Exploiting Impaired-Quality Sources (Seawater and Wastewater Effluent) for Drinking Water

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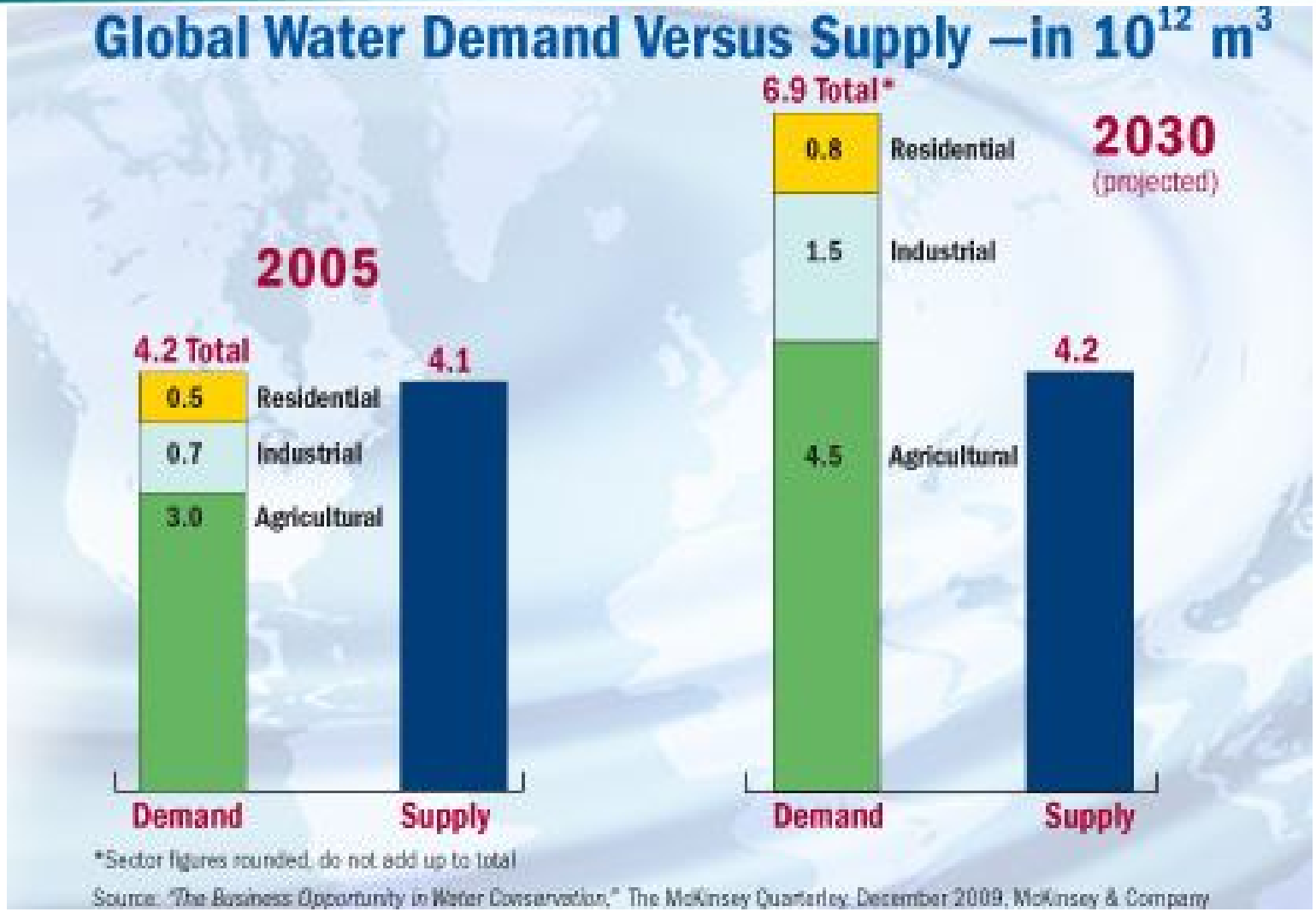
Impaired Quality Sources and *Drivers* for their Use

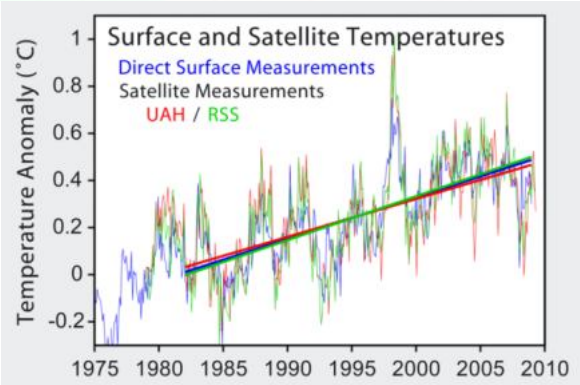
Global Water Demand vs. Supply



Traditional Sources: Inadequate

Drivers for Increased Exploitation of Impaired Quality Sources

- Climate Change
  - ➢ Water Scarcity
  - ➢ Water Quality (and Temperature)
- Urbanization
  - ➢ Increased Water Demand
  - ➢ Peri-Urban Growth
    - → outside service area
- Demographics
  - ➢ Population Shifts
  - ➢ Developing → Transitional → Developed Countries (example of China)



