Sustainability of Desalination using Renewables and Nuclear Energy Sources.

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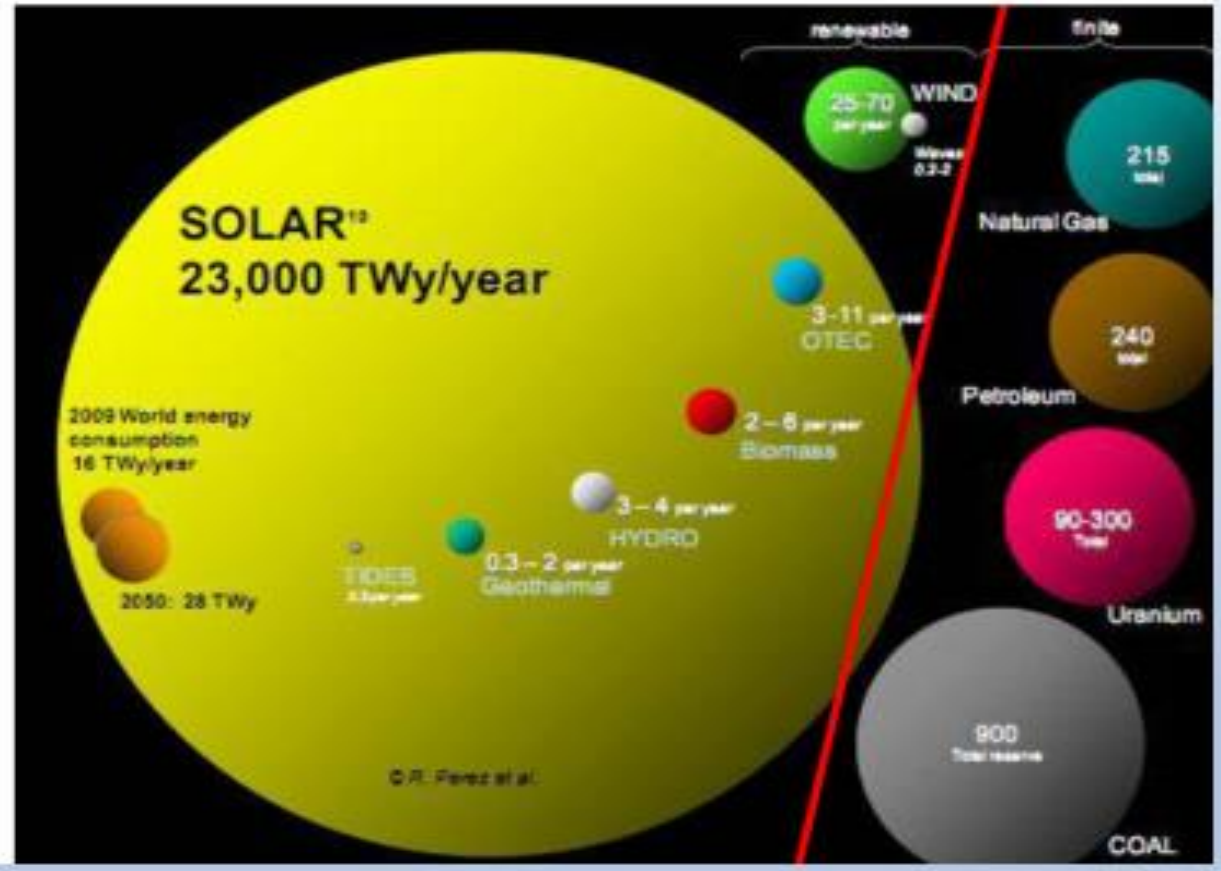
A transformation in the energy and water sector has begun. The momentum toward low-carbon energy and desalination generation -- driven by our need for secure, affordable and sustainable energy supply -- will see the days of fossil fuel domination fade into obscurity.

SOLAR and ENERGY SOURCES COMPARISON

The annual solar radiation on the earth surface is 1400 times higher than the annual world energy consumption and 25 times higher than the total coal reserves



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The intermittency of solar and wind has always been a challenge for grids, especially ones with high renewable penetration levels, At the same time desalination is looking for solutions that direct renewable or alternative energy can operate 24/7 without grid availability and at minimum cost of overbuilding the solar and desalination plant.

Solar Thermal and Nuclear sources of energy and Hybrid Systems can offer based loaded operation of desalination plants today without depending on grid and battery storage.

Novel Thermal Desalination Coupled with Solar or Nuclear Energy

Hybrid of solar or nuclear thermal energy with Multi–Effect Distillation solutions is able to operate with low temperature using hot water transformer. The idea is relevant also to solar pond, low temperature geothermal resources as well as coupled with more conventional concentrated solar Parabolic Trough Collectors or Solar Tower.

MED is an established technology for desalinating seawater and large fossil fuel power desalination plants are operating successfully to deliver efficiently high purity desalinated water with specific power consumption of 1.0-1.3 kWh/ton of distillate, significantly lower than MSF typically 4 kWh/ton or RO with 3.3 kWh/ton of product and heat coming from backpressure power plants.

This combination of lower energy consumption and intrinsic durability due to reduced temperatures compared to MSF as well as no requirement for pre-treatment for the seawater feed, unlike RO makes MED ideal for desalination. Secondly, MED's ability to run with a partial load make it an ideal technology to integrate with PV-T as it can handle fluctuations in energy delivery caused by unstable weather.

