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Al-Khafji Solar Water Desalination

The Saudi International Water Technology Conference 2011

Omar Al-Harbi, KACST, KSA
Karl Lehnert, IBM, USA

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2. KACST Solar Power Engagement
3. KACST SWRO-Desalination Engagement and

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4. Solar – SWRO Integration

The Initiative's Phases

Phase I (2010 - 2013)

Building a desalination plant with a capacity of thirty thousand cubic meters per day (30,000 m^3/day) to meet the needs of one hundred thousand dwellers of Al-Khafji City (Arabian Gulf). Power an RO Plant from a solar energy farm.

Phase II (2013-2015)

Building a desalination plant with a production capacity of three hundred thousand cubic meters per day (300,000 m^3/day) at a site that will be chosen later. The implementation period for this is three years, and will start after the completion of the first phase.

Phase III (2016-2018)

The implementation of several water desalination plants using solar energy in various locations of the Kingdom. This phase will start after the completion of the second phase

1: **King Abdullah Initiative for Solar Water Desalination**

- Motivation and Driving Forces
- Al-Khafji Project Road Map Overview

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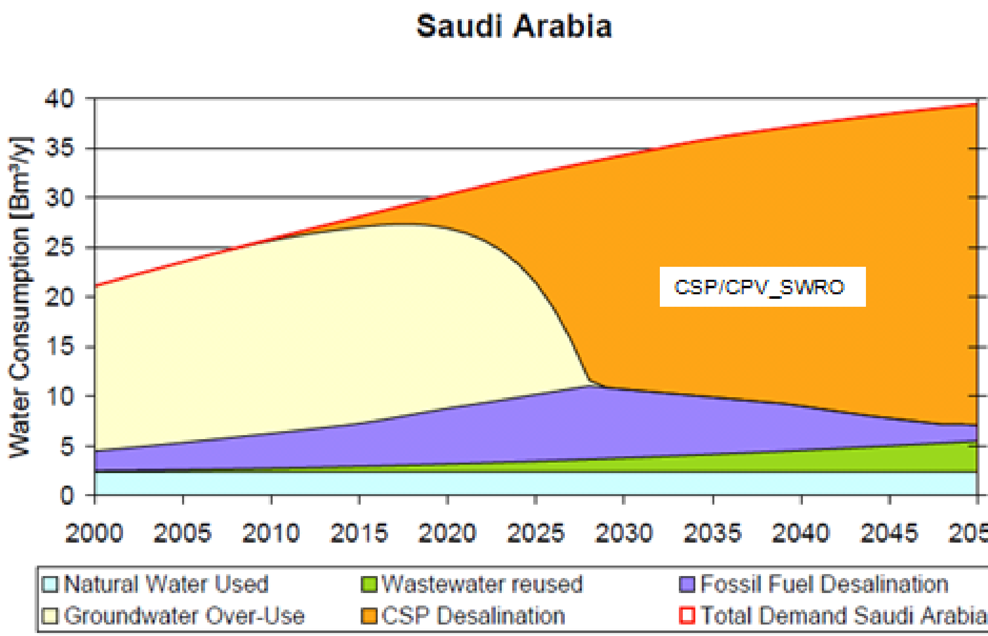
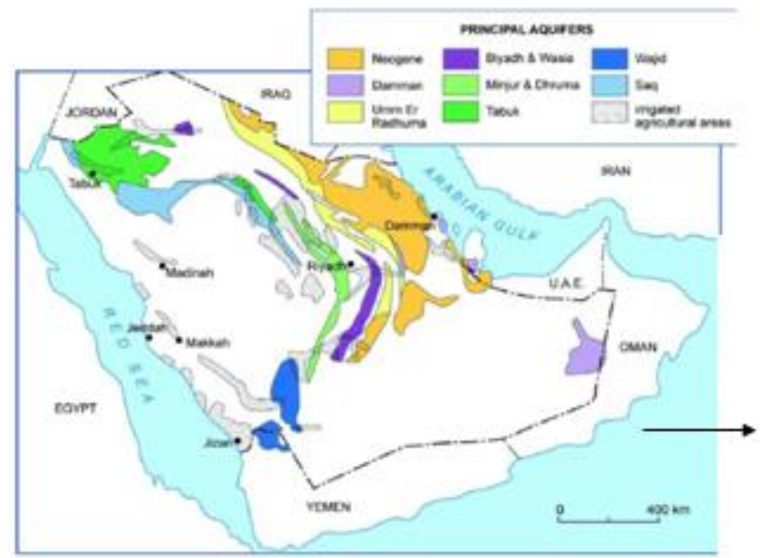
Strategic Water Outlook

The driving force for a solar seawater desalination initiative

Aquifers on the Arabian Peninsula are facing a serious situation at the current rate of withdrawal.
The Kingdom is continuously pushing to implement best and new technologies for seawater desalination.





Source of Graphics: AQUA-CSP, DLR www.dlr.de

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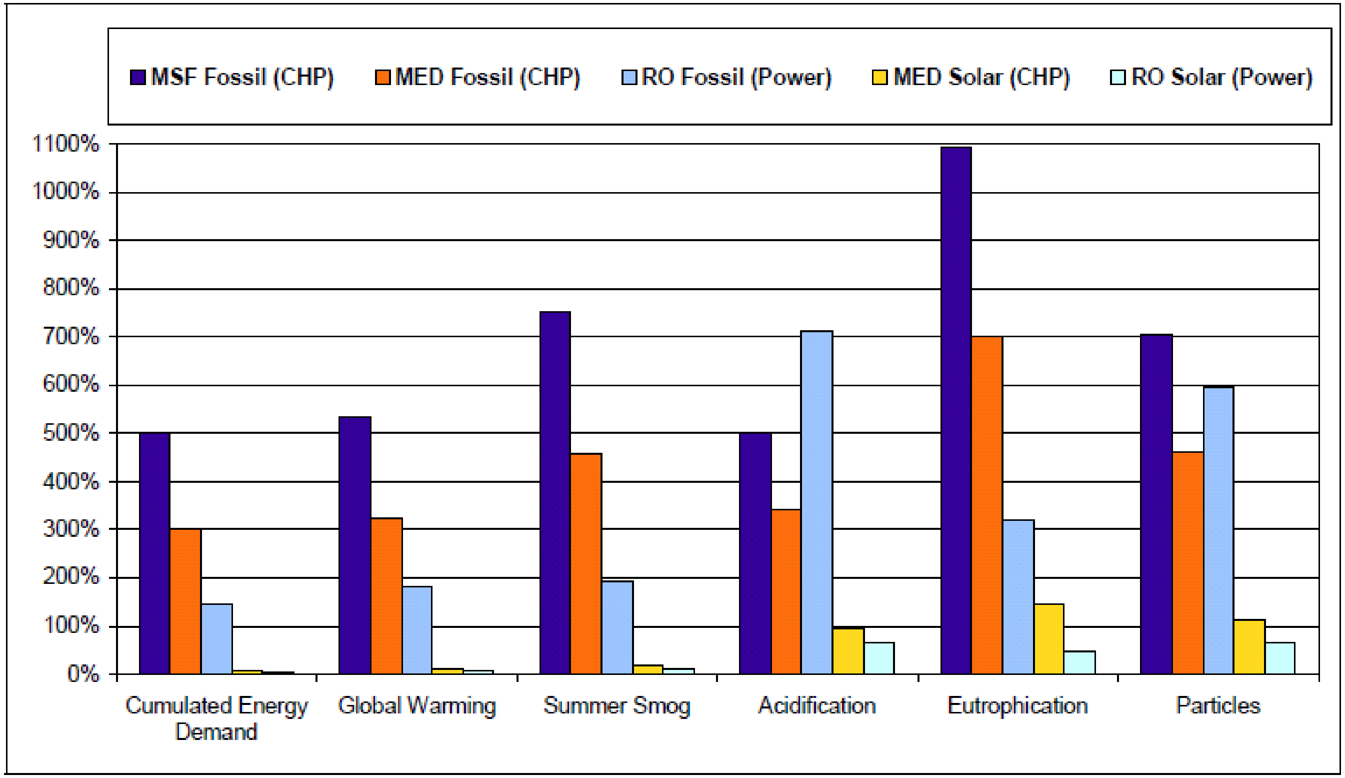
Life Cycle emissions of seawater desalination technologies

The driving force for King Abdullah Initiative for Solar Water Desalination

The environmental impact of the new desalination capacities must be as low as possible.



Source of Graphics: AQUA-CSP, DLR, www.dlr.de

Power Consumption of Desalination Technologies

Desalination Technology	Total Electric Energy	Heat Consumption
Multiple Stage Flash	3-5 kWh/m^3	250-330 kJ/kg
MED/TVC Multi effect desalination	1.5-2.5 kWh/m3	145-390 kJ/kg
MVC Mechanical Vapor Compression	8-15 kWh/m3	---
RO Reverse Osmosis	2.5-7 kWh/m3	---

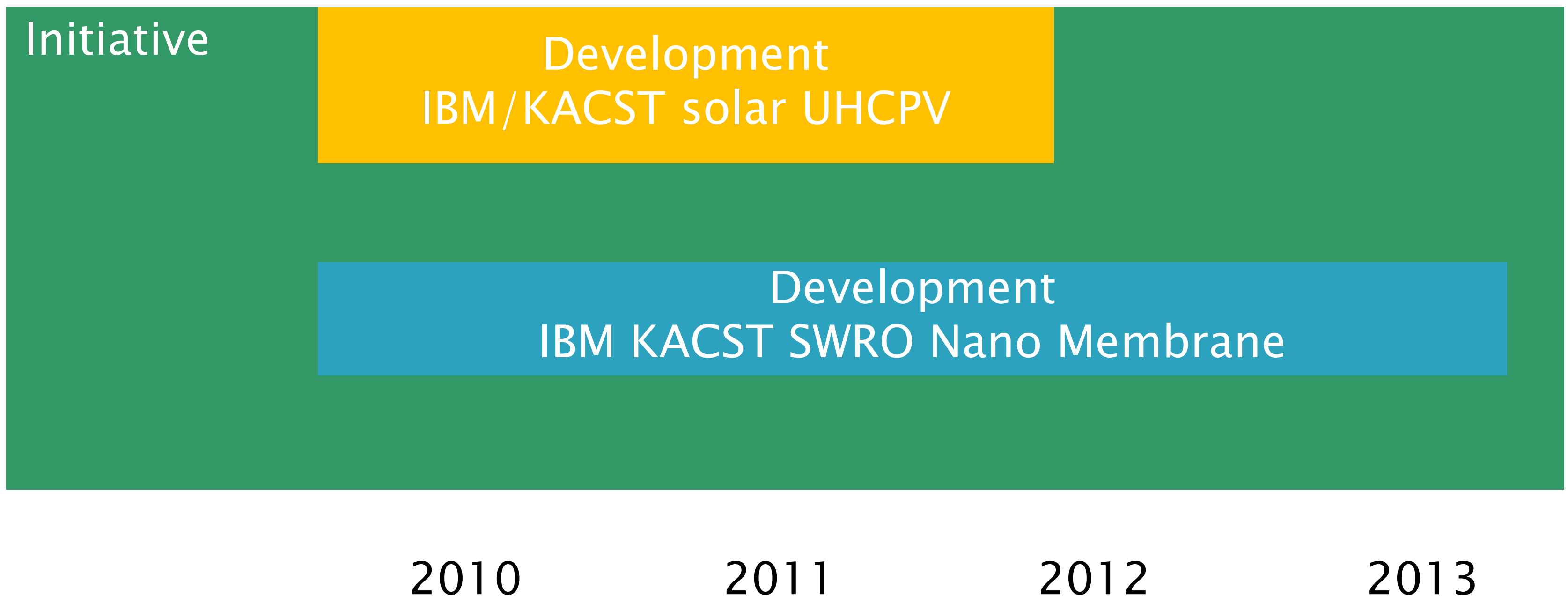
Source: AQUA-CSP, DLR, www.dlr.de

Reverse Osmosis is the best option for a low electrical power desalination solution.

