Application Solutions Guide

DESMALINATION

Experience In Motion
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THE GLOBAL DESALINATION LANDSCAPE
The global demand for fresh water is continuously growing, but fresh water sources are limited and not always available where population and industry need them. Only 2.5 percent of the world’s water is fresh, and 70 percent of this remains frozen in polar ice caps and snow. The remaining 97.5 percent of the world’s water is in the oceans and seas. Desalination allows this large water resource to be tapped for human consumption and many manufacturing processes.

Desalination plants operate in more than 120 countries, but they only provide 1.5 percent of the world’s water supply. Some countries, such as Saudi Arabia and the United Arab Emirates, count on desalination plants for over 70 percent of their water.

The climate for capital expenditures (CAPEX) in desalination is a good one. Global Water Intelligence forecasted a 14.8 percent CAGR. Sixty-five percent of this growth will take place in the Middle East and North Africa, where investment has not kept pace with demand and ground water conservation is a priority. More than 70 percent of these investments will be on large Seawater Reverse Osmosis (SWRO) plants with a capacity greater than 50,000 m$^3$/d.

While there is plenty of optimism for growth in desalination, it does not come without a few significant cautions:

- Political unrest is a risk.
- Anticipated restructuring and/or privatization of state-owned concerns in Saudi Arabia and other Gulf States in response to low oil prices and revenues has the potential to slow the pace of investment.
- Environmental approvals and activism in the U.S. and Europe can delay investments. Projects are generally subject to intensive scrutiny, especially where seawater intake and brine disposal may harm the environment.

However, the need for new desalination capacity is real and will likely remain a priority in many areas of the world, even with many state budgets under strain. Advances in membrane technology and energy recovery are making desalination more economical. Ground water conservation, a major driver for future demand, will likely remain a priority in growth areas. Finally, CAPEX forecasts for Asia-Pacific and Americas are strong, even though these regions represent a small percentage of the total sum.
IMPORTANT DESALINATION TERMINOLOGY AND ACRONYMS

Seawater and Brackish Water Concentrations

The mineral or salt content of water is defined in terms of total dissolved solids (TDS) using units of mg/l or parts per million (ppm). The maximum concentration for potable water is 500 mg/l. Water with TDS from 500 to 15 000 mg/l is generally classified as brackish, while water with higher concentrations is classified as seawater. The salt concentrations in seawater can vary quite significantly. In the Pacific Ocean along the U.S. coast, concentrations vary from 33 000 to 36 000 mg/l, while the Persian Gulf sees concentrations as high as 45 000 mg/l.

Technologies

• Membrane Desalination
  – Seawater Reverse Osmosis – SWRO
  – Brackish Water Reverse Osmosis – BWRO

• Thermal Desalination
  – Multistage Flash – MSF
  – Multi-Effect Distillation – MED
  – Thermal Vapor Compression – TVC (not covered in this document)
  – Mechanical Vapor Compression – MVC (not covered in this document)

Market Segmentation by Technology and/or Plant Size

• SWRO <10 000 m³/d >> small and medium
• SWRO <50 000 m³/d >> large
• SWRO >50 000 m³/d >> extra-large
• Thermal >> MSF, MED, TVC, MVC
• BWRO and Nanofiltration
Membrane Desalination

In membrane desalination systems, dissolved minerals are separated from the intake or source water with a semipermeable membrane.

The dominant membrane technology used today is Reverse Osmosis (RO). If high and low salinity water sources are separated by a semipermeable membrane, water will move from the low salinity side to the high salinity side by a natural process called osmosis. The water being transferred exerts a pressure on the membrane known as osmotic pressure, which is proportional to the difference in total dissolved solids concentrations on each side of the membrane, and is also dependent on the source water temperature and the nature of the dissolved solids. The osmotic pressure does not depend on the type of membrane used.

This process can be reversed by applying pressure to the salt water side of the membrane. This is the operating principle behind all RO desalination plants.

With its inherently simple design, significantly lower energy consumption and smaller footprint than thermal technologies, the RO process is often the choice for municipal and commercial water supply. This applies to both SWRO and BWRO applications. With its semipermeable membranes, the RO process requires a pretreatment to ensure all larger particles and suspended solids are removed from the feedwater to protect the membranes. Pressurized feedwater is fed to the membranes where the water stream is split into a high-quality product water stream at lower pressure and a high salinity discharge (reject) stream, which remains at high pressure. Hydraulic energy is recovered from the reject stream with different energy recovery devices (ERDs) to lower the overall energy consumption of the plant. To improve the operational flexibility and minimize downtime, chemical additives are required to prevent scaling and fouling of the membranes.
Membrane Principles

The RO section is one of the most vital steps in the desalination process, as more than 80 percent of the total energy required by the plant is used in this section. RO membranes are considered the most important equipment in the process.

The membranes used in RO systems are designed to separate dissolved solids and cannot remove or store large amounts of suspended solids. If suspended solids are allowed to enter, the membranes will foul quickly. As a result, RO plants include sophisticated pre-treatment systems to remove suspended solids before the source water is introduced to the membranes.

The spiral-wound membrane is the most common type used in the industry today. They are produced in a flat sheet sealed like an envelope and wound in a spiral.

The most common RO elements currently in use are 20 cm (8 in) diameter and 100 cm (40 in) long. These are enclosed in a pressure vessel that typically holds about seven elements. In such a configuration, each element produces about 13 to 25 m³/d of permeate, and the whole vessel therefore produces 91 to 175 m³/d. Larger 16-, 18- and even 19-inch elements are commercially available but have not gained popularity, partly because they are too heavy to be easily handled by one person.