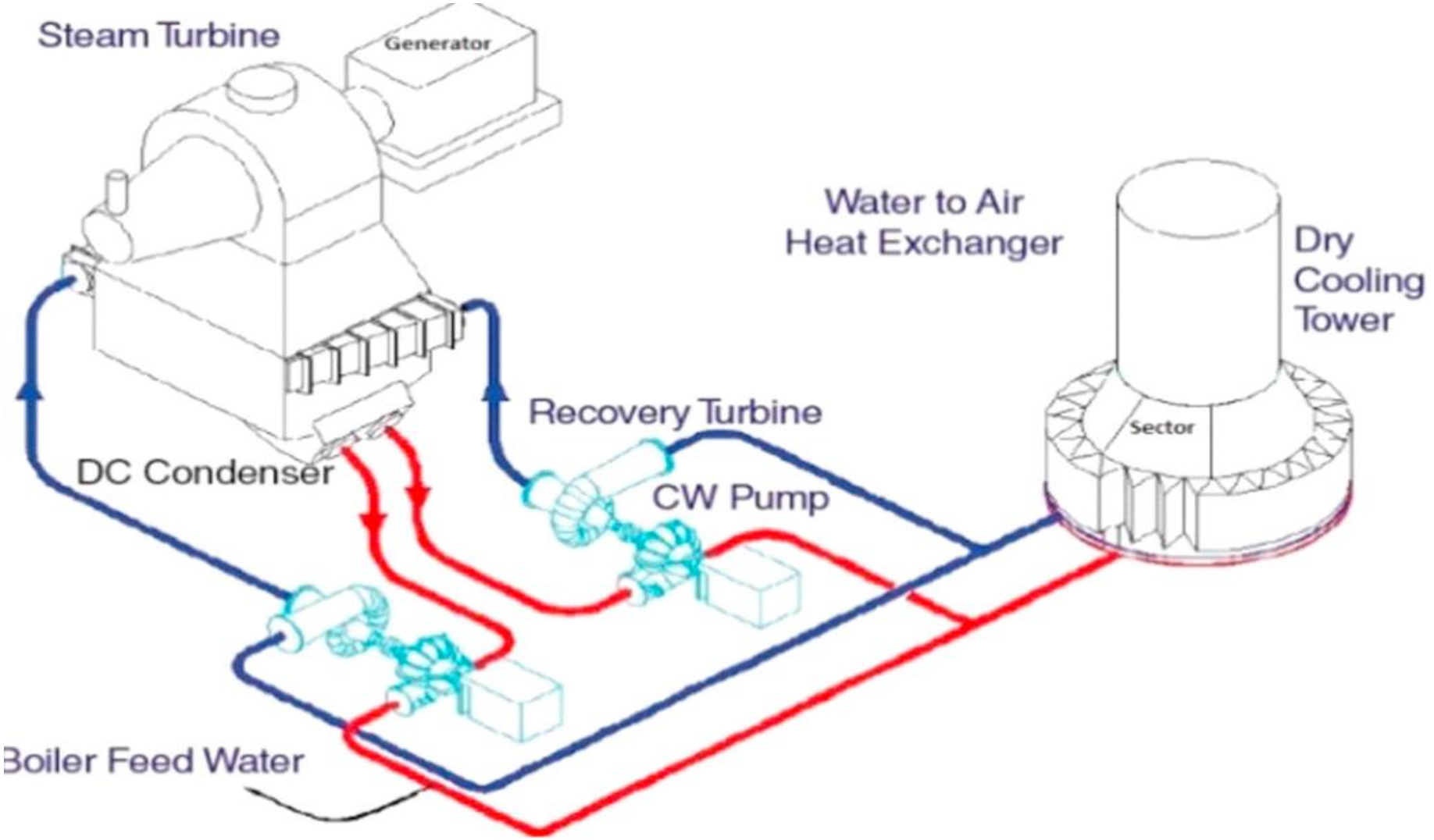
Mohammed Bin Rashid Al Maktoum Solar Park 950 MW

Innovative Awerbuch-Heller system coupling Steam Turbine to MED, applicable to Solar Thermal, Fossil or Nuclear power

The AWERBUCH-HELLER System is an indirect energy transfer. The power plant backpressure or extraction heat is initially exchanged in a condenser to a closed cooling water circuit. The heat absorbed by the water is transferred by pipeline to MED flashing chamber to provide steam for the first effect of MED.

The modified AWERBUCH-HELLER System evolved from an idea to use a direct contact jet condenser in a similar way to the dry cooling towers solution of the professor HELLER developed in Hungary by EGI (now GEA).

Heller Dry Direct Contact Cooling System



The advantages of dry cooling towers and direct contact condensers

The advantages of dry cooling tower is minimizing water needs for in desert solar thermal CSP systems,

The direct contact condensers has low terminal temperature difference:

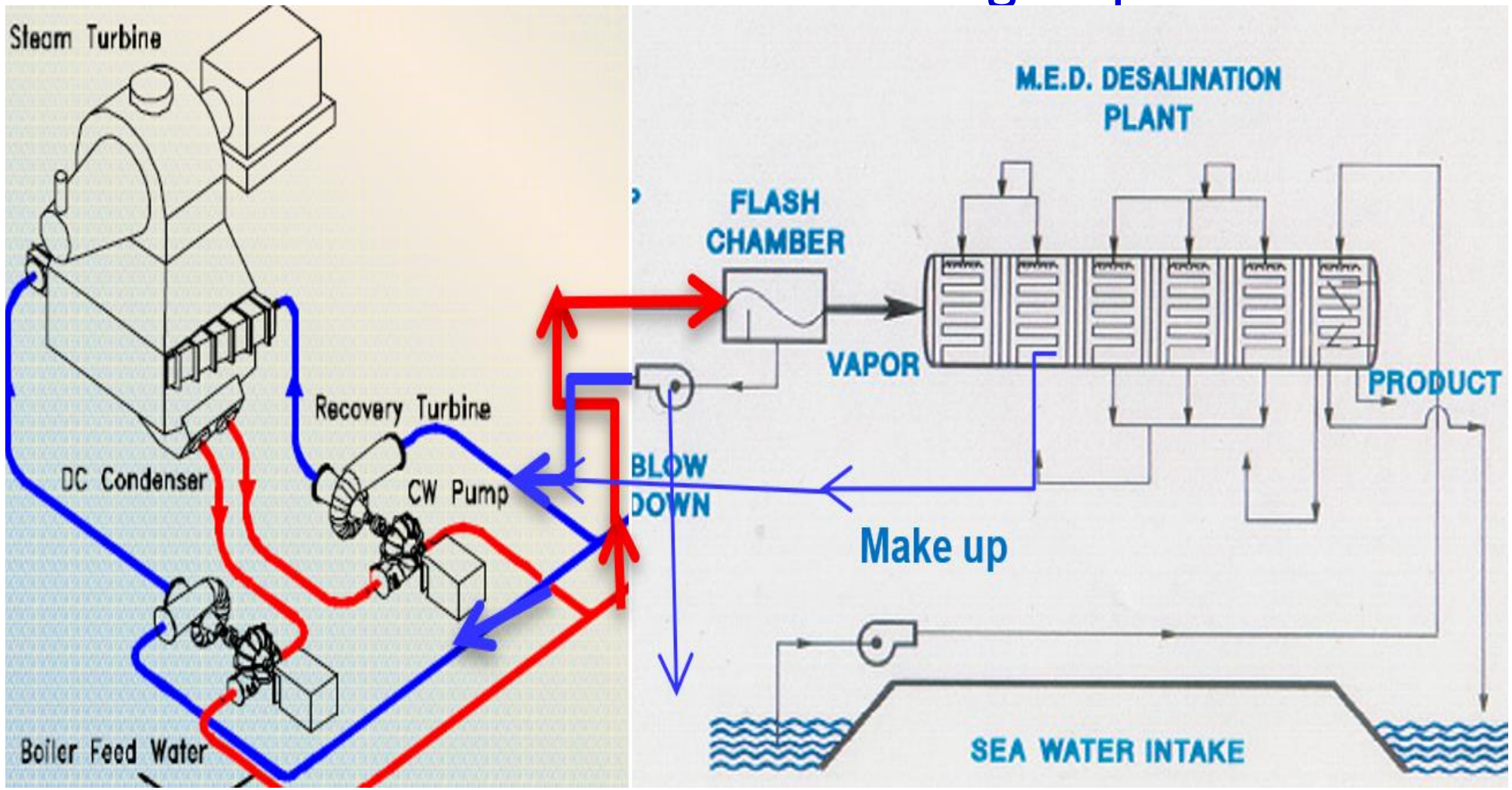
- **Conventional Surface Condenser TTD ~ 3-4°C**
- **Direct Contact (DC) Jet Condenser TTD ~ 0.3°C**
- **Elimination of shell and tube, typical titanium condenser**
- **A completely closed and pressurized cooling circuit, where vacuum is limited to the small space of DC condenser.**

