Advanced Wastewater Treatment using Functionalized Membranes

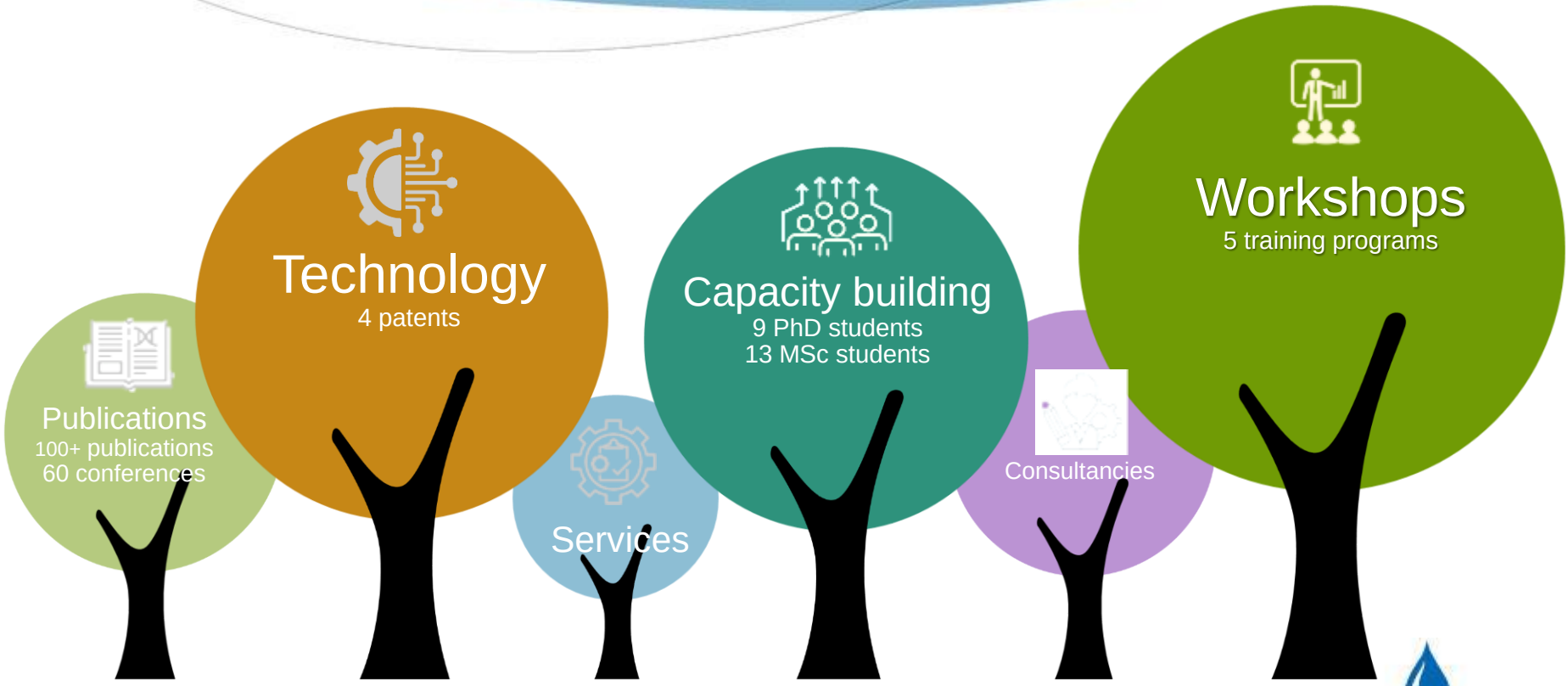
Mohammed Al-Abri
Nanotechnology Research Center
&
Petroleum & Chemical Engineering Department
College of Engineering
Sultan Qaboos University

