is being done at all in that sphere. They are doing it in a big way in Israel and in Australia but here, where conditions are so very suitable, nothing at all is done, or very little. I am referring to the use of solar ponds for generating electricity. We had the visit here of Professor Carl Neilson, Professor of Physics at the Ohio University in the U.S.A. and he was here for nearly a month. He gave a talk at the end of his visit and I do wish he had given it earlier. He is perhaps the leading world-authority on solar ponds. On hearing what he had to say I knew how very well we are situated for such a set-up here, particularly at Pondicherry. I am sure that we can set up a 5 Megawatt plant with a solar pond which may be enough for the whole requirement of the Pondicherry town. This idea I am now investigating and, if found feasible, I will approach the Government. For one thing I feel we can count on Professor Neilson to help us quite a bit.

Udar

13. Sri Aurobindo's Action-February 1984, *Letter from the Secretary*

In our Dec. 83 issue I mentioned briefly about the solar pond system of producing electricity. I will develop this a bit further now. But first I must mention about the very important and dedicated work in solar energy that is being done here by Dr. Chamanlal Gupta, one of the members of the Ashram, under the aegis of the Tata Energy Research Institute, and his fine collaborator, his wife Shipra. Presently they are setting up in several places installations of solar water heating systems and they are manufacturing very efficient solar cookers. They had also set up a solar pond in one of our estates but it was a small pond for experiment and they were able to collect valuable data. Now for the big pond that we propose in Pondicherry it is they who will help prepare the scheme.

Let us see how the solar pond works. Generally the water should be to a depth of about three meters and the lowest meter should have a very high concentration of ordinary salt dissolved in it. The middle layer is of a middle concentration and the top layer of a still less concentration. The layers remain separate by themselves and do not mix. When the sunlight falls on the pond it heats the water, but most of the heat goes to the lowest level and stays there leaving the upper layer relatively cool. There is a substantial temperature difference between the lowest level and the top level. In Pondicherry this will be around 46 ˚C. In the hot, lowest level are laid coils of pipe carrying a low boiling-point fluid like Freon. It is vaporized by the heat and the vapor turns a steam turbine which is coupled to an electric generator. After passing through the turbine the vapor is led into the top layer of the pond where it is cooled back into a liquid and led to the lowest level of pipe coils. The whole system is a closed circuit.

This method of generating electricity is used quite effectively in Israel where they have a 5 megawatt unit. Australia also has some units. But India is ideally suited for such systems and particularly here in Pondicherry we are very well placed.

We have found an area where there is a large expanse of waste water and the whole place is left unused. This can easily be made into a solar pond. As there is a good salt industry in Pondicherry, salt will also be easily available. The proposal has been put to the Govt. of Pondicherry and has been enthusiastically received. Dr. Chamanlal Gupta of TERI has been requested to produce an urgent primary estimate of costs for sanction and then to see about a more detailed scheme. It is suggested that a 50 KW unit be set up in the first instance. It can be expanded later. It will be a unique achievement in this country.

Here are some general facts about solar ponds' electric generation: 1 sq. meter will generally produce 3 to 4 watt-hours. The solar pond keeps its heat even during the night, so the power generation is for 24 hours.

Udar

14. Sri Aurobindo's Action---May 1984, *Letter from the Secretary*

As there seems to be so much interest in Solar Ponds, I follow up the previous notes given in my letter by some more notes.

The 3 zones of the solar pond can be shown in the cross-section diagrammatic sketch of a solar pond given below:

1. Low Density Surface Mixed Zone
2. Gradient Zone
3. High Density Storage Zone

It will be noted that the 3 zones are not of equal depth as had been wrongly stated before. The top, cooling layer is relatively thin and the lowest layer, with the high density salt solution and which contains the heating pipes, is much deeper.

Stagnation temperature may exceed 100°C in this lowest level. The fraction of solar energy converted to useful heat can vary from 20% to 35%, which is very large, indeed, compared to other systems.

Solar ponds can be used to provide process heat for such applications as water heating, crop drying, desalination, absorption refrigeration etc., as well as to operate thermal power units to generate electricity.