Innovative solution for Solar CSP to couple to MED Desalination

Suggested innovation to increase solar power efficiency by direct contact condensing steam in order to obtain the following results:

1. **Maximum recovery of low temperature energy extracted or exhausted from CSP power plants for desalination production. It utilizes an advanced hybrid concept of combining High Temperature Nanofiltration softening membranes (HTNF) for Multi-Effect Distillation (MED) to significantly increase thermal efficiency and recovery of desalination process.**
2. **Provide a unique solution to transfer solar energy from low pressure exhausted turbine backpressure steam to MED distillation plant using modified Heller-Awerbuch approach of cooling loop allowing further turbine expansion of steam from 2.9 bars to .5 bar. Significantly increasing efficiency of power generation and improving performance of the MED process.**

Novel Awerbuch-Heller system for coupling Direct Condenser with MED via flashing loop



IDCA innovative system coupling steam turbine to MED via Water Transformer

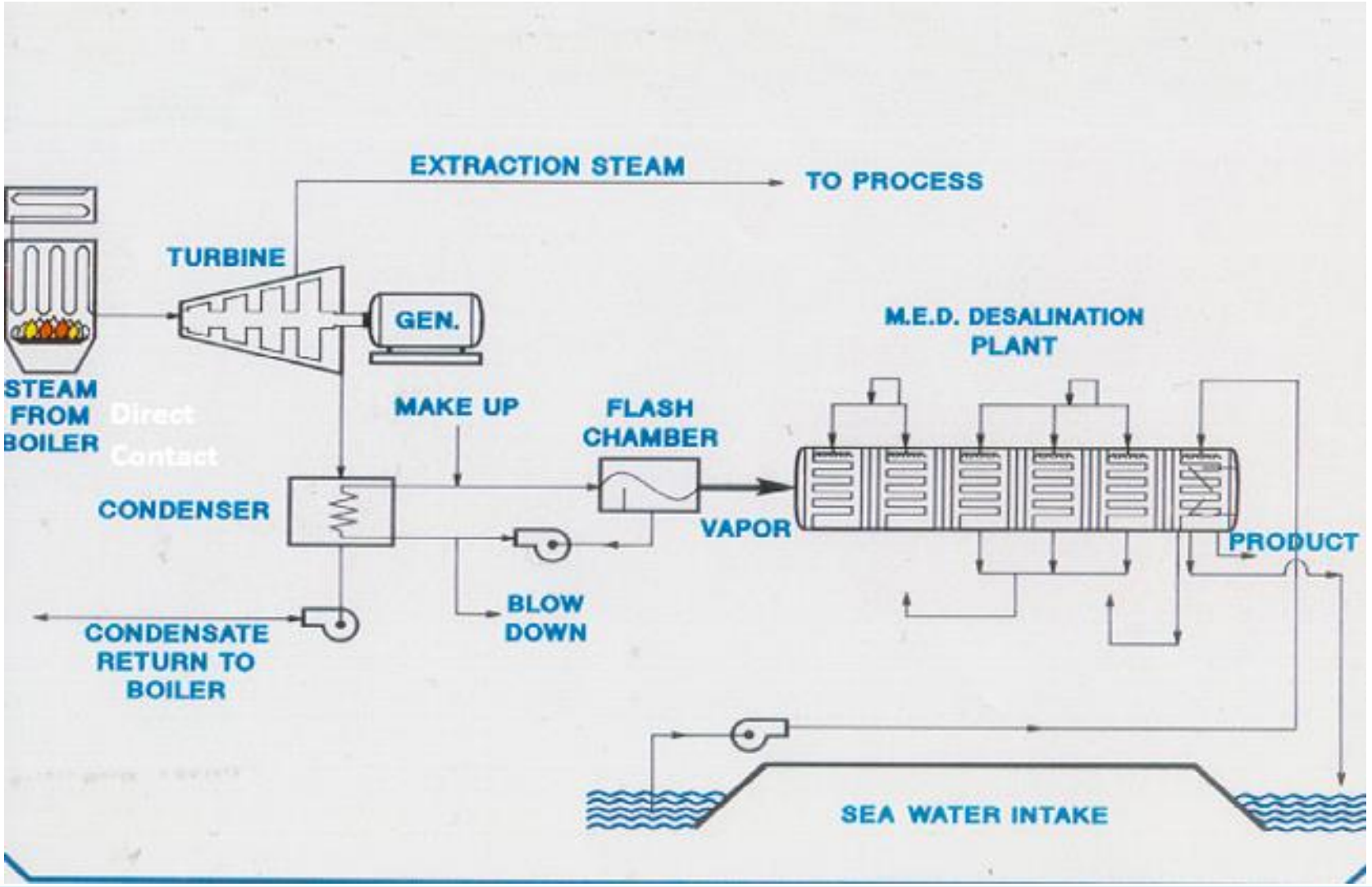
The significant results and changes of such design is listed below:

- **The power plant produces significant more power considering that steam can be expanded to 80-85°C and absolute pressure .4741-.5 bar versus current 2.8 bars. I estimate it will produce additional 110MW.**
- **Reducing cost of MED as design of effects is uniform compare with MED-TVC**
- **Elimination of the steam piping from power plant to the evaporators, including heat and steam pressure loss.**
- **Elimination of MED steam transformer as there is no thermocompressors. The condensate is re-flashed deareated and totally returns from first effect. No hydrazine contamination of the product.**
- **There is a need to add additional effects to achieve the same performance ratio.**
- **There is a need to add closed cooling water circuit piping and pumping**