Impaired Quality (Drinking Water) Sources

- Seawater
  - Infinite Resource; Generally Constant Quality
  - Constraints: High Salinity (TDS) and Proximity to Coast
- Wastewater (Effluent)
  - A Proximate Source (Sewer Mining Possible)
  - Possible to Target Separate Wastestreams (e.g., Grey Water)
  - Also, Wastewater-Impacted Drinking Water (% effluent)
  - Constraints
    - Organic Micropollutants and Emerging Pathogens
    - Delivery Reclaimed Water to Point(s) of Use
- (Urban) Stormwater Runoff
  - Constraints: Delivery Pattern, and Trace Metals and Organics

Potential for Use of Impaired Quality Sources

Where is the Water?

	Volume (km^3)	% of Total
Surface	230,000	0.017
Subsurface	8,400,000	0.625
Icecaps and Glaciers	29,200,000	2.15
Atmosphere	13,000	0.001
Oceans	1,321,000,000	97.2

40 % of World's Population
Live within 100 km of Coastline
(and increasing)

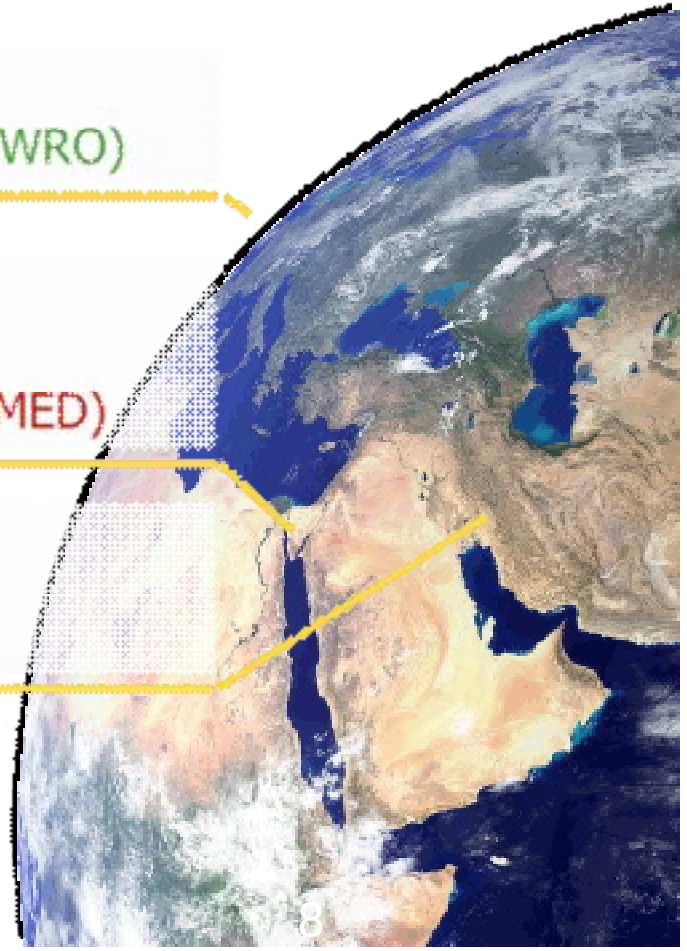
Global seawater desalination capacity: concentrated in GCC and MENA regions

- **76% of the global capacity is located in three sea areas:**

17% in the Mediterranean Sea, of which
70% is produced by seawater reverse osmosis (SWRO)

14% in the Red Sea, of which
72% is produced by distillation
(Multi-Stage Flash, MSF; Multi-Effect Distillation, MED)

