THE MIDDLE EAST DESALINATION RESEARCH CENTER

Cost Estimating of SWRO Desalination Plants

Day 1: Plant Cost Fundamentals

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9:00-10:30

1.2 Project Cost Factors

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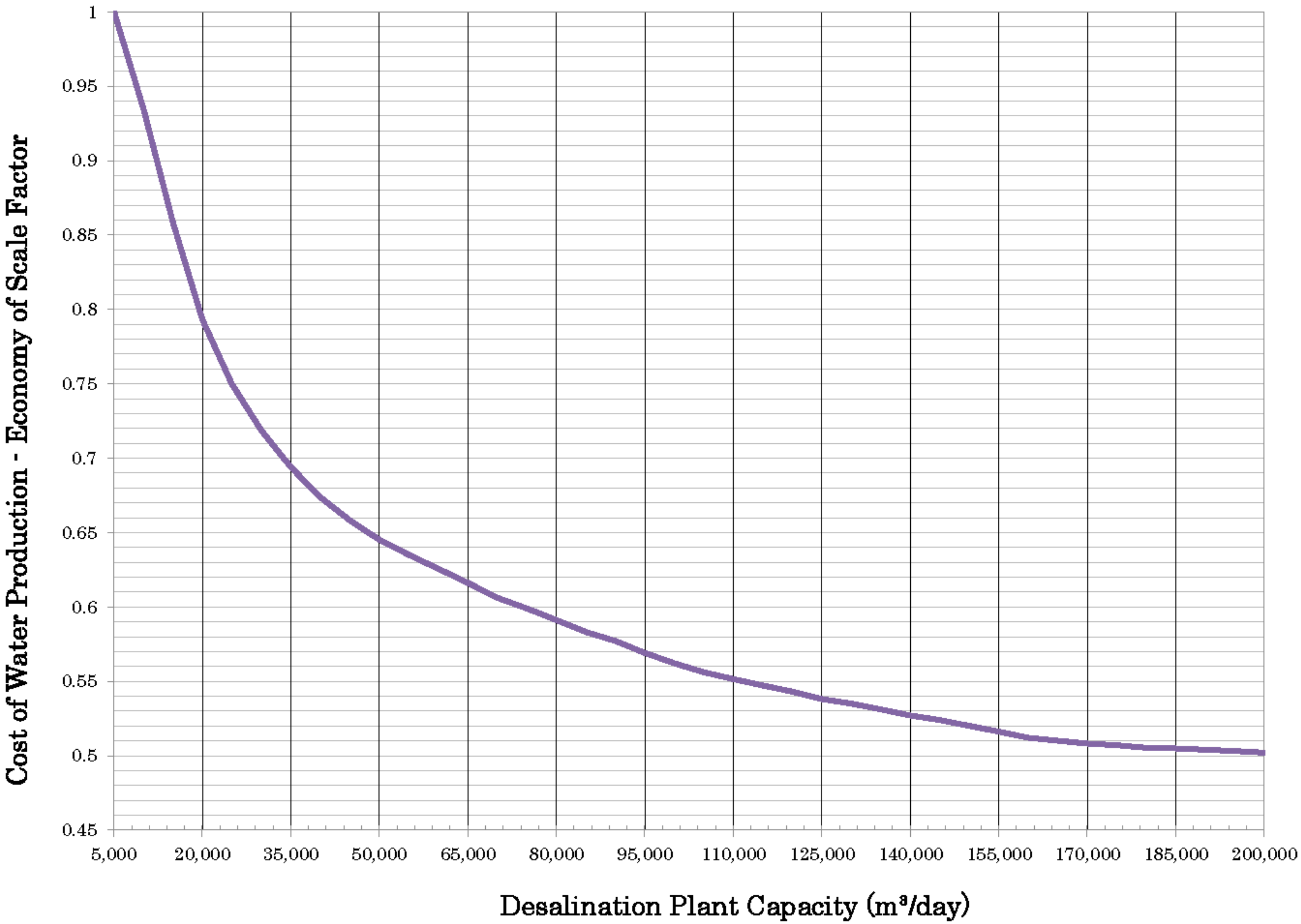
Water Globe