In large RO plants, anywhere from 100 to 200 pressure vessels are assembled in parallel into a rack. When combined with the necessary pumps, valves and energy recovery devices, this rack forms an RO train. An extra-large RO plant would consist of several independent trains, each capable of providing a product water flow of 20 000 to 25 000 m³/d. The image below shows an installation with five trains, where each train includes a rack of about 144 pressure vessels.
**Thermal Desalination**

**Multistage Flash Distillation**

The first large commercial scale desalination plants used the MSF process to produce potable water. In this process, seawater is heated to 90°C to 115°C by steam provided from a co-located power plant. The heated seawater enters a chamber (called a *stage* or *effect*), which is maintained at a lower pressure, causing some of the seawater to flash to steam. This pure distillate is condensed on tubes that are cooled by the incoming seawater and collected in trays to be transferred to product water storage tanks.

The remaining brine concentrate passes through several more effects, each operated at a lower pressure, causing more seawater to flash. Each stage produces about 1 percent of the total plant product water volume. Commercial MSF plants typically have 19 to 28 stages. As a result, the recovery rate of an MSF plant (finished product, or permeate, divided by seawater intake) is typically in the 19 to 29 percent range.

After the last stage, a portion of the brine is recirculated back into the source water stream, reducing the total intake water requirements and improving the thermal efficiency of the process.

*Schematic diagram of an MSF desalination plant*
Multi-Effect Distillation

Able to operate at temperatures as low as 62°C, MED plants require less heat input and lower pumping power (0.8 to 1.4 kWh/m³) than MSF plants. The main difference between MED and MSF systems is that in MSF systems the vapor is created by flashing, while in MED systems the source water is evaporated by heat transfer from steam in condenser tubes.

As with MSF plants, MED plants require a large source of steam and are therefore always co-located with a thermal power plant.

In the past, thermal desalination has been economically advantageous where water salinity is very high, because the energy required for separation is practically independent of the salinity of the source water. As a result, MSF and MED have been particularly popular in the Arabian Peninsula, which is bound by water bodies with the highest salinity in the world and demand for power and potable water has historically grown at a compatible pace. Approximately 85 percent of the global thermal desalination capacity is located in the Arabian Peninsula, with 70 percent of that in Saudi Arabia and the UAE.

There are new technology developments in thermal desalination, including hybrid systems that may bring about a revival in thermal plant construction. For example, approaches that combine desalination with concentrated solar heat and electricity production are advancing. Longer term, this could be an opportunity for Flowserve due to its combined experience in desalination and concentrated solar power. These technologies are not covered in this document.

Note that because of significant improvements in membrane and isobaric energy recovery technology, most near-term growth in desalination will take place in SWRO at the expense of thermal desalination. Accordingly, this document focuses mostly on SWRO.
DESALINATION PROJECT MODELS

Desalination plants are built under a variety of commercial models involving different influencers and decision makers. This section summarizes the primary project models, the key players in each model and current trends.

Fixed Engineering Procurement and Commissioning (EPC) Projects

This conventional approach to plant construction still represents 50 percent of the market. While every project has its own nuances, these projects generally involve the following scenario:

- The plant owner (government or private entity) uses a design engineer (consulting and specifying engineer) to handle the initial technology selection and plant design.
- The plant owner engages with multiple engineering and procurement contractors for bids on engineering, purchasing and construction of the plant.
- These are generally price-driven scenarios based on an agreed-upon cost per cubic meter of desalinated water produced.

Build-Own-Operate (BOO) and Build-Own-Operate-Transfer (BOOT) Projects

These privately financed ventures are becoming more prevalent in the global desalination market, especially for RO projects >50 000 m³/day. These projects typically involve a BOO(T) contractor who will own and operate the plant for a period of time after they complete construction. In some models, an independent developer who sells water (and sometimes power) to the owner plays the role of owner/operator. In cases where a power plant is also involved, you may see the terminology Independent Water and Power Project (IWPP) used.

In these cases, roles are as follows:

- The BOO(T) contractor handles engineering, purchasing and construction of the plant. The BOO(T) contractor owns and operates the plant instead of the end user government or private entity, selling water (and power) to the end user. In Transfer (T) scenarios, ownership is transferred after the defined contract duration, typically 25 years.
- In some cases, a private developer serves as the owner/operator. They engage directly with an EPC for plant construction.

The extent to which the end user is involved in equipment specification is dependent upon their role in the project. Very often, the end user involves a consultant to prepare specifications.
THE DESALINATION-FLOWSERVE INTERFACE
According to GW 2016 Data, 65 percent of desalination opportunities are located in the Middle East and Northern Africa. Seventy percent will be spent on large SWRO plants > 50,000 m$^3$/d in capacity.

While only 20 to 30 percent of the projected spend in EMEA, the total desalination CAPEX in Asia-Pacific and North America is expected to double from 2017 to 2020. Australia, India and California show signs of growth, and there are also indications of a potential boom in China. Chile is becoming an important market due to high demand for desalinated water for industrial and mining applications. Note also that some plants are considering switching from thermal to RO as membrane and energy recovery technologies improve, making the long-term economics favorable.

There is a large opportunity not only for original equipment, but even more so for aftermarket parts and services.
Due to advances in membrane and energy recovery technologies, SWRO will claim the lion’s share of CAPEX for the foreseeable future. Because Flowserve has a strong portfolio of pumps, ERDs and services that align perfectly with SWRO, this market segment is a critical focus area. Our experience in power generation and oil and gas is extremely relevant, as our pump portfolio is regarded as one of the most efficient and reliable in the world. Our expertise in ERDs is critically and integrally important to this fastest-growing segment of desalination.

Finally, our extensive investment in aftermarket services and supporting infrastructure is extremely important, especially with the emergence of BOO and BOOT commercial models where contractors and developers are assuming operational risks. Turnkey maintenance contracts, local service capability and equipment monitoring services are all in high demand from owners and operators of these massive plants.
PRODUCTS FOR DESALINATION — AT-A-GLANCE

There are many different technologies and project scales for desalination plants. Accordingly, the products Flowserve typically delivers for desalination projects will vary. A high-level discussion of our desalination offerings follows.