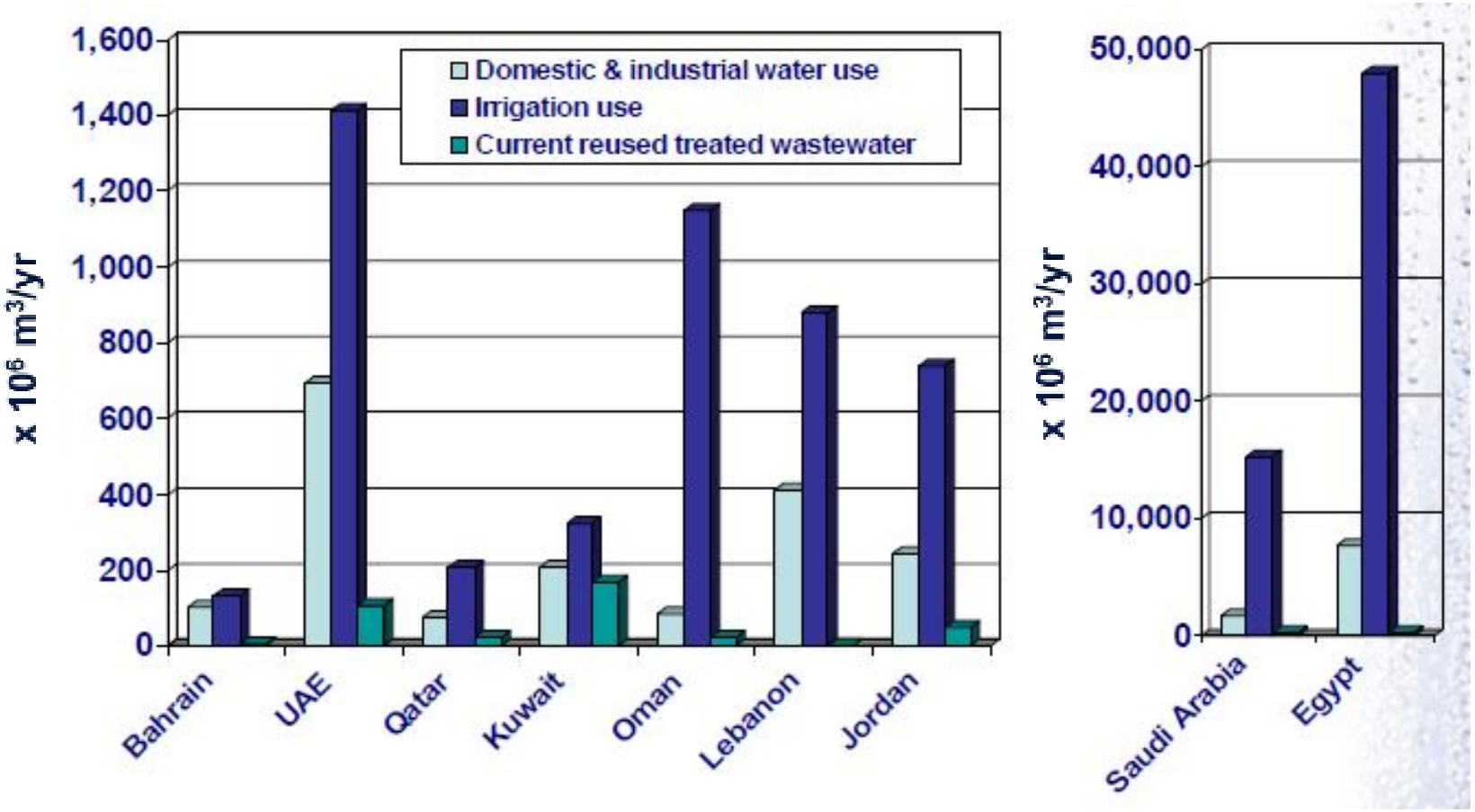
45% in the Arabian Gulf, of which
90% is produced by distillation (MSF, MED)



In GCC/MENA Regions: Dominated by (Energy) Inefficient Thermal Processes

Data source: IDA Worldwide Desalting Plant Inventory (2007, 2009)

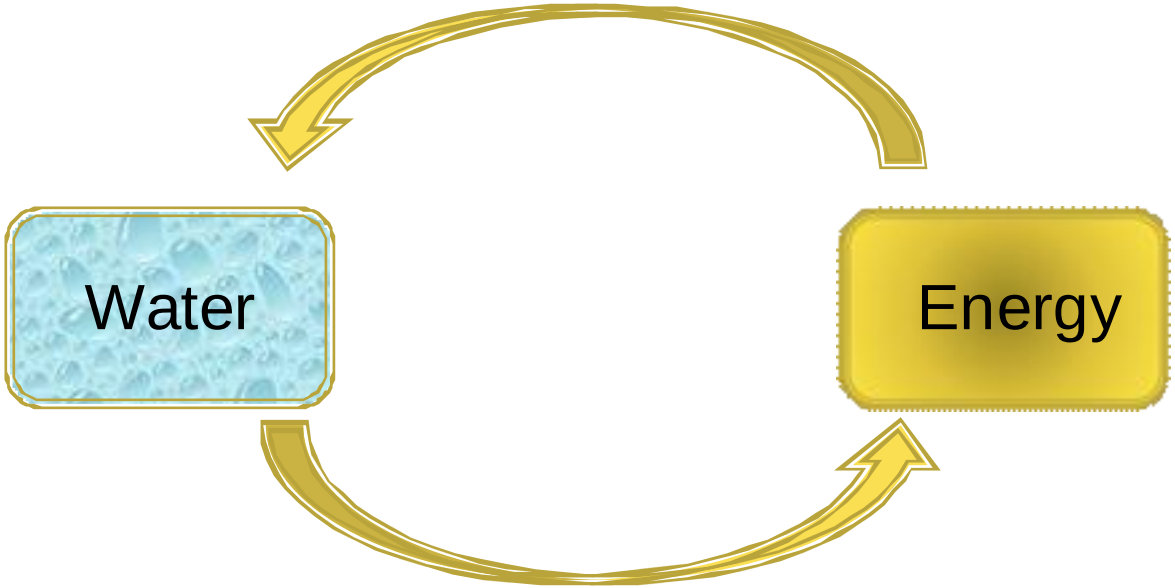
WASTEWATER GENERATION AND REUSE in GCC/MENA Region (GWI, 2006)



