Renewable energy water desalination: future and challenges

منتدى المياه السعودي
saudi water forum SWF 2022
استدامة المياه .. مسؤولية الجميع

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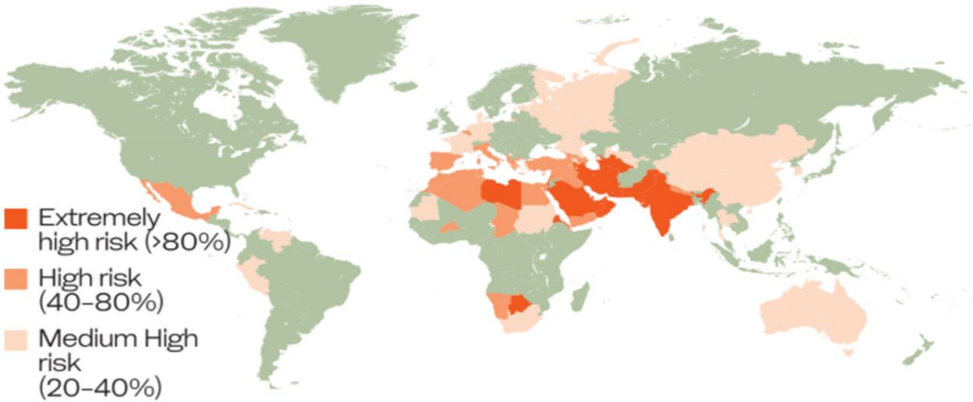
INTRODUCTION

Overall water risk



12/17 most water-stressed countries in the world are in the MENA region

8 Saudi Arabia's rank in the Aqueduct Water Risk Atlas

6–14% Projected GDP loss due to climate-related water scarcity in the MENA region by 2050, according to the World Bank

82% Amount of MENA's wastewater that is not reused

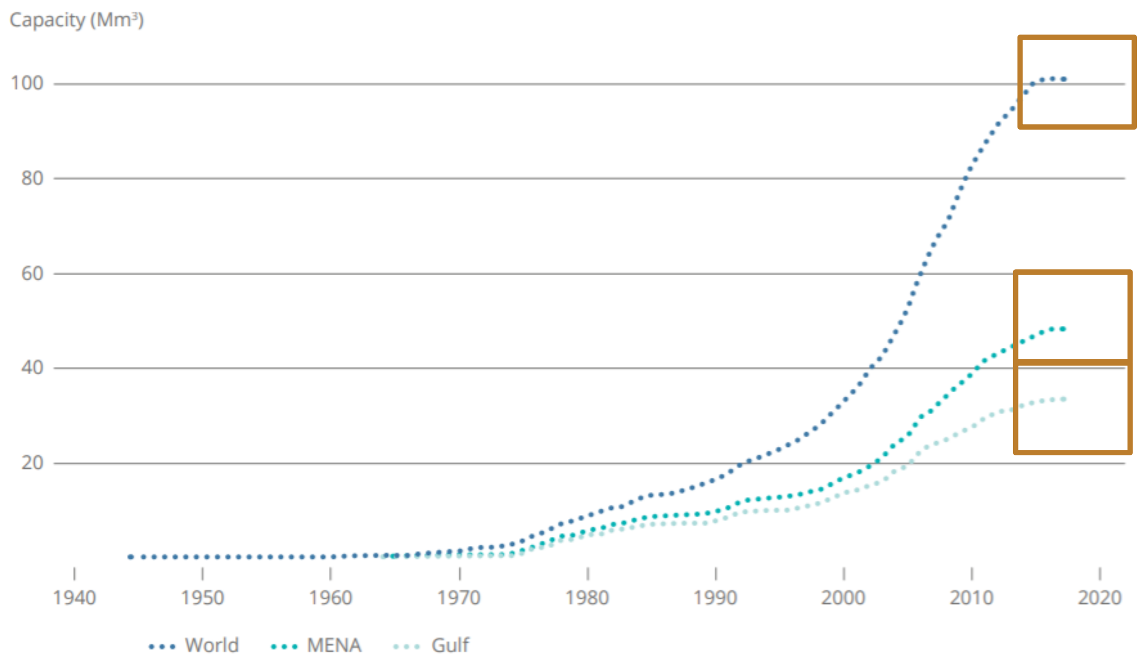
43% Amount of water usage that is expected to be saved in the next decade through Saudi Arabia's Qatrah program

44% Amount of treated wastewater in the Gulf region that is reused

84% Amount of wastewater collected that is treated to safe levels in GCC countries

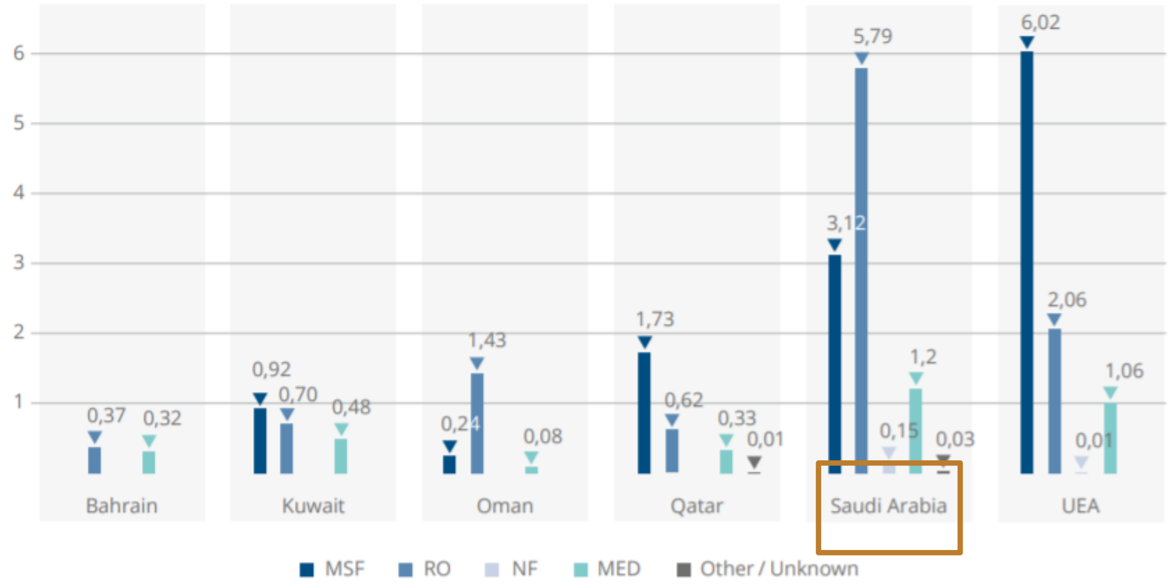
World Resources Institute

Introduction – Global water desalination



Cumulative contracted capacities globally and per region since 1944 (m3 /d) Source: Desal Data/GWI

Introduction – Desalination technologies distribution (Capacities in Mm3 /d) in GCC



Source: Desal Data/GWI

How much energy is then needed ?