Strategic Direction

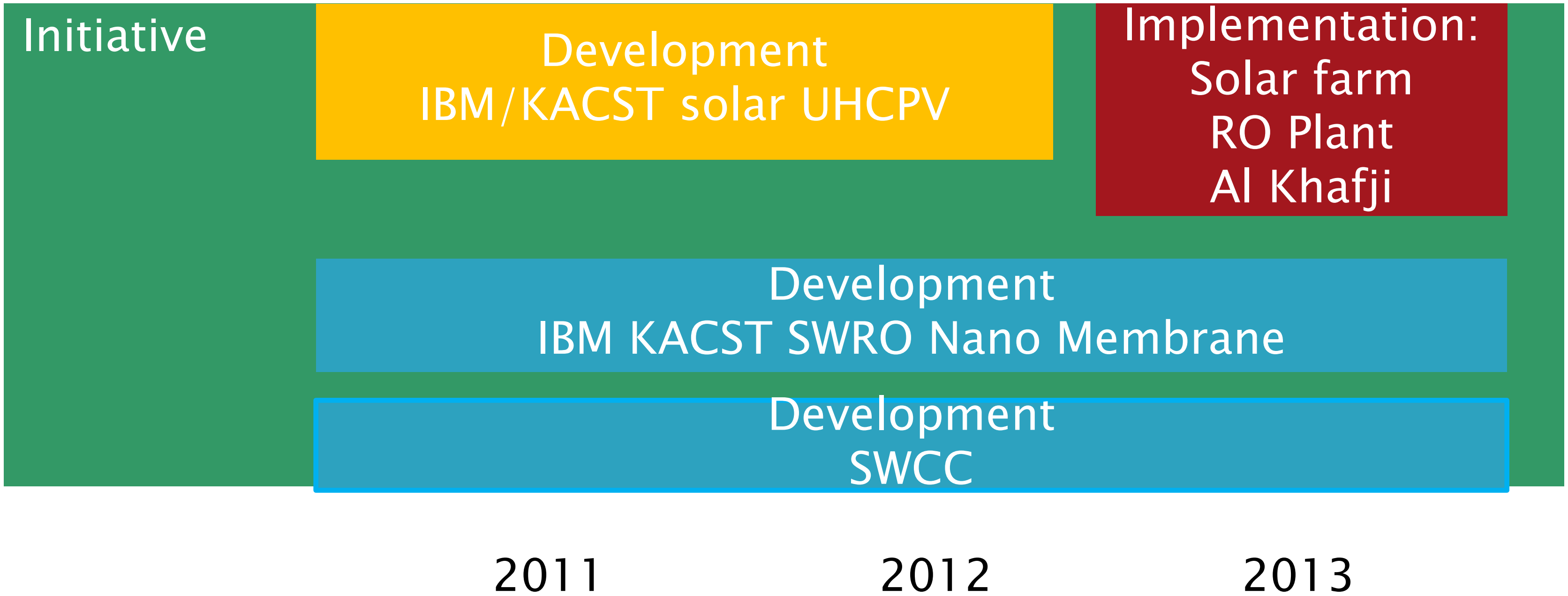
- Power and desalination plants consume more than 1.5 million barrels of oil per day
- The environmental impact of the new desalination capacities must be as low as possible.
- It is essential for the region to use Solar Energy instead of fossil energies

Al-Khafji Project Road Map



Two years ago, in the spirit of the King Abdullah Initiative for Solar Water Desalination, KACST and IBM researchers started activities around solar power and RO membranes with the vision to innovate and to combine both technologies

Al-Khafji Project Road Map



To complete the Innovation Cycle:
KACST is pushing research results of solar power and RO membrane work into commercial use ! SWCC continuous expertise will be utilized.

Phase I:

The worldwide first large scale solar powered SWRO plant Al-Khafji

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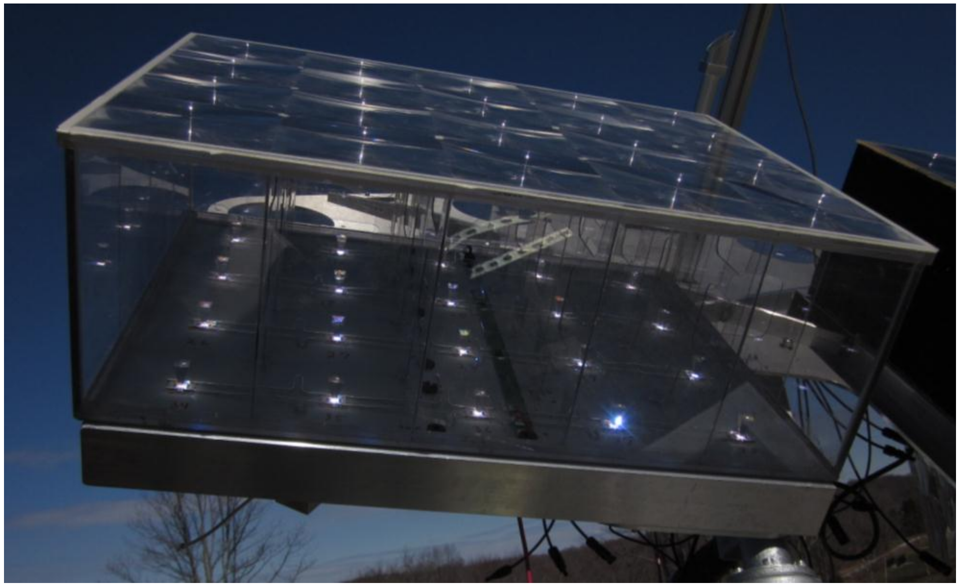
2: KACST UH-CPV Solar Power Engagement

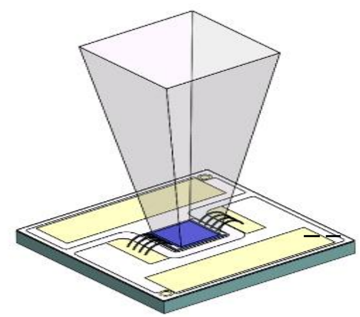
Project Status: UHCPV

- KACST is pioneer with more than 30 years experience on Solar technologies
- One recent research focus is (UHCPV)
  Ultra-High Concentrator Photovoltaic
- Details of the UHCPV R&D project will be given in the presentation of Dr. T. van Kessel and Dr. H. Khonkar
- The R&D work is currently transferred into Volume rollout
- First Modules are installed at KACST Solar City near Riyadh and in Al-Khafji

Inside View of UHCPV Module



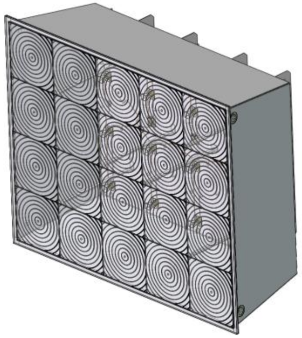
Triple Junction Cell
40% Efficient



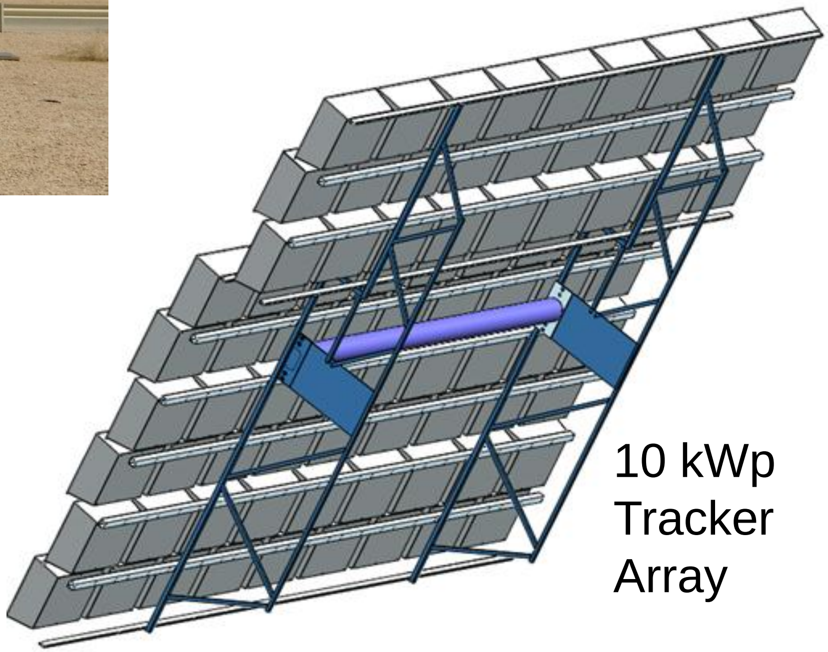
Cell and Light Pipe

- **Leading Ultra High CPV System**
- **~ 30% module efficiency**
- Advanced triple junctiontechnology
- Highest Concentration 1600x
- World leading system cost ~ $2/watt

KACST 10kW UHCPV installation



81 Modules per tracker



10 kWp Tracker Array

- Tracker installation at the Solar Village undergoing trials
- Second installation Al Khafji Oct 2011 started