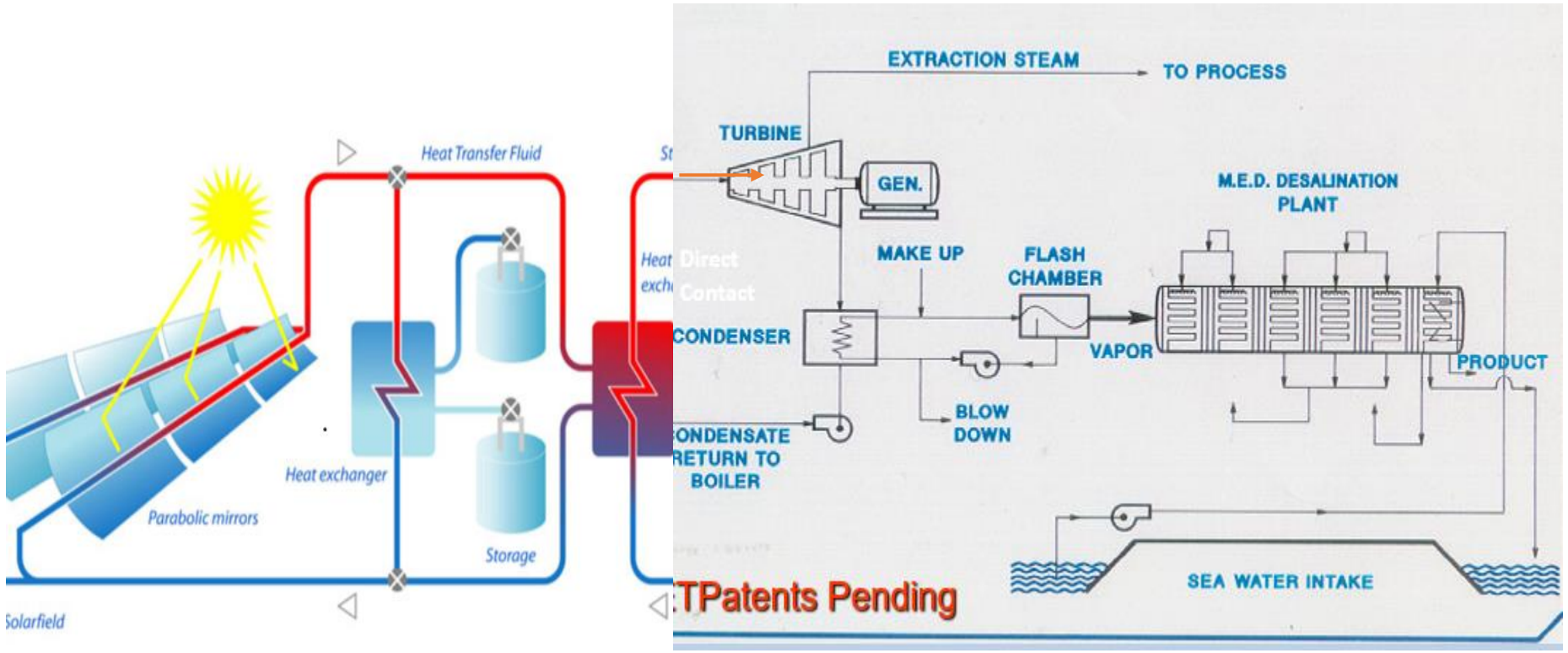
Innovative Heller-Awerbuch system coupling Steam Turbine to MED, applicable to Solar Thermal, Fossil or Nuclear power

The most dramatic change in increasing power output and efficiency and to reduce cost is a modified Heller-Awerbuch System adopted by me for Power-MED.
The concept is based on a condensation of steam from the turbine with recirculating condensate at 85 to 67.5°C. The condensate is in a closed cooling water circuit. This warm condensate is pumped by water pipeline to the distillers where generates steam for the MED process by re-flashed in flashing chamber. The flashed condensate at 67.5°C, together with steam condensed in the first effect is pumped again by water pipeline to DC..

Novel Awerbuch-Heller Power condenser using pure water in circulation to preheat pure water to 85 ˚C is the simplest solution no changes to condenser, no risk of contamination. Flashing in one stage to provide steam to MED and return colder 67.5ºC to condensate loop.



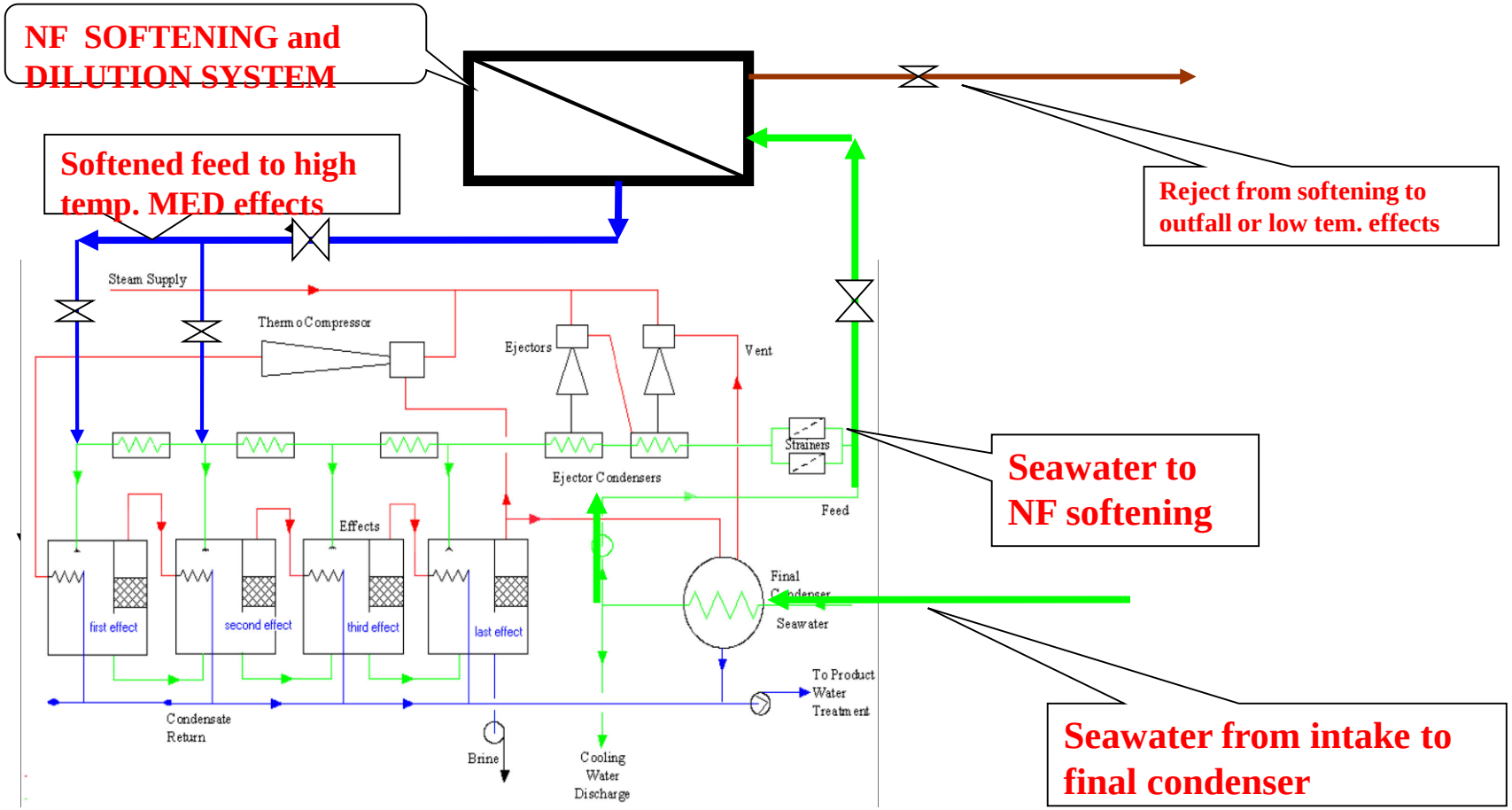
Novel Parabolic solar power coupling to MED via Hot Water Transformer Loop