Main drivers:

- Population growth
- Growing agriculture
- Growing industrial sector

-This indicates huge market potential

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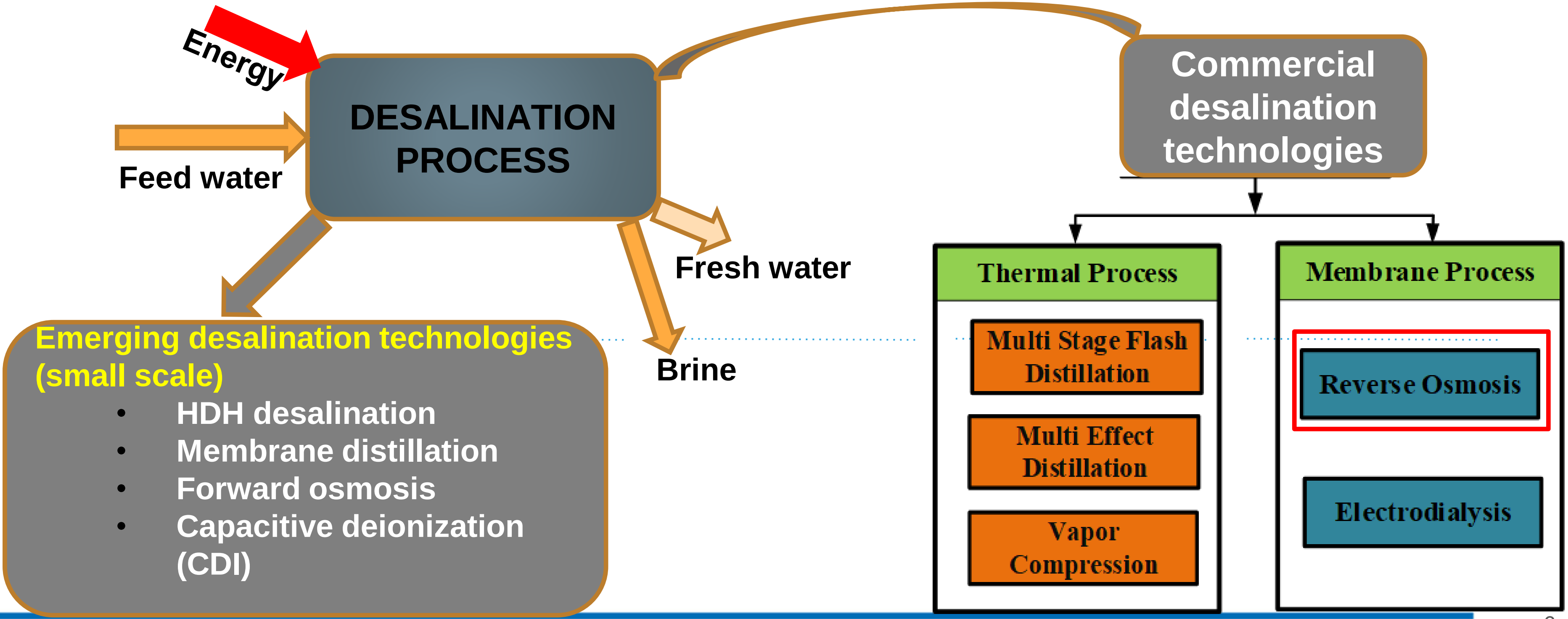
Overview of Desalination and Renewable Energy technologies

Desalination technologies



Introduction –Important factors regarding desalination

Energy need
- Consumes high
- Mostly fossil fueld
- Electric or thermal

Feed water
- Seawater, underground
- Different salinity levels

DESALINATION

Cost of desalinated water
- Varies based on tech
- Unit currency per m^3

Environment
- Brine disposal/management
- Aquatic life
- CO_2 emission

Energy requirement for desalination

Properties	Desalination technology						
	MSF	MED	MVC	TVC	SWRO	BWRO	ED
Typical unit size (m3/day)	50,000–70,000	5,000–15,000	100–3,000	10,000–30,000	Up to 128,000	Up to 98,000	2–145,000
Electrical energy consumption (kW h/m3)	2.5–5	2–2.5	7–12	1.8–1.6	4–6 with energy recovery	1.5–2.5	2.64–5.5 recovery
Thermal energy consumption (MJ/m3)	190–282	145–230	None	227	None	None	None
Equivalent electrical to thermal energy (kW h/m3)	15.83–23.5	12.2–19.1	None	14.5	None	None	None
Total electricity consumption (Kw h/m3)	**19.58–27.25**	**14.45–21.35**	**7 – 12**	**16.26**	**4 – 6**	**1.5–2.5**	**2.64–5.5, 0.7–2.5 at low TDS**
Product water quality (ppm)	≈10	≈10	≈10	≈10	400–500	200–500	150–500

Source: Al-Karaghouli 2013

Costs of desalinated water

Desalination method		Capital costs (million US$/MLD)		O&M costs (US$/m³)		Cost of water production (US$m³)	
		Range	Average	Range	Average	Range	Average
MSF		1.7-3.1	2.1	0.22-0.30	0.26	1.02-1.74	1.44
MED-TVC		1.2-2.3	1.4	0.11-0.25	0.14	1.12-1.50	1.39
SWRO Mediterranean Sea		0.8-2.2	1.2	0.25-0.74	0.35	0.64-1.62	0.98
SWRO Arabian Gulf		1.2-1.8	1.5	0.36-1.01	0.64	0.96-1.92	1.35
SWRO Red Sea		1.2-2.3	1.5	0.41-0.96	0.51	1.14-1.70	1.38
SWRO Atlantic and Pacific oceans		1.3-7.6	4.1	0.17-0.41	0.21	0.88-2.86	1.82
Hybrid	MSF/MED	1.5-2.2	1.8	0.14-0.25	0.23	0.95-1.37	1.15
	SWRO	1.2-2.4	1.3	0.29-0.44	0.35	0.85-1.12	1.03

Note: Costs are at 2016 values. MED-TVC = multiple effect distillation with thermal vapor compression; MLD = million liters per day; MSF = multistage flash distillation; O&M = operation and maintenance; SWRO = seawater reverse osmosis.