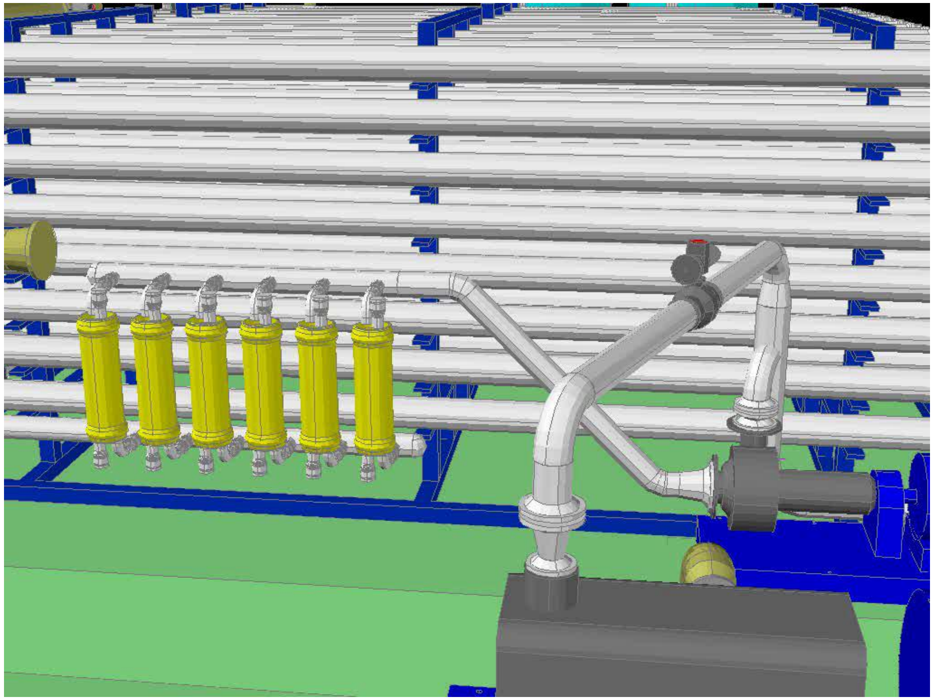
First 10,000 watts Ultra High CPV (UHCPV) at
Al Khafji Site

Two axis tracker:

Tracker motor drives

Monitoring high wind conditions

3: KACST SWRO-Desalination Engagement and Design assumptions of the Al Khafji Desalination Plant



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Overview of the recent KACST SWRO-Desalination Engagement

- **Transfer** membrane technology to industry in the Kingdom with the participation of private sector.
- Details of the R&D work of New Nano Membranes are given in the presentation given by Dr. Ankit Vora and Dr.Sulaiman Al-Fadel
- The design of the SWRO plant has been started
  - Feasibility Study and local marine works to be completed YE 2011
- The plant shall start production in 2013
- The following design assumptions are based on current knowledge and may be modified after the completion of the local studies

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Al-Khafji Project Schedule

Task	2011	2012
Technology Assessment – Marine, geological & topographic works		
Feasibility Study		
Basic Design		
Detailed Design		
Order & Construction		

Design assumptions of the Al Khafji Desalination Plant

INITIAL ASSUMPTIONS

INTAKE WATER

PRETREATMENT

REVERSE OSMOSIS

POSTTREATMENT

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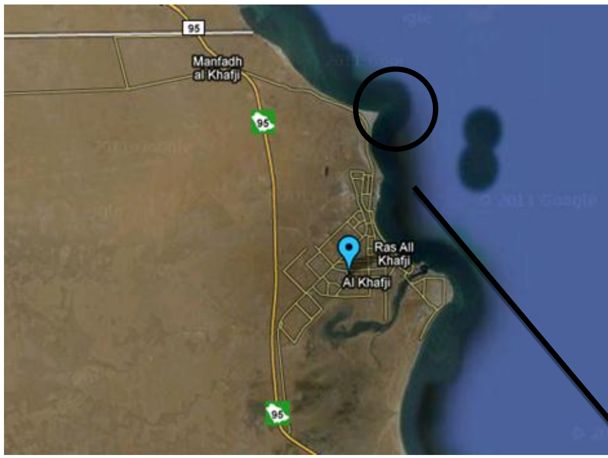
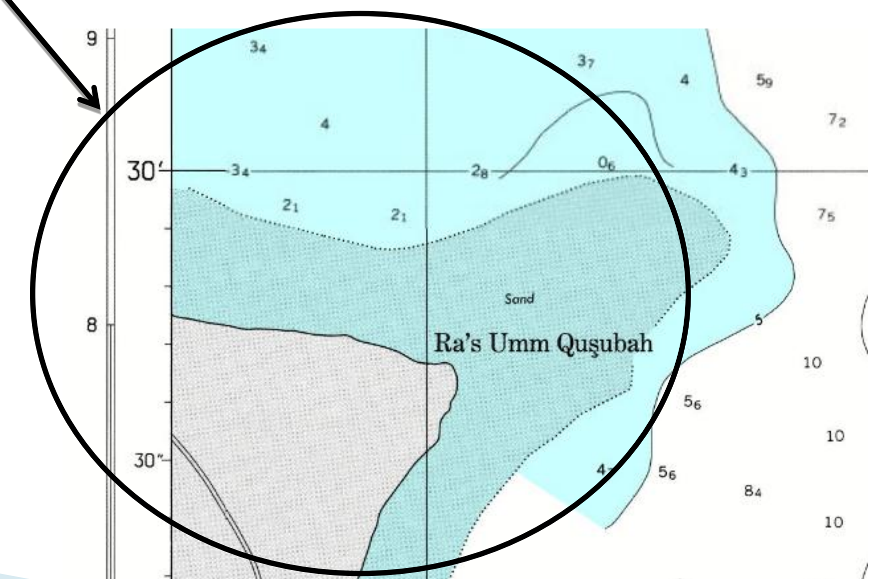
Al-Khafji Sea Bed



Desalination Plant

Al Khafji is located in the upper north east part of Saudi Arabia close to the Kuwait border

Very Shallow sea bed at Al Khafji 2 to 3m



DESIGN ASSUMPTIONS FOR SEAWATER QUALITY

		Basic design Worst conditions	Basic design Best conditions
TDS	ppm	46.500	43.000
Boron	ppm	6	5
Chlorides	ppm	25.700	23.700
Temperature	ºC	35.0	20.0

The seawater quality is in this area of the Arabian Gulf is characterized by challenging conditions for SWRO :

-High salinity
-High Boron content
-High water temperatures

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DESIGN ASSUMPTIONS FOR CAPACITY

The plant is build in two phases:

	40.000 m3/24 h	50.000 m3/24 h
Summer average daily production	25.000 m3	33.000 m3
Peak summer daily production	30.000 m3	37.500 m3
Intake capacity	125.000 m3	125.000 m3
RO Efficiency	42/43 %	42/43 %
Overall efficiency	40/41 %	40/41 %

RO : POTABLE WATER LIMITS

		WHO (2011)	SASO (2001)	GCC (2008)
Boron	ppm	<2,4	<0,5	<0,5
Chloride	ppm	<250*	<250	--
Sodium	ppm	<200*	<200	--
TDS	ppm	--	<1.000	100–1.000

* Recommended

WHO → World Health Organization

SASO → Saudi Arabian Standards Organization

GCC → Cooperation Council for the Arab States of the Gulf (UAE – Bahrain – KSA – Oman – Qatar – Kuwait)

The permeate has to comply to the current SASO standard for drinking water.

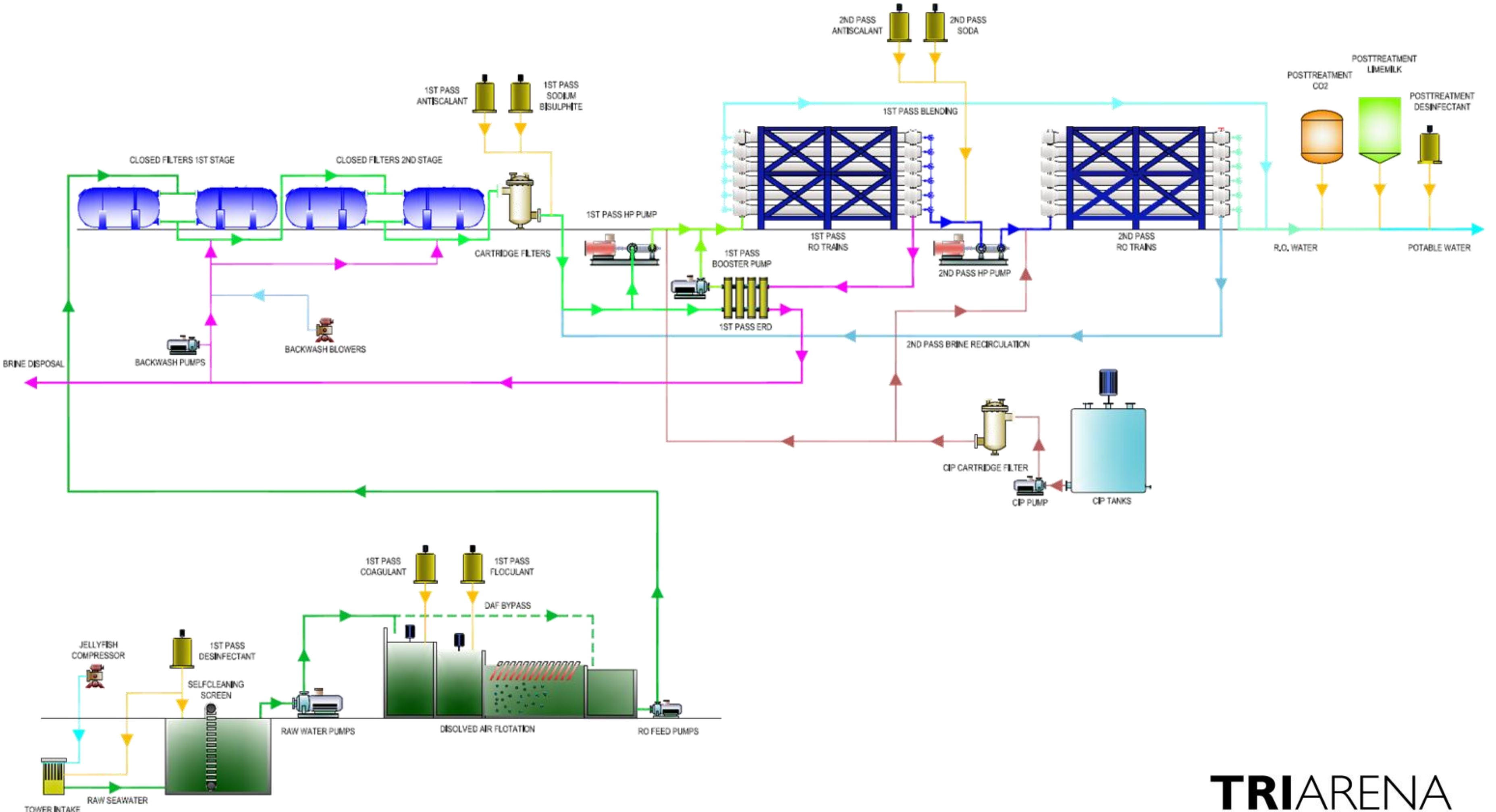
Desalination Plant Design

SEAWATER INTAKE → PRE-TREATMENT → HIGH PRESSURE PUMP AND ENERGY RECOVERY → REVERSE OSMOSIS MEMBRANES → POST-TREATMENT

- In-take design concepts
- Pre treatment of water
- High Pressure pumps
- Reverse Osmosis design
- Disposal design
- Power control
- KACST/IBM/Triarena design

Existing Al Khafji plant

Overview : Desalination Plant



Design assumptions of the Al Khafji Desalination Plant

INITIAL ASSUMPTIONS

INTAKE WATER

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POSTTREATMENT

Intake Water: Alternatives

1. OPTION 1: Cape Deep Open Intake
   - ADVANTAGES: Good seawater quality, simpler pre-treatment.
   - DISADVANTAGES: Terrestrial pump station and pipeline. Permissions.