Another important advantage of a Solar Pond power generating unit is that it can be operated at peaking modes. For example, the power output available from the 7,000 m^2 in Bokek pond is less than 2 W per m^2 or around 14KW electric. Yet it has been operating a 150KW power unit on an intermittent basis. This shows the feasibility of extracting heat for peak loads at more than ten times the average rate without damaging the gradient zone structure of the pond. On this basis, in Israel, the new 250,000 m^2 pond will operate a 5 Megawatt power station on a duty cycle of between 15 and 20 percent.

From the experience at the Solar Pond at Bhavnagar in India, some of the problems a pond has to face are wind mixing and poor transparency from silt and algae in the sea water used. For a wind barrier, to minimize the wind mixing, at the Pondicherry project it is suggested that effective blocks of Casurina trees be grown all around especially on the side of the incoming winds in the different seasons i.e. in the South West and North East sides. But this will increase the clouding of the water surface with the dead leaves falling from the trees. So a simple surface cleaning system should be introduced, with a long rope and simple brush, to clean the surface daily or even twice a day. This can be quite easy and inexpensive.

There may be some other practical problems that will arise but it is anticipated, that they will not be serious ones and will be easily met. The experimental pond at Pondicherry, with which I hope to be closely associated as also Dr. C. L Gupta and his wife Shipra, will give us valuable data for larger ponds in India. We have this wonderful gift from God, of so much sun shine that it is a criminal act to let it go to waste.

Now we come to costs. This is the question everyone who is interested will ask. I will give some material on this in the next follow-up letter.

I must here state that practically all the information I have given and will give comes from a brochure, not generally available, titled "A Programme for Solar Pond Development in India" by (1) Shri V.V.V. Kishore of the Central Salt and Marine Chemicals Research Institute, Bhavanagar, (2) Prof. C. E. Nielsen of the Ohio State University, U.S.A., (3) Shri K.S. Rao of the Gujarat Energy Development Agency, Baroda, and Dr. C. L. Gupta, of the Tata Energy Research Institute, at Pondicherry.

I gratefully acknowledge my debt to the above persons and thank them for the data they have provided me.

I pray to the Divine Mother, to bless this adventure in the sun, with Her Light and Grace.

Udar Pinto

14 Sri Aurobindo's Action---June 1984, *Letter from the Secretary*

In my last letter I wrote that I would follow up with some cost details on Solar Ponds as this will be the decisive factor in the scheme of a Solar Pond. These cost estimates will be very tentative as there are so many varying factors to consider. These varying factors are principally whether a lined or unlined pond will be required. If the soil at the spot chosen is impermeable then an unlined pond can work and this will reduce the cost very much. The lining of a pond with cement concrete walls will be relatively costly.

Other factors which will determine the costs are the availability of salt and its cost. Here at Pondicherry salt is easily available and is relatively cheap. Then to maintain an efficient temperature gradient in the pond the ready supply of cool sea water which we will have here will reduce the cost appreciably. Then the size of the installation is a very important consideration as the larger the pond the less the cost per KW-installed. Finally there must be some comparison with the cost of power generation with a coal-fired thermal unit.

I give rather briefly some figures from the brochure I have mentioned in my last letter, "A Programme for Solar Pond Development in India", prepared by Messers Kishore, Neilson, Rao and Gupta. They have studied first the cost of Industrial Process from a Solar Pond in relation with that by coal burning.

In this, from the figures given which are fairly recent they show that the cost per KWhr (thermal), including the cost of the land at Rs. 50/- per m^2, is at Rs. 0.10 and Rs. 0.08 for a lined and an unlined pond. For a coal burning system, with coal price taken at Rs. 600/- per tonne, the corresponding cost would be Rs. 0.22 per KWhr (thermal). This shows the solar pond installation at an advantage. For Power Generation there would be additional factors such as more heat exchangers and turbo generators. But they stress the great difference in the costs of small and larger installations. The tables they have given show the costs of Power Generation of two installations, one of an area of 5.000 m^2 and another of 1 km^2, in lined and unlined ponds. Here they find that for the 5.000 m^2 pond the cost of the power plant per KW installed is Rs. 63,000/- and Rs. 46,900/- for lined and unlined ponds. Against this, for the 1 km^2 pond the costs are Rs. 45,000/- and Rs. 35,000/- per KW installed for lined and unlined ponds.