<< 10 % of Wastewater Generated is Reused in GCC/MENA

Water-Energy Nexus

Energy for Water (e.g., SWRO, thermal distillation)



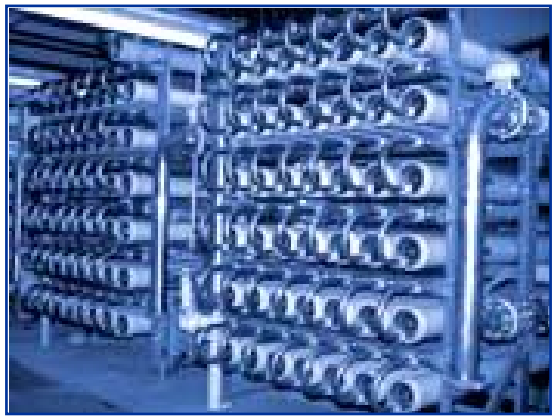
Water for Energy (e.g., oil extraction, cooling water)

Trends
- Energy Compensation in SWRO (Greening of SWRO)
- Energy Recovery (Self Sufficiency) in Wastewater Treatment
- Exploitation of WW RO over SWRO First (1-2 vs. 3-4 kWh/m^3)

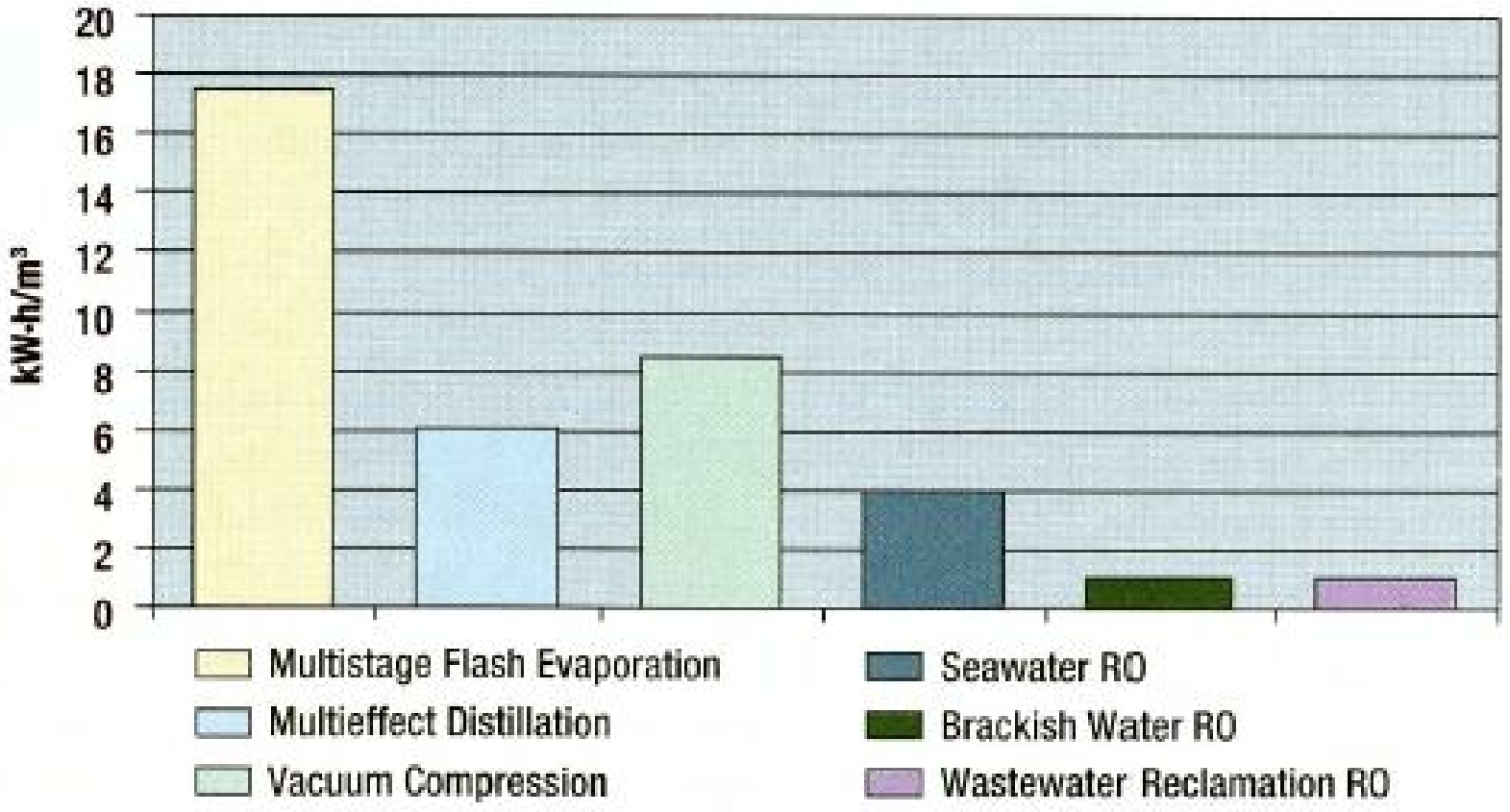
How to Exploit Impaired Quality Sources

Water Scarcity Leads to Consideration of Advanced Treatment

- **Potable water from sea water**
  - ➢ **Removal of dissolved salts (membrane treatment)**
- **Reclaiming used water**
  - ➢ **Removal of dissolved salts (membrane treatment)**
  - ➢ **Efficient disinfection with fewer by-products (UV)**
  - ➢ **Removal of dissolved contaminants (membrane treatment, oxidation, or adsorption)**



Total Energy Requirements Of Various Desalination Processes (Wilf, 2009)



- **Thermal (w/o Waste Heat > RO**
- **WW RO < BWRO < SWRO**

Advanced Technology Trends: Wastewater Reuse

- **UV Disinfection**
  - ➢ **Increasing Use of Both Low Pressure (LP) and Medium Pressure (MP) Technologies for Primary Disinfection Targeting Protozoa (Cryptosporidium)**
  - ➢ **LP → MP**
    - ⇨ **Footprint, Lamp Replacement**
  - ➢ **Disinfection with Minimal DBPs; reduction of nitrate to nitrite w/ MP**