alabri@squ.edu.om

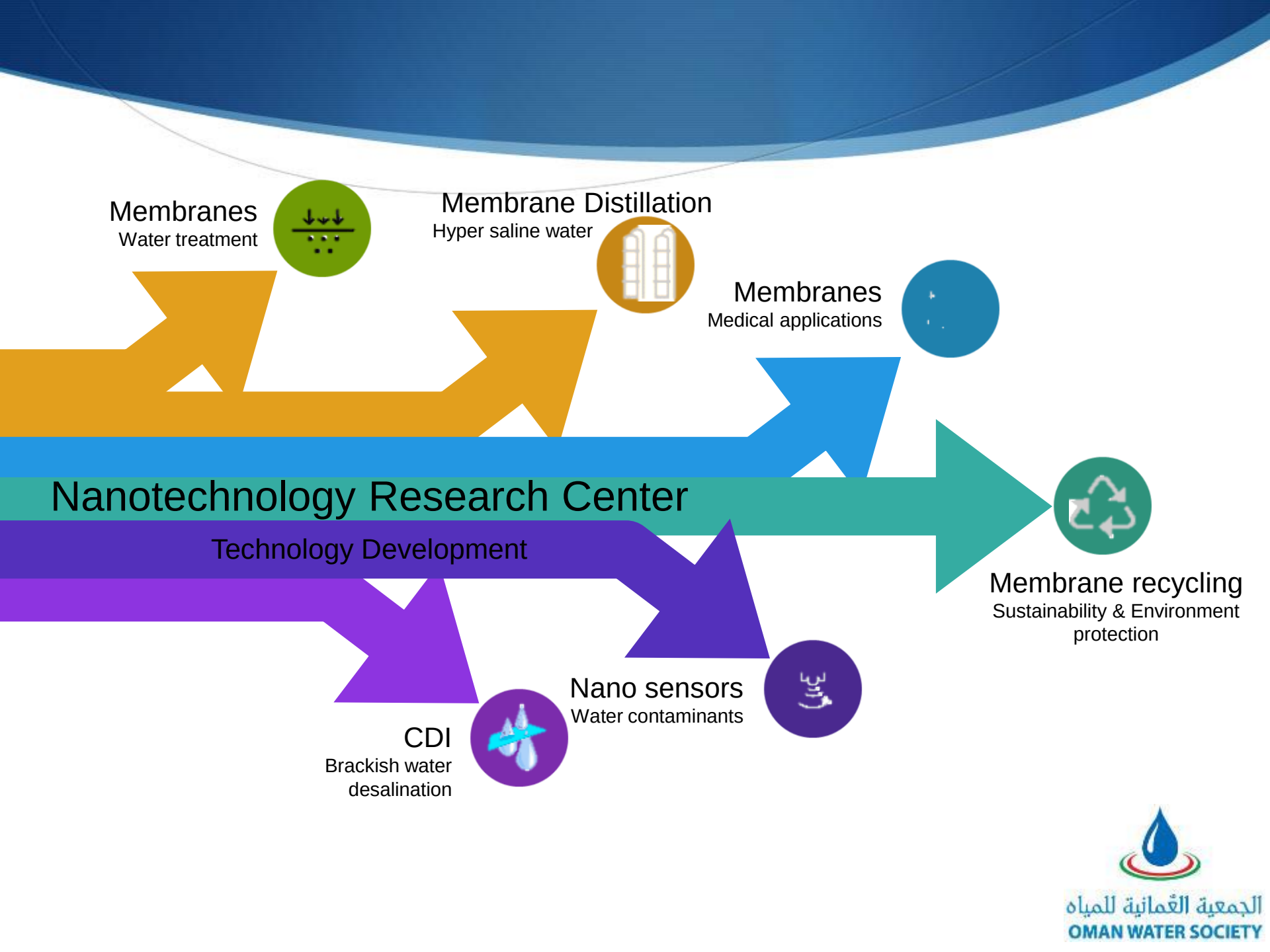
WSTA 15th Gulf Water Conference

28-30 April, 2024, Doha, Qatar

Scientific Output

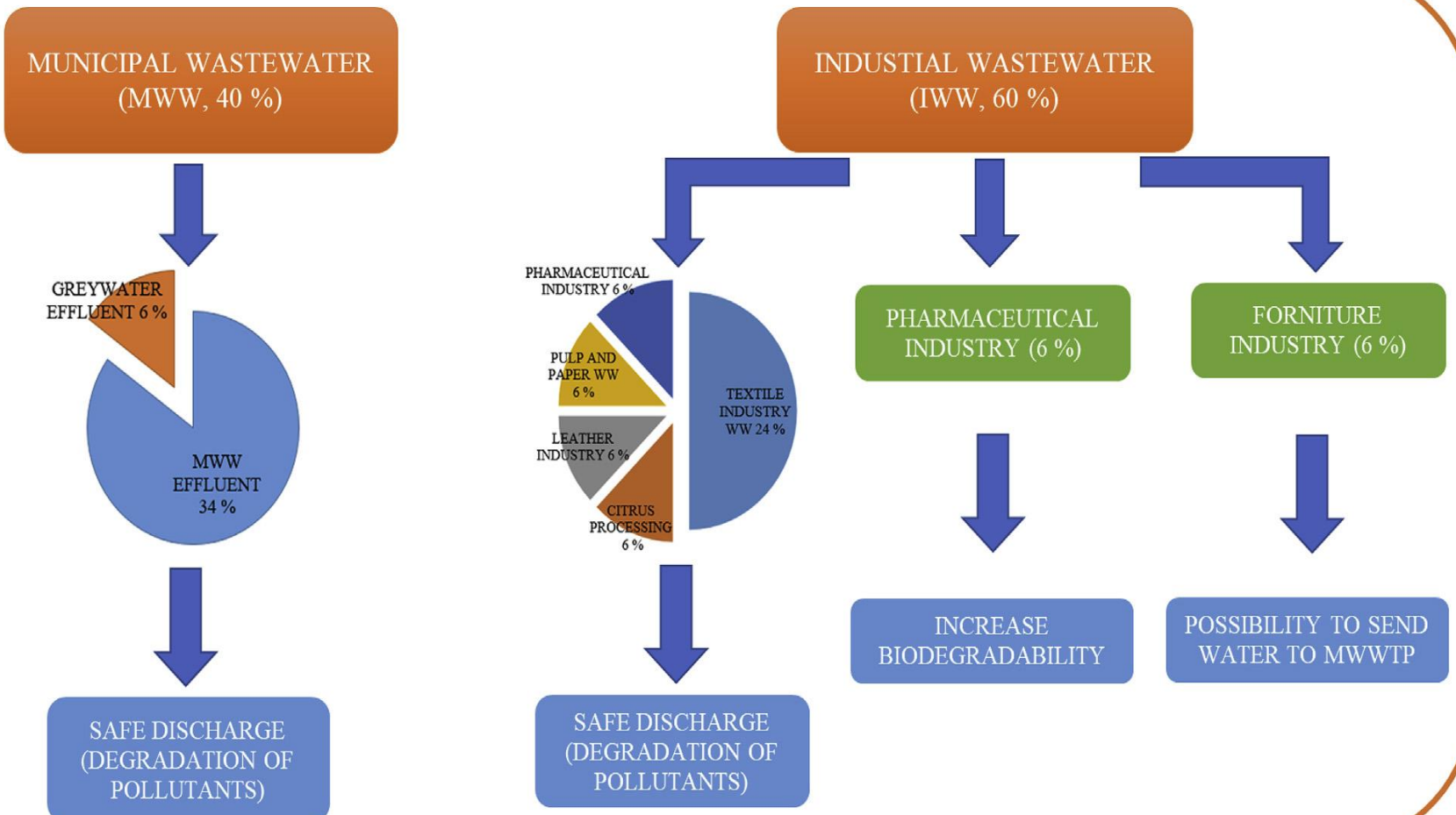


الجمعية العُمانية للمياه
OMAN WATER SOCIETY



الجمعية العُمانية للمياه
OMAN WATER SOCIETY

Industrial wastewater



Rueda-Marquez et al. (2020) Journal of Cleaner Production 258 (2020) 120694

الجمعية العُمانية للمياه
OMAN WATER SOCIETY

Emerging Contaminants

- Emerging (Persistent) Contaminants
  - Microplastics; Average secondary and tertiary WWTPs removal of 88% & 94%, respectively[1]
  - Caffeine > acetaminophen > salicylic acid detected in river water & drinking water in Québec, Canada.
  - Carbamazepine, ibuprofen & sulfamethoxazole also detected[2]

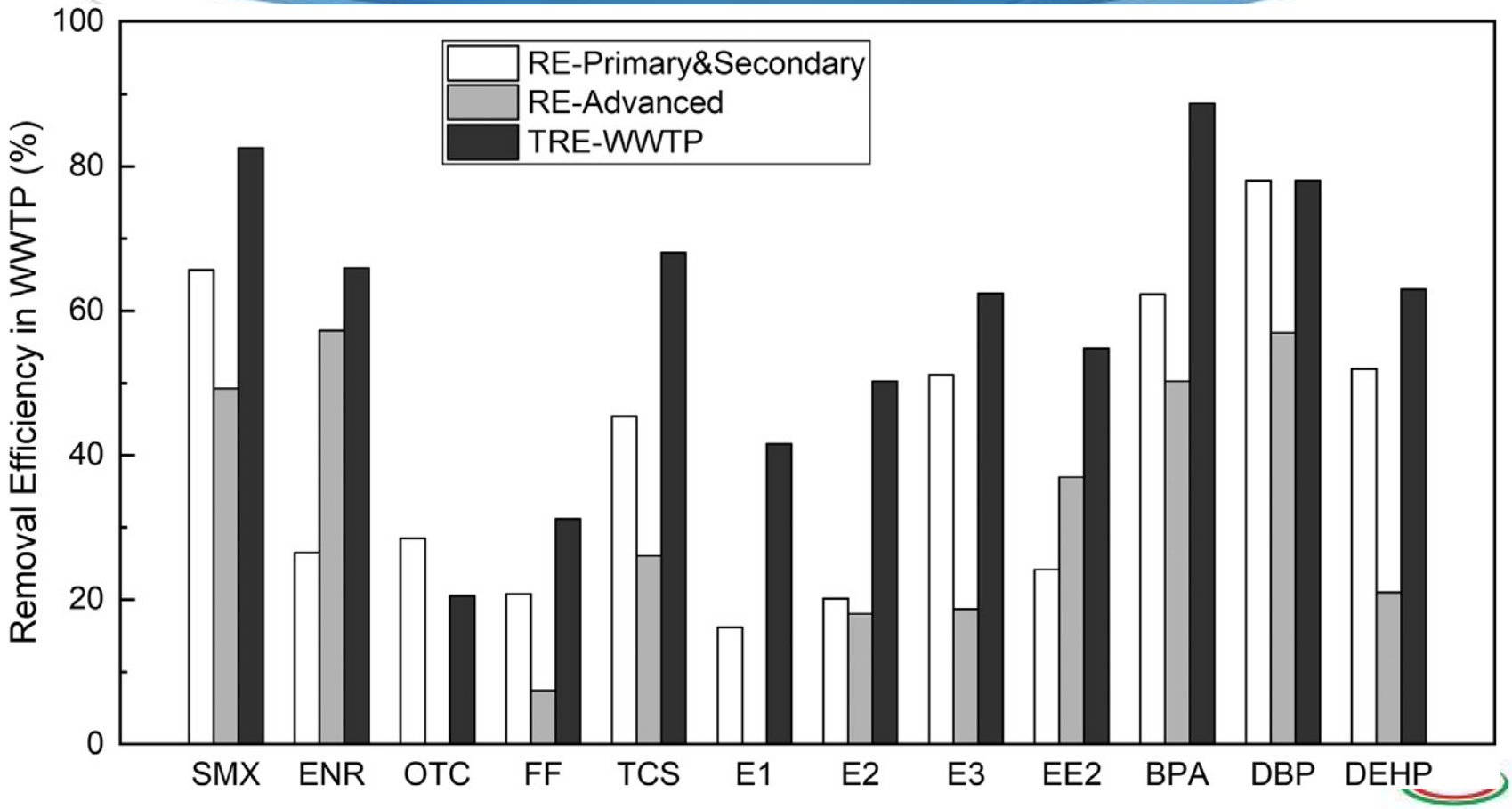
Treated Water Quality Standard (Oman)	
BOD_5	15 ppm
COD	150 ppm

- Iyare et al. (2020) Environmental Science: Water Research & Technology
- Pulicharla et al (2021) Science of The Total Environment

الجمعية العُمانية للمياه
OMAN WATER SOCIETY

Emerging Contaminants

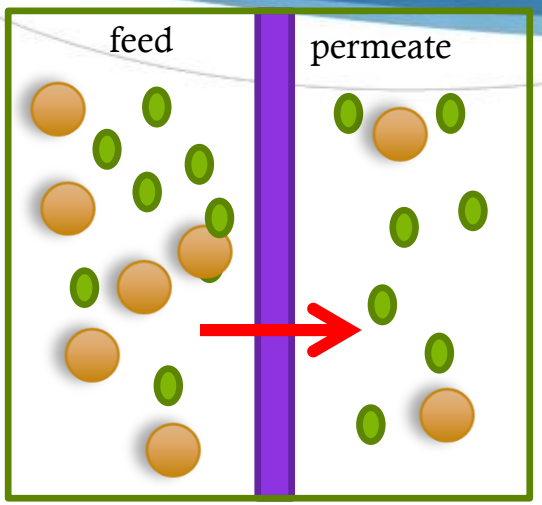
- Removal efficiency of 35 emerging contaminants (pharmaceutical and personal care products & endocrine disrupting chemicals in WWTP in China.