A detailed entry on specific Flowserve products for key applications in thermal and SWRO plants can be found in the next section.

**Pumps**

Desalination applications for pumps run the gamut, from source water intake and pressure boosting to various feed and chemical applications. Therefore, numerous configurations of pump products can be applied in desalination. Key among them:

- Vertical wet- and dry-pit configurations (VTP, SUBM, VCT, LNNV)
- Between bearings, single-stage (LNN, LR)
- Vertical inline process pumps (LNNV)
- Horizontal, overhung process pumps (HPX, HHPX, Mark 3™, PolyChem™, CBT, ZLN)
- Between bearings, multistage (DMX, CS/CSX, MSC)

The project opportunity for pumps varies by size, of course, but typical expenditures for pumps on a new construction SWRO plant are always in the millions of U.S. dollars, with pump costs exceeding US$15 million for some mega projects. *Note: costs include mechanical seals.*

**Energy Recovery Devices**

Energy is generally the biggest cost driver in any SWRO desalination facility, thereby making energy recovery equipment critical to the process. Flowserve is a world leader in the manufacture and supply of the most efficient energy recovery devices for the SWRO desalination process. Through its Calder™ brand, Flowserve has more than 30 years of experience and has recovered more than 750 MW of energy.

There are three main technologies used for energy recovery: isobaric devices; rotating impact machines or energy recovery turbines; and turbochargers. Flowserve offers:

- **Dual Work Exchanger Energy Recovery (DWEER)™** – an isobaric energy recovery device capable of recovering up to 98 percent of the energy in the brine waste stream
- **Energy Recovery Turbines** – capable of recovering as much as 90 percent of the hydraulic energy in the brine waste stream

Note that SWRO is trending toward isobaric energy recovery devices due to increasing energy costs. Energy recovery turbines remain common in BWRO and small SWRO plants where there is more sensitivity to capital costs.
INSTALLATIONS AND EXPERIENCE

Flowserve *pumps* or energy recovery devices are installed in 90 percent of the world’s desalination plants. Our customers include some of the world’s most important desalination EPCs, contractors, developers and end users. The table below includes a partial list of Flowserve customers and end user locations. A more complete list of projects awarded to Flowserve since 2010 can be found in Appendix A.

### FLOWSERVE CUSTOMERS AND END USER LOCATIONS (PARTIAL LISTING)

<table>
<thead>
<tr>
<th>Customers</th>
<th>End Users</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABB UK</td>
<td>AAN</td>
<td>Chile</td>
</tr>
<tr>
<td>Abeinsa</td>
<td>Abu Dhabi Water &amp; Electricity Authority</td>
<td>UAE</td>
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<tr>
<td>Abengoa</td>
<td>Advanced Water Technology</td>
<td>Saudi Arabia</td>
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<tr>
<td>Acciona Agua</td>
<td>Aguas Antofagasta</td>
<td>Chile</td>
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<tr>
<td>Acuamed</td>
<td>Algerienne des Eaux</td>
<td>Algeria</td>
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<tr>
<td>Aguas Antofagasta</td>
<td>Aquatect</td>
<td>Curacao</td>
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<tr>
<td>Alifatah Water &amp; Power</td>
<td>Aquamarin</td>
<td>Scotland, UK</td>
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<tr>
<td>Aqualia</td>
<td>Cargill</td>
<td>Spain</td>
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<tr>
<td>Aquatech</td>
<td>Cargill S.L.U.</td>
<td>China</td>
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<tr>
<td>Cadagua</td>
<td>Colt Engineering</td>
<td>Canada</td>
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<tr>
<td>Cameron System, Ltd.</td>
<td>Croon Caribe</td>
<td>Aruba</td>
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<td>Cargill S.L.U.</td>
<td>EAC</td>
<td>Cyprus</td>
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<tr>
<td>Clyde Union</td>
<td>Emalsal</td>
<td>Spain</td>
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<tr>
<td>Colt Engineering</td>
<td>Federal Electricity &amp; Water Authority</td>
<td>UAE</td>
</tr>
<tr>
<td>Degremont</td>
<td>H2 Oil &amp; Gas, Ltd.</td>
<td>Saudi Arabia</td>
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<tr>
<td>Doosan</td>
<td>Haileah</td>
<td>USA</td>
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<tr>
<td>Emalsal</td>
<td>Inalsal</td>
<td>Spain</td>
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<tr>
<td>GS Inima</td>
<td>KNEW</td>
<td>Kuwait</td>
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<tr>
<td>Hylux</td>
<td>KWS</td>
<td>Saudi Arabia</td>
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<tr>
<td>IDE Technologies</td>
<td>M&amp;G Resins</td>
<td>USA</td>
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<tr>
<td>Inalsal</td>
<td>M.N. Larnaca</td>
<td>Cyprus</td>
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<tr>
<td>International Water Treatment</td>
<td>Mekorot Israel National Water Co.</td>
<td>Israel</td>
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<tr>
<td>Italveco SRL</td>
<td>Minera Escondida</td>
<td>Chile</td>
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<tr>
<td>IVM (Minrav Sadyt)</td>
<td>Morrojable</td>
<td>Spain</td>
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<tr>
<td>Mekorot</td>
<td>NLC</td>
<td>India</td>
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<td>MHI</td>
<td>OCP</td>
<td>Morocco</td>
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<tr>
<td>Morrojable</td>
<td>Oman Power and Water Procurement Co.</td>
<td>Oman</td>
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<tr>
<td>Osmofero International FZE</td>
<td>Peregrino</td>
<td>Brazil</td>
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<tr>
<td>Repsol Exploration</td>
<td>Poseiden Resources Corporation</td>
<td>USA</td>
</tr>
<tr>
<td>Saline Water Conversion Corporation</td>
<td>Public Utilities Board Singapore</td>
<td>Singapore</td>
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<tr>
<td>Southern Seawater JV</td>
<td>Punj Lloyd, Ltd.</td>
<td>Qatar</td>
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<tr>
<td>Suez Degremont</td>
<td>Pupuk</td>
<td>Indonesia</td>
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<tr>
<td>SWCC</td>
<td>Reliance Industries</td>
<td>India</td>
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<tr>
<td>Tecton Engineering</td>
<td>Repsol</td>
<td>Algeria</td>
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<tr>
<td>Tedagua</td>
<td>Salalah</td>
<td>Oman</td>
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<tr>
<td>UTE Lanzarote</td>
<td>Saline Water Conversion Corporation</td>
<td>Saudi Arabia</td>
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<tr>
<td>Va Tech Wabag</td>
<td>SMN Barka Power Company SAOC</td>
<td>Oman</td>
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<tr>
<td>Valoriza Agua/Sadyt</td>
<td>Sorek</td>
<td>Israel</td>
</tr>
<tr>
<td>Vasilikos SWRO</td>
<td>Via Maris</td>
<td>Israel</td>
</tr>
<tr>
<td>Veolia (OTV)</td>
<td>Water Corporation</td>
<td>Australia</td>
</tr>
<tr>
<td>Via Maris</td>
<td>ZADCO</td>
<td>Abu Dhabi</td>
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<td>Wabag</td>
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FLOWSERVE OPPORTUNITIES IN DESALINATION — PRODUCTS AND CAPABILITIES
OVERVIEW