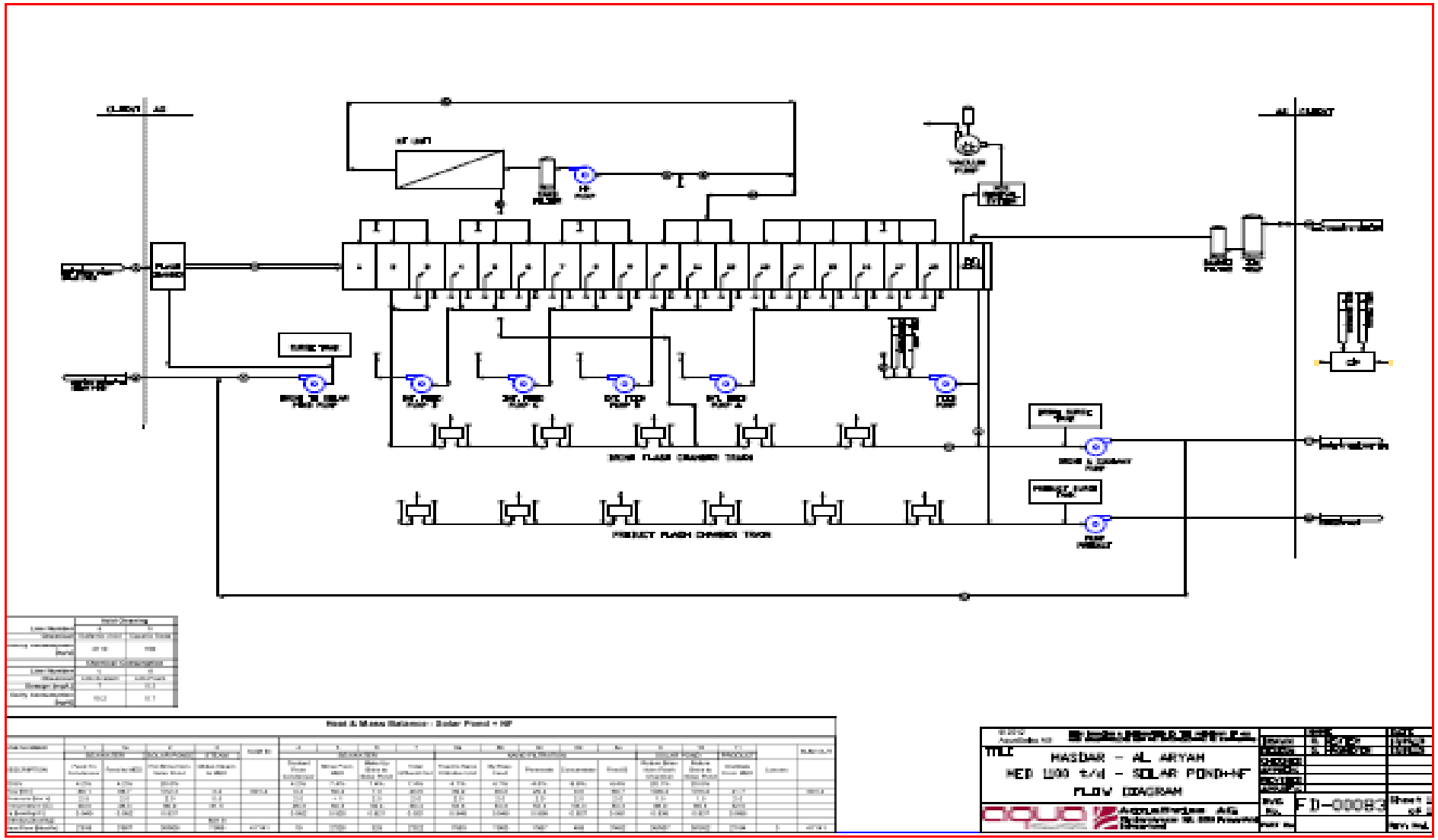
Renewable Energy coupled to NF-MED

We already have done a preliminary design of Advanced Solar Desalination shown above, using 18 effects MED hybridized with Nanofiltration NF to soften feed for the hottest groups. This will decrease the specific thermal energy consumption to 168.2 kJ/kg or PR=13.8, never achieved without thermocompression TVC with heat input at 90 ºC. We have also designed a full size commercial unit of 25,000 m3/day with 20 effects desalination plant with thermal energy consumption to 137.6 kJ/kg or PR=16.25.

Process and apparatus for partial blending of softened feed to high temperature effects of MED in order to increase TBT



Multi-Effect Distillation with Nanofiltration only for High Temperature Effects.



Nuclear Energy

Interest in using nuclear energy for producing desalinated water is growing and has been considered as an option by several countries around the world, as well as countries with existing operating nuclear power plants (NPPs).

- In 31 countries 450 nuclear power plant units with an installed electric net capacity of about 392 GW are in operation and 60 plants with an installed capacity of 60 GW are in 16 countries under construction.
- In USA 99 nuclear reactors are in operation producing net 98.868 MWe and 4 reactors are under construction to generate 4.468 MWe. The USA has 99 nuclear power reactors in 30 states. Since 2001 these plants have achieved an average capacity factor of over 90%, accounting for 20% of total electricity generated.
- In Abu Dhabi 4 units of 1400 MW are being constructed at Al Baraka site which will have significant implication on the Abu Dhabi power and desalination program.
- Egypt sign agreement with ROSATOM to built El Dabaa 2X1200 MW NPP and 2X 170,000 m3/day MED desalination plant

Preferred Technical Solutions for Nuclear Desalination

With dramatic interest in finding solutions to combat climate change in view of the impacts of global warming on water resources, nuclear desalination can offer significant potential to substitute fossil fuel as a source of energy for desalination.