Project Cost Factors - Outline

- Factors Within Control of Project Proponent
  - Project Size
  - Capacity Availability Factor
  - Source Water Quality
  - Target Product Water Quality
  - Concentrate Disposal Method
  - Power Supply and Unit Power Costs
  - Project Risk Profile
  - Environmental, Public Participation and Other Cost Factors
- Factors Outside of the Control of Project Proponent

Project Size – Bigger is Cheaper



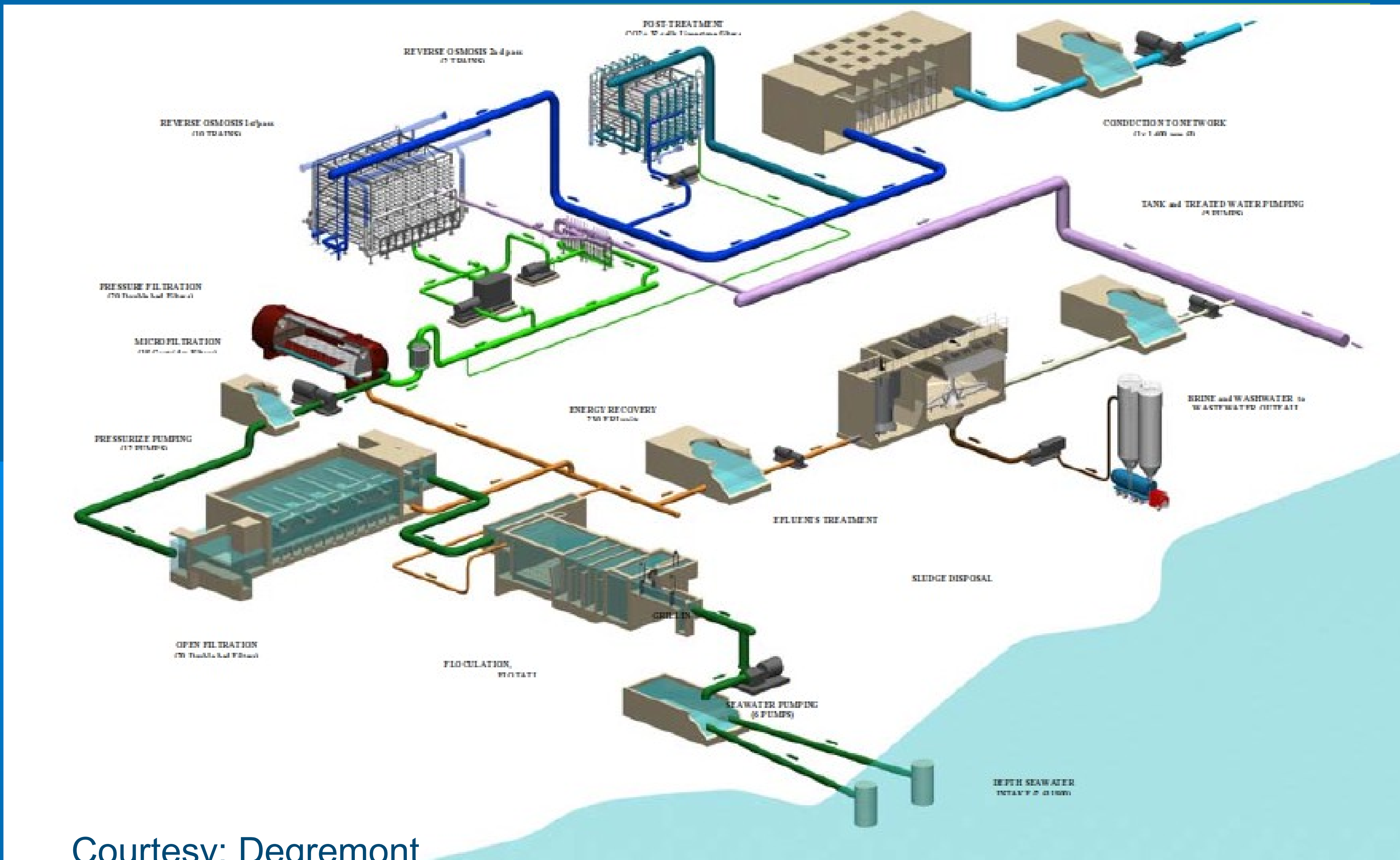
Capacity Availability Factor

- Availability Factor - % of Time per Year the Plant is Producing Flow Equal to Or Higher than its Design Capacity
- Downtime = 100 % - Availability Factor
- Current Plant "Standard" Availability Factor is 95 %.
- Best-in-Class Plants Show Availability Track Record of 98 % or More.
- Increasing Availability Factor from 95 to 100% Results in Capital Cost Increase of 20 to 30 %.