In this section you’ll find a detailed listing and description of the key products and capabilities Flowserve offers for desalination plants. Because the market has shifted primarily to SWRO, the emphasis of this section is on SWRO technology. But first, a quick summary of our product offerings for thermal desalination technologies.

Flowserve Products in Thermal Desalination – MSF and MED

The diagrams below provide basic schematics of multistage flash distillation and multi-effect distillation. The pump symbols in red provide a snapshot of the key applications for which Flowserve has an offering.
Seawater Intake Service

Arguably, the most important pump application in an MED or MSF plant is the seawater intake service. Because of the relatively low recovery rate of these processes, these pumps are much larger than the ones that may be found in an SWRO plant.

Brine Recirculation

Another important application in MSF plants is brine recirculation. MED plants also employ brine recirculation in some cases. The most frequently used product for this application is a QL pump.

Flowserve also provides pumps for brine blowdown, distillate extraction and condensate service. Pumps for these services may include the VPC and QL Series.
FLOWSERVE PRODUCTS AND CAPABILITIES IN SWRO

As noted previously, the simple design, lower energy consumption and smaller footprint of the reverse osmosis process have made this technology the choice for most municipal and commercial desalination projects. The combined capability of Flowserve to address all of the major pump and energy recovery requirements makes seawater reverse osmosis particularly attractive to our business and customers.

This section contains an overview of the main processes for SWRO, followed by a summary of the major Flowserve products used in these areas.

RO Process Applications Overview

This section focuses on SWRO. It should be noted that brackish water reverse osmosis (BWRO) processes follow the same principles as SWRO, but the necessary pressure and conversion rates in the membranes are different due to the lower salinity levels.

**Seawater Intake and Filtration:** This is the starting point for desalination. There are two main intake designs. The most common design is an open intake where a large pipe is positioned at the sea level about 20–100 meters from the shoreline.

The other design is referred to as *beach wells*. Close to the shore line, large vertical pumps take the water from the beach wells and pump the seawater to the plant site. Beach wells are advantageous because the seawater is pre-filtered to some extent. They are less common, however, because of the destruction of the landscape that occurs when building these pumping stations at the shoreline.

**Pretreatment:** It is important to remove foreign particles and organics before seawater enters the desalination plant. RO membranes must be protected against these particles to increase performance and service life. Therefore, the pretreatment process is viewed as very important and constitutes a significant capital and operating expense. It is often the largest performance and operating cost variable.

If necessary, chemicals can be added to the feedwater to ensure the plant operates at reasonable recovery rates. This process can vary greatly from location to location based on feedwater quality.

Seawater chlorination is used to avoid biological fouling. Over time, chlorine blocks the membranes, so a dechlorination process which injects sodium bisulfite or metabisulfite is used to clean and protect the membranes.

To further treat the feedwater and remove natural organic matter, particles and colloids, plants may employ additional steps such as coagulation and deep media filtration. Based on water quality (pH) and other process variables like time and velocity, plants may also incorporate additional pretreatment steps such as flocculation and sedimentation. Newer, unconventional pretreatment steps might include ultrafiltration.
Before the feedwater enters the membranes, an additional antiscalant solution is injected to protect membranes from scaling. As a last step, many plants incorporate a final filtration step as a safeguard against debris, sand or other foreign particles that could damage membranes.

**Reverse Osmosis:** Feedwater is pressurized and fed into semipermeable membranes (reverse osmosis). Here the feedwater is separated into a permeate (product) stream at low pressure and a concentrated reject stream which is still at a high pressure. The pressure difference ($\Delta P$) across the membranes produces a lot of hydraulic energy available for energy recovery. To reduce overall power consumption, energy recovery devices are incorporated to recover and use hydraulic energy from the reject stream. Refer to where different ERD methods are explained.

**Post-Treatment:** Industrial plants, agricultural applications and public utilities have different requirements for product water quality; therefore, the post-treatment process used therein can vary. In some cases, the first-stage process is sufficient to achieve the water quality necessary for use. Most often, a second-stage membrane arrangement is used to reduce the remaining boron to an acceptable level and further improve overall water quality. Water stored in product tanks can be further processed to fulfill specific industry requirements, such as remineralization for public use.
**SWRO vs. BWRO**

While SWRO and BWRO desalination operate on the same principles, there are significant differences. The table below highlights some of the major differences.