The figures given are necessarily tentative and can vary with coal the conditions and also on the experience gathered by installing The smaller units. From the figures in the table referred to above, the cost per KWhr (Electrical) is shown as Rs. 2.68 and Rs. 2.31 for lined and unlined ponds of 5000 m2 area and Rs. 1.24 and Rs. 1.02 for a 1 km^2 area. At Pondicherry we have very favorable conditions and so these cost figures can be very substantially reduced to make them quite competitive with a coal-fired thermal unit. These favorable factors are the easy availability and low cost of salt, the sea water, the low cost of the land, the comparatively low cost of labor, especially for the maintenance of the cleanliness of the pond which is very important. And then we have a very good fall of sunlight which can be well above the estimated average of 250 W per m^2. In their calculations they have taken a solar input of 240 per m^2.

Finally, from the progress the writers foresee in this field they come to a reserved but optimistic cost estimate which can drop from the present estimate of Rs. 1.0 per KWhr to Rs. 0.40 per KWhr (electrical). This is very encouraging.

Udar Pinto

15 Sri Aurobindo's Action---December 1989, *Letter from the Secretary*

A friend has sent me a copy of an article published in "The (Brockton) Enterprise" of the 8th May 1989 written by Christopher Callahan of the Associated Press. It is about a solar car and I found it very interesting for various reasons, so I share my interest with others. The car was designed and built by James Worden, a 1989 graduate of the MIT (Massachusetts Institute of Technology). It is a single seater car, weighing only 270 pounds and named by the designer as "SOLECTRIA". It has a 11ft. by 6 ½ ft. flat panel on the top which carries the photo voltaic cells. The panel is quite low so there is a plastic bubble in it through which the driver can see things. The electric power generated by the cells drives a small electric motor which can move the car up to 90 mph on a flat road. James Worden drove his car from Los Angeles to Washington, a distance of 3,200 miles in two weeks which is a record for such cars. At Washington he was greeted by Senators at the Capitol who praised the car and found it as a great forerunner to a model which will really solve the problem of pollution-free transport and a very good alternative to the dwindling fuel resources.

What interested me most is that this is part of the Mother's vision. Mother had told me very forcefully that the days of the fossil fuels were over and it had to be so. We were living on our past, our dead past as the word fossil itself indicates. We should now move to our future, our glorious future, to an energy from the sun, the physical symbol of the Supramental. Mother had had a vision in which she saw a very large area covered with some kind of flat panels and from this there was a constant supply of electric power coming. Mother asked me if I could interpret her vision in terms of what I knew of the scientific approach in such matters. I told her that it was very clear that the panels were covered with Photo Voltaic Cells which generate electricity directly from the sunlight that falls on them. The current is direct but this could easily be changed to alternate current if required. Mother then said that this is the true future of our power supply and we, especially Indians, should do maximum research in this field. I informed the Mother that the research, at present, had to be in two fields.

- To find more easily made and cheaper materials which give this photo voltaic reaction and with a much higher efficiency than at present.and then for more efficient collection of the sunlight on to the cells, such as with Fresnel Lenses etc.

Then there was the research to be done on much better ways of storing the power generated in daylight to be used at night. Research is going on in these fields all over the world and in India also but here on a very small scale, with quite a low priority. We have the talent, quite good talent but much of this goes elsewhere where there is more appreciation and better opportunity for advance than in our country. This must change, it really MUST.

There was one point in the report which really shook me. One Senator said that the amount of carbon emitted from the exhaust of one single car in one year was equal to the weight of the car itself. This statistic seems quite exaggerated and yet it may be true.

There is more that I will write about Solar Energy in subsequent letters.

23.10.98 *Udar*

16 Sri Aurobindo's Action---August 1991, *Letter from the Secretary*

Further to my letter in the June issue of our Journal on the Sri Aurobindo Learning Centre at Baca in the U.S.A. here is some more news about it and the Peace Ship project.