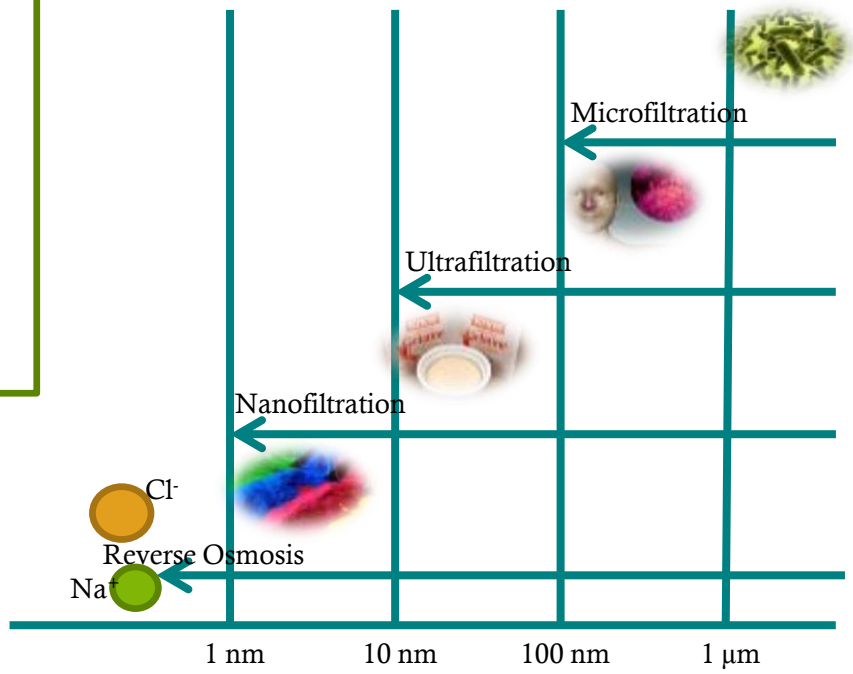


Lin et al. (2020) Science of the Total Environment (744) 140977

الجمعية العُمانية للمياه
OMAN WATER SOCIETY

Membrane definition and classification





الجمعية العُمانية للمياه
OMAN WATER SOCIETY

Membrane fouling

Fouling Types

- Colloidal fouling
- Organic fouling (Protein, Humic substances, oil, NOM)
- Scaling ($CaSO_4$, $MgSO_4$)
- Biofouling (bacteria and Fungi)

Fouling Forms

- Adsorption
- Pore blocking
- Gel/cake formation
- Deposition

Fouling Consequences

- Blocking of membrane pores
- Permeate flux decreases
- Production efficiency decreases
- Operation time increases

Fouling Prevention

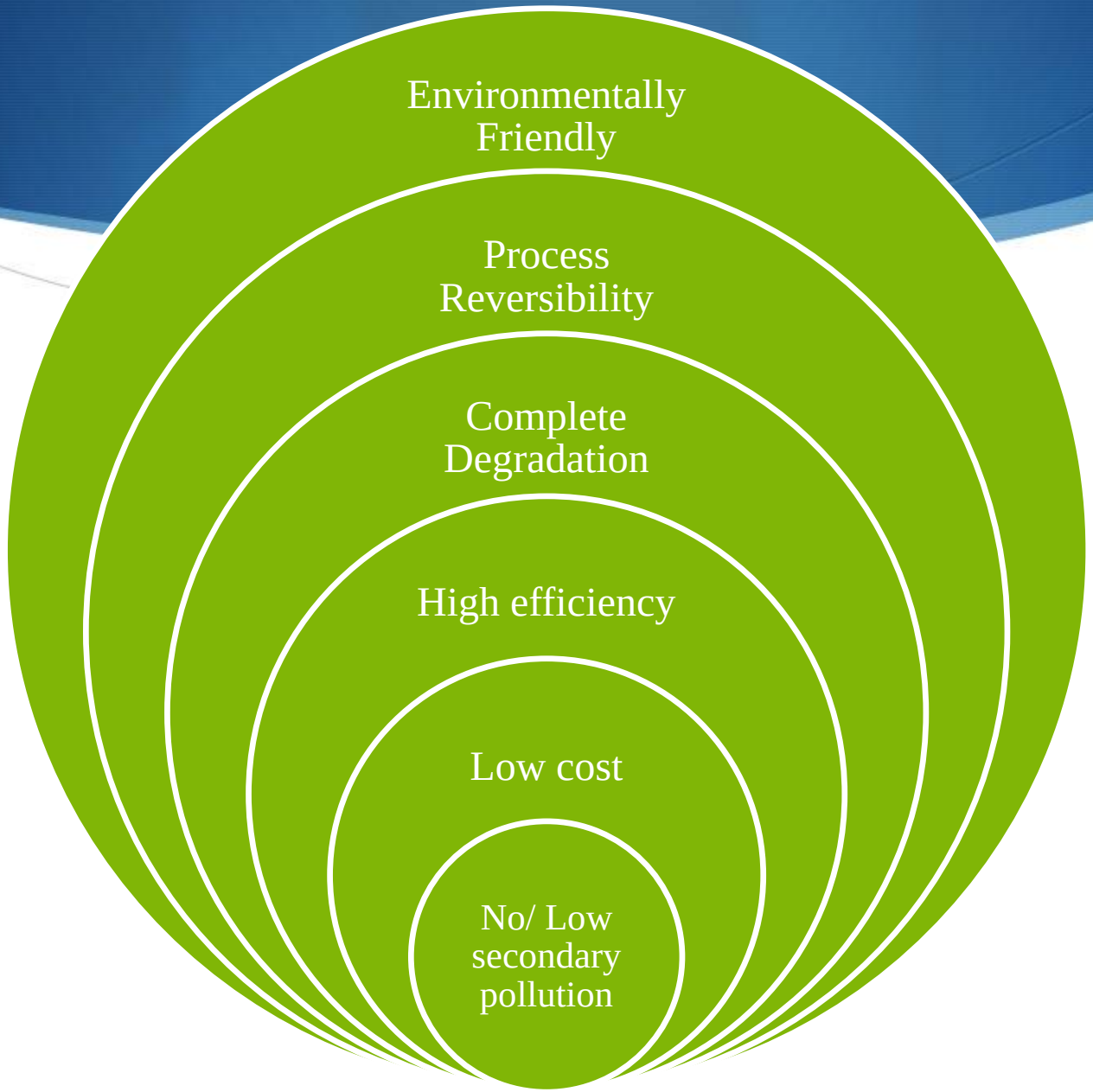
- **Pre-treatment of feed solution**
- **Membrane modification**
- Physical cleaning
- Chemical cleaning
- Self-cleaning process
- Optimization of operating parameters

الجمعية العُمانية للمياه
OMAN WATER SOCIETY

Nanotechnology Processes

الجمعية العُمانية للمياه
OMAN WATER SOCIETY

Nanotechnology Advantages



الجمعية العمانية للمياه
OMAN WATER SOCIETY

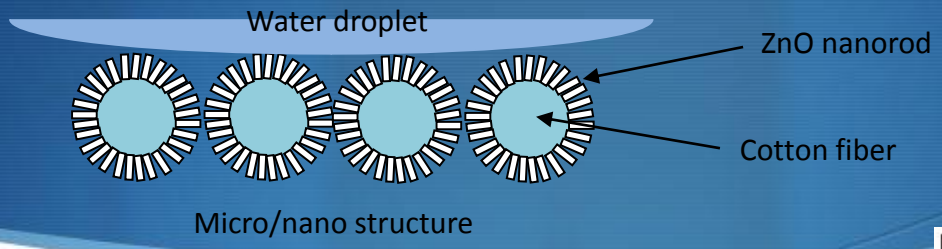
Nanomaterials Enhanced Membranes

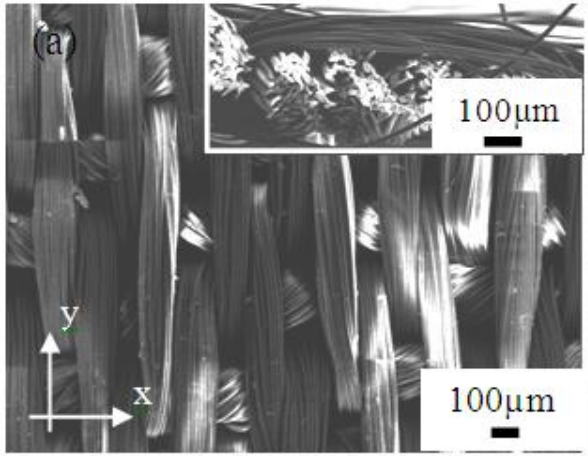
Incorporation of nanomaterials in polymeric membranes improves