<table>
<thead>
<tr>
<th>DIFFERENCES</th>
<th>IMPLICATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Source water differences:</strong></td>
<td>Submersible pumps are more important in BWRO applications than in SWRO.</td>
</tr>
<tr>
<td>• Source water for SWRO plants is surface water from an ocean or sea.</td>
<td></td>
</tr>
<tr>
<td>• BWRO is usually, though not exclusively, from saline streams or sub-surface aquifers and artesian wells.</td>
<td></td>
</tr>
<tr>
<td><strong>RO driving pressure is dependent on source water salinity.</strong></td>
<td>High-pressure multistage pumps are key in the SWRO product portfolio.</td>
</tr>
<tr>
<td></td>
<td>Efficiency is extremely important in SWRO. In large plants, the membrane rack sizes are largely determined by the availability of proven and competitive high-pressure pumps in the market.</td>
</tr>
<tr>
<td></td>
<td>Opportunities also exist for critical service high-pressure valves in SWRO.</td>
</tr>
<tr>
<td></td>
<td>BWRO plants use IPO products almost exclusively. The high-pressure pumps are single-stage and technically less critical.</td>
</tr>
<tr>
<td><strong>The desalinated water produced as a percentage of intake source water (recovery rate) differs.</strong></td>
<td>SWRO produces a higher volume of reject water (concentrate) at higher pressure, resulting in strong emphasis on high-efficiency energy recovery devices.</td>
</tr>
<tr>
<td></td>
<td>CAPEX-driven projects still may consider using turbocharger or energy recovery turbine technologies.</td>
</tr>
<tr>
<td></td>
<td>High-pressure packages with high-pressure and ERD pumps are seen as an integrated sub-system. SWRO is trending away from power recovery turbines and turbochargers and toward isobaric energy recovery devices due to increasing energy costs.</td>
</tr>
<tr>
<td></td>
<td>Turbochargers and energy recovery turbines remain common in BWRO and small SWRO plants.</td>
</tr>
<tr>
<td></td>
<td>Intake and pre-filtration systems are much larger in SWRO plants (three times larger than BWRO) due to the lower recovery rate; the result is larger pumps and valves are used.</td>
</tr>
<tr>
<td><strong>Seawater is much more corrosive than brackish water.</strong></td>
<td>SWRO equipment needs to be made in duplex or super duplex stainless steels with PREN(^1) &gt; 40.</td>
</tr>
<tr>
<td></td>
<td>Materials are a major pain point in the SWRO industry. Breakthrough non-metallic technologies have the potential to be a major product differentiator.</td>
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<tr>
<td></td>
<td>The BWRO market mainly uses 316L stainless steel. Corrosion is less of a pain point, though non-metals are still of interest.</td>
</tr>
</tbody>
</table>

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1. PREN refers to Pitting Resistance Equivalence Number and is calculated from the percentages of key alloying components in the material. 
   \[
   \text{PREN} = \%\text{Cr} + (3.3 \times \%\text{Mo}) + (16 \times \%\text{N})
   \]
Pumps for SWRO

Source Water Intake Pumps

SWRO source water intake requires pumps that are corrosion resistant and have the versatility to fit various intake methods. Flowserve offers several highly efficient vertical and horizontal pump models with proven performance to suit application needs.

Flowserve vertical source water intake pumps include conventional line shaft or submersible motor designs. Both options offer broad capacity ranges to maximize system efficiency while minimizing initial cost. Flowserve also offers horizontal pumps for dry-pit installation or space-saving vertical configurations which provide the same premium efficiency with a reduced footprint.

- **Configurations:** Wet-pit and dry-pit
- **Materials:** Duplex and super duplex stainless steels
- **Models:** LNN, LNNV, VCT, VTP
Filtered Seawater, Low-Pressure Feed Booster, High-Pressure Feed

- **Configurations**: Single-stage, end suction or between bearings
- **Materials**: Duplex or super duplex stainless steels; non-metallic materials
- **Models**: Mark 3, LNN, LR, PolyChem, CBT, ZLN
High-Pressure Membrane Feed

The heart of the SWRO system is the high-pressure membrane feed pump. Flowserve offers high-efficiency membrane feed pumps, all utilizing the latest technology and designed using computational fluid dynamics to provide best system performance. These critical pumps are manufactured in corrosion-resistant materials to ensure long performance life without degradation. Whether the design is horizontal split case (DMX) or ring section type (CS or WDX), Flowserve has the pump for this service.

- **Configurations:** Multistage, between bearings
- **Materials:** Duplex or super duplex stainless steels; Alloy 885
- **Models:** DMX, CS, CSX, WDX, MSC
ERD Booster

Flowserve high-pressure booster pumps are designed to efficiently operate under SWRO system pressure where suction conditions can exceed 60 bar (870 psi). Flowserve offers horizontal and vertical inline designs for these tough applications.

- **Configurations:** High suction pressure, end suction or between bearings designs
- **Materials:** Super duplex stainless steels (PREN 40)
- **Models:** HPX, HPX-H, HHPX, LPLD, LNNV
High-Pressure Second Pass, Product Service, Potable Water

- **Configurations:** Single-stage end suction or between bearings
- **Materials:** 316 stainless steel or non-metallic materials
- **Models:** Mark 3, LNN, LR, PolyChem, CBT, ZLN
Pumps for SWRO continued

Backwash and Flushing Pumps

- **Configurations:** Single-stage end suction or between bearings
- **Materials:** Super duplex stainless steels or non-metallic materials
- **Models:** Mark 3, HPX, HPX-H, HHPX, PolyChem, CBT
Energy Recovery Devices for SWRO

The figures below schematically show the three main energy recovery technologies and their integration into the SWRO desalination process. Flowserv energy recovery offerings include: (1) isobaric devices, often called pressure or work exchangers and (2) rotating impact machines or energy recovery turbines. This equipment is essential to any SWRO or BWRO desalination facility, since energy is the biggest operational cost for these facilities.