There was a consensus among participant of IAEA several meetings on the use of straight MED technology hybridized with RO, being best suited for nuclear desalination. The optimum technology solutions for nuclear desalination was considered hybrid of Multi-Effect Distillation (MED) with Reverse Osmosis (RO).

Preferred Technical Solutions for Nuclear Desalination

The integrated hybrid MED-RO design can make use of warmer seawater discharged from NPP or reject sections final condenser of MED to reduce energy consumption, reduce size of seawater intake and outfall. To minimize energy consumption and reduce power losses of NPP it is recommended to use straight MED with the lowest extractions steam pressure available using straight MED, rather than MED-TVC. To use steam from extraction section of NPP turbine .15 MPa cannot be send directly to MED, because of high volume of steam at lower pressure the piping would be too big with very large diameter, making economically not practical. We proposed an indirect energy transfer trough water transformer system. The power plant low pressure extraction steam is initially exchanged in a separate smaller Condenser to a closed cooling water circuit. The heat absorbed by the water is transferred by pipeline to MED flashing chamber to provide steam for the first effect of MED at about 68.5 °C. The flashed water cooled to 68°C together with portion of the vapor condensed in the first effect is pumped by return water pipeline to Condenser at the steam turbine proximity

The significant benefits of preferred design of Nuclear Desalination

- Elimination of the large steam piping from power plant to the evaporators, including heat and steam loss.
- Elimination of the MED steam transformer as there is no need for a thermocompressor. The condensate is re-flashed deaerated and totally returns from first effect. No hydrazine contamination of the product.
- The heat can be transferred in water pipeline a long distance allowing NPP power and water islands to be at optimum location.
- We recognized that there is significant difference in construction time of NPP of at least 6 years versus desalination plant of 30 months, therefore it was recommended that the Feasibility Study and Minimum Functional Specification (MFS) be prepared at the beginning of the NPP project and the Final Specification for Desalination Plant with optimum Ratio of MED to RO portion will issue closer to beginning of constructions of desalination plant.
- The consideration has to be given to different life time design for NPP sixty years and desalination of 20-30 years with rapid changing and improving desalination technology.
- In specifying NPP and desalination islands it is recommended that the standards for desalination island both design and operations does not use nuclear design criteria but more conventional established desalination practice, however the monitoring of safety, radioactivity of air and water, quality of desalination products and brine needs to be responsibility of nuclear developer.

ROSATOM with Turbine K-1200, Power Machines JSC

Example of specific solution is based on the extraction steam from Turbine K-1200, Power Machines JSC can be effectively used in the design desalination capacity for each NPP of 170,000 m3/day, with the amount of steam available from extraction point III and IV, we could use the 0.823 MPa and .471 MPa steam and send by pipelines a reasonable distance to drive the Steam Transformers. The Steam Transformer provides clean steam for thermocompressors TVC. Steam Transformer also prevents from chemical contamination of the steam as is re-boiling pure water vapor-steam to drive MED-TVC.

El Dabaa, Egypt 2X1200 MW NPP &
2x170,000 m^3/day desalination

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NF-MED Coupling with NPP steam/water transformer

- The heat for the MED unit will be supplied from steam water transformer.
- The hot water will be sent to a flash chamber and will generate the required steam to the MED unit.
- From the flash chamber the colder water will be pumped back to the steam/water transformer.
- In order to improve the overall specific energy consumption a nanofiltration unit has been added to treat the feed water to the hot group.
- The NF unit will remove all the sulphates dissolved in the feed, allowing to operate the MED at a top brine temperature of 80°C without scaling problems.