Advanced Technology Trends: Wastewater Reuse - cont

- **Ozone and**

  UV Based Advanced Oxidation

  - **Using Ozone for *Selective*, or**

    UV Based AOP (OH•) for

    ***Non-Selective* Oxidation**

    of Organic Micropolutants

    in Wastewater Effluent

Advanced Technology Trends: Wastewater Reuse - cont

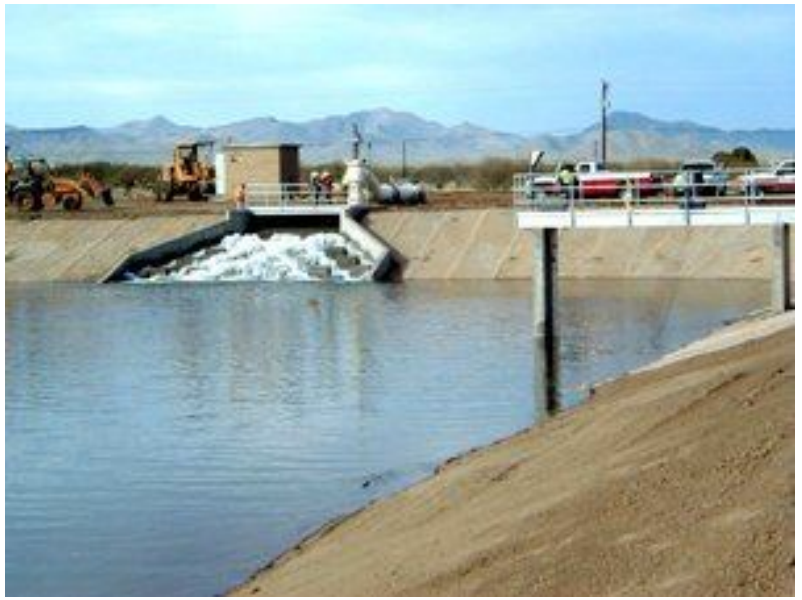
- **Membranes**
  - **Low-Pressure Membrane Filtration (MF/UF)**
    - Larger Module, Greater Flux
    - Standardization of Modules
  - **High Pressure Membrane Separation (NF/RO)**
    - More Energy Efficient, Greater Water Recovery
    - Nanotechnology Applications (improved permeability, selectivity, self cleaning membranes)
  - **New Materials (e.g., modified surfaces, ceramic materials)**
  - **New *Systems* (e.g., Integrated Membrane Systems (IMS))**

Advanced Technology Trends: Wastewater Reuse - cont

- ***Selective*** **Adsorbents**
  - **Selective Iron-Oxides (e.g., GFH) for Targeting Inorganic Micropollutants and P from Urban Stormwater Runoff**
  - **Selective Ion Exchange Media for Targeting Anionic PhACs**

Natural Treatment Technologies

- **Wastewater Reuse**
  - ARR, SAT
  - Removal of Organic Matter, Organic Micropollutants, Pathogens, and Nitrogen from Wastewater Effluent
  - A Potentially Complete System
- **Seawater Pretreatment**
  - Beach Wells
  - No Chemicals,
    Low Environmental Impact