To anyone who may be interested the address of the Centre at Baca is: Seyril Schochen, "Savitri House", BACA, P.O. Box 88, Crestone Co. 81131, U.S.A. The new news is that they are going for Solar Energy in as large a way as possible for them in their present circumstances and are setting up what they call the "Solar Bridge" which will be an all solar electric home. They want to give expression to The Mother's very clear direction that the future world energy must come from the sun which is the physical symbol of the Supramental. In addition there is a plan for a Solar Conference Room, and a Savitri Solar School and in the future a Savitri Solar Village.

Now, the Peace Ship Project. On the ship, on its voyage out to Auroville and back to Rio de Janeiro in Brazil there will be a Floating Seminar on Human Unity and related subjects where some well known world persons will participate. These include Mr. Devan Nair, once President of Singapore Republic, Dr. Karan Singh, The Dalai Lama, Robert Muller, Chancellor of the Peace University, some Youth leaders etc. Dr. Maurice F. Strong, Secretary General of U.N. Conference on Environment & Development at the U.N., New York, is taking a very active part in all these projects. He is one of the candidates to the U.N. Secretary General post when the present incumbent retires. Dr. Strong has donated 61 acres of land to the Sri Aurobindo Learning Centre at Baca Bluffs which will be developed into the proposed Savitri Solar Village.

28.6.91 *Udar*

16.1. Sri Aurobindo and Solar Power

MOTHER INDIA , April 1967

May 8, 1926, SRI AUROBINDO: In the West the highest minds are turned not towards spiritual truth but towards material science. The scope of science is very narrow; it touches only the most exterior part of the physical plane.

And even there, what does science know really? It studies the functioning of the laws, builds theories ever renewed and each time held up as the last word of truth! We had recently the atomic theory, now comes the electronic.

There are, for instance, two statements of modem science that would stir up deeper ranges for an occultist:

1. Atoms are whirling systems like the solar system.
2. The atoms of all the elements are made out of the same constituents. Different arrangement is the only cause of different properties.
3. If these statements were considered under their true aspect, they could lead science to new discoveries of which there is no idea actually and in comparison with which the actual knowledge is poor.

According to the experience of ancient Yogis, sensible matter was made out of five elements, Bhutani: Prithivi, Apas, Agni (Tejas), Vayu, Akasha.

Agni is threefold:

1. Ordinary fire, Jala Agni,
2. Electric fire, Vaidyuta Agni and
3. Solar fire, Saura Agni.

Science has only entered upon the first and the second of these fires. The fact that the atom is like the solar system could lead it to the knowledge of the third.[1]

Beyond Agni is Vayu of which science knows nothing. It is the support of all contact and exchange, the cause of gravitation and of the fields (magnetic and electric). By it, the action of Agni, the formal element, the builder of forms, is made possible.

1 This statement heralds the later scientific discovery of nuclear energy and even of "fusion" (solar fire). (Editor)

17. Syllabi of the Presentation of Dr. Kalam, President of India, to the Legislators of the Pondicherry Legislative Assembly, 1st of November 2004