200 MLd Barcelona SWRO Plant – Example of 100 % Availability Design

Courtesy: Degremont

200 MLd Barcelona Plant Treatment Facilities



Courtesy: Degremont

Site Layout of Barcelona SWRO Plant

Courtesy: Degremont

Source Water Quality – Salinity & Temperature Variations

Seawater TDS and Temperature of Various Ocean Water Sources

Seawater Source	Typical TDS Concentration (mg/L)	Temperature (^{0}C)
Pacific/Atlantic Ocean	35,000	9 – 26 (avg. 18)
Caribbean	36,000	16 to 35 (avg. 26)
Mediterranean	38,000	16 to 35 (avg. 26)
Gulf of Oman and Indian Ocean	40,000	22 to 35 (avg. 30)
Red Sea	41,000	24 to 32 (avg. 28)
Arabian Gulf	45,000	16 to 35 (avg. 26)

Note: Seawater TDS and temperature may be outside the table ranges for a site-specific location.

Source Water Quality – Cost Impacts

Seawater Source	Unit Construction Costs	Unit O&M Costs	Unit Capital Costs
Mediterranean	1.0	1.0	1.0
Gulf of Oman	1.09	1.07	1.08
Red Sea	1.12	1.10	1.11
Arabian Gulf	1.16	1.14	1.15

Effect of Product Water Quality on RO System Costs

Effect of Target Product Water Quality on Water Costs

Target Product Water Quality	Construction Costs	O&M Costs	Cost of Water
TDS = 500 mg/L Chloride = 250 mg/L Boron = 1 mg/L Bromide = 0.8 mg/L	1.00	1.00	1.00
TDS = 250 mg/L Chloride = 100 mg/L Boron = 0.75 mg/L Bromide = 0.5 mg/L	1.15 – 1.25	1.05 – 1.10	1.10 – 1.18
TDS = 100 mg/L Chloride = 50 mg/L Boron = 0.5 mg/L Bromide = 0.2 mg/L	1.27 – 1.38	1.18 – 1.25	1.23 – 1.32
TDS = 30 mg/L Chloride = 10 mg/L Boron = 0.3 mg/L Bromide = 0.1 mg/L	1.40 – 1.55	1.32 – 1.45	1.36 – 1.50