Source: World bank group – March 2019

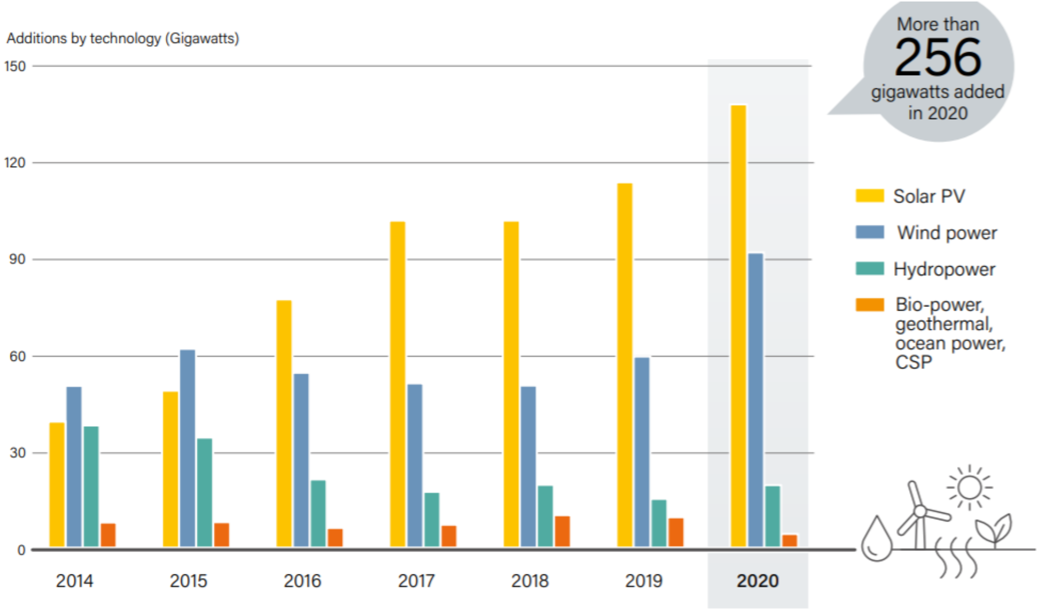
Overview of Renewable Energy (RE)

Why renewable energy ?

- Save excess crude oil and increase its export
- Grow contribution of renewables to the national energy mix
- Increase the localization of non-oil sectors
- Reduce carbon emissions (pollutions)
- Ensure the sustainable use of water resources
- Develop economic ties with global partners

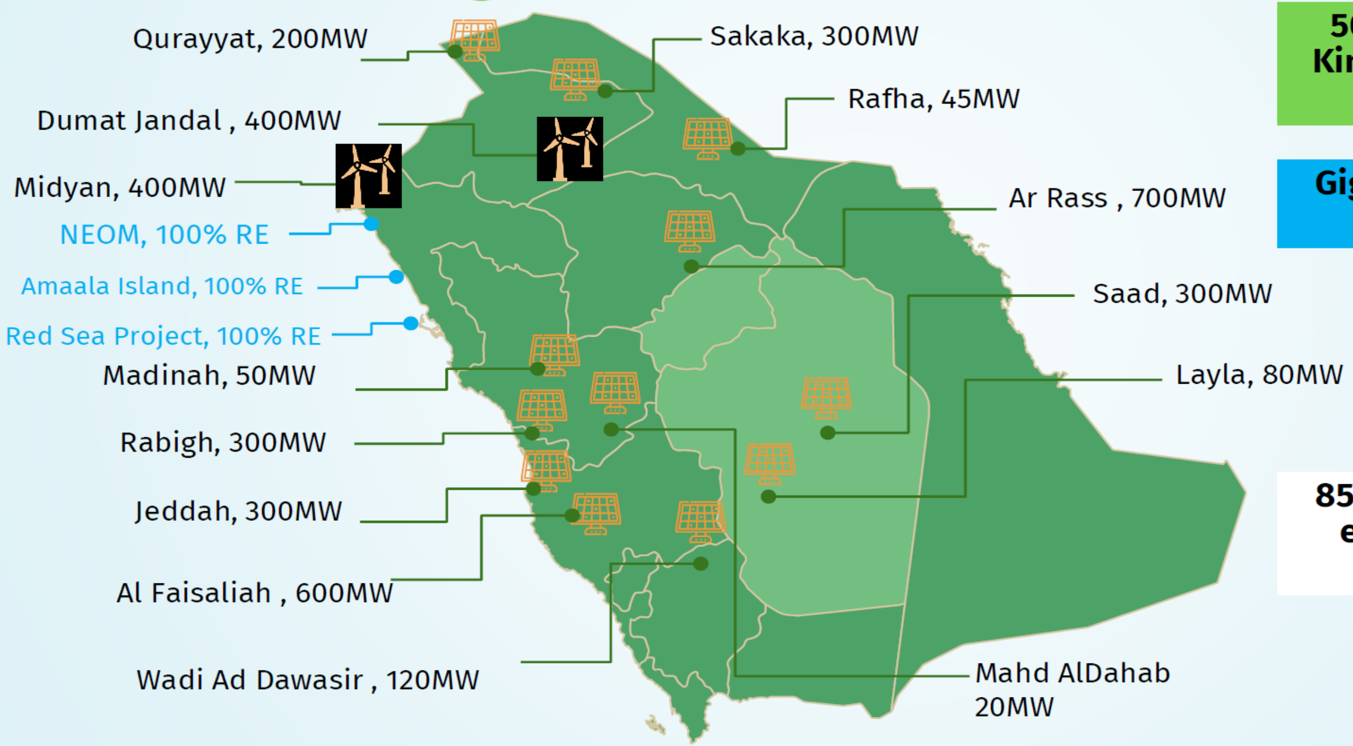
Global Renewable Energy

- With increasing renewable energy power generation capacity, desalination plants powered by RE are most promising.
- By 2020, a total of 2,839 GW of power is generated through RES with a share of 29% in global electric production.
- Solar PV generation of **139 GW (50% of REs)** and wind generation of **93 GW (36%)** were added respectively in 2020.