Ten immediate missions

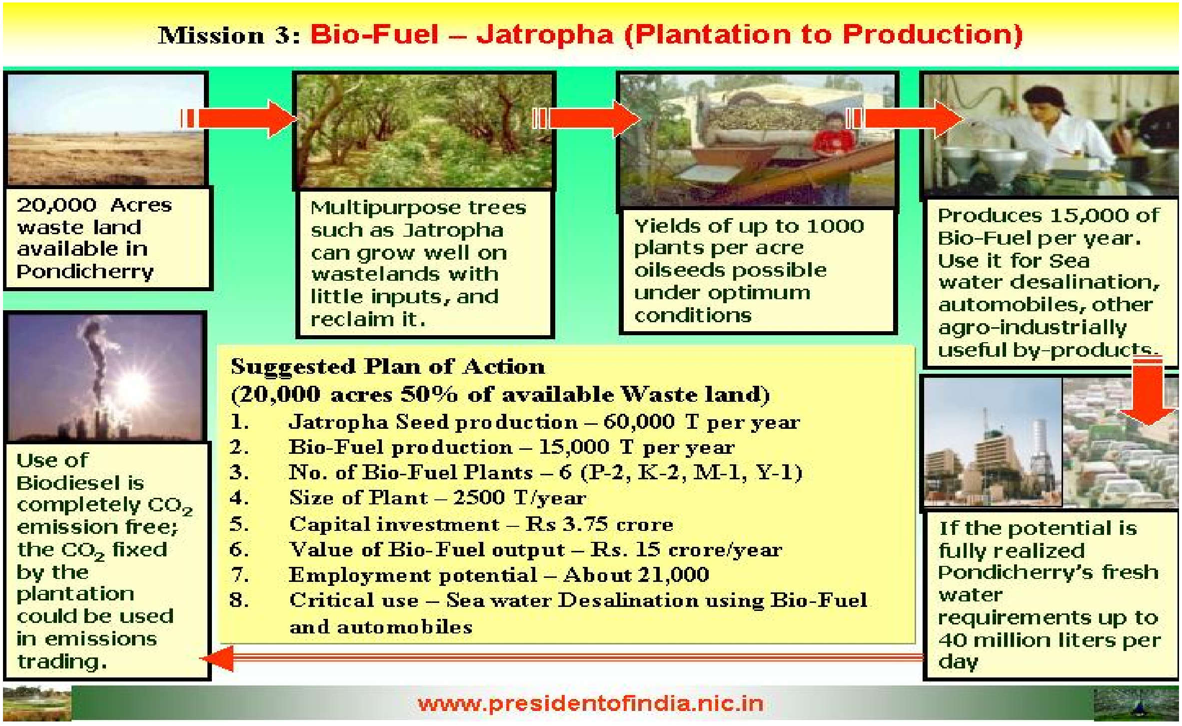
Dear Members, may I now summarize the ten important missions for your consideration and implementation for sustained prosperity and empowerment of Pondicherry and its regions besides providing employment opportunities for over one lakh of the people of Pondicherry and its regions.

1. 100% literacy for all and Health Care for through Medical Insurance.
2. Establishing 7 - PURA clusters (P3, K-2, M-1, Y-1).
3. **Waste Land Development – 20,000 acres leading to 15000 tones of bio-fuel per annum.**
4. Total self-sufficiency in milk and dairy products, vegetables, fruits, poultry through intensive Commercial Agriculture
5. **Sustainable Water Resource management and arresting further penetration of salinity and setting up of small desalination plants with renewable energies.**
6. **Establishment of 100 mega watt (VLS-PV) solar power stations, 6 Bio-fuel production plants each of 2500 tones per year capacity and 7 units each of six megawatt municipal waste based power plants Renewable Energies.**
7. ICT business alone has to generate revenue of Rs. 500 crores.
8. Thrust in infrastructure for doubling of our tourist arrival and increasing the foreign tourist visits by a factor of five.

9. Aqua Culture and deep sea fishing added with high sea sales should lead to the target of Rs. 300 crores business per year through a collaborative program.