Single-Pass RO System

Partial Second Pass RO System

Full Two-Pass RO System

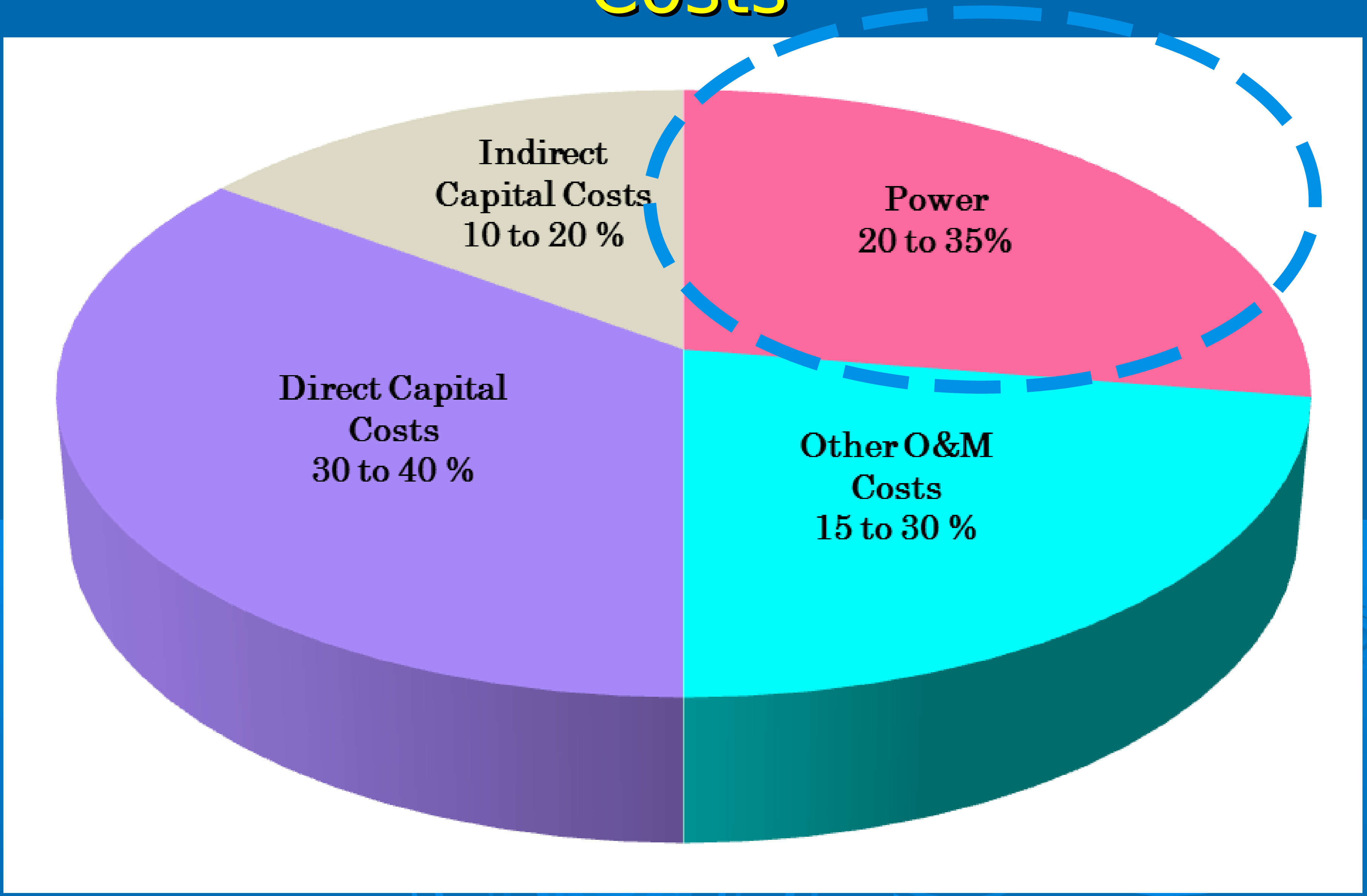
Full Two-Pass RO System + IX

Concentrate Disposal Method

Concentrate Disposal Method	Disposal Construction Cost (US$/m³.day)
New Surface Water Discharge (New Outfall with Diffusers)	50 – 750
Collocation of Desalination Plant and Power Plant Discharge	10 - 30
Co-Disposal With Wastewater Treatment Plant Discharge	30 - 150
Sanitary Sewer Discharge	5 – 150
Deep/Beach Well Injection	200 – 625
Evaporation Ponds	300 – 4,500
Spray Irrigation	200 – 1,000
Zero Liquid Discharge	1,500 – 5,000