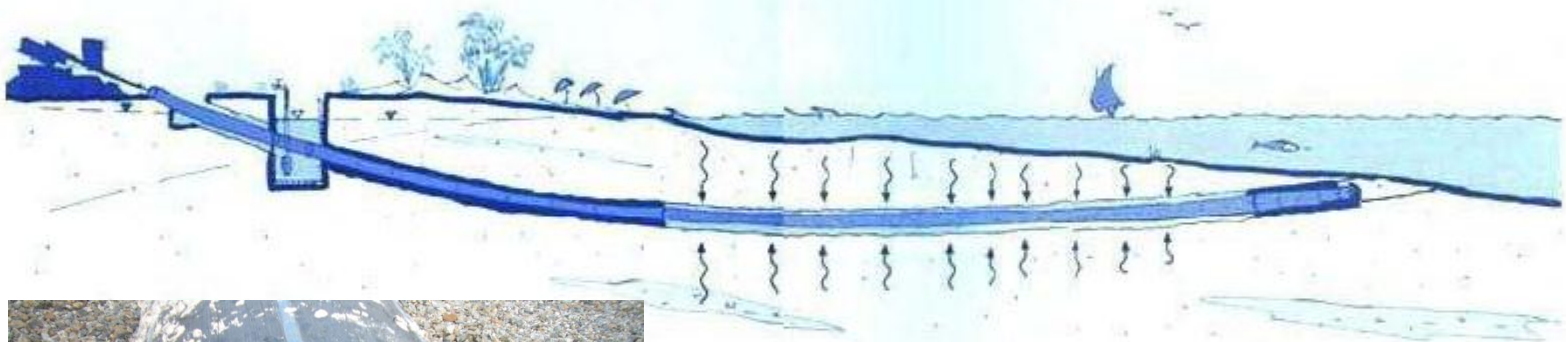
2. OPTION 2: Deep Open Intake
   - ADVANTAGES: Good seawater quality, simpler pre-treatment.
   - DISADVANTAGES: CAPEX due to complex marine works.

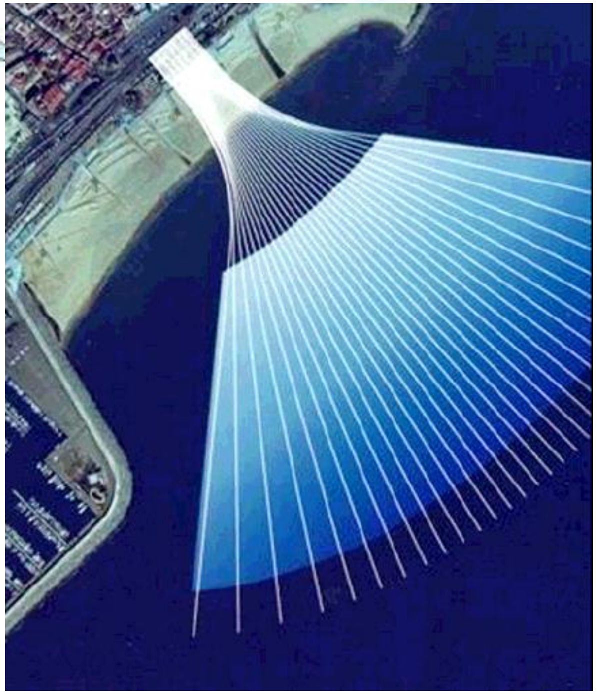
3. OPTION 3: Shallow Intake
   - ADVANTAGES: Simple marine works.
   - DISADVANTAGES: CAPEX due to complex pre-treatment. Irregular seawater quality.

4. Option 4: Sub-Seabed Intake Solutions (Neodrene)
   - ADVANTAGES: up to 90 % less pre-treatment chemicals
   - DISADVANTAGES: Seabed permeability must be deeply understood

Neodren Intake System

Horizontal drilling and pipe placement





source: Catalana de Perforacions

Intake Water: Alternatives

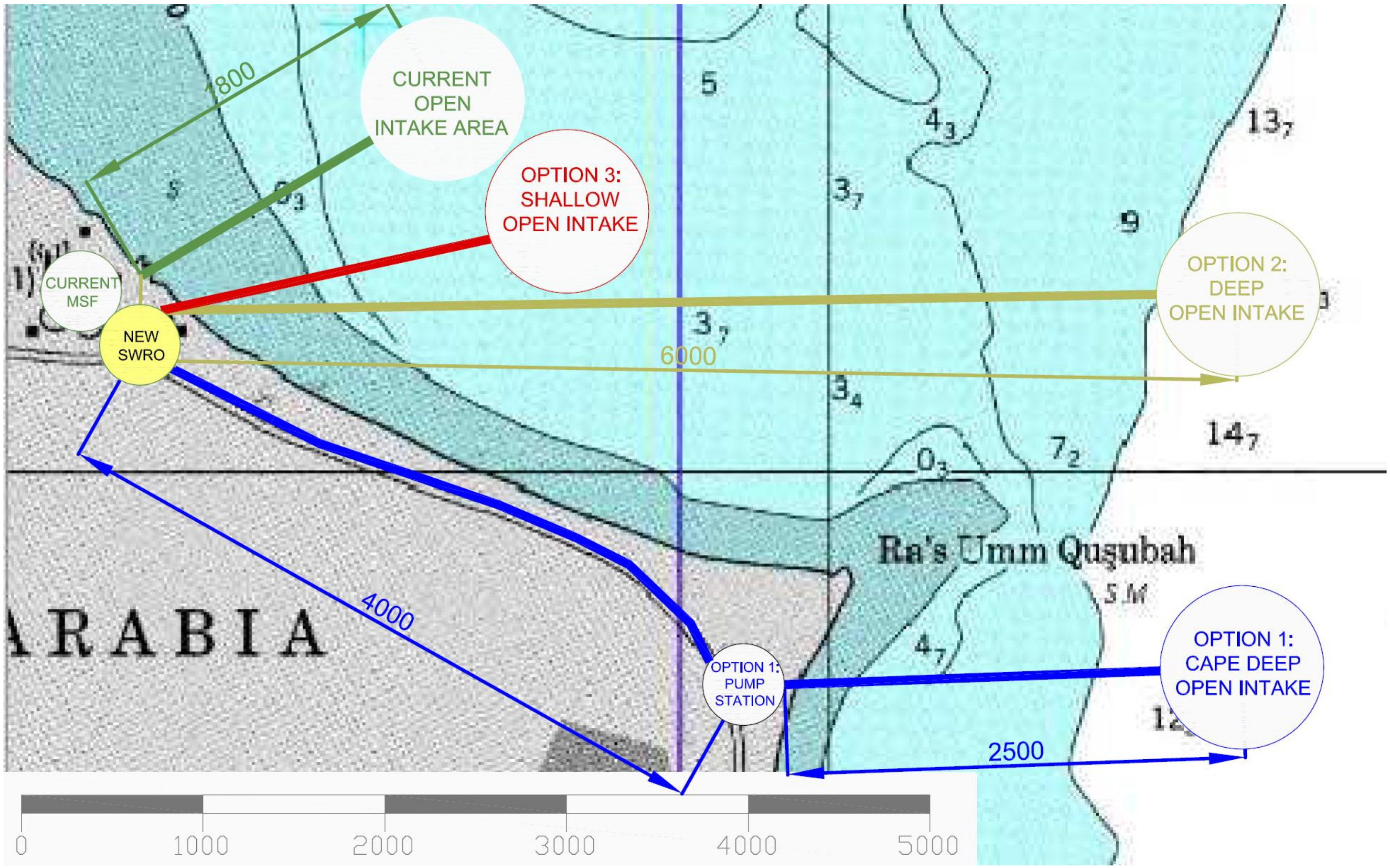
The intake will strongly influence the pretreatment setup

Preferred Solution:

1. Sub-seabed Intake Solutions (Neodrene)
   - Expectation: Seabed characteristic will not support this solution

2. Open Deep Intake
   - Most probable solution

Intake Water: Alternatives



Design assumptions of the Al Khafji Desalination Plant

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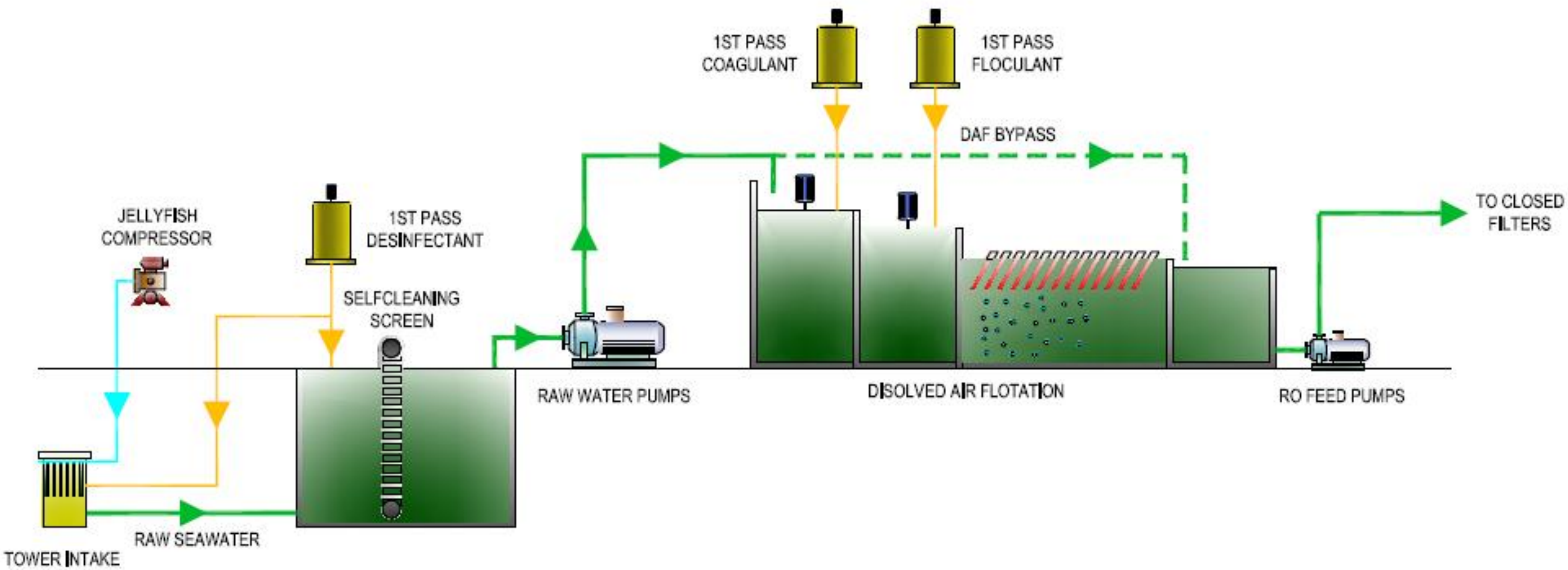
Pretreatment: Proposed system