Source: ren21.net/

KSA Energy Mix Plan



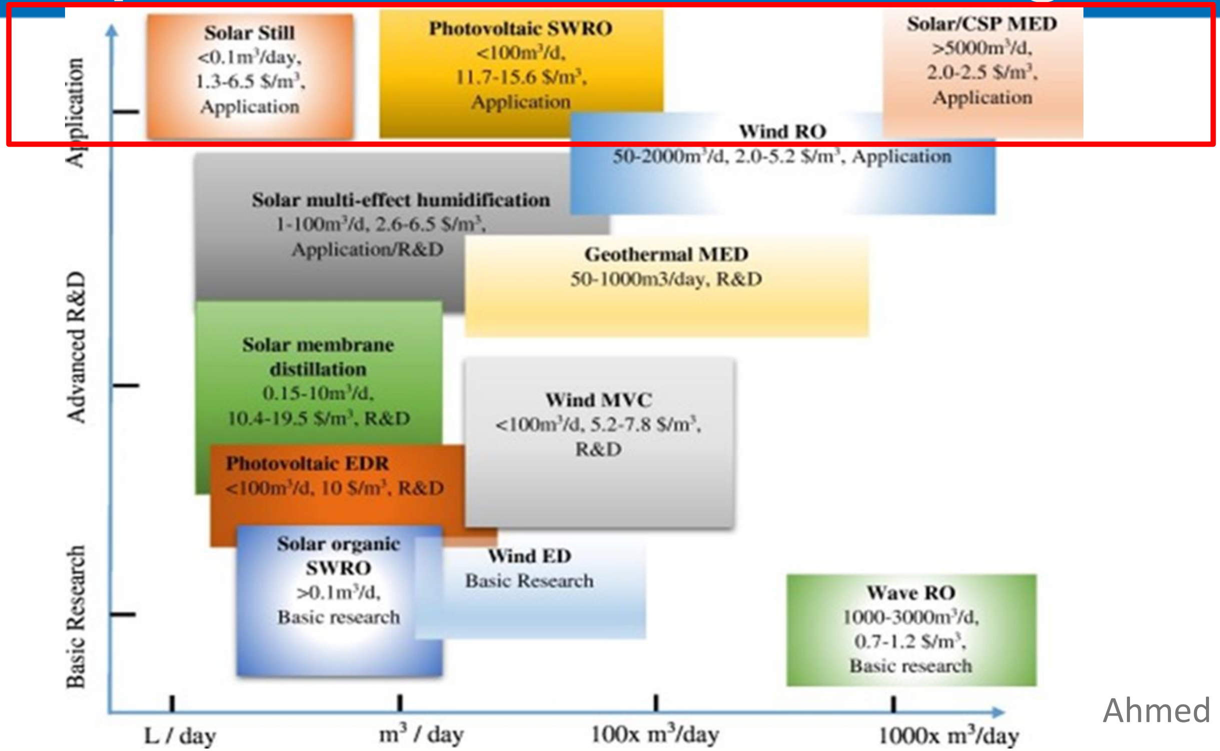
50% renewables in the Kingdom's energy mix by 2030

Giga projects with 100 % RE, NEOM, Red Sea

85 GW of non-renewable electricity generation capacity in 2019

Progress of Renewable Energy Water Desalination

Status of operated RE desalination technologies



Ahmed et al. 2019

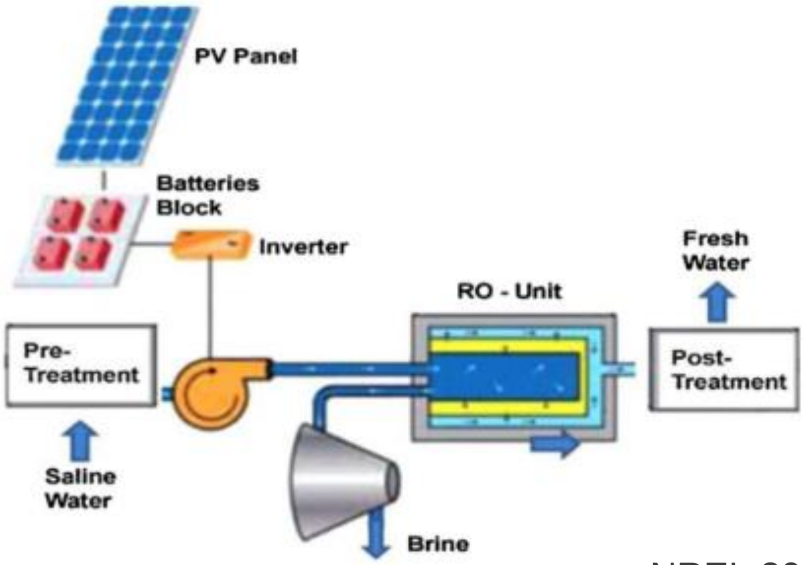
Energy consumption and water production costs of RE

RE-desalination process	Typical capacity (m^3/day)	Energy demand (kW he/m^3)	Water production cost (US$/$m^3$)
Solar still	< 100	Solar passive	1.3–6.5
Solar MEH	1–100	Thermal: 29.6 Electrical: 1.5	2.6–6.5
Solar MD	0.15–10	45–59	10.5–19.5
Solar pond/MED	20,000–200,000	Thermal: 12.4–24.1 Electrical: 2–3	0.71–0.89
Solar pond/RO	20,000–200,000	Seawater: 4–6 Brackish water: 1.5–4	0.66–0.77
Solar CSP/MED	> 5,000	Thermal: 12.4–24.1 Electrical: 2–3	2.4–2.8
Solar PV/RO	< 100	Seawater: 4–6 Brackish water: 1.5–4	11.7–15.6 6.5–9.1
Solar PV/EDR	< 100	1.5–4	10.4–11.7
Wind/RO	50–2,000	Seawater: 4–6 Brackish water:1.5–4	6.6–9.0 small capacity 1.95–5.2 for 1000 m^3/d
Wind/MVC	< 100	7–12	5.2–7.8
Geothermal/MED	80	Thermal: 12.4–24.1 Electrical: 2–3	2–2.8

Esfahani et al. 2016

Example PV-RO desalination pilot plants

Location	PV Capacity	Production
Al-khafji, KSA	15 MW	60,000 m^3/day
Jordan	32 kWp	40 m^3/day
Nauru, Australia	131 kWp	100 m^3/day
Oman	3.25 kW	7.5 m^3/day
Ethens	18 modules	0.35 m^3/day
Gran Canarian Islands	4.8 kW	3 m^3/day
Egypt	------	5 m^3/day