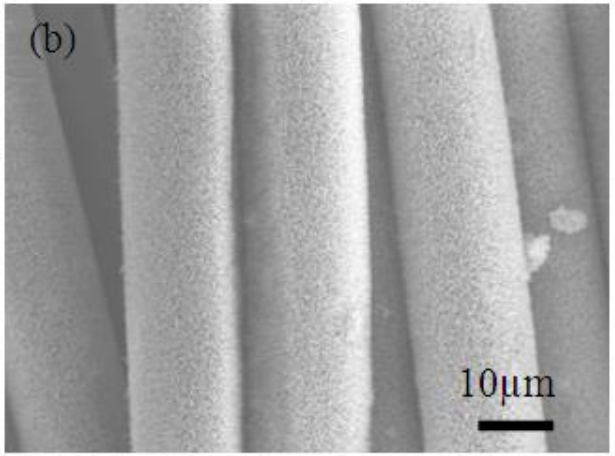
- Permeability
- Mechanical strength
- Thermal stability
- Fouling resistance
- Rejection
- Pore structure and porosity
- Photocatalysis

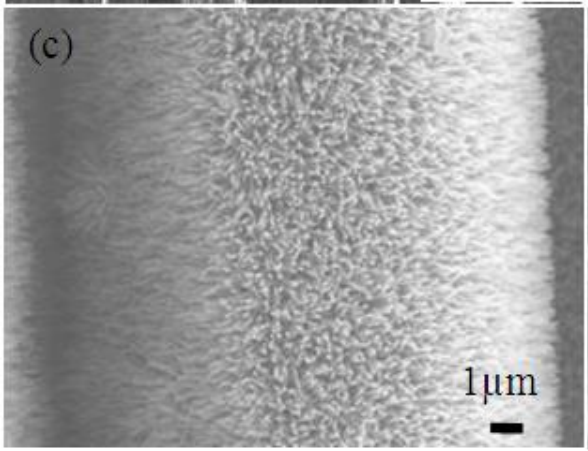
- PES-CNTs
- PES-rGO
- PES-ZnO
- PES-HMO
- PES-Fe_2O_3
- PAN-ZnO
- PAN-β-cyclodextrin
- PEI and PEI-TiO_2
- PES-Ag

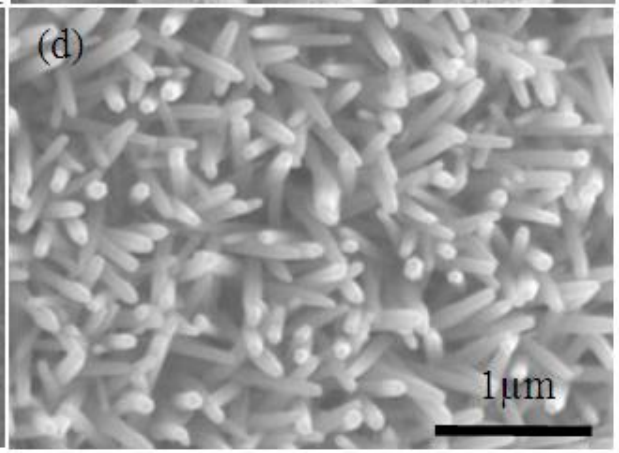
Nature inspired superhydrophobic cotton fabric

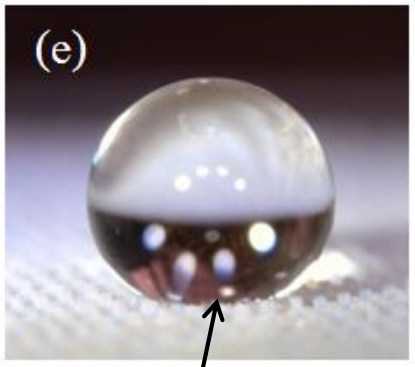


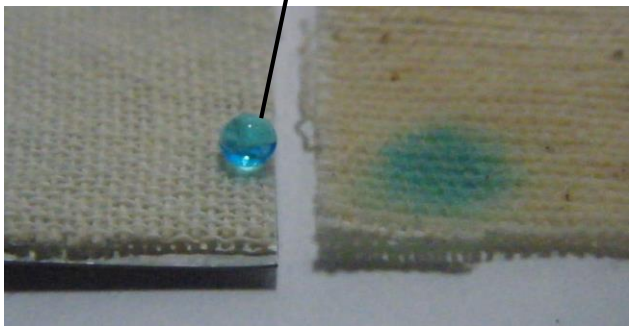






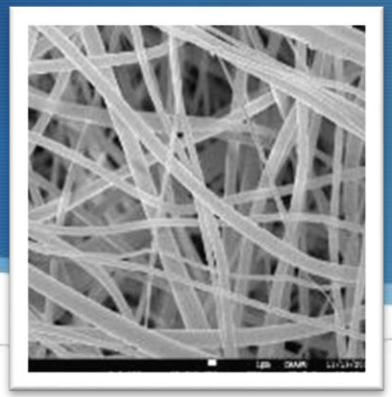


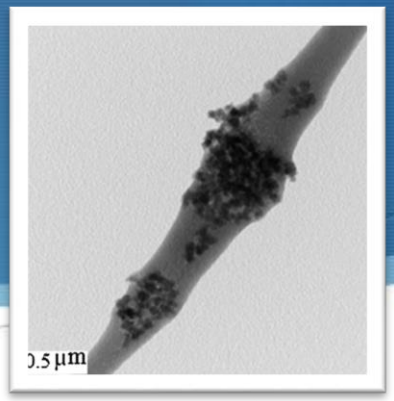


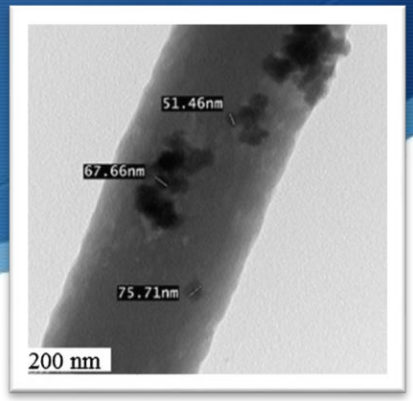


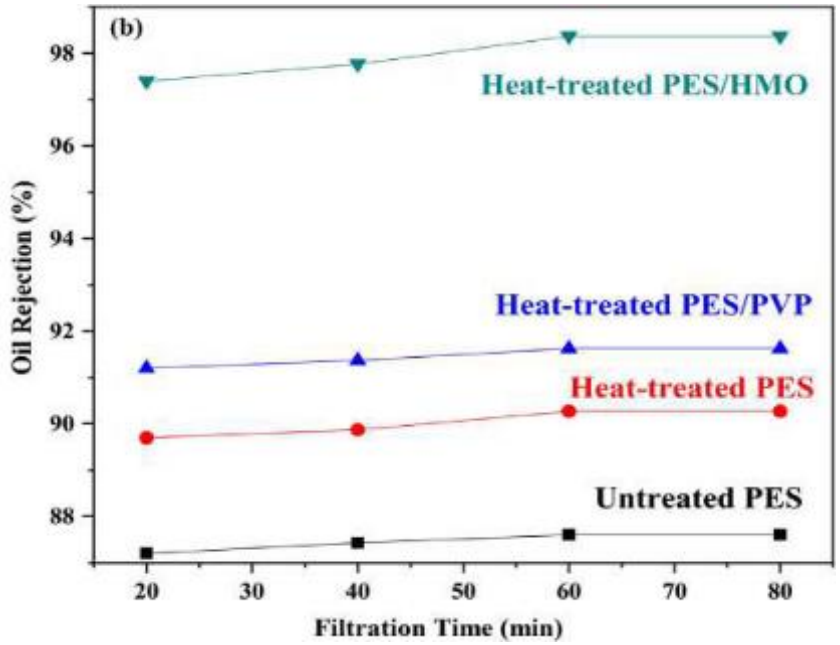
الجمعية العُمانية للمياه
OMAN WATER SOCIETY