Note: US$1/m³.day = US$3,785/MGD

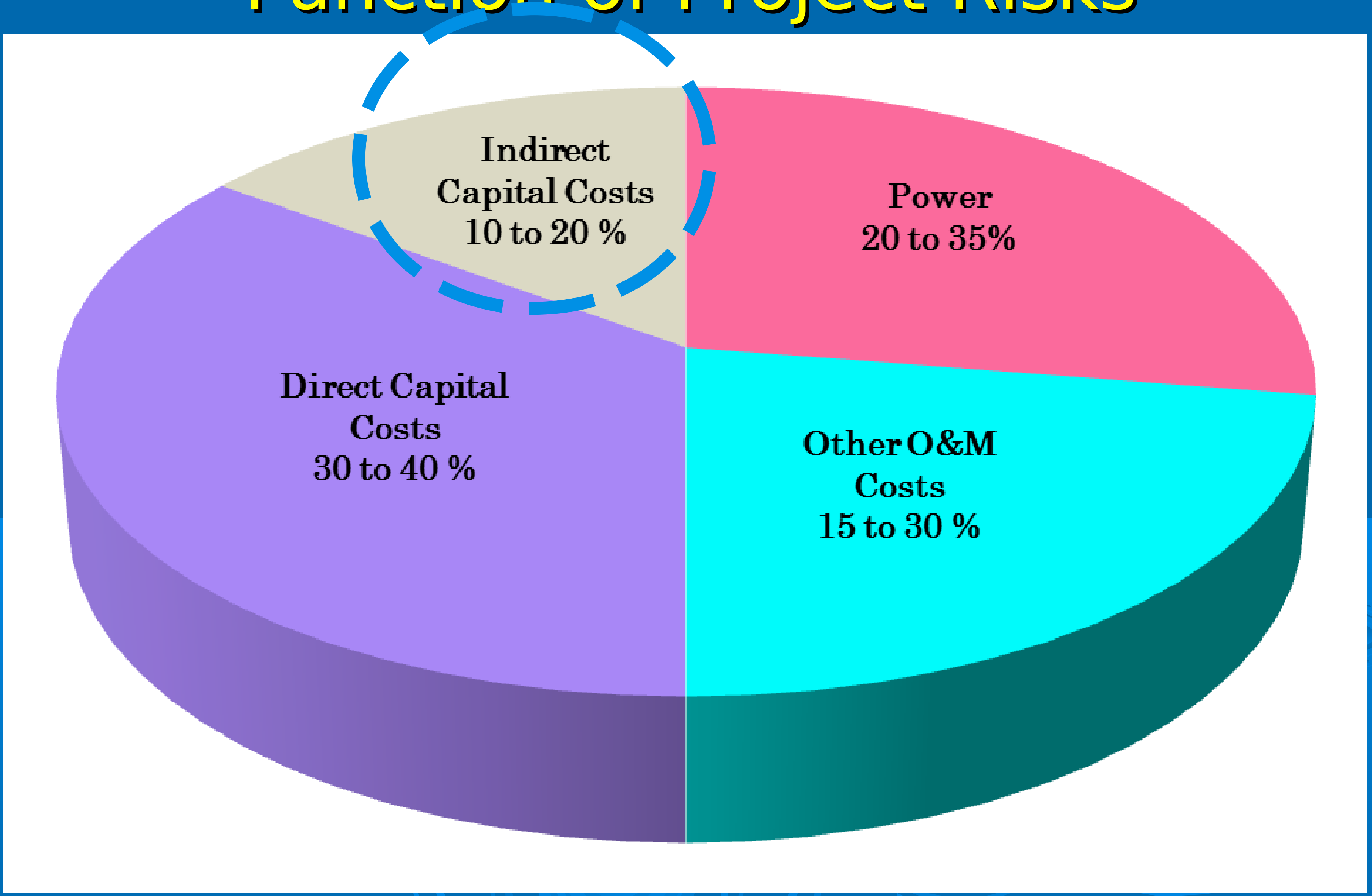
Power Supply and Unit Power Costs



Types of Power Supply and Costs

- Interruptible vs. non-interruptible power supply;
- Tariff-driven power demand;
- Use of natural gas vs. electrical energy for power supply of RO high-pressure pump engines;
- Power self-generation from natural gas;
- Collocation w/ power plants to avoid payment of the transmission portion of the Power Tariff.

Indirect Capital Costs are Direct Function of Project Risks



Key Project Risks with Cost Impact

- Permitting (Licensing) Risks;
- Entitlement Risks;
- Power Supply Risks;
- Construction Risks;
- Source Water Risks;
- Technology Risks;
- Regulatory Risks;
- Operational Risks;
- Desalinated Water Demand Risks;
- Financial Risks.