- STAGE 1: COARSE AND FINE SCREENING. (Raw water pump station)
- STAGE 2: PHYSICAL-CHEMICAL AND CLARIFIER (Flotation).
- STAGE 3: CLOSED FILTER

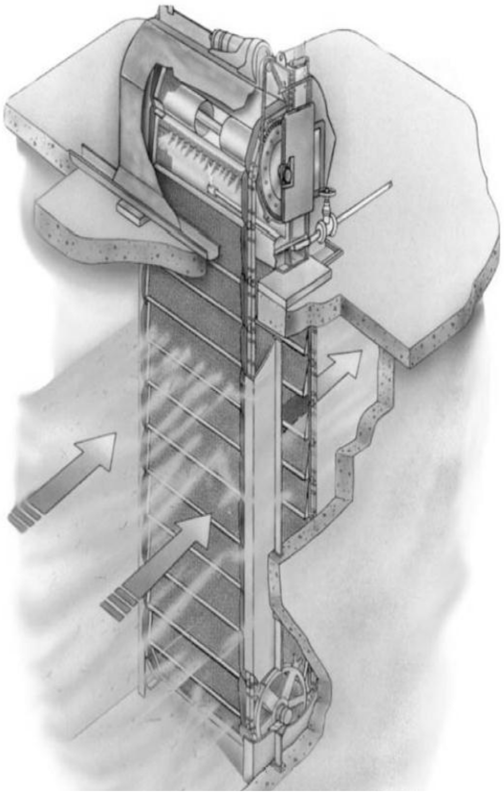
Intake and Pretreatment



Pretreatment: Stage 1 proposed system.

STAGE 1: COARSE AND FINE SCREENING. (Raw water pump station)

- **to protect the plant of large objects as seaweed, fish, sand or others that can block the plant process.**



Pretreatment: Stage 1 proposed system.

STAGE 1: COARSE AND FINE SCREENING. (Raw water pump station)

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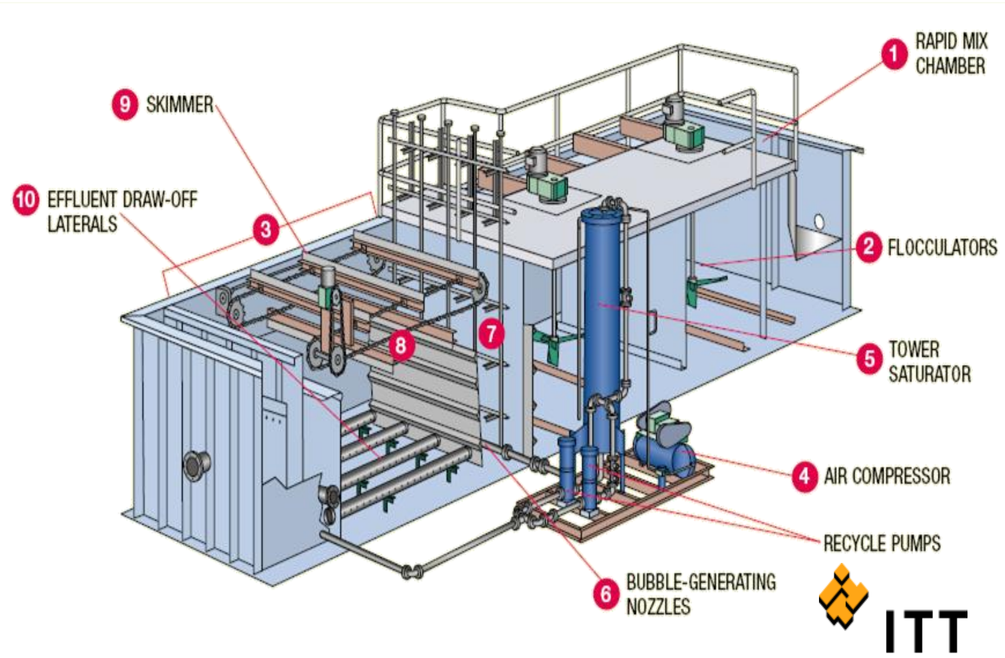
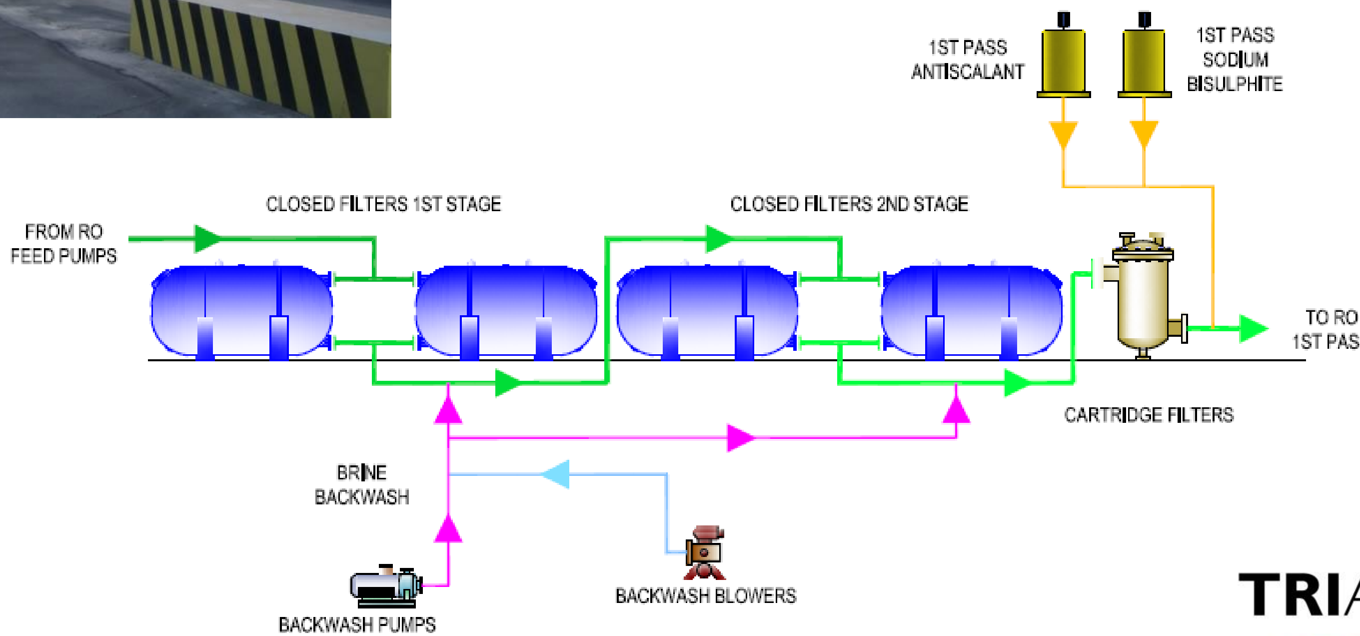
Pretreatment: Stage 2 proposed system.

STAGE 2: PHYSICAL-CHEMICAL AND CLARIFIER (Flotation).



➢**Using this type of process it is feasible to remove 85 to 95% of total suspended solids (TSS), grease and oils, red algae, etc.**

Intake and Pretreatment



Pre-treatment: Stage 3 Closed Filters

	GOOD QUALITY INTAKE		BAD QUALITY INTAKE	
	40.000 m3/d	50.000 m3/d	40.000 m3/d	50.000 m3/d
Flow (m3/h)	3.968	4.960	3.968	4.960
1st stage velocity	8-10 m/h		5-6 m/h	
2nd stage velocity	12-14 m/h		8-10 m/h	
Filter dimensions	3,6 x 12 m		3,6 x 12 m	
1st stage Nº of filters	10	12	16	20
2nd stage Nº of filters	7	9	10	12
1st stage velocity (m/h)	9,2	9,6	5,7	5,7
2nd stage velocity (m/h)	13,1	12,8	9,2	9,6
Total Nº of filters	17	21	26	32

- **Its main objective is to hold seawater particles in a porous filtration media to retain particles throughout the medium. (Sand, Anthracite). One or two steps.**