10. Establishing value added Garment industry with an export target of Rs. 1000 crores.

Mission # 3: Bio-fuel from Wasteland Cultivation



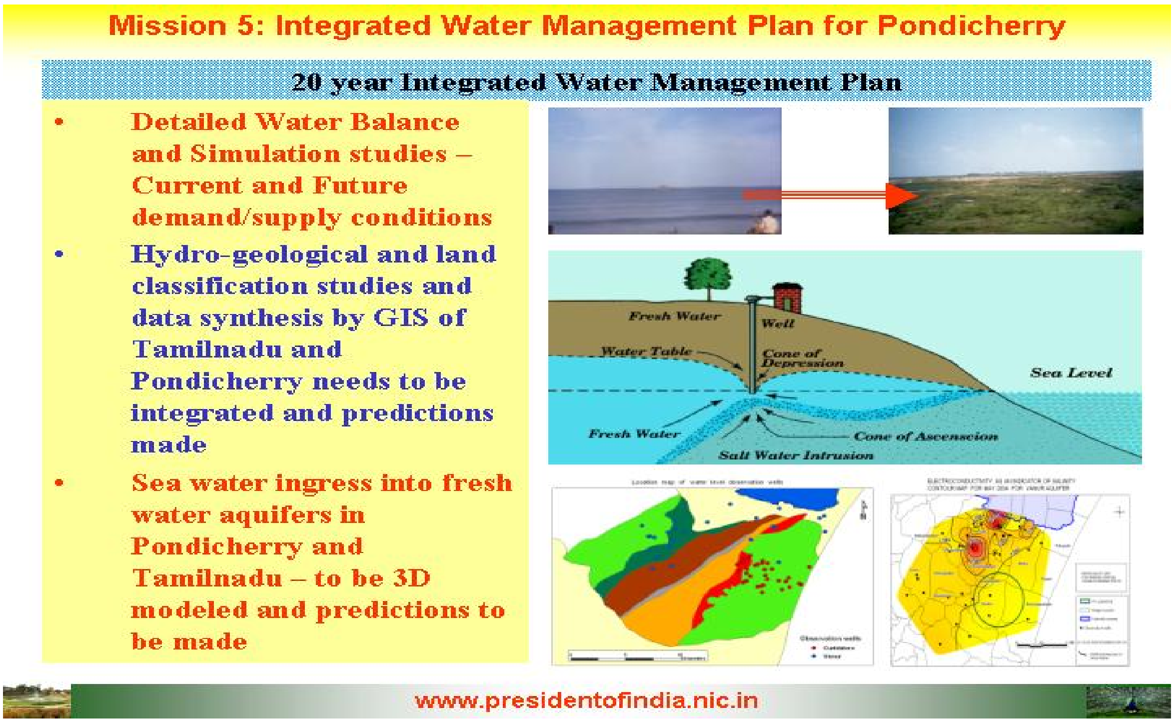
The total non-agricultural wasteland in Pondicherry is about 15,000 hectares or about 42,500 acres which is about 31% of the total land area in Pondicherry, Karaikal, Mahe and Yanam. Even if we transform 50% of this area to serve a Bio-fuel Mission, nearly 15,000 tones of bio-fuel can be produced from the four regions of Pondicherry in a manner that will serve to integrate their economies, ensure balanced economic growth and generate employment for about 21,000 persons.. This will need setting up of 6 plants at a total cost of about Rs 4.0 crores to process Jatropha seeds into bio-fuel, with each plant having an output of 2500 tones of bio-fuel per annum, yielding a total bio-fuel production turnover of about Rs 15 crores.

Using Bio-fuel to Produce Drinking Water from Seawater The normal use of bio-fuel is to be a substitute for diesel fuel for automotive and industrial purposes. However, for your coastal economy, I suggest a unique application of bio-fuel. Studies carried out in India show that perennial supplies of fresh water can be obtained in a cost-effective manner by desalination of seawater using renewable energies, a system and technology option which is particularly useful for population centers living on the coast line.

Pondicherry and its regions are also endowed with plentiful sunlight. Hence, small desalination plants can be set up at selected sites on the East and West coasts of India using solar energy and bio-fuel as hybrid renewable energy systems. The bio-fuel production from wasteland cultivation if used exclusively for production of sweet drinking water from the oceans will enable Pondicherry to create 40 million liters of fresh water daily from the oceans.

In this manner, Pondicherry can resolve major two problems with one integrated solution viz- productive use of wastelands and providing sweet drinking water to population centers living along the coastline, through use of new technologies.

Mission # 5: Integrated Water Resource Management.



I understand that in Auroville, a UNESCO endorsed International Seminar brought out the problem of seawater ingress into fresh water aquifers in Pondicherry and Tamil Nadu. It is essential to formulate a 20-year Integrated Water Management Plan based on further detailed studies, and then implement the Plan, in an integrated manner. I shall now discuss about the immediate measures for water table improvement and establishment of desalination plants.

Water harvesting and Recycling: Water harvesting should become mandatory for all. To improve water table we need to build check dams; develop water sheds, de-silt ponds and rivers, clear the inlets and outlets to the ponds and water bodies and recharge the wells. If our rural areas are made to have operational water bodies, recharging of the wells will take place automatically. These activities will also generate employment.

Water Desalination: In the coastal regions where ground water availability is scarce, India with large coastline of 7500 kms can afford to have number of seawater desalination plants using solar energy. I have seen many of the desalination plants in UAE, where the fossil fuel power sources are abundant. India should use solar power for desalination process, which will be cost effective. Desalination technology has advanced in such a way that there are plants in the world today, which can produce 1000 liters of potable water for Rs. 25. The allocation of special fund in the Central Government Budget 2004-05, brings out a necessity to have a mission-mode programme for setting up of desalination plants. For Pondicherry, it is equally important to plan such a desalination plant using solar power /bio-fuel.