Permitting (Licensing) Risks

- Risks Associated with Obtaining Permits and Licenses for Plant Construction and Operation

- Key Permitting Risks & Costs:
  - Obtaining of Environmental Permits
  - Environmental Impact Mitigation Costs
  - Air pollution emission permits – for power self-generation
  - Source water intake permits – for subsurface intakes
  - Risk of public non-acceptance of the facility

Entitlement Risks

- Risks associated with:
  - Control of the costs of use of the desalination plant site;
  - Use of existing intake and outfall infrastructure and rights of way;
  - Potential changes of technology and capacity of existing host facilities (i.e., power plants and wastewater plants).

Power Supply Risks

- Risks associated with the availability of low-cost power supply sources.
- Use of renewable power could double unit power costs
- Requirements to reduce carbon footprint of the desalination plant operations in the future could trigger needs for purchase of CO2 emission credits.
- Low Power Supply Availability Factor, Poor Power Quality and Frequent Power Interruptions can Increase Power Costs

Construction Risks

- Risks of potential increase in the construction costs due to:
  - Unusual subsurface site conditions (i.e., buried oil contamination, asbestos pipe, etc.);
  - Delay of delivery of key equipment and materials;
  - Construction cost overruns;
  - Designer and construction contractor errors and omissions;
  - Performance and reliability risks during start up and commissioning.
- Solution: Select Only Construction Companies and Engineers with Proven Track Record and Desalination Experience.

Source Water Quality Risks

- Risks related to:
  - Seasonal or annual changes in source water quality due to climate impacts, waste dischargers in the vicinity of the intake, algal blooms and changing location of underwater currents.
  - Wastewater and industrial discharges with contaminants that can destroy RO membrane integrity.
  - Highly fouling effects of ship traffic and dredging.
- Solutions:
  - Use deep (> 12 m) offshore intakes;
  - Avoid intake location in underwater currents;
  - Complete a full 12-month source water quality characterization.

Technology Risks

- Potential downsides of using new and unproven technologies with limited track record.
- New technologies could result in loss of plant productivity and availability due to downtime. Consider such downsides against the magnitude of potential upsides from energy savings, reduced chemical consumption or increased plant fresh water production.
- Example – Membrane Pretreatment

Seawater Membrane Pretreatment Experience to Date

Membrane Filters - Operational Challenges & Lessons Learned -1

Utility No.	Primary Membrane System Problems	Root Cause of Problem	Lessons Learned
1	• Unable to Meet Design Capacity	• Lower Achievable Flux than Projected. • Pilot Testing Did Not Address Extreme Water Quality (WQ) Conditions.	• Pilot-test During Extreme WQ Conditions. • Use Conservative Safety Factor When Up-scaling Pilot Testing Results.
2.	• High CIP Frequencies; • Excessive Downtime & O&M Costs.	• Excessive Membrane Fouling. • Pilot Testing Did Not Address Extreme Water Quality (WQ) Conditions.	• Pilot-test During Extreme WQ Conditions. • Additional Pretreatment May be Needed to Address Extreme WQ Conditions.
3.	• Unable to Meet Design Capacity	• Undersized Membrane Ancillary Support Systems.	• Ancillary Support Systems Can Be a Significant Bottleneck if Undersized.
4.	• Higher Membrane Replacement Costs	• Lower Than Projected Membrane Life. • Potential Membrane Fouling & Lack of Previous Data by Suppliers.	• Additional Pretreatment May be Needed to Obtain the Useful Membrane Life Indicated by Membrane Supplier.

Membrane Filters - Operational Challenges & Lessons Learned -2

5.	• Excessive Downtime & Maintenance • Lower than Projected WQ.	• Excessive Fiber Breakage. • Fouling or WQ Putting Higher Stress on the Fibers than Expected.	• Lack of Experience with Use of Membranes for Given WQ May Require Change in Membrane Chemistry & Durability
6.	• Unable to Meet Design Capacity	• Higher than Anticipated Downtime. • Manufacturer Missed to Include Valve Opening/Closing Time for Integrity Tests. • More Membrane Capacity Needed to be Installed.	• Complete Thorough Review of the Downtime for All MF/UF System Operational Steps Under Worst-Case Operations Scenario.
7.	• Higher than Expected O&M Costs	• More Frequent Chemical Cleaning Needed than Initially Projected.	• Pilot-test During Extreme WQ Conditions. • Use Conservative Safety Factor When Up-scaling Pilot Testing Results.
8.	• Excessive System Downtime	• Failures in Membrane Potting. • System Not Handling Water Pressure/Potting Materials Not Tested Previously.	• Never Use Membrane that Has Components or Materials that Have Never Been Tested Previously!
9.	• Difficult System Operation.	• Insufficient System Training for Staff.	• Plan for Additional Staff Training Beyond the Minimum Offered by the Manufacturer.
10	• Excessive Downtime. • Failure to Meet Product WQ Targets	• Frequently Failing Membrane Integrity Testing. • Air Leaking form Gaskets and Valves.	• Make Sure that Replacement of Failed Gaskets, Valves and Seals is Included in Manufacturer Membrane System