NREL 2016

AL-KHAFJI Solar SWRO Plant Project

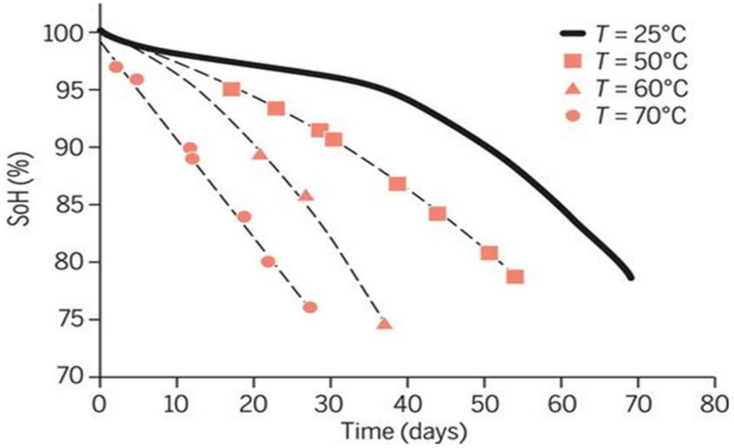
- World's **first** large scale solar powered desalination project.
- Reduction of Power Consumption From **4.2 kW**h/m^3 to **3.7** kWh/m^3.
- Advanced Dosing System Resulted in **15%** Reduction in Chemical Usage.
- Project Capacity **60,000** m^3 per day.

RE Desalination challenges

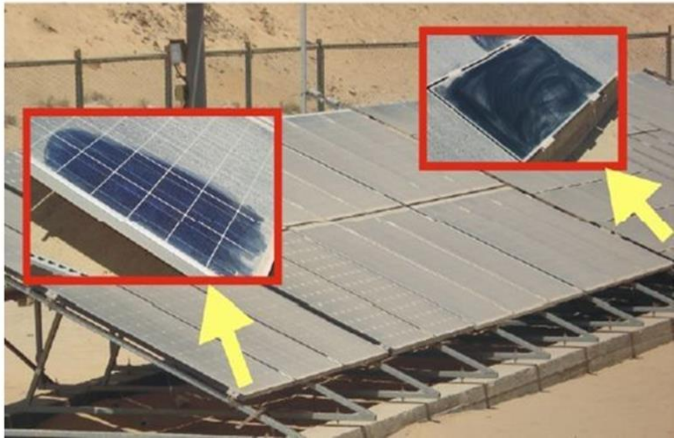
- High investment and financial burden.
- Salt and air conditions effect on the solar system performance.
- Renewable energy sources are Non-dispatchable and intermittent nature .
- Lack of reliable solar resources data in some regions.
- Water crisis in remote areas and small communities
- Environmental issues related to desalination like brine disposal. Chemicals and waste membranes

RE Desalination challenges…

- KSA harsh conditions (temperature , dust, UV) have an impact on the performance of PV modules, solar receivers and batteries.
- Lack of standards and policies regarding grid integration of RES.



Temperature effect on a Li-ion cell Battery



RE Desalination Opportunities

- Hybrid renewable energy sources, energy efficiency and advanced desalination technologies.
- Advanced system control and optimization with intermittency, and autonomous grids.
- Implementation of energy storage.
- Develop a regulatory framework for regulating, evaluating and monitoring the performance of the Renewable Energy water desalination industry.

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IRC-REPS/KFUPM EXPERIENCE IN RE DESALINATION

IRC-REPS Focus Areas

RE Materials

- PV cells and systems under harsh weather (temperature, UV, and dust).
- Thermal (heat) management in different renewable energy technologies and smart building.
- Wind turbine and concentrated solar power (CSP) materials.

Power Systems

- Power system planning, operation, control, protection, stability, and resilience considering bulk RE integration.
- Smart grids, micro-grids, IR4.0, IIoT, cybersecurity, block-chain technologies.
- Energy storage systems and electric vehicle integration into electric grid.
- Electricity markets and power electronic converters for RE grid integration

Hybrid Renewables

- Integrated and hybrid renewable energy systems for power, cooling, and heating applications.
- Hybrid RE systems for ammonia and hydrogen production.
- Hybrid RE systems for water desalination.
- Hybrid RE systems for other applications (agriculture, park, and military).
- RE systems assessment under harsh weather conditions (dust, UV, and temperature).
- RE systems maintenance (cleaning and operation).

Intelligent Energy Management

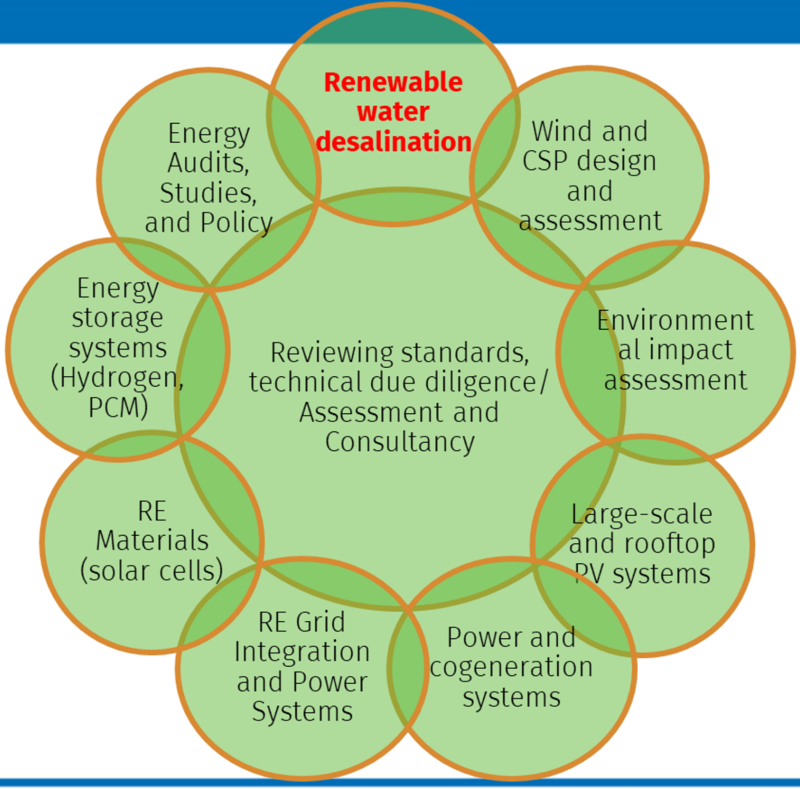
- Smart energy systems management for buildings, industries, and commercial facilities.
- Application of IR 4.0 technologies for energy managements.
- Energy auditing and efficiency improvement recommendations for buildings and plants.
- Policies and standards for energy systems and IR 4.0 technologies.
- Supporting Saudi Energy Efficiency Center.