Mission # 6: Renewable Energies

India's power generating capacity is one-lakh megawatts. For meeting the development targets till 2020 our generating capacity has to increase to three lakh megawatts. This additional power has to come from nuclear energy, hydroelectric systems, renewable energy and thermal energy. The contribution of renewable energy especially from solar energy and wind energy has to be increased to one hundred thousand mega watts. Urgent measures are needed to reduce the distribution loss to less than 5% from the existing 25%. Use of bio-fuel has been discussed earlier for wasteland development mission, which has tremendous potential in the Pondicherry region.

Solar Energy: Productivity and profitability of farmers is affected by unreliable power supply, high cost of electricity, and availability only at night. With increasing demand for energy and increasing oil prices this problem is going to be more serious for farmers in the future. Installation of centralized solar photovoltaic systems, which can be fed to a grid, will be a long-term economically viable solution with added benefits of pollution control. We should build a few 100-megawatt solar power stations, capable of meeting the needs of the farmers with minimum maintenance expenditure. VLS-PV systems can be set up in Pondicherry regions, and gridlocked into the national electricity grid.

Power through Municipal Waste: Increased urbanization has led to a serious problem of accumulation of municipal solid waste in many towns and cities. Efficient and environmentally clean disposal of garbage has always been a major technological challenge. While being a threat to the environment, mounting garbage is also a rich source of energy. The potential for converting this waste into useable energy, which will eliminate a major source of urban pollution, was realized by one of our innovative organizations- Technology Information Forecasting and Assessment Council (TIFAC) of DST, which helped in developing a completely indigenous solution for the processing of waste into a source of fuel. This fuel could, in turn, be used for generation of electricity through mini-plants. Already in our country two plants, which generate 6.5 megawatt electric power using municipal waste bricks, are in operation. India needs thousands of mini power plants using municipal waste. This can be replicated in Pondicherry and its regions including cities and village clusters as an infrastructure build-up project with the aid of Corporate Houses. This project apart from being an employment generator will provide a clean environment for the people to live in.

18. About the Authors

18.1. Martina Schimanski

Martine Schimanski graduated 2004 her Master in environmental engineering from the University Of Applied Sciences Weihenstephan, Germany. Main subjects of her studies were renewable energy systems and waste management. The usage of solar energy by a photo bioreactor was her main interest and the topic of her thesis (Diploma), that she carried out at the Commonwealth Scientific and Industrial Research Organization CSIRO, Melbourne, Australia.

Parallel to her studies, she was employed at the Fraunhofer Institute for solar energy systems ISE, Freiburg and at the Hahn-Meitner-Institute HMI, Berlin, Germany. During this period she was able to gain valuable experiences in this subject on solar energy systems.

In January 2005, she joints the Team of Walter Wagner and Dirk Nagelschmidt as consultant for renewable energy systems.

18.2. Dirk Nagelschmidt

Dirk Nagelschmidt started his career 1988 as professional draughtsman in civil engineering for water, roads and landscaping. From 1992 to 1998 he studied civil engineering at the University of Applied Sciences, Aachen. During his study he specialist in water, waste water and waste. He finished successfully the University with the German title “certified Diploma Engineer” (Dipl. Ing.) which is equal to Master of Engineering (M.Eng.).

Mr. Nagelschmidt has worked as project coordinator and planning engineer at different companies in Aachen and Cologne/ Germany.

In 2002 he came to Auroville/India where he started his company AQUA ENGINEERS.

Mr. Nagelschmidt is member of:

German Desalination Association DME e.V.

&

German Association for Water and Waste Water DWA.

18.3. Walter Wagner

Walter Wagner studied landscape architecture and environmental care at the University of Munich/Weihenstephan, Germany, from 1970-1975. As a certified engineer in landscape architecture and environmental care he worked for different companies in Germany and Egypt. He lives and works in Auroville, India, since 1987 and was a member of the Matrimandir management until 2003.