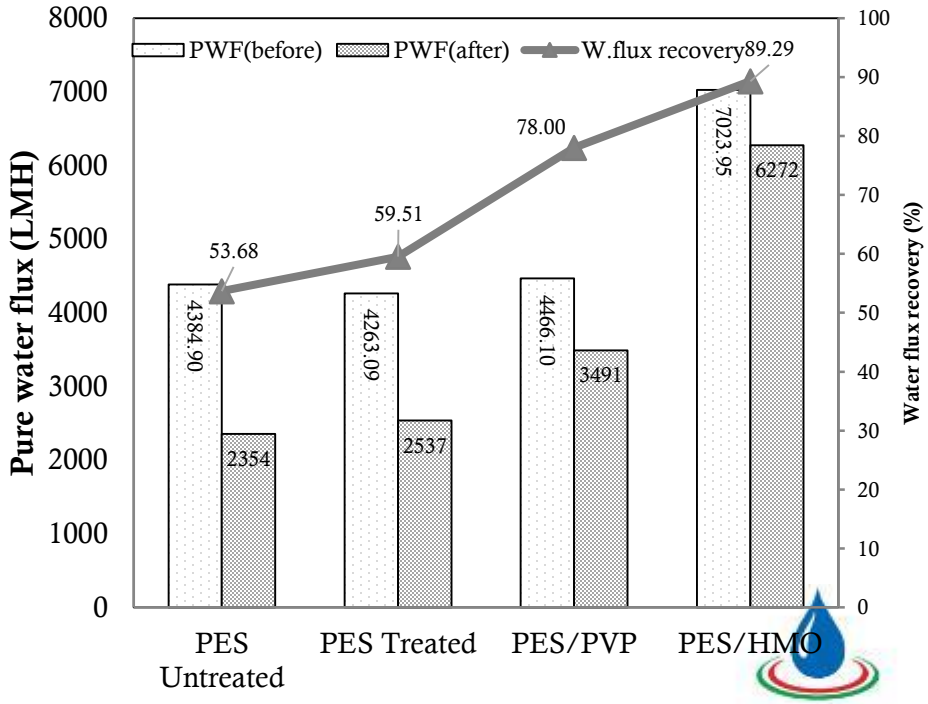
PES-Hydrous Manganese Dioxide ENMs







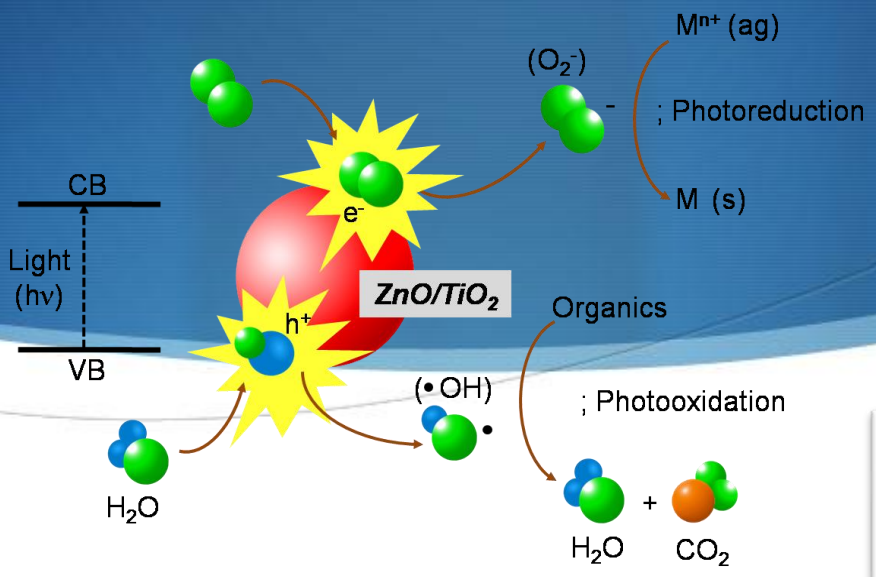


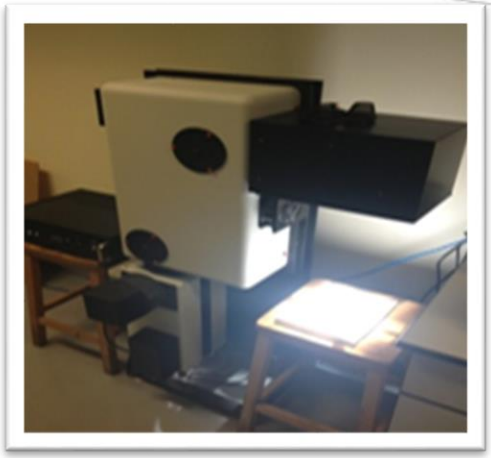


Al-Husaini et al (2019) *Separation and Purification Technology* (21) 205-214

الجمعية العُمانية للمياه
OMAN WATER SOCIETY

Photocatalysis



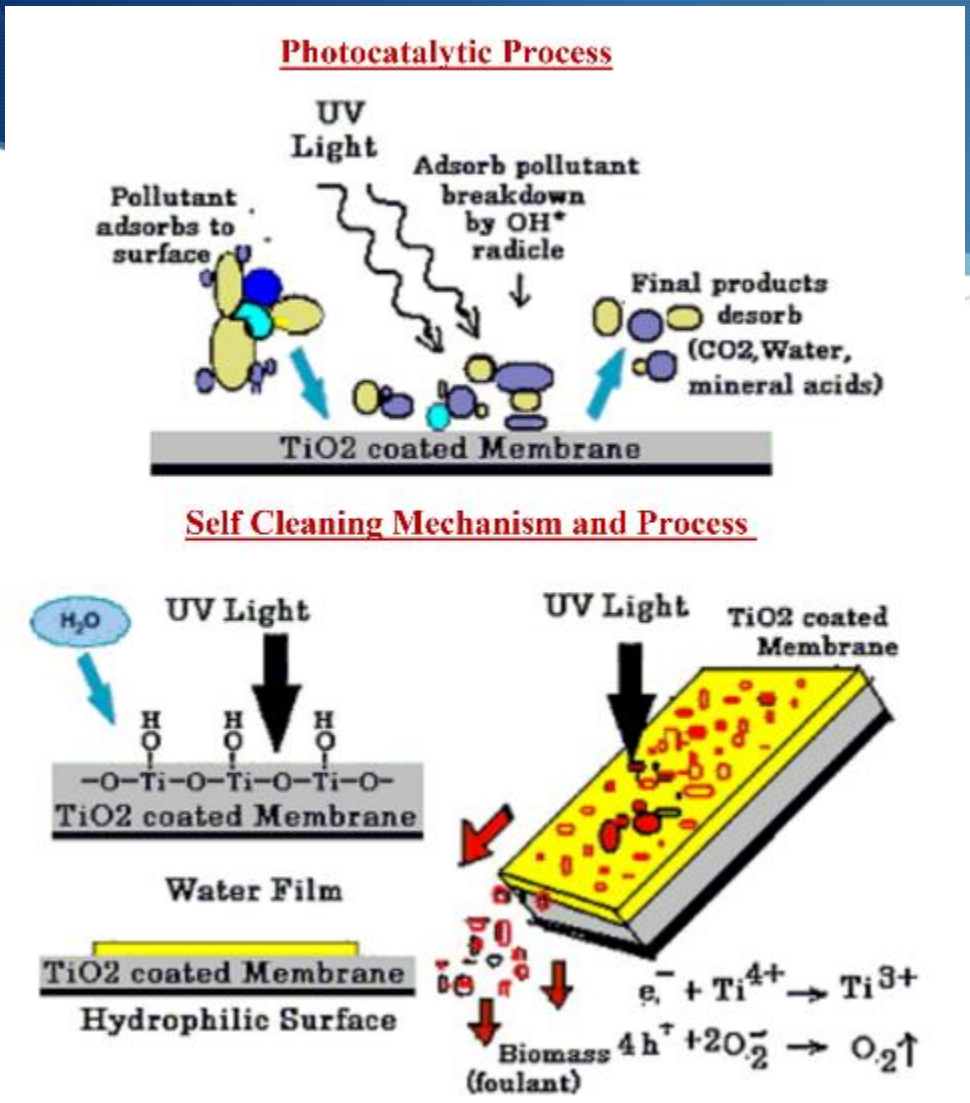


semiconductor (ZnO)

$$\text{Organic pollutant} + O_2 \xrightarrow[\text{hv (UV or visible)}]{} CO_2 + H_2O + \text{mineral acids}$$