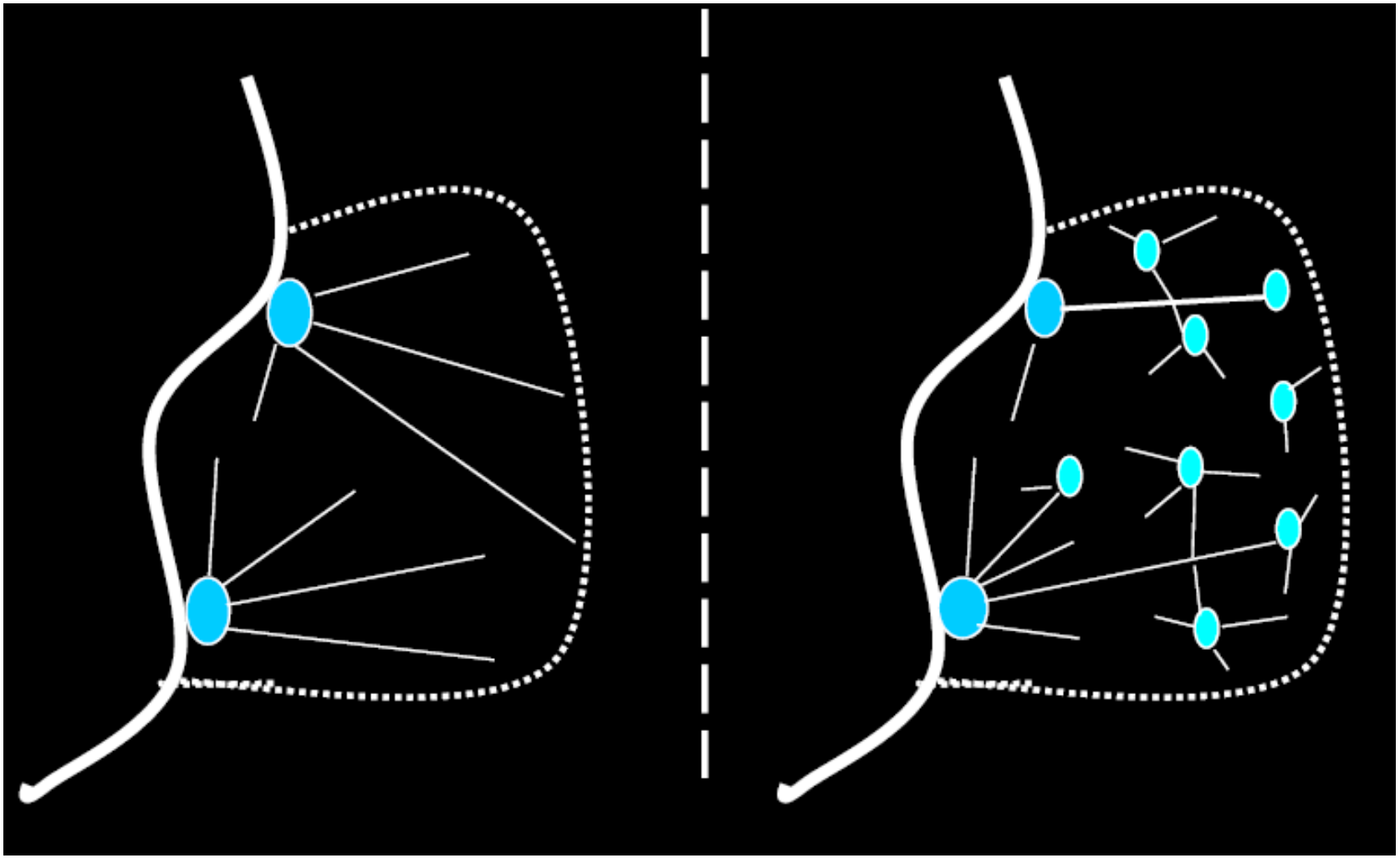
Advanced Treatment Hybrids

- **ARR → Membranes**
  - **Lowered membrane fouling; secondary barrier for micropollutants**
- **Oxidation → ARR**
  - **Biodegradation of oxidation metabolites**
- **Oxidation → Membranes**
  - **Chemical tolerance of ceramic membranes**
- **Adsorption + Membranes**
  - **Nanoparticles as adsorbents (Fe), catalysts (Pd), or disinfectants (Ag) coupled with (UF) membrane**

Centralized vs. Decentralized Options for DW Treatment of Impaired Sources

- Continuum of Choices
  - Centralized, Larger System (seawater)
  - Nodal Systems (WW effluent)
  - Clusters (WW effluent)
  - Point of Use (POU) (grey water reuse)
- Considerations
  - Efficiency
  - Sustainability
  - Appropriateness

Moving from a Centralized to a WW Reuse Nodal System (Reiter, 2008)