Design assumptions of the Al Khafji Desalination Plant

INITIAL ASSUMPTIONS

INTAKE WATER

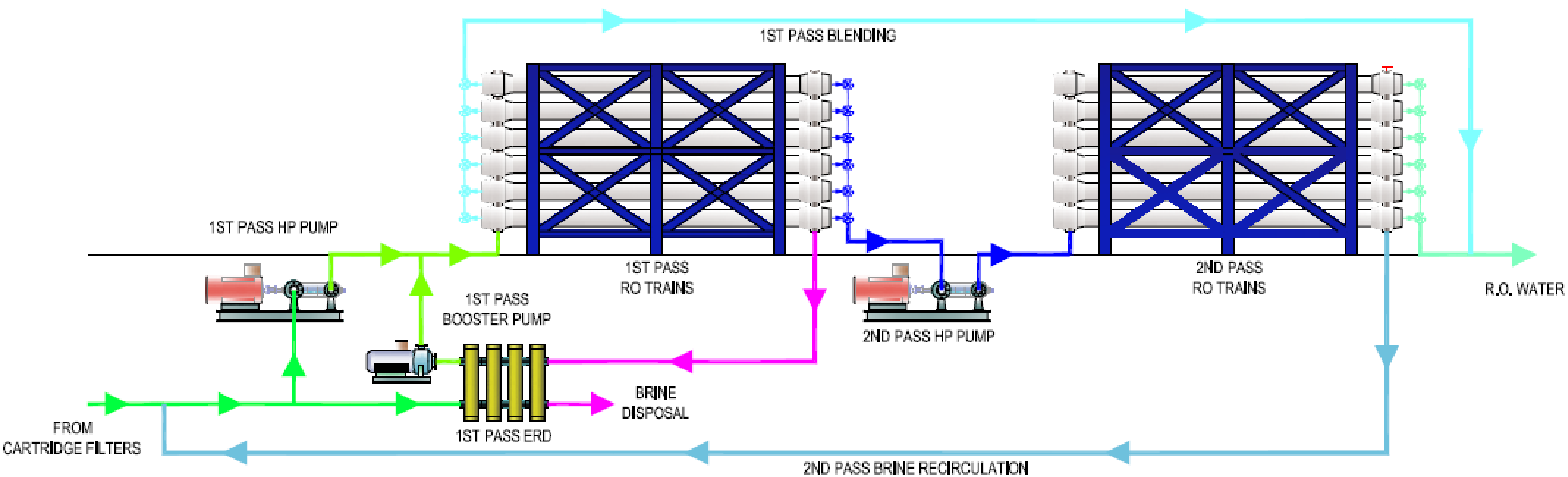
PRETREATMENT

REVERSE OSMOSIS

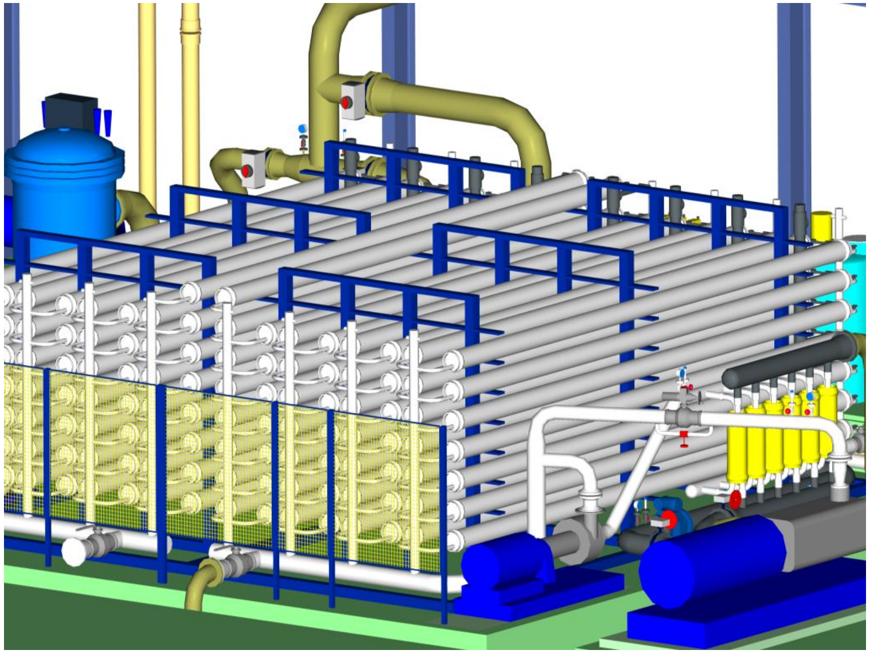
POSTTREATMENT

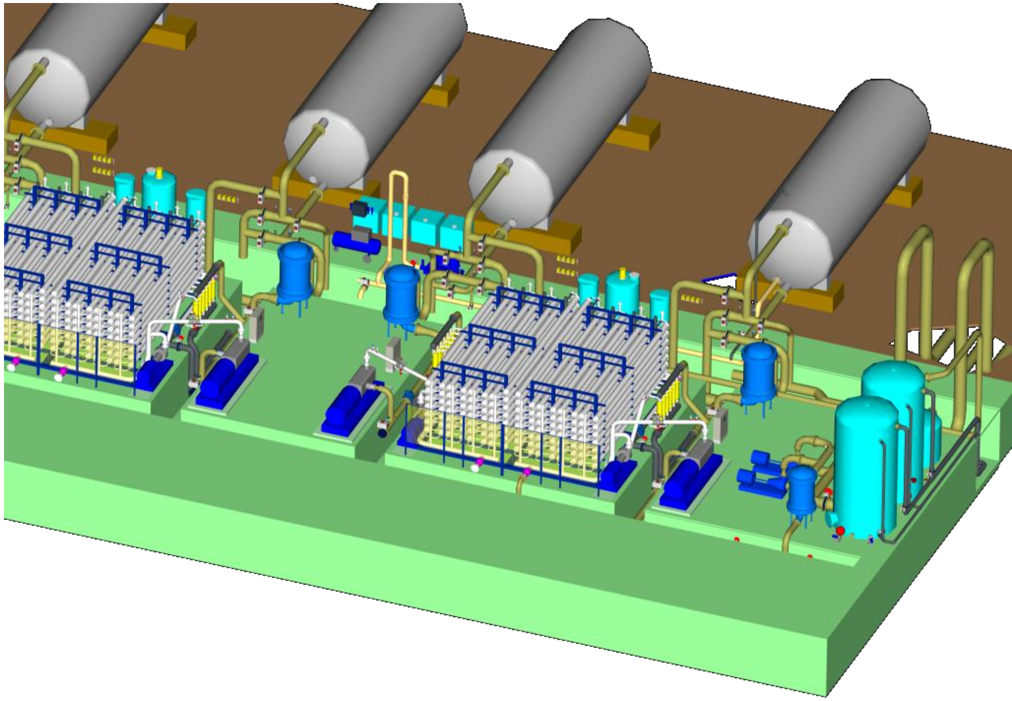
Proposed RO System Overview:

- 2 Stage RO with variable permeate split at stage 1
- 8-10 trains
- High efficient energy recovery



Proposed 1st pass RO Train Overview:





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King Abdullah Initiative for Solar Water Desalination

DESIGN ASSUMPTIONS FOR PERMEATE QUALITY

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	Option	Option	Option
Boron limit	**0,5 ppm**	**1ppm**	**2,4 ppm**
1st pass elements/vessels	3.304/472	3.304/472	3.304/472
2nd pass elements/vessels	2.352/336	1.960/280	1.344/192
First pass recovery	45%	45%	45%
Second pass recovery	90%	90%	90%
Overall recovery (summer/winter)	42,5/43,0	42,9/43,6	43,6/45
1st pass feed pressure (summer/winter)	62,8/66,7	63,0/66,9	63,3/70,0
2nd pass feed pressure (summer/winter)	9,6/10,5	9,6/8,8	9,5/--
Boron (summer/winter)	0,41/0,42	0,87/0,86	1,93/1,52
Chlorides (summer/winter)	53/55	120/100	224/220
TDS (summer/winter)	95/90	207/170	385/370

The size and operation of the second pass is strongly driven by the Boron requirements of the drinking water

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Design assumptions of the Al Khafji Desalination Plant

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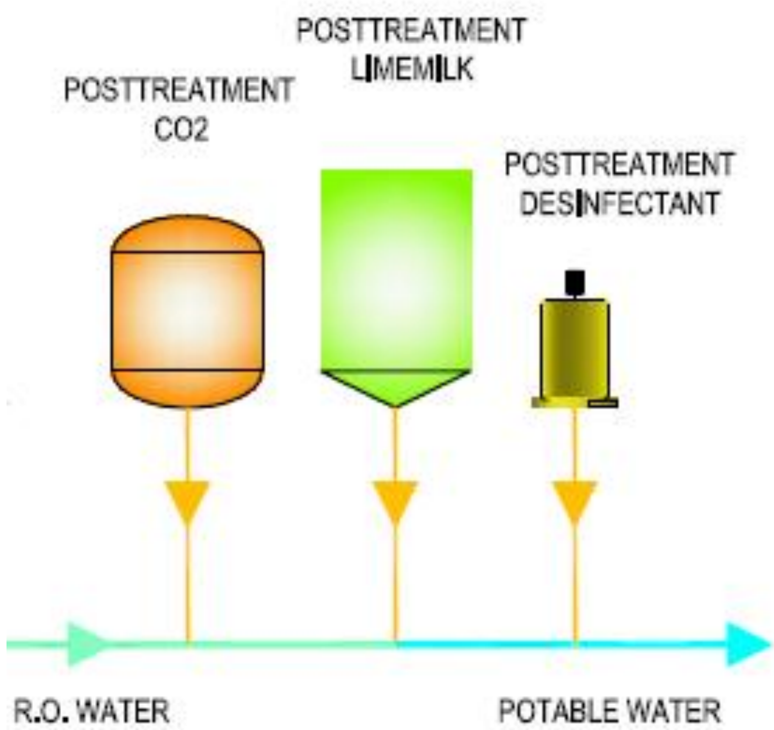
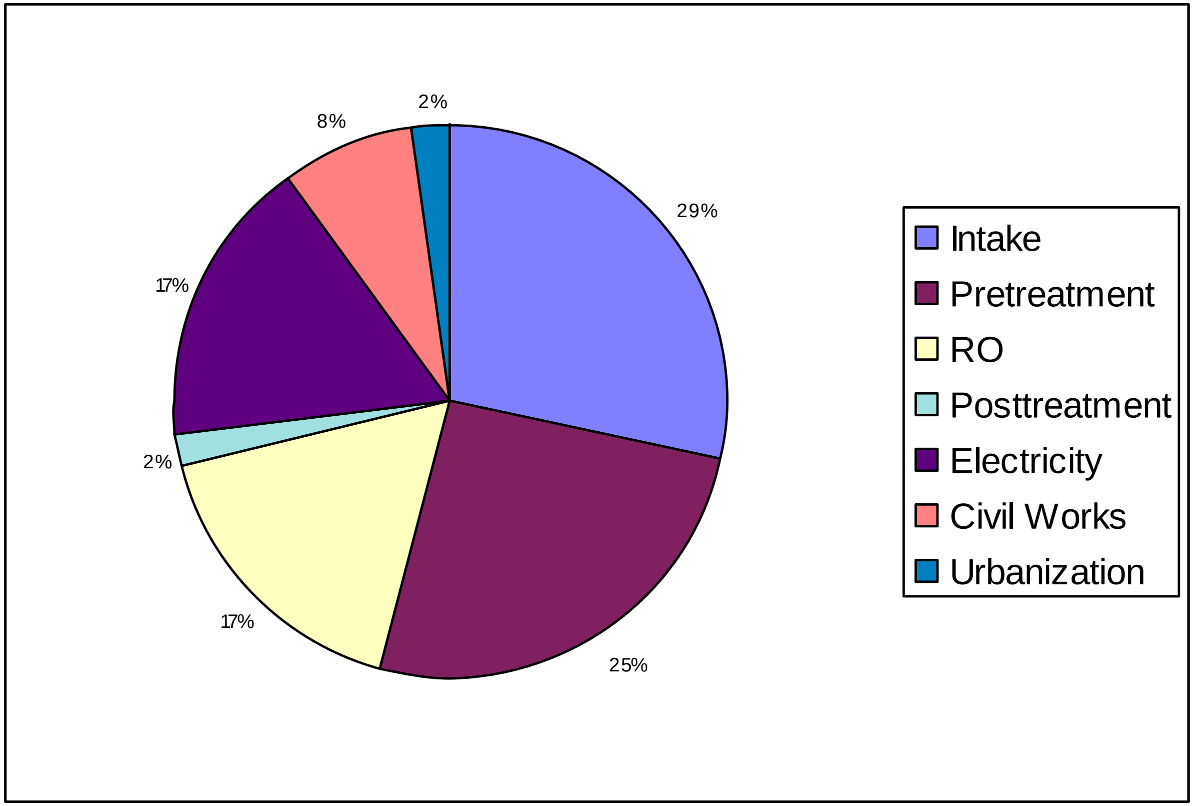
Post treatment: Proposed system