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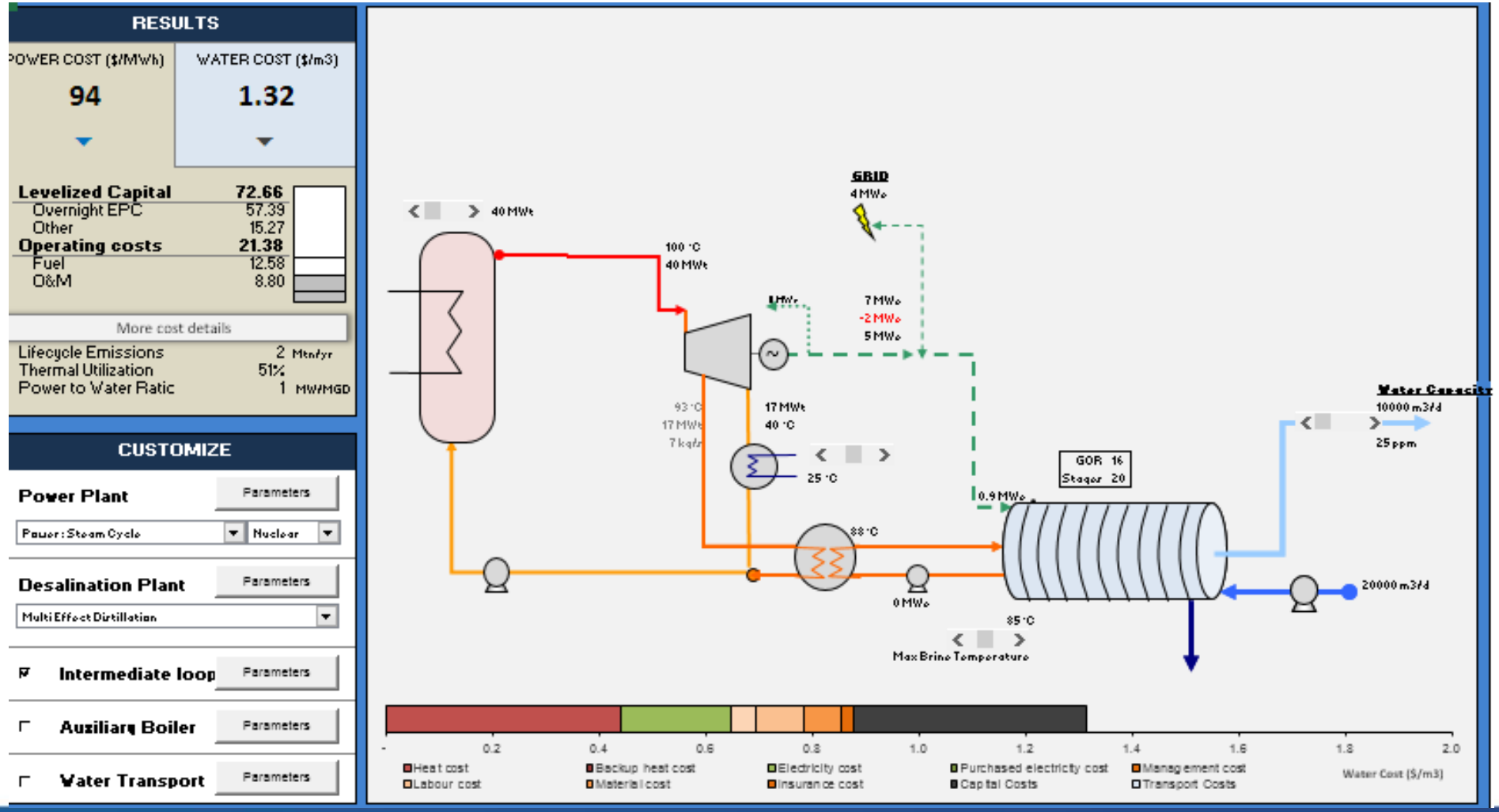
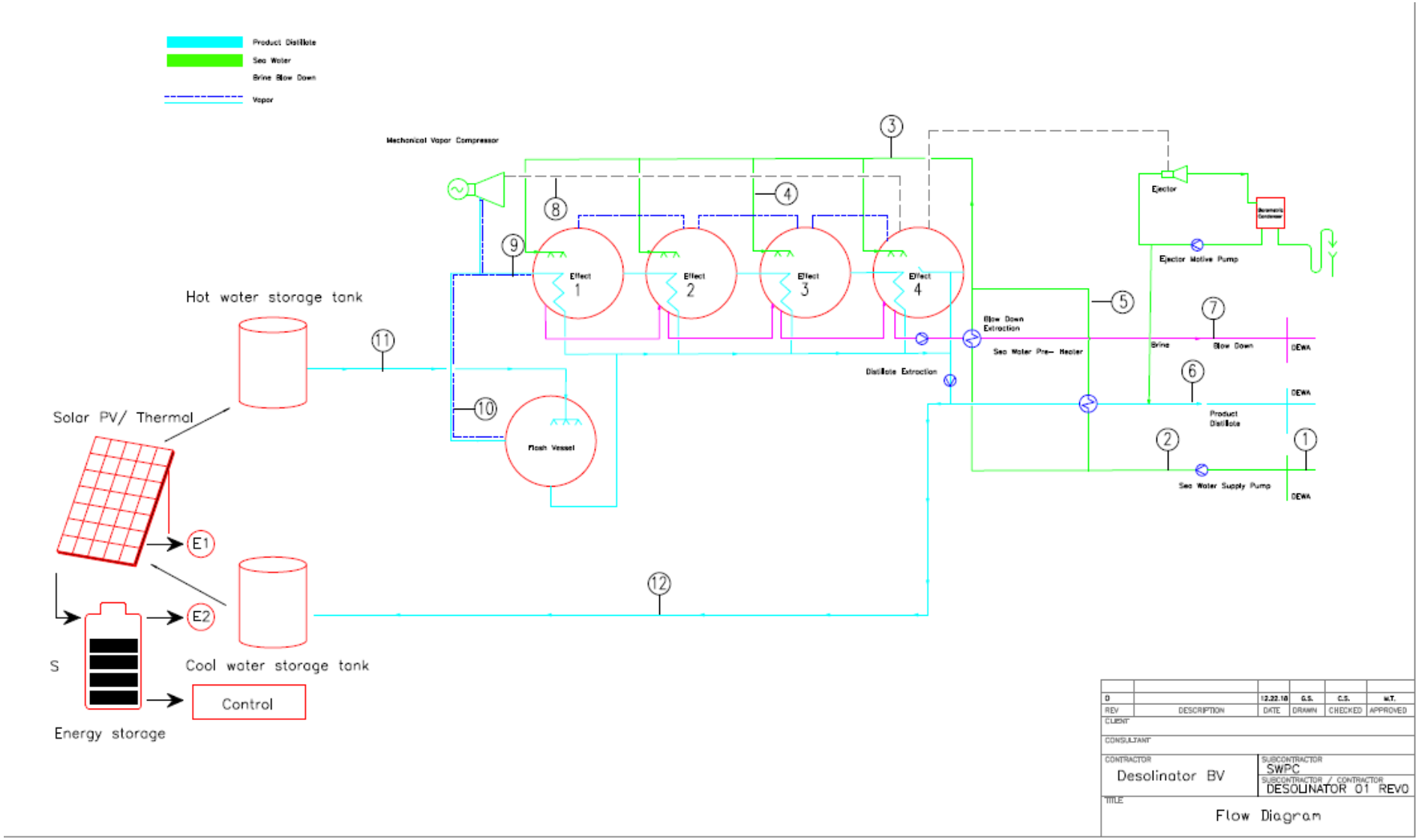
Extracted steam from 40 MWt NPP at 92 ˚C using hot water transformer to NF-MED having 20 effects resulting in GOR 16 and 10,000 m^3/day