Isobaric Chamber (IC)

Energy Recovery Turbine (ERT)

Turbocharger (TC)

Main energy recovery technologies in schematic layout
Energy Recovery Devices for SWRO continued

Isobaric Energy Recovery Device—DWEER

The Flowerve product offering for isobaric energy recovery is the Dual Work Exchanger Energy Recovery (DWEER). The DWEER is the most efficient energy recovery device ever developed. It can recover up to 98 percent of the energy in the brine waste stream. The recovered energy is used to pressurize raw water, reducing the energy input required for the high-pressure feed pumps by up to 60 percent. With the DWEER, the high-pressure pump does not have to be connected to the energy recovery device. This permits the use of fewer, but larger, high-efficiency pumps.

There are two DWEER sizes available to the market today: DWEER 1200 and DWEER 1550. Each has a maximum capacity per unit. In cases where the flow exceeds this maximum, the DWEER equipment is installed in parallel. With this technique, the size of a rack is theoretically open-ended. Currently, the largest installed rack contains 20 DWEERs running in parallel. Most trains have two to six DWEERs running in parallel. Details on DWEER ERD operating principles, construction and operational advantages can be found in Appendix B.

**DWEER 1200** — Pressure: to 76 bar (1100 psi)

**DWEER 1550** — Pressure: to 82 bar (1190 psi)
Energy Recovery Turbine Impact Machine

Flowserve offers a standard range of energy recovery turbines (ERTs). They are available in 50 and 60 Hz models for global application. Flowserve can manufacture custom-engineered products for applications outside this operating range. Seven standard models are summarized in the table below. Example configurations are also shown.

Details on ERT operating principles, construction and operational advantages can be found in Appendix C.
### Pump Models and ERDs Application Guide — At-a-Glance

<table>
<thead>
<tr>
<th>Application</th>
<th>RO Membrane</th>
<th>MSF/MED</th>
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<tbody>
<tr>
<td></td>
<td>Intake</td>
<td>Filter Feed</td>
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<tr>
<td>Plueger SUBM</td>
<td>X</td>
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<tr>
<td>VTP</td>
<td>X</td>
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<tr>
<td>VCT</td>
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<td>VPC</td>
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<td>QLC</td>
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<td>LNNV</td>
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<td>LNN</td>
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<tr>
<td>DMX-RO</td>
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<td>CSX</td>
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<td>HHPX</td>
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<td>HPX</td>
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<td>HDX</td>
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<td>FRBH</td>
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<td>MARK 3</td>
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<td>DWEER</td>
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<tr>
<td>ERT</td>
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</table>
Mechanical Seals for SWRO

Mechanical seals, of course, are integral to the range of pumps used in an SWRO desalination plant. Generally, they are not a significant consideration during new construction, although the utmost care is spent in specifying the correct configurations and materials of construction for the application to provide maximum reliability with minimal downtime. Our expertise in metallurgy and the application of sophisticated mechanical seal technology in the toughest applications allows Flowserve to excel in extending mean time between failure (MTBF) of critical equipment.

As a general guide, the following seals are used in SWRO services:

**ISC2-PX**
Single cartridge O-ring pusher seal for general applications

**ISC2-BX**
Single cartridge metal bellows seal for crystallizing fluid conditions

**QB**
Single cartridge O-ring pusher seal for higher-pressure requirements

**BX**
Single cartridge metal bellows seal for higher-pressure crystallizing service
Mechanical Seals for SWRO continued

Materials of Construction

Materials of construction for mechanical seals used in SWRO applications can be summarized as follows:

- **Metal Components:** Stainless steel for general water service; Alloy for seawater, brine and chlorides; super duplex when specified commonly in Europe
- **Metal Bellows:** Alloy for all services
- **Seal Faces:** carbon vs. silicon carbide for clean services; silicon carbide vs. silicon carbide for services with solids or abrasives; add diamond coatings to extend life

Flush Plans

Plan 11 bypass flush from pump discharge (see illustration) is usually recommended. Additional cooling may be required for greater water temperatures incorporating a cooler such as in a Plan 21 or 23.

Aftermarket Services

Because of our proven ability to quickly respond to unplanned equipment downtime through our local Quick Response Centers worldwide, our aftermarket services may prove to be a point of differentiation. Our aftermarket service teams are well-equipped to troubleshoot and correct mechanical seal issues, bringing real value to owners and operators responsible for delivering desalinated water at an agreed-upon cost. In addition to professional technical advice and repairs, QRCs provide seal upgrades, inventory management, equipment service, and accessories such as Bearing Gards to protect bearings and cyclone separators to remove sand and particulate from flush lines.
Valves for SWRO

Flowserve can supply competitive products for the butterfly and check valve packages required in SWRO plants.

For butterfly valves, Valtek Valdisk, Durco TX3 or Durco BX are recommended. Each of these products is available in the requisite materials of construction, including duplex and super duplex stainless steels.

For check valves, the Edward Tilting Disk is recommended. This product meets the necessary material and pressure class ranges.
In the desalination industry, equipment is operated in a very corrosive environment. This is especially true in SWRO applications where equipment is in contact with total dissolved solids (TDS), seawater or even brine. Therefore, all Flowserve equipment that is in contact with seawater or brine is delivered in super duplex stainless steel.