New Desalination Concepts and Trends

Desalination Trends

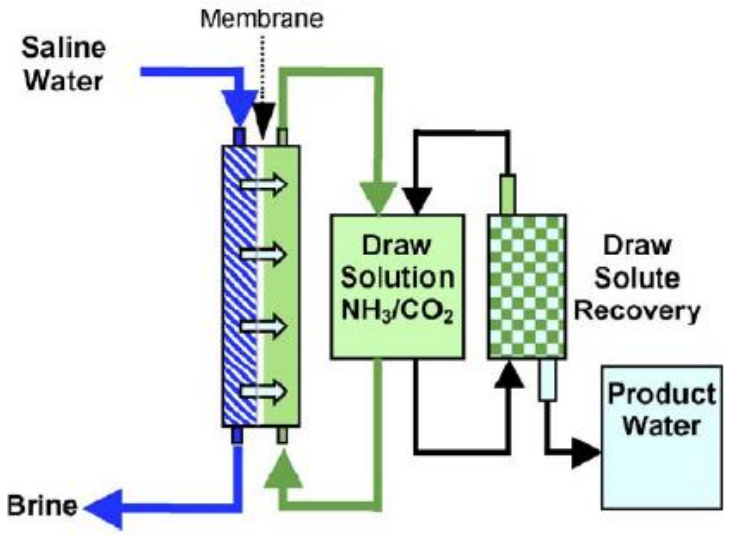
- Membrane-Based (SWRO) > Thermal
- Integrated Membrane System (IMS)
  - C-MF or UF w/o chemicals + RO
- Beach Wells (a biofiltration process)
- Exploitation of Estuarine/Bay Sources (lower TDS)
- Pre-treatment of SWRO with Nanofiltration (NF)
  - NF removal of divalent ions responsible for scaling
  - Higher RO recovery
- Tandem NF-NF (in series, two-pass of permeate)
- Renewable energy hybrids (energy compensation)
  - Australia: Wind Farms (wind turbines) + SWRO
- New membrane membrane materials
  - Carbon nano-tubes or Zeolyte composites for high flux polymeric membranes
  - Ceramic materials
- Partial Desalination (e.g., single-pass NF) for Salt Tolerant Crops

Greening of SWRO

- **Subsurface Intake (beach well)**
  - **No impingement/entrainment**
  - **Pretreatment w/o chemicals**
- **Minimize Chemical Use**
  - **UF w/o chemicals**
  - **No antiscalants (scaling control by acid addition and/or limiting recovery)**
- **Brine Disposal through Outfall (Multiport) Diffuser**
  - **Minimize extent of mixing zone)**
- **Integration of Renewable Energy (e.g., wind or solar) into Design and Operation**

New (Membrane-Based) Desalination Approaches

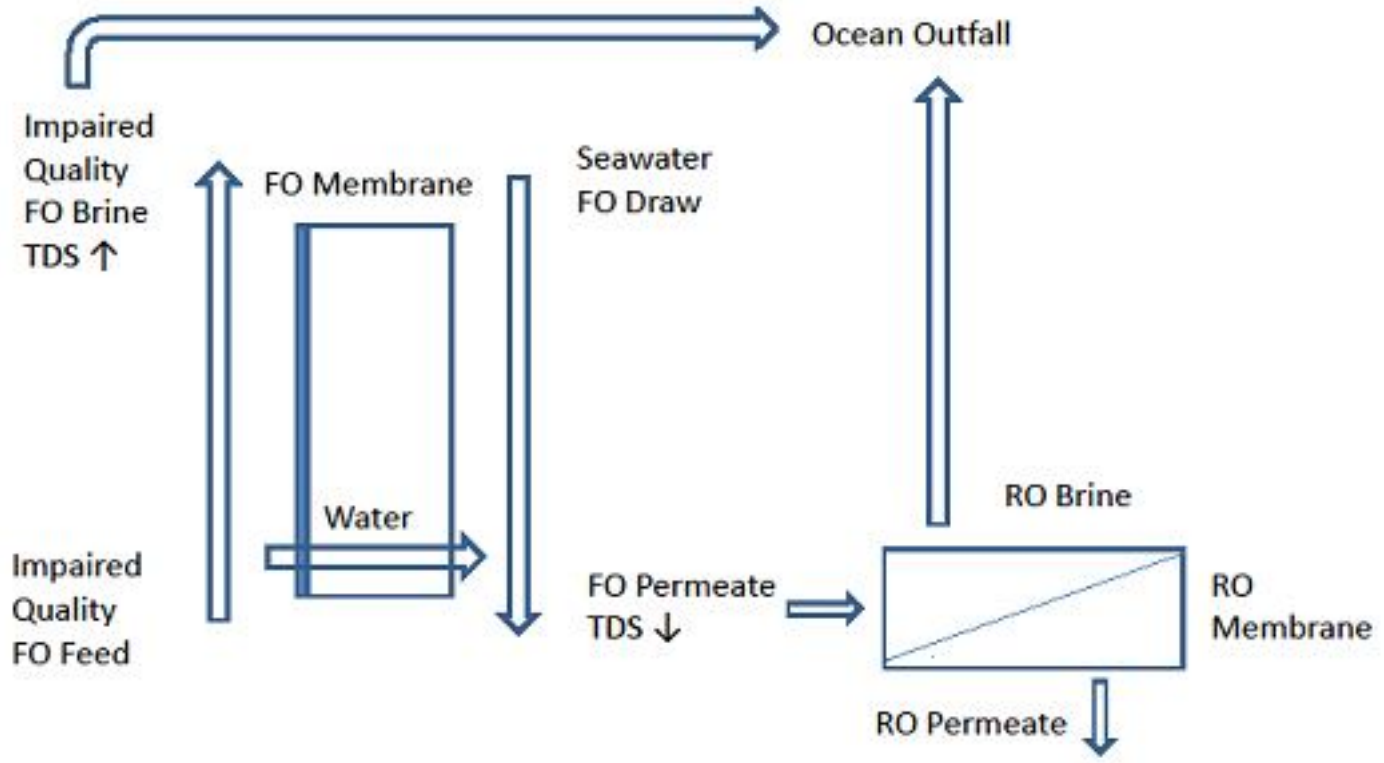
- **Forward Osmosis (FO)**
  - RO membrane, but osmosis not pressure-driven
  - Low energy, low fouling
  - FO/RO Hybrid
  - Challenges
    - Better FO Membrane (lower resistance)
    - More Imaginative Draw Solutions (e.g., magnetic nanoparticles)
    - Element/Module Configuration