Desolenator Innovative Concept



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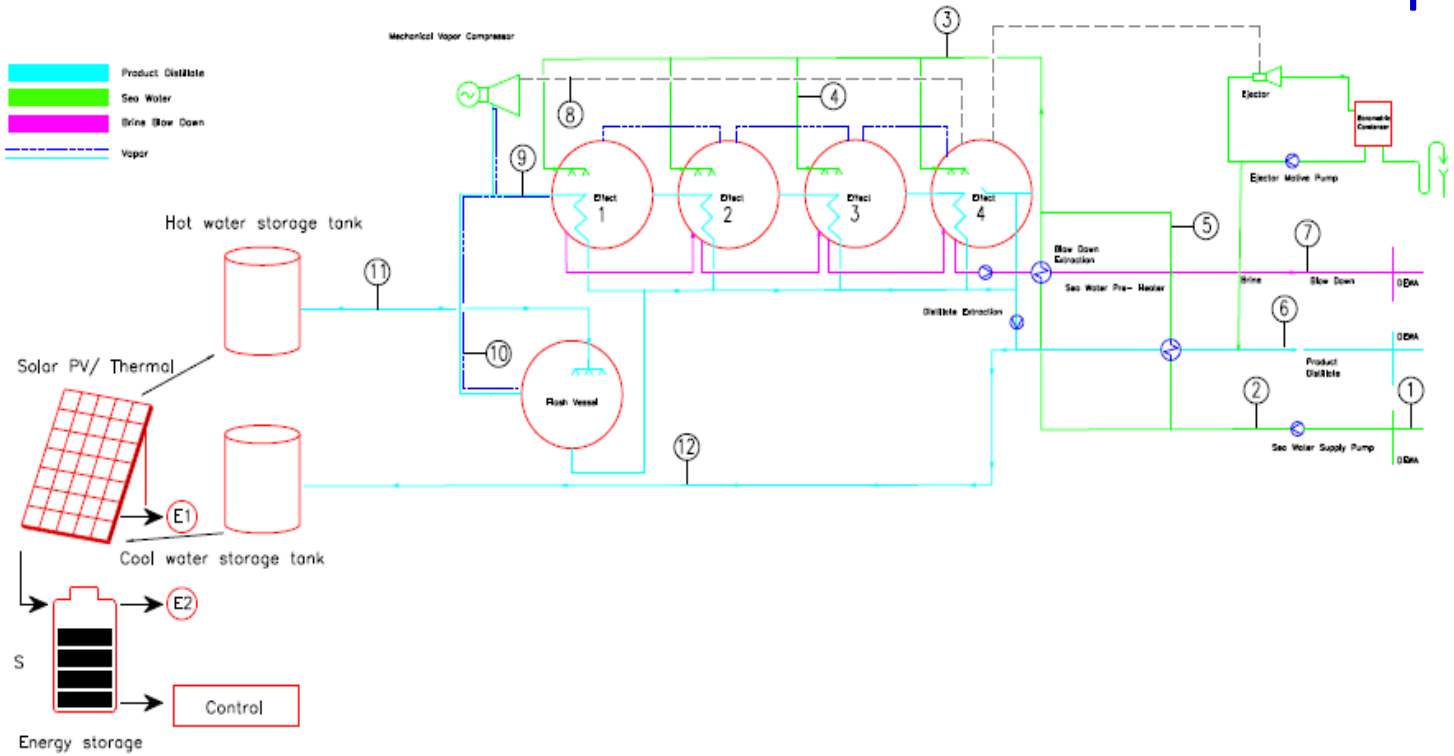


Description	Unit Measure	Sea water	Sea water	Sea water	Sea water	Sea water	Distil late	Blow Down	Vapour	Vapour	Vapour	Hot Water	Distil late
Stream Line	/	1	2	3	4	5	6	7	8	9	10	11	12
Flow Rate	kg/s	0.66	0.66	0.66	0.16	0.28	0.28	0.38	0.07	0.086	0.016	0.170	0.170
Flow Rate	l/s	0.642	0.642	0.643	0.161	0.273	0.282	0.362	1346	662	123	0.176	0.171
T.D.S.	ppm	44000	44000	44000	44000	44000	0	76421	N.A.	N.A.	N.A.	0	0
Temperature	°C	30	30	35	35	35	35	35	40	60	60	85	40
Pressure	bar	1.5	2.5	8	8	1	1.5	4	0.075	0.2	0	1	1
Density	kg/m³	1028	1028	1026	1026	1026	993	1050	0.052	0.13	0.13	968	992
Pipeline Diameter	mm	50	50	50	25	50	25	25	300	200	100	25	25
Velocity	m/s	0.33	0.33	0.33	0.33	0.14	0.57	0.74	19.05	21.07	15.68	0.36	0.35
Enthalpy	KJ/Kg	119	119	139	139	139	146	134	2574	2608	2608	356	167

REV	DESCRIPTION	DATE	DRAWN	CHECKED	APPR
0		12.22.18	G.S.	C.S.	

CLIENT

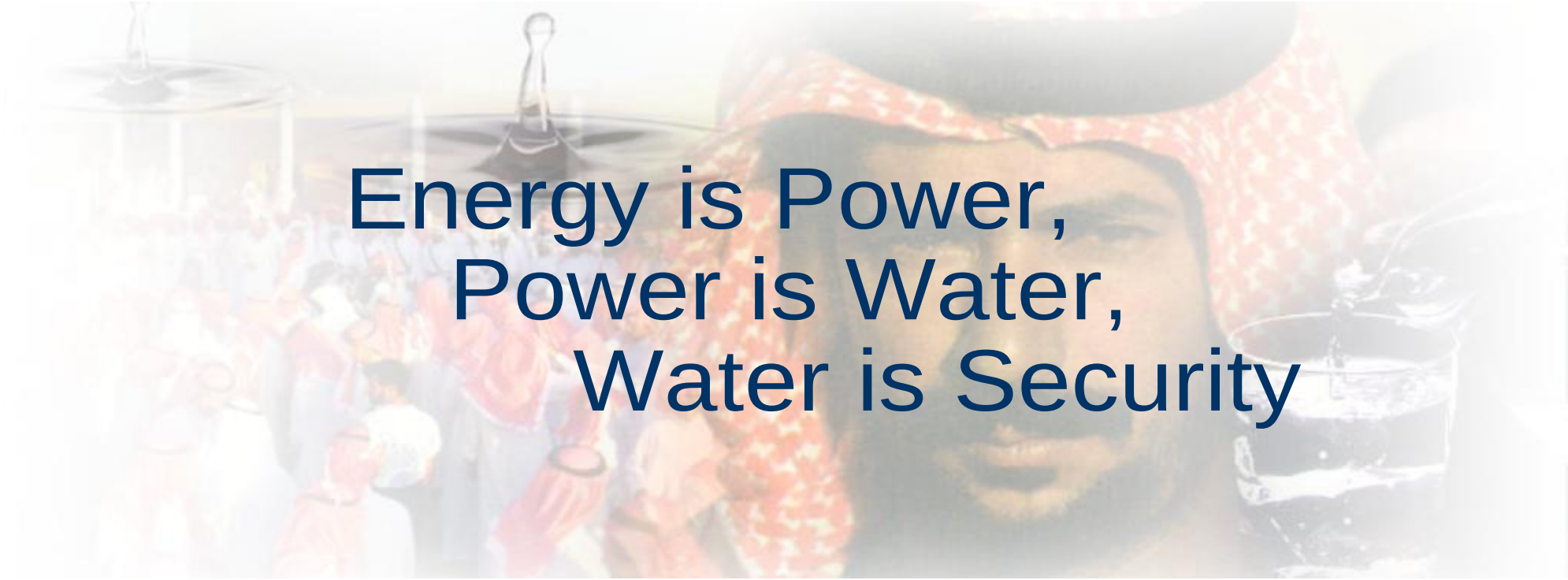
CONSULTANT

CONTRACTOR: Desolinator BV

SUBCONTRACTOR: SWPC

SUBCONTRACTOR / CONTRACTOR: DESOLINATOR 01 RE

TITLE: Heat and Mass Balance (Day Operation)



Energy is Power,
Power is Water,
Water is Security