LIME MILK/LIME SATURATED WATER + CO2

Well known method also used in other plants in Saudi Arabia



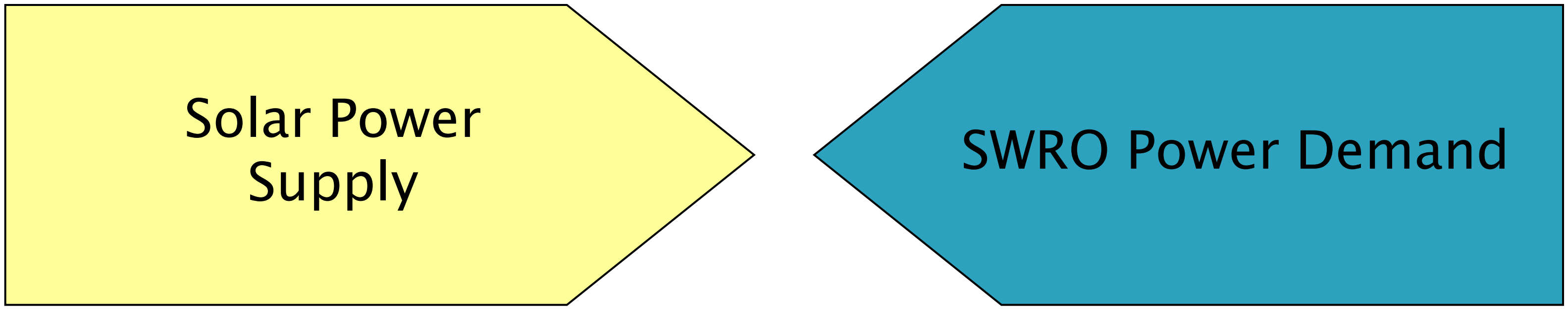
Capital Investment Breakdown:



For the Al Khafji plant more than 50%
Of the investment is spend for Intake and Pre-Treatment

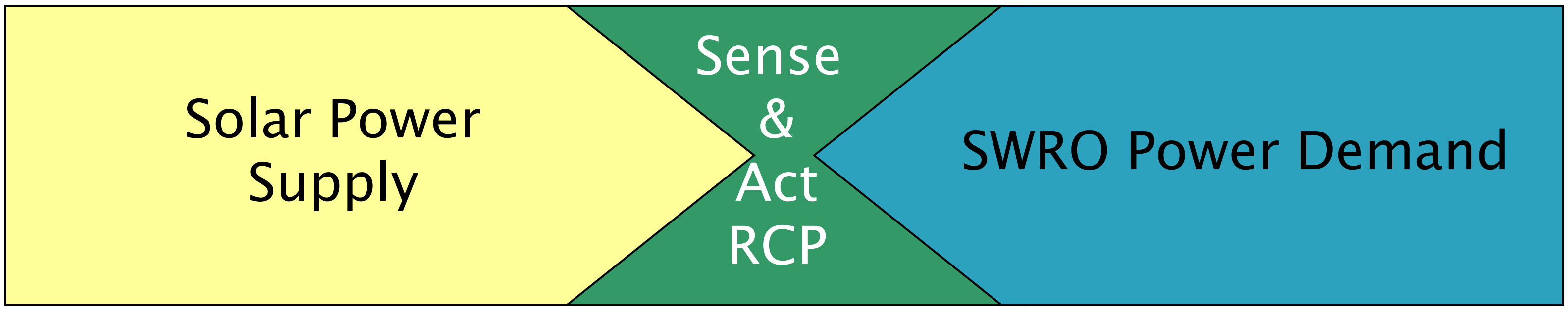
Integration of Solar and RO Desalination

Challenges to be met



- The SWRO plant design: Island Operation
  - SWRO Power consumption to follow closely the power supply curve (daily ramp up, ramp down)
  - Train shut down and restart at least 1/ day
  - Realtime reaction on power variations due to dust and clouds
- Grid power to extend the operational hours optional

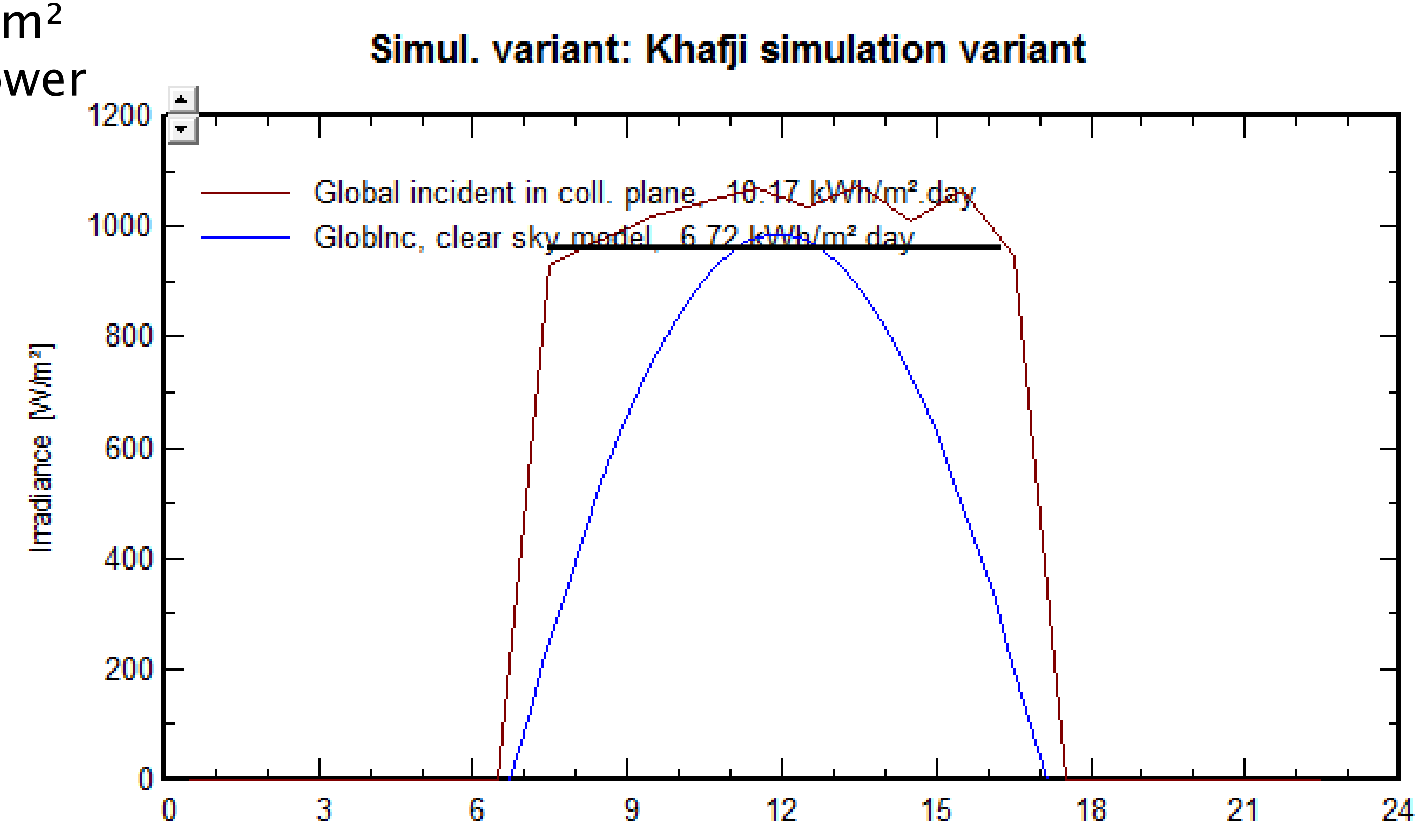
Challenges to be met



- Implementation of a Realtime Control Program (RCP)
  - Sense and Model Solar Power Availability
  - Act on the SWRO demand and follow the supply curve

Example: Typical Winter Solar Supply Curve

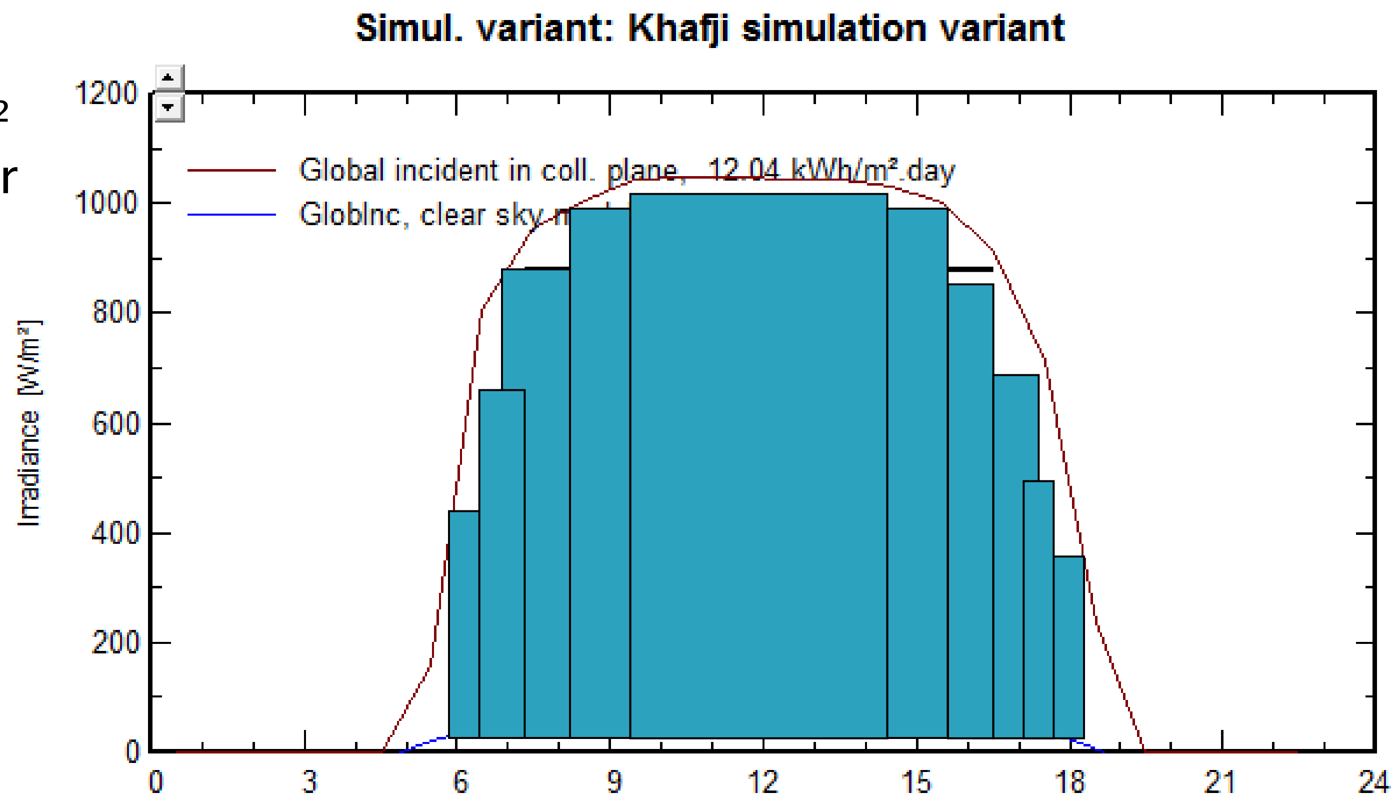
Winter
Full sun 1000W/m²
8.5 hours full power