For high-pressure and ERD booster pumps, Flowserve can supply equipment in Flowserve Alloy, a special austenitic stainless steel. Flowserve has specified this material in desalination applications very successfully for decades. It is ideal for applications in desalination where high temperatures and salinity make for very aggressive fluids.
Aftermarket Opportunities

Over the last few decades, ERDs, pumps and membranes have been continuously improved as new technologies are developed. With efficiency and reliability improvements, there is a high potential for upgrading existing installations to help owner/operators in three areas:

- Increasing plant efficiency
- Increasing plant production
- Reducing plant maintenance
- Increasing availability

This can be accomplished by overhauling existing equipment with additional reliability features, upgraded hydraulics or other capabilities. In addition, existing ERDs can be replaced with newer technologies that improve efficiency or product capacity. Here are four specific upgrade opportunites for RO installations:

Brine Concentrator
Add booster pump and skid with high-salinity membranes to increase production capacity and lower specific energy consumption (SEC).

Full Retrofit
Combine membrane skids or add new ones to lower SEC and potentially increase production capacities.

Partial Retrofit (ERT Replacement)
Flow to DWEER depends on possible high-pressure membrane feed pump capacity, since the high-pressure membrane feed pump has to be powered with less ERT support.

Cascade Retrofit
Use DWEER to feed added RO skid (with or without booster pump) to increase plant capacity.
COMMUNICATING OUR VALUE
# FLOWSERVE VALUE PROPOSITION IN DESALINATION

<table>
<thead>
<tr>
<th>FLOWSERVE</th>
<th>PROPOSITION</th>
<th>CUSTOMER BENEFIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethical business practices</td>
<td>Flowserve sets the highest standards in business integrity in its dealings with suppliers and customers.</td>
<td>A trustworthy partner to work toward their project success</td>
</tr>
<tr>
<td>Quality</td>
<td>Flowserve manufactures to the most rigorous quality standards to provide reliable products.</td>
<td>Satisfaction in supplier choice, on-time commissioning and project startup</td>
</tr>
<tr>
<td>Engineering excellence</td>
<td>The Flowserve depth of engineering experience is unparalleled in SWRO desalination.</td>
<td>Optimized product and material selection for each application ensures reliable operation.</td>
</tr>
<tr>
<td>Experience</td>
<td>Flowserve has been a leader in desalination since the process was commercialized on a large scale.</td>
<td>Lessons learnt have been built into today’s products, increasing reliability, maintainability and product life.</td>
</tr>
<tr>
<td>Broad product range</td>
<td>Flowserve comprises a list of world-renowned heritage brands and a wide portfolio of products and services.</td>
<td>A product for every service designed by specialists in their respective fields ensures low-cost, high-efficiency solutions, from intake to distribution and energy recovery.</td>
</tr>
<tr>
<td>Project management</td>
<td>Dedicated project managers certified by IPMA</td>
<td>Professional team to handle documentation and ensure on-time delivery</td>
</tr>
<tr>
<td>After-sales support</td>
<td>Dedicated after-sales support engineers</td>
<td>Implanted within project management, with the sole objective to resolve warranty issues quickly and painlessly</td>
</tr>
<tr>
<td>Local Quick Response Centers</td>
<td>Fully equipped Quick Response Centers in the region</td>
<td>Skilled team to handle upgrades and repairs; localized to reduce downtime, full access to Flowserve component drawings, procedures and standards</td>
</tr>
<tr>
<td>Aftermarket solutions</td>
<td>Long-term maintenance</td>
<td>Specialist group capable of maintaining, servicing and upgrading equipment to meet operating goals throughpu</td>
</tr>
</tbody>
</table>
## INNOVATIVE WAYS FLOWSERVE ADDRESSES CUSTOMER CHALLENGES

### Expertise and Experience
- Flowserve has over 30 years of experience in desalination
- More than two out of every three mega SWRO projects have Flowserve pumps and/or ERDs
- Specialist “Center of Excellence” focusing on desalination

### Single-Source Provider
- Optimizing equipment selections from early stage
- Optimized overall efficiency of interacting products – pumps and ERDs
- Specialist Desalination Center of Excellence
- Less time evaluating
- Reduced procurement activities

### Streamlined Execution
- Global project management:
  - Single point of contact, flawless execution
- Simple communication and fast clarification channels
- Reduced time to operation

### Local Support Worldwide
- Local support ensured through a global network of service centers
- Support during installation and commissioning
- Service and maintenance contracts for highest availability and continuous efficiency optimization
- Support and repair ensured through local service centers
- Upgrade opportunities through Desalination Center of Excellence
- Full operation and service training

### Optimizing Efficiency
- Highly efficient and reliable pump range for desalination
- Reverse Osmosis Energy Recovery Device, DWEER, with highest efficiency plus low mixing and leakage
- Continuous Improvement Program (CIP) specifically for desalination

- Optimized high-pressure feed pumps
  - Highly efficient and reliable pump range for desalination
  - Reverse Osmosis Energy Recovery Device, DWEER, with highest efficiency, low mixing and leakage
  - Continuous Improvement Program (CIP) specifically for desalination

- Optimized ERS booster pumps
  - Full OH2 API 610 mechanical and rotor dynamics compliance ringless impellers — reduced running clearances
  - Robust Timken roller thrust bearing
  - Fluid-cooled bearing housing
  - Centerline mounted

- Optimized DWEER Energy Recovery Device
  - FRP vessel to reduce costs and risk for corrosion
  - Improved LinX internals to improve efficiency and reduce maintenance costs
  - Electrical actuator to eliminate maintenance for hydraulics
  - Flowserve-designed check valve for better performance and reduced maintenance

STRUCTIONS FOR UNDERSTANDING A FIGURE OR TABLE

COMMUNICATING OUR VALUE
FLOWSERVE DWEER OPERATING PRINCIPLES AND OTHER USEFUL INFORMATION

As noted, the DWEER is the most efficient energy recovery device ever developed. It can recover the hydraulic energy of the brine stream.