Policies & Regulations

- Would provide a research and academic hub for the interdisciplinary study of energy policy.
- Work collaboratively with stakeholders and researchers on the economics and politics of energy to find new and innovative approaches for enabling the transition to a low carbon, sustainable and affordable energy system in KSA.

KFUPM/IRC-REPS Activities

Design / Modelling, Simulation, and Optimization / Demonstration / Reviewing standards, technical due diligence/ Assessment and Consultancy



Selected RE Desalination Projects

Research Cluster	Projects	Thesis	Publications
Solar	70+	40+	700+
Wind	30+	7	100+
Desalination	80+	20+	200+

No.	Title	Status	Agency
1	Innovative Sustainable Water Desalination hybrid system	In progress, 2016-	DISC-KFUPM
2	Development and Assessment of a New Water Humidifier for Water Desalination Applications	In progress 2017-	DSR, KFUPM
3	Seawater Desalination using Thermal, Solar, and Hybrid Systems, including Humidification Desalination	2010-2014	Center for Clean Water and Clean Energy, MIT-KFUPM

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Renewable Energy Laboratories and Facilities at KFUPM

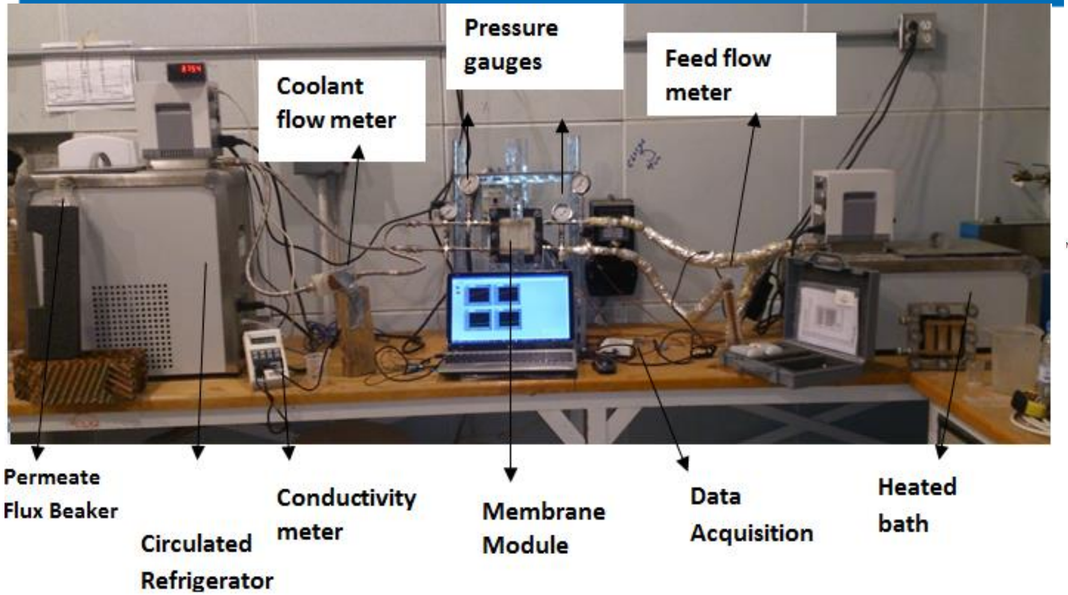
Renewable Energy desalination solutions at KFUPM

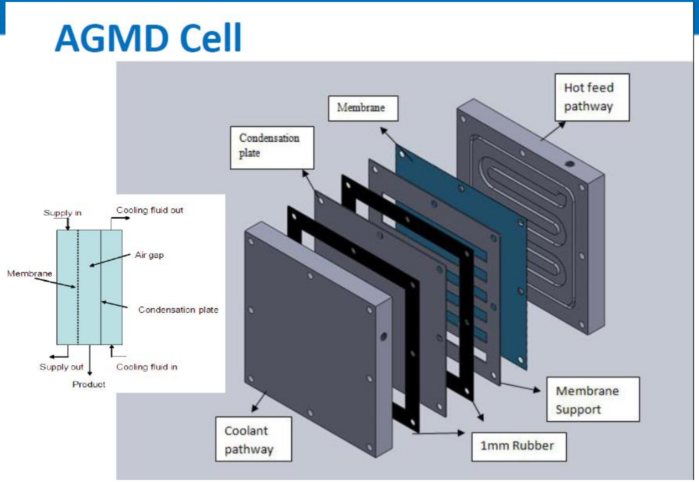
Solar PV-Wind hybrid desalination system at KFUPM

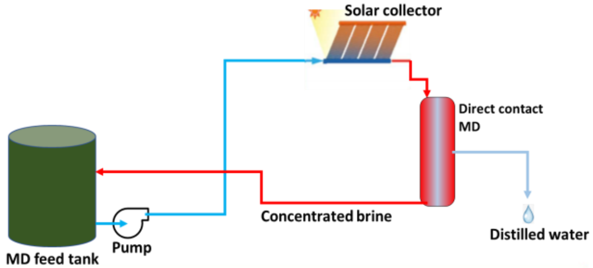
Solar air-heated HDH desalination system

Solar PV-RO unit

Renewable Energy desalination solutions at KFUPM..