الجمعية العُمانية للمياه
OMAN WATER SOCIETY

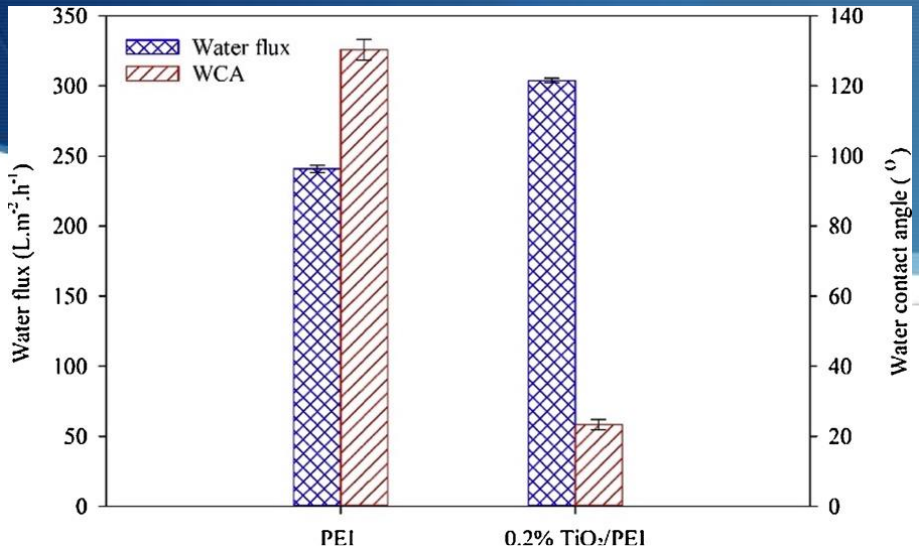
Hybrid Photocatalytic Membranes

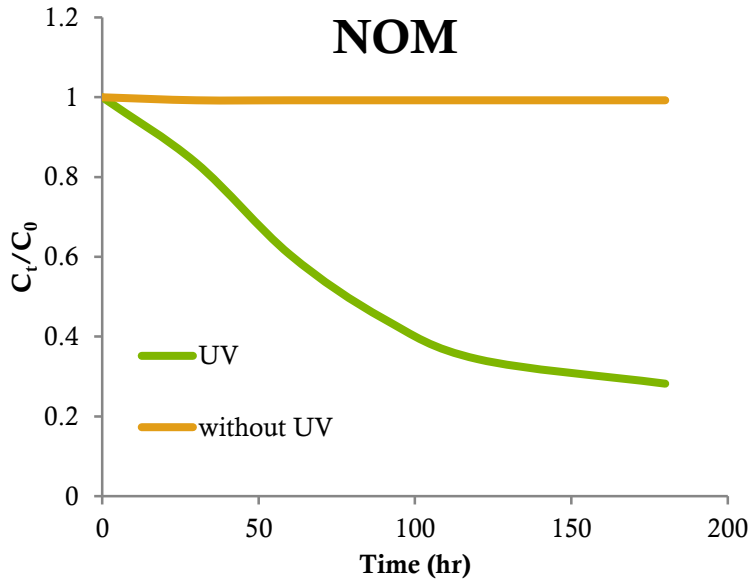


Damodar et. al., Hazardous Materials, (2009) 172

الجمعية العُمانية للمياه
OMAN WATER SOCIETY

PEI-Titanium Dioxide ENMs



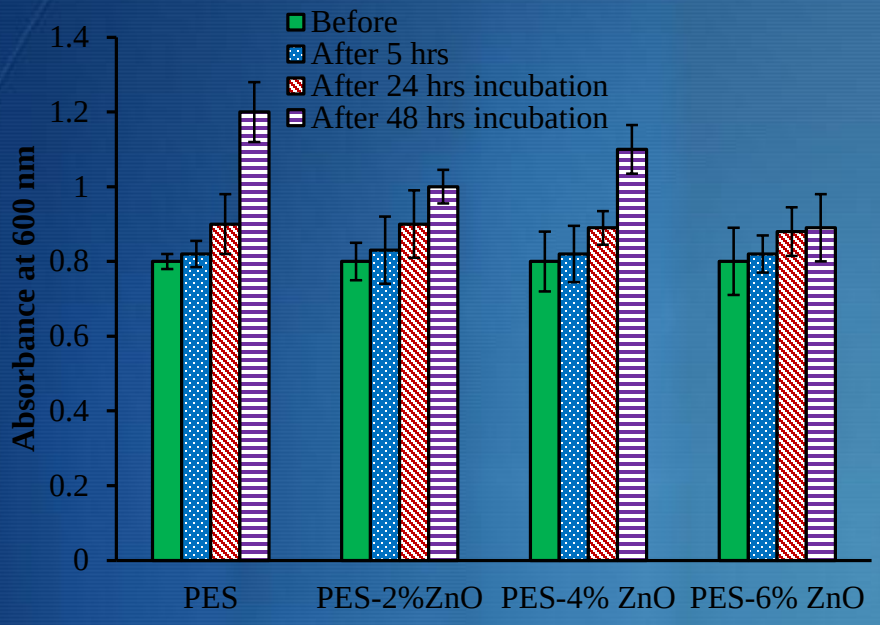


Degradation of > 77% in NOM concentration

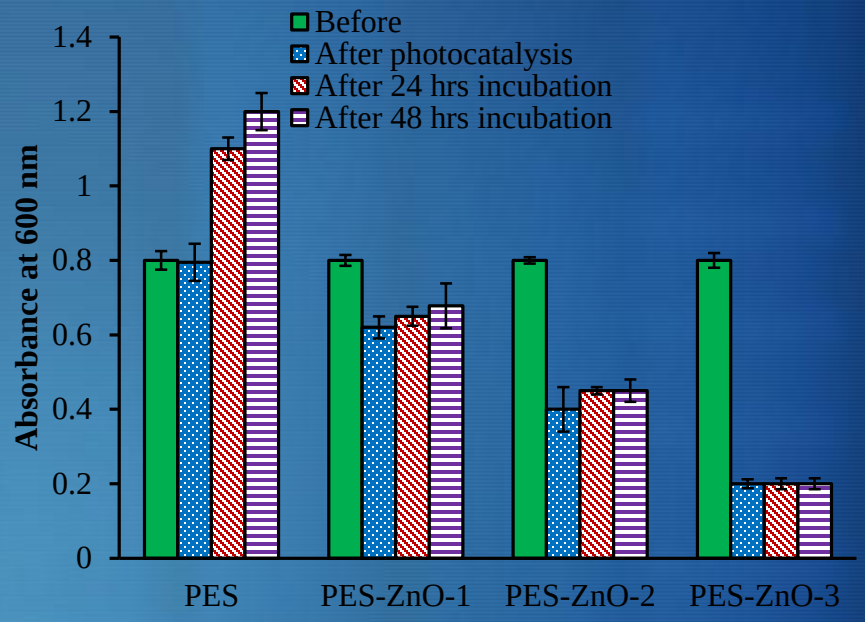
Al-Ghafri et al (2019) *Journal of Water Process Engineering* (32)