The DWEER is frequently specified where the highest efficiencies and lowest OPEX are required in SWRO plants. Typically, it is used in mid- to extra-large sized projects. Flowserve has installed more than 650 units, which recover energy in excess of 330 MW.

DWEER Advantages

Performance advantages summary:

• Hydraulic efficiency
• Lowest mixing (total dissolved solids increase); approximately 1 percent at membrane inlet. Therefore, system requires lower membrane feed pressure to achieve same production.
• No leakage means the DWEER can take full advantage of the energy available in the brine.
• No brine outlet pressure required
• Stable efficiency over lifetime of product means no performance degradation.

Operation advantages summary:

• Robust design
• Low noise level
• Slow operating speed
• Easy, minor maintenance requiring only low-cost parts
• Self-adjusting to flow and pressure changes
• Controls support plant diagnostics
• Materials in super duplex stainless steel
The DWEER Operating Principle

Simplified cross-section of a DWEER system in operation

IMPORTANT: DWEER operating principles are difficult to understand without strong visual reference. A helpful animation describing these principles is available at: https://www.youtube.com/watch?v=QaKYhLv4k4.

DWEER Selection Programs

Flowserve offers two programs to calculate and optimize the number and size of trains for a specific project. In addition to providing performance information for the DWEER system, the programs also offer a preliminary indication of the complete high-pressure section of an SWRO desalination plant/train, including the relevant pumps. Please visit https://www.flowserve.com/en/more/support-resources/software-downloads to download both tools and the necessary information to use the programs.
Advances in Flowserve DWEER Technology

**Electric Actuators**
We now supply DWEERs as standard with electric actuators. This completely eliminates the need for the hydraulic units formerly used to drive the LinX valve. Although at minimal cost, the hydraulic units were responsible for about 70–80 percent of maintenance work. The electric actuator reduces maintenance costs and substantially increases availability.

**FRP Vessels**
Flowserve developed a special FRP design for vessels. They have operated successfully since 2011 in various desalination plants. In addition to eliminating the risk for corrosion, these vessels also have the potential to reduce investment costs.

**Check Valves**
Flowserve has developed and integrated its own DWEER check valves. The design was improved to optimize efficiency and minimize maintenance. As of the publishing of this guide, we have experienced four years of service with no check valve failures since its introduction in 2012.

**LinX Piston Seals**
The LinX piston seals ensure highest efficiency because leakage can be reduced to basically 0 percent. Also, no lubrication flow is required, so the high-pressure pump flow and power consumption can be minimized.

**Supply of Complete Racks**
Flowserve now supplies the DWEER as complete racks, preinstalled and aligned. This significantly reduces installation time and risk.
FLOWSERVE ENERGY RECOVERY TURBINE PRINCIPLES AND OTHER USEFUL INFORMATION

Flowserve energy recovery turbines are designed and manufactured specifically for reverse osmosis desalination. They can recover the hydraulic energy remaining in the brine stream, converting it into rotary power for the high-pressure pumps. Highly efficient and reliable, Flowserve ERTs are installed in nearly 1000 SWRO and BWRO plants worldwide, with a total installed capacity in excess of 350 MW.

The ERT is a Pelton turbine design, which has been used very successfully in RO desalination for more than 30 years. The main advantage of the product is its simplicity and robustness, resulting in almost maintenance-free equipment. The ERT has a wide range of standard models and is therefore used in all project sizes, from small to extra-large. For BWRO projects, the product’s hydraulics are typically specially designed for the application. The product is selected in projects where the focus is simplicity, low CAPEX and the cost of energy is relatively low.

ERT Advantages

Performance advantages summary:
• Hydraulic efficiency
• No mixing (total dissolved solids increase) or leakage
• No brine outlet pressure required
• Takes full advantage of the total brine energy
• Flat efficiency curve covering typical flow and pressure variations in RO plants

Operation advantages summary:
• Simplicity product and process; easy to apply
• No ERS booster pump required (necessary for isobaric devices)
• Less piping, valves and instrumentation required compared to isobaric devices
• Robust design
• Basically maintenance-free except bearing lubrication
• Self-adjusting to flow and pressure changes within typical RO plant range
• Supplied and tested as part of the high-pressure pump package – single-source responsibility
• Materials in super duplex stainless steels

The ERT Operating Principle

Flowserve ERTs capture the high-pressure energy that remains in the concentrate (brine) from the reverse osmosis process. The high-pressure concentrate drives the ERT rotor, which then produces rotating power used to assist the main electric motor in driving the high-pressure pump. The Calder ERT rotor and nozzle are optimized to convert the kinetic energy of the jet into rotating mechanical energy, enabling the turbine to operate at maximum efficiency. Because of this, smaller, less costly motors may be utilized to drive the high-pressure feed pump. It is possible to size the electric motor for as little as 60 percent of the total power required to drive the high-pressure pump.

Flowserve ERTs are designed to operate with either centrifugal or positive displacement pumps and may be direct coupled to motors or pumps. A range of standard turbines is available with a power recovery potential up to 1.5 MW. Larger units are available as engineered products.
ERT Selection

In order to select a turbine, Flowserve needs the following minimal information:

- Number of units
- Brine flow
- Brine pressure
- Turbine speed (usually same as pump speed)

With this information, business units can make a turbine selection and prepare a proposal. Special selections can be made with the help of desalination specialists at one of our manufacturing locations.

Advances in Flowserve ERT Technology

**Horizontal Split Casing**

The horizontal split case design ensures easy access for inspection.

**Precision Design**

3-D modeling and investment (lost wax) casting ensure precision of the Pelton wheel – the heart of the Pelton turbine.

**Labyrinth Seals**

Non-metallic, non-contact labyrinth seals ensure maintenance-free sealing of the turbine casing.