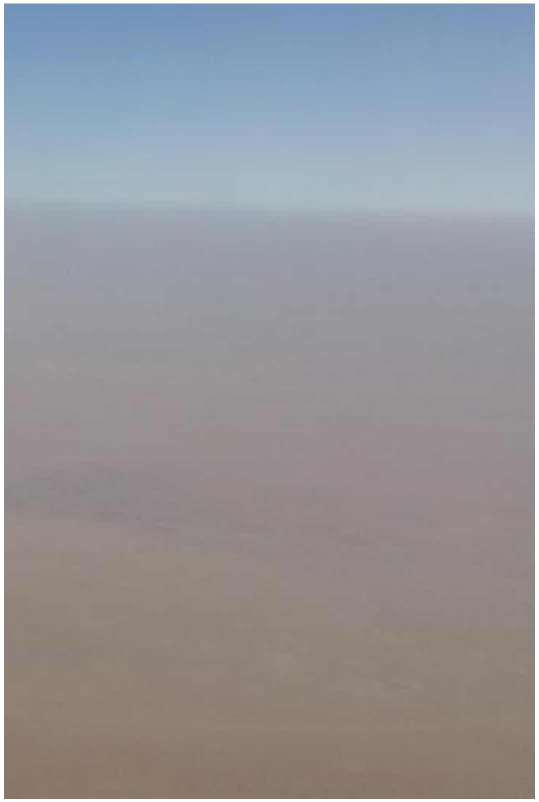
Example: Typical Summer Solar Supply Curve

Summer
Full sun 1000W/m²
12 hours full power

Water production



Weather and Cloud Conditions



High Atmospheric Dust

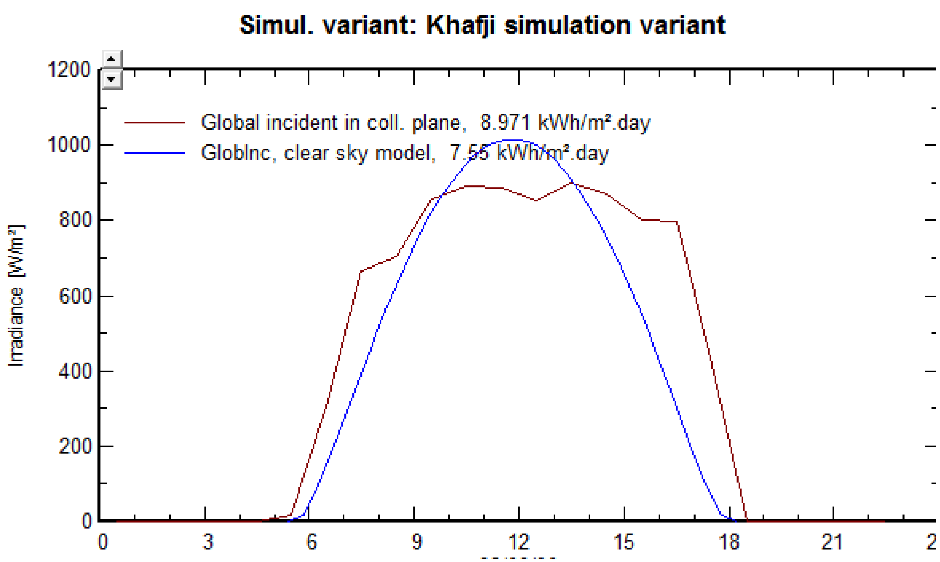
Short Cloud Coverage

Heavy Cloud Coverage

Example: Typical Influence of dust and clouds

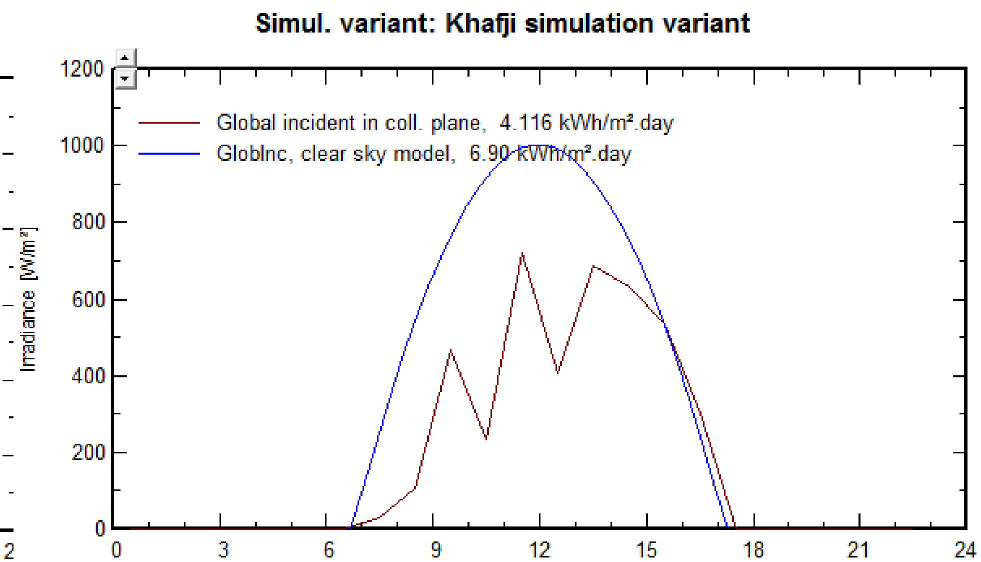
Summer

Influence of dust



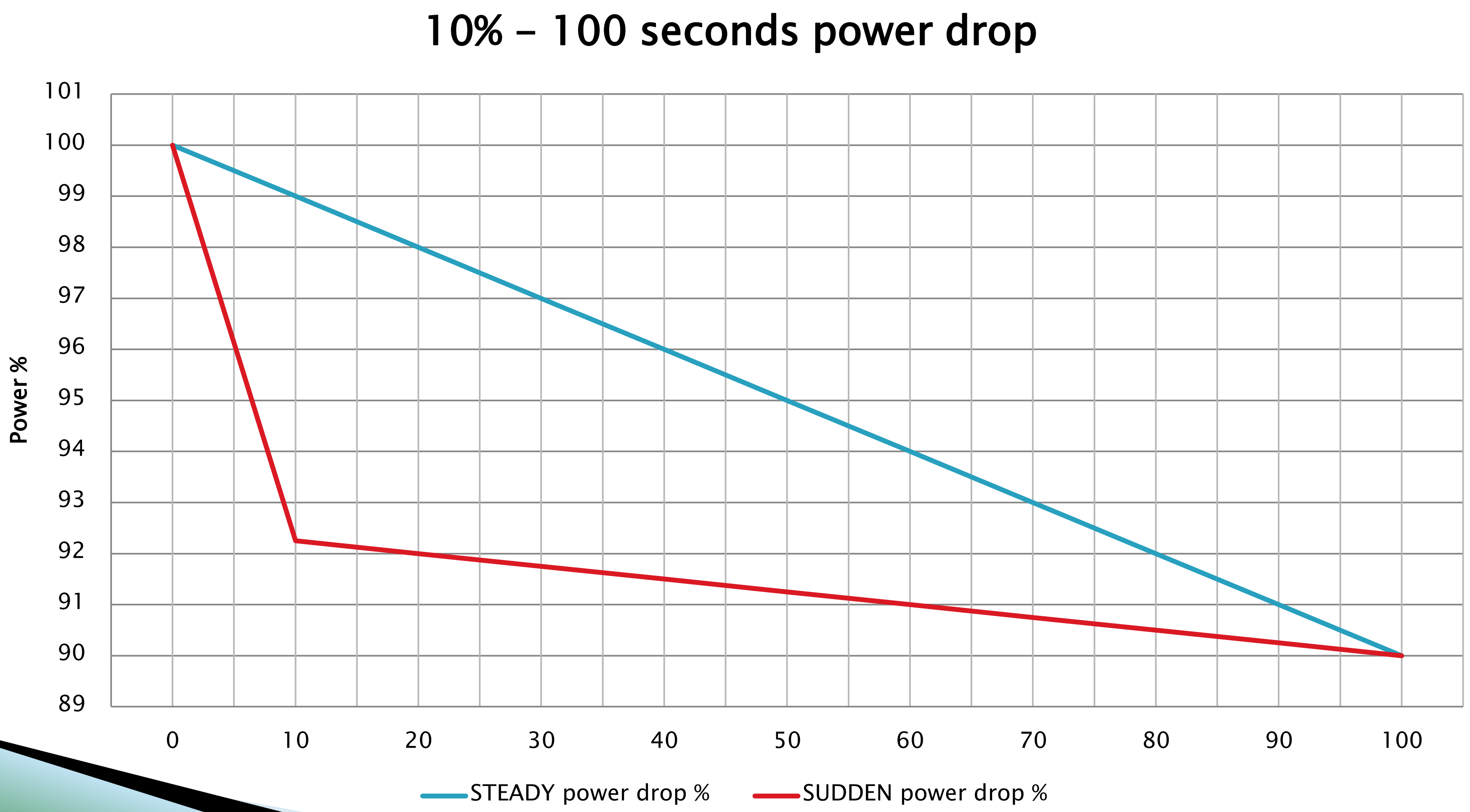
Winter

Influence of clouds



Special power requirements

1. Solar power drops.
   - It is essential to 'react' on the SWRO demand side sudden and steady power drops



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Summary:

- The Al Khafji plant will be the world wide first high volume SWRO Desalination plant powered by Solar Energy
- To be most efficient, the plant design will profit from latest KACST/IBM UHCPV and Nanomembrane R&D results.
- The successful demonstration is the key to boost the national implementation to use of solar power at desalination
- The successful implementation of Solar/SWRO plants with lowest environmental impact is vital for the whole world

Leaders in Solar Desalination
KACST – SWCC

Thank you for your attention !