الجمعية العُمانية للمياه
OMAN WATER SOCIETY

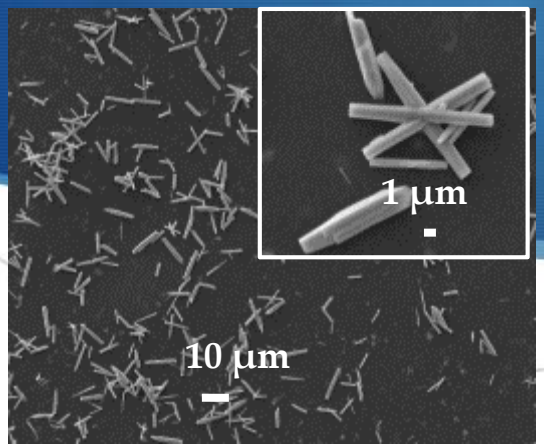
PES membrane modification with ZnO

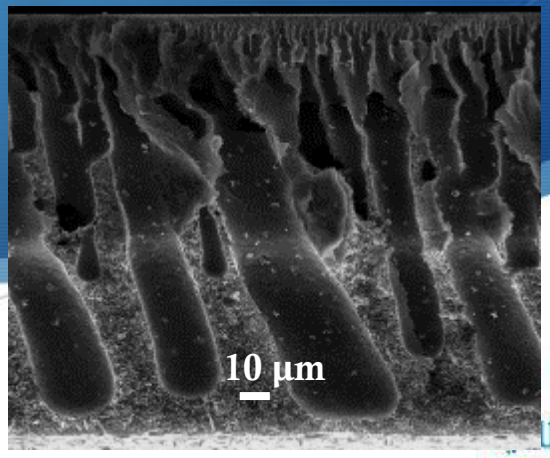


PES-ZnO NPs membranes controlled bacterial growth



PES-ZnO NRs membranes bacterial growth inhibition



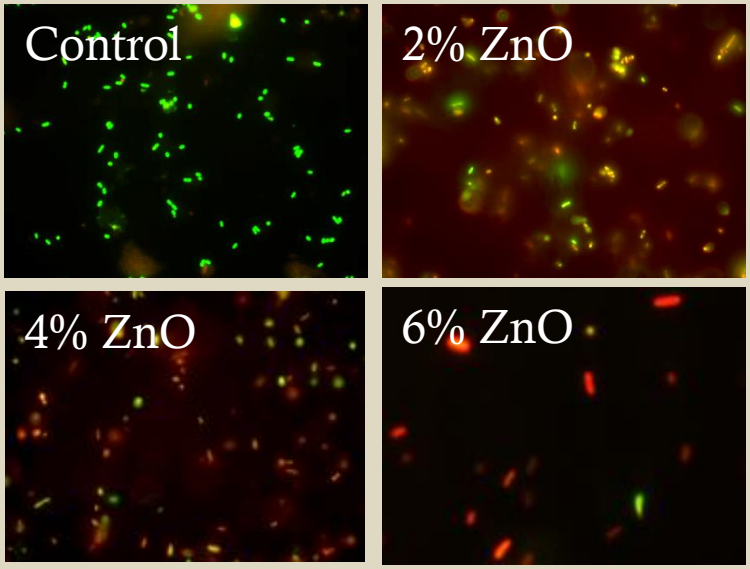


الجمعية العُمانية لـ
OMAN WATER SOCIETY

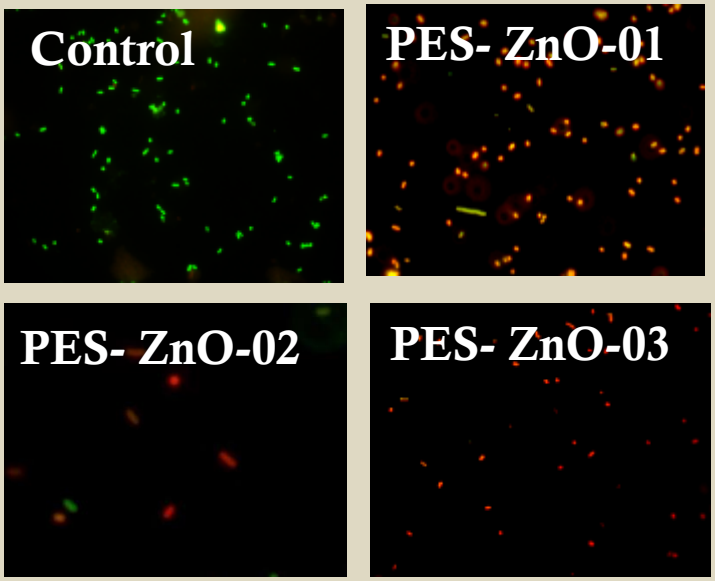
PES membrane modification with ZnO

Antibacterial Activity

ZnO NPs



ZnO NRs



Al-Hinai et al (2017) A*CS Omega* (2) 3157-3167

Technology readiness level

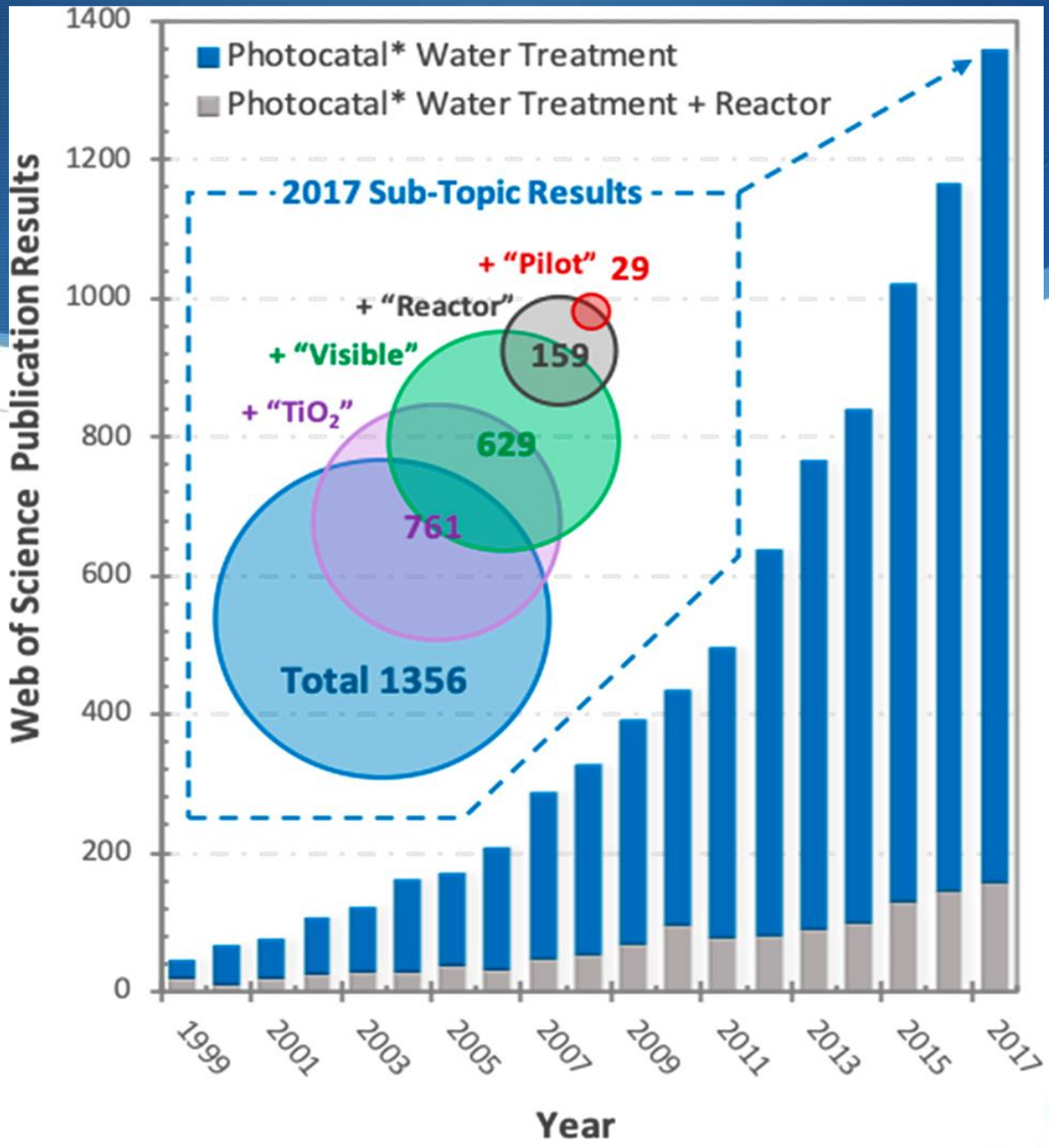
TRL1	Basic principles observed
TRL2	Technology concept formulated
TRL3	Experimental proof of concept
TRL4	Technology validated in lab
TRL5	Technology validated in relevant environment
TRL6	Technology demonstrated in relevant environment
TRL7	System prototype demonstration in operational environment
TRL8	System prototype demonstration in operational environment
TRL9	Actual system proven in operational environment