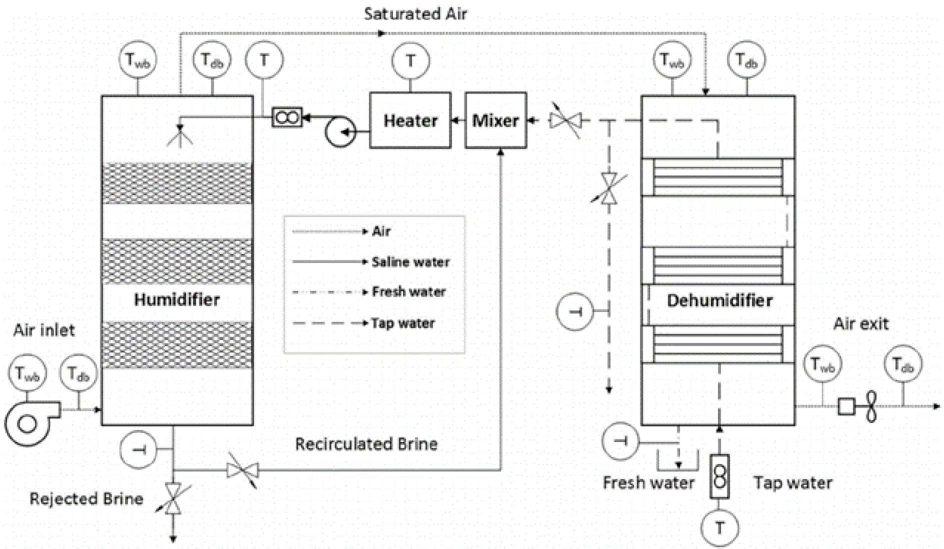


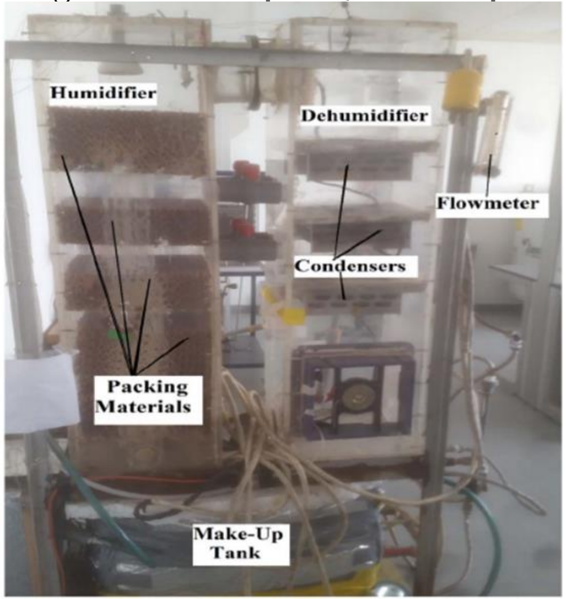
Solar driven air sweeping multistage membrane desalination

- An Air sweeping multistage MD modules was designed and constructed
- Integration of solar heating system to MD system was investigated

Renewable Energy desalination solutions at KFUPM..

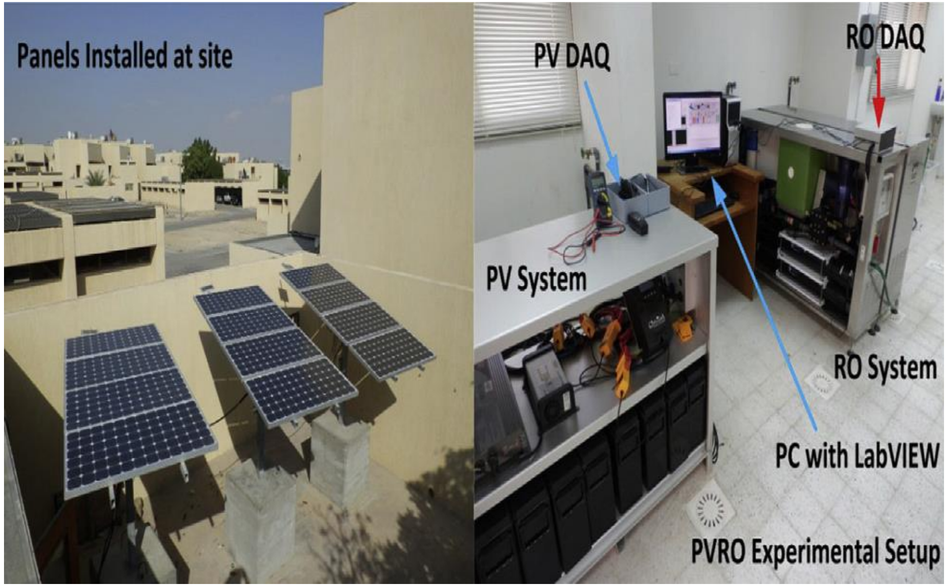
- **A novel design** of a humidification-dehumidification (HDH) desalination systems with heat recovery options was proposed and investigated.
- The cost of the desalinated water produce by Modified HDH ranges between **$0.79/m3 and $2.25/m3**



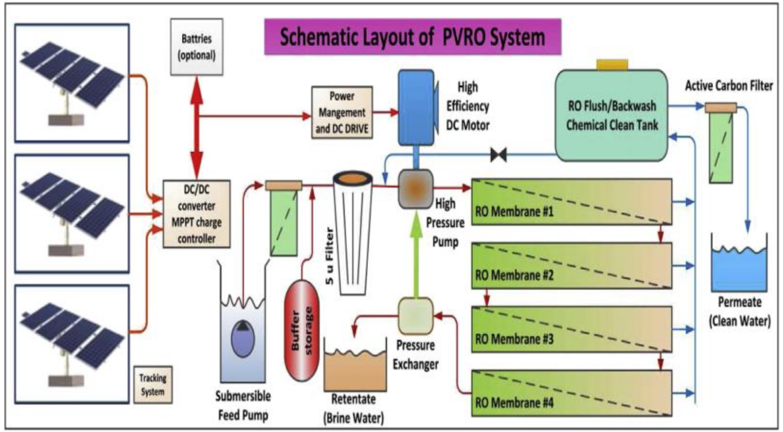


Renewable Energy desalination solutions at KFUPM…

- A **controller that** generates the optimum set point for feed and pressure control loop was designed and tested
- **An Optimized tracked-PV panels system** was developed and implemented to improve water production of a community scale PVRO water desalination system.

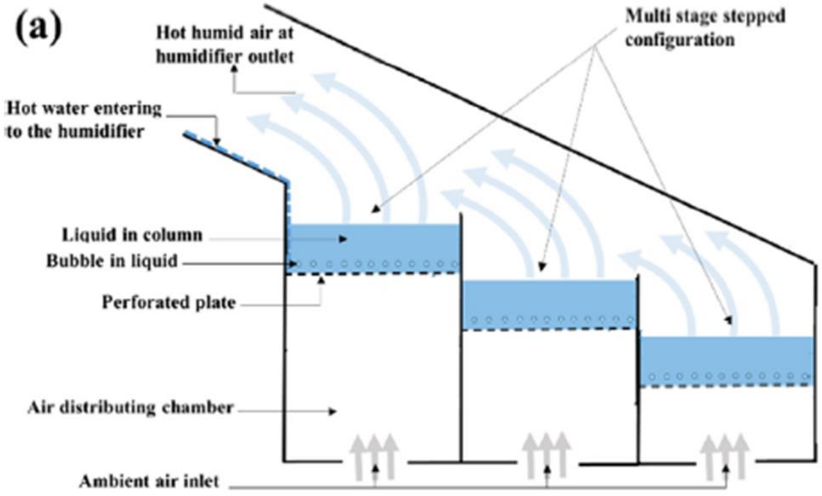


Process flow diagram and Setup PV-RO water desalination



Renewable Energy desalination solutions at KFUPM…

- **A novel design** of a multistage stepped bubble column humidifier for the humidification of air was developed and tested.