Regulatory Risks

- Risks associated with the effect of change in environmental, engineering, construction or other government regulations and their impacts of project capital and O&M costs.
- Examples:
  - Changes in Building Codes;
  - Change in discharge regulations;
  - Increasingly stringent product water quality requirements.

Operational Risks

- Risks associated with inadequate and/or negligent desalination plant operation and maintenance:
  - Inexperienced Contractors;
  - Selection of poor quality materials and membranes
- Consequences:
  - Permanent Damage of RO Membrane Elements;
  - Reduced energy efficiency of large pumps and energy recovery devices.
- <u>Solution</u>: Use of Experienced Contractors with Proven Track Record

Desalinated Water Demand Risks

- Risks associated with limited use of the desalination plant due to variable seasonally driven or temporary drought driven demand for desalinated water.
- Solutions:
  - Plant operation at all times;
  - Take-or-pay contractual arrangements with wholesale supplier
  - Subsidy for desalinated water to cover idle periods.

Financial Risks

- Risks related to:
- The financial strength (credit capacity) of the entity which will be the main desalinated water user.
- Political stability of the country hosting the desalination project.
- Stability of local currency.
- Project lenders favor financial agreements with entities which have proven track record in servicing their depth and equity obligations and which do not carry excessive amount of previous fiscal obligations.

Other Factors Under the Control of the Owner which Impact Project Costs

Other Project Cost Factors

Other factors that have a measurable impact on project costs are listed below:

- Intake Type and Design Configuration:
  - Open ocean vs. subsurface intakes;
  - Collocation of intake and discharge with existing power plant;
  - Collocation of discharge with WWTP discharge.
- Pretreatment System Type and Design;
- SWRO System Configuration:
  - Number and size of individual RO trains;
  - Redundant installed capacity;
  - Number of vessels per RO train;
  - Number of SWRO membrane elements per vessel;
  - Number and location of points of permeate collection from the individual vessels;

Other Factors Under the Control of the Owner which Impact Project Costs (Continued)

- Architectural Design;
- Structural Design:
  - Buoyancy control;
  - Structural reinforcement for wind and earthquake forces;
  - Foundations (piles, slab footings, etc.).
- Electrical Design:
  - Power source (electrical grid; self-generation; direct connection to existing power generation units);
  - Site power supply system configuration – location and size of power substations and connecting conduits;

- Selection of Key Materials (Piping, Equipment and Structures);
- Site Work Including:
  - Plant layout;
  - Lightning;
  - Roadways;
  - Site drainage and storm water management;
- Corrosion Control:
  - Protective coatings of structures, equipment and piping;
  - Cathodic protection.

Cost Factors Outside of the Control of the Project Owner

- Regulatory Design Standards, Building and Fire Codes;
- Schedules Mandated by Third Parties (Regulatory Agencies, Emergency Response Needs, etc.);
- Conventions of Prudent Engineering Practices;
- Construction, Equipment and Consumable Supplier Market Conditions;
- Local Labor and Material Costs;
- Construction Time Constraints Driven By Local Noise and Traffic-related Ordinances, and Limitations of Hours of Operation of Construction Equipment;

- Use and Condition of Existing Facilities;
- General Economic Environment;
- Climate Conditions;
- Seasonal Water Demand and Power Tariff Variations;
- Land Costs and Site Subsurface Conditions (i.e., soil and groundwater contamination; soil load bearing capacity and liquefaction potential; and subsurface obstacles).

Questions?

Lunch Break