Membranes
AOPs
Adsorption

Nano Processes

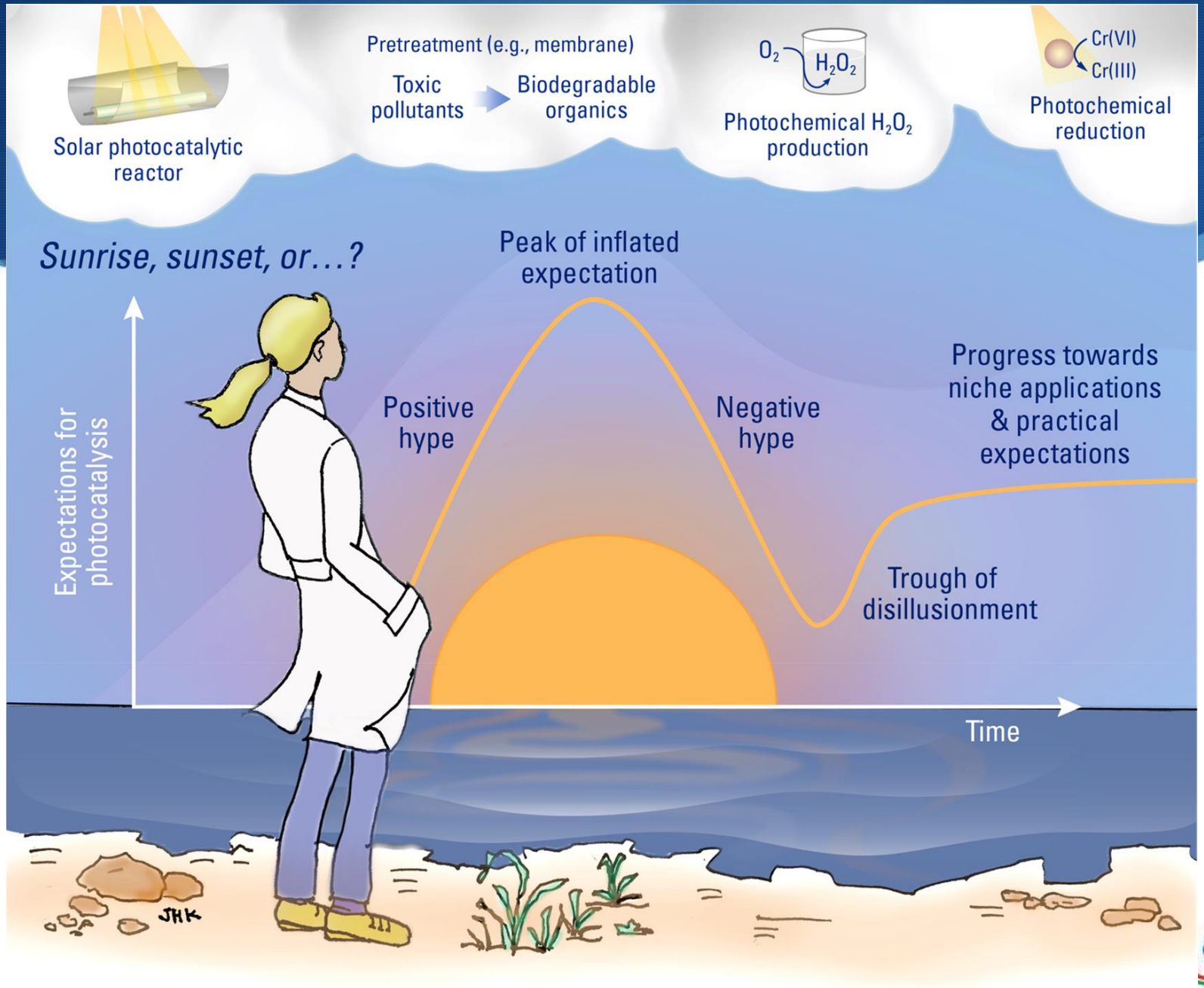
Challenges

- Cost Uncertainty
- Scalability
- Process Development & Operation
- Competition with Conventional Technologies
- Environmental Considerations



Loeb et al Environ. Sci. Technol. 2019, 53, 2937−2947

الجمعية العُمانية للمياه
OMAN WATER SOCIETY



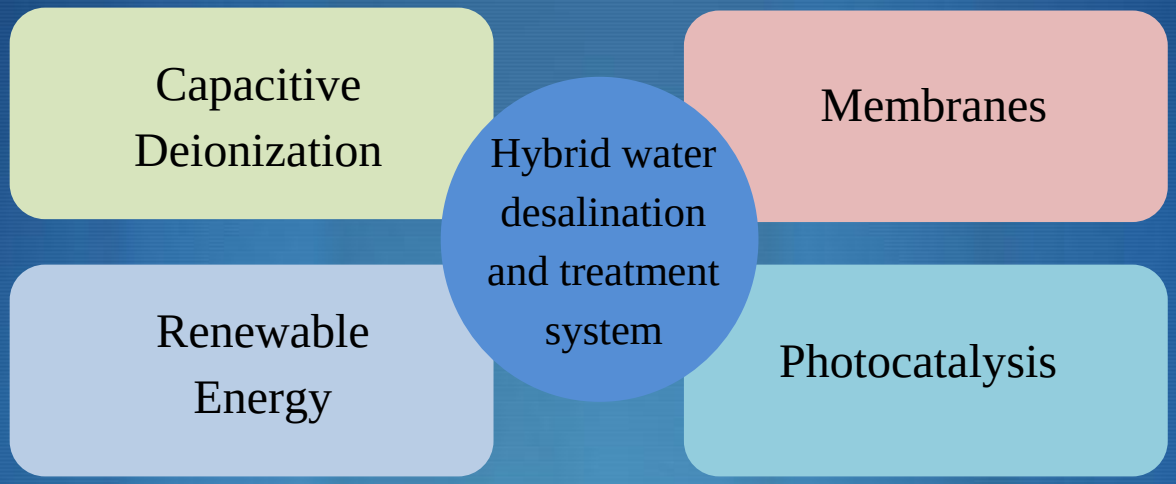
Loeb et al Environ. Sci. Technol. 2019, 53, 2937−2947

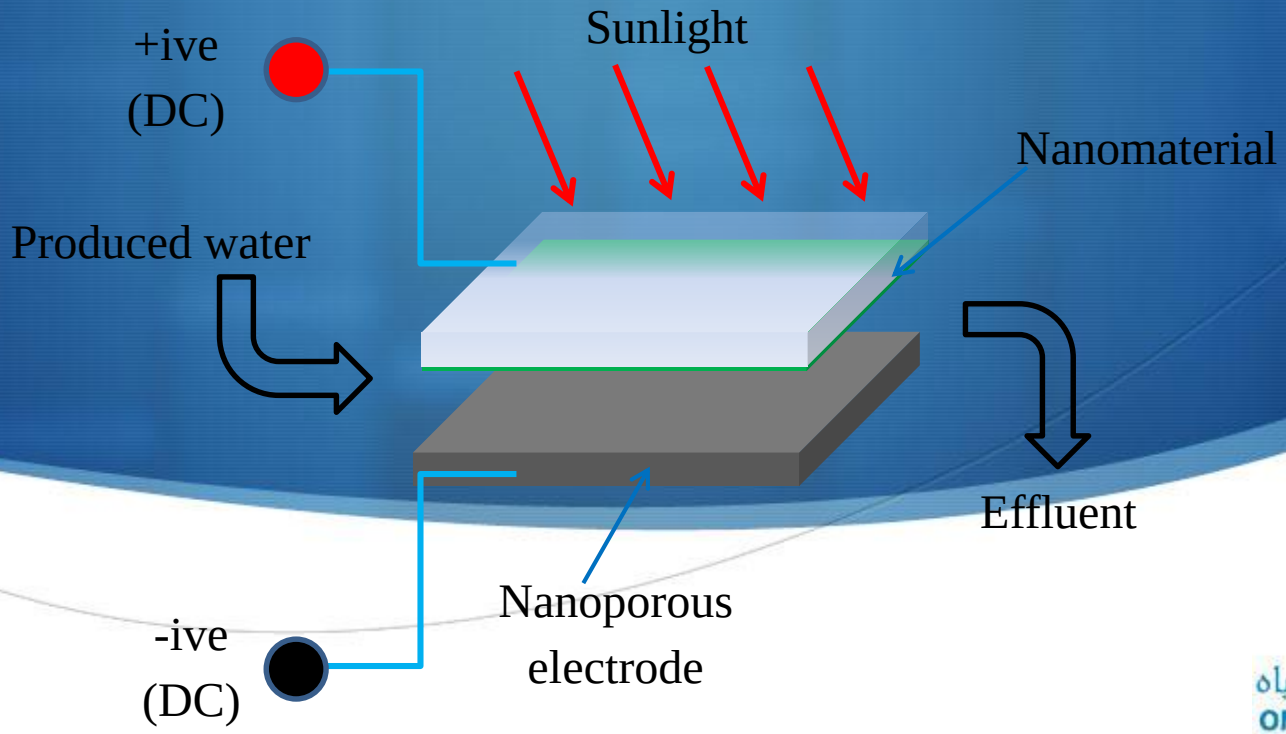
الجمعية العُمانية للمياه
OMAN WATER SOCIETY

Future Prospect

- Identify the Niche Market
- Technology Integration
- Large-Scale Research & Application
- Comprehensive Cost Analysis
- Long-Term Operation

Hybrid produced water desalination system





Partners

سلطنة عمان
وزارة الثروة الزراعية والسمكية وموارد المياه

وزارة التعليم العالي
والبحث العلمي والابتكار

Omantel
عمانتل