Proposed design and set up of the multistage bubble column humidifier

Renewable Energy desalination solutions at KFUPM...

Carrier gas extraction plant using HDH technique

- KFUPM faculty and MIT developed high efficient humidification-dehumidification technique.
- Many **patents obtained**, and a spin-off company in the USA established.
- Invented HDH process implemented in many industrial applications (Desalination, treatment and recycle contaminated oilfield water).

Renewable Energy Research Facilities at KFUPM

Solar Cell Fabrication Lab

PV testing units

Vacuum tube CPC-18 Solar Collectors

PV Cell Fabrication & Module Testing
- KFUPM Campus
- KFUPM beach

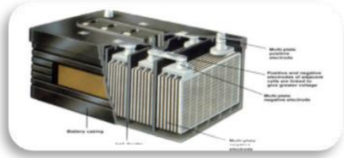
Solar Desalination
- PV-RO
- Solar thermal

Solar Heating & Cooling
- Solar absorption refrigeration & air-conditioning

Energy Storage & Conversion
- Fuel cell
- Phase change materials
- Battery research

PV –RO unit

Fresnel CSP system



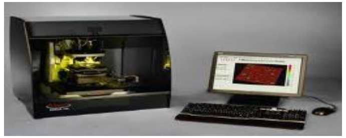
Electrical storage

Thin Film Laboratories

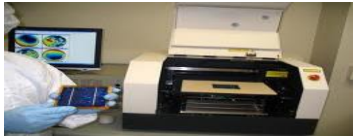
Solar Simulator

Solar cell measurement system

Kithley I-V and C-V system



Stylus Profilometer



μ-PCD

Ellipsometer

FT-IR spectrometer

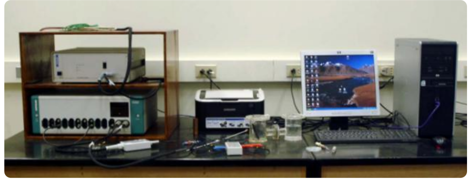
Hall Effect System

Others

- Dual target sputtering system
- Electrospinner
- QE SR system
- Florolog3 PL system
- Weather station
- JASCO UV-Vis system
- Thermal evaporation system
- Tubular furnace
- Accelerated Weathering Tester

Plasma Enhanced Chemical Vapor Deposition (PECVD)- to be operational soon

Energy Storage Laboratories



Potentiostat/Galvanostat

Pure Lab-2GB Glovebox

Furnaces

Fuel Test Station

Electro-chemical Reactor

Membrane Casting Machine

Gas Chromatograph

Solar Thermal Laboratories

KFUPM-University of Stuttgart

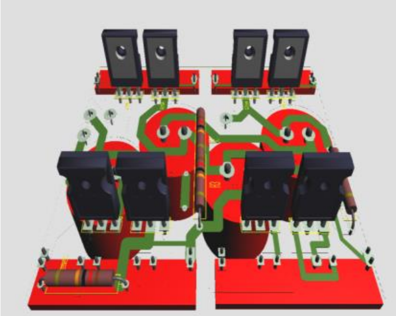
Vacuum tube CPC-18
Solar Collectors

Efficiency: 45%
T_v: -6°C
T_e: 8.5°C min

Universität Stuttgart

Absorbtion Chiller (front) & Hydraullic Unit (back)

RE Grid Integration Laboratories



Hardware capabilities:

- RTDS
- STATCOM/FACTS
- Power Amplifier
- Active Filter
- SEL Relays
- Phasor Measurement Units
- OPAL-RT
- dSPACE Controller
- Wind Generator (PMSG, IG)
- PV Panel and PV Simulator
- Advanced Power Electronics
- Electrical Machine
- Programmable AC/DC Loads/Supply

KFUPM On-campus Test facility

MIT

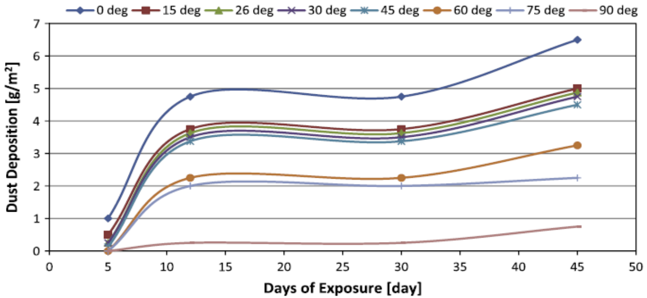
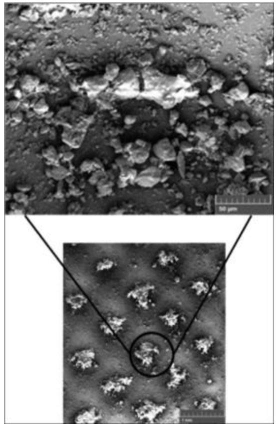
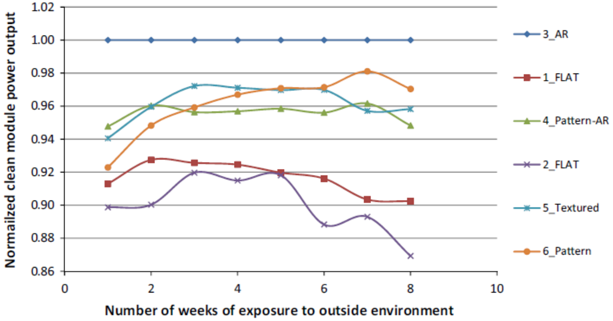
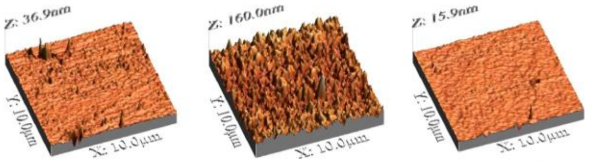


Fig. 8. Dust deposition with exposure periods for different tilt angle.

Fraunhofer







RE Research Facilities at KFUPM Beach

Fresnel CSP system (CER- Ri)

PV testing system

Hybrid (PV-Wind) setup (CER -RI)


Thank you