New (Membrane-Based) Desalination Approaches - cont

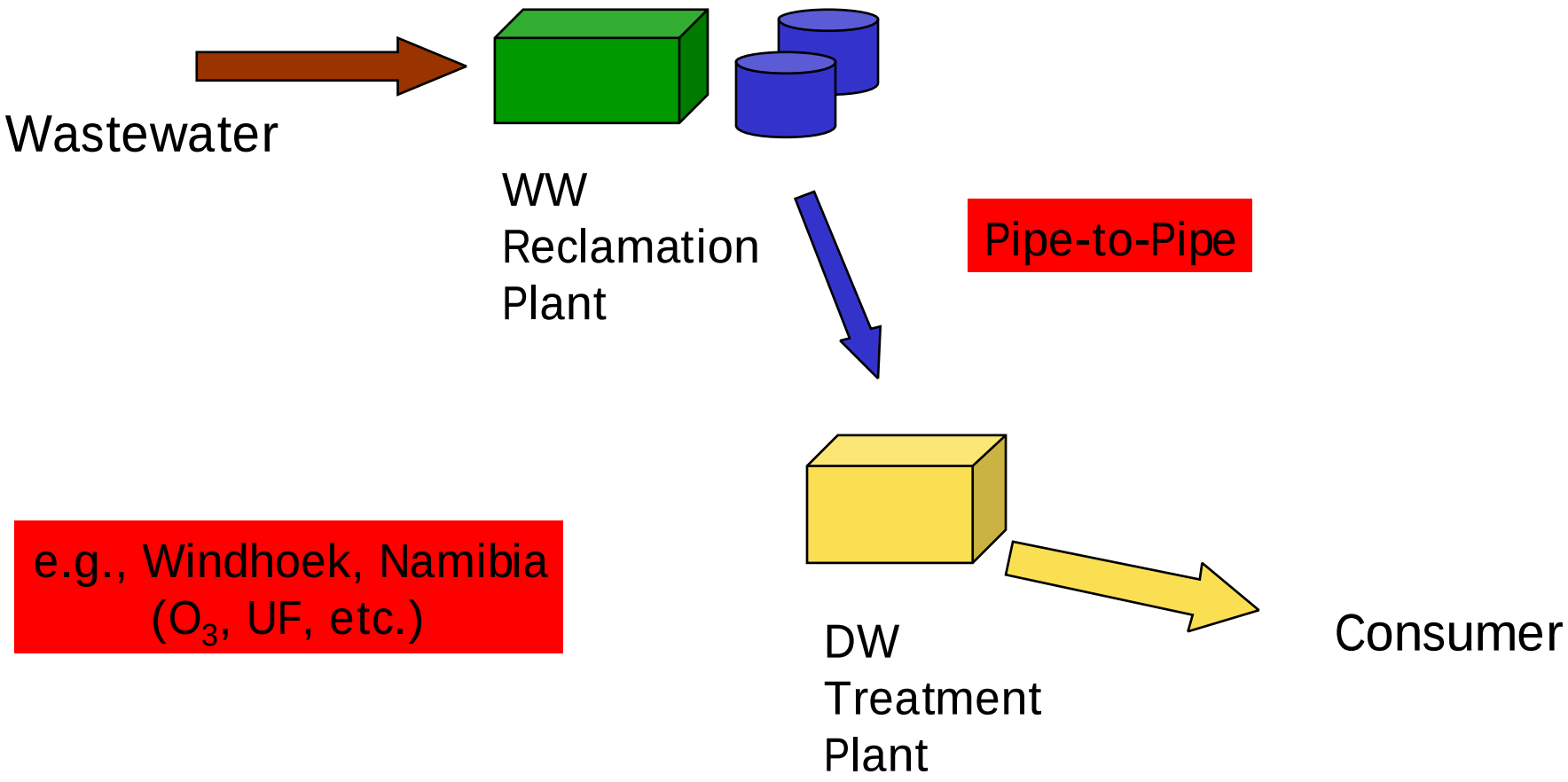
- **Membrane Distillation (MD)**
  - **Hydrophobic membrane + evaporation process**
  - **Temperature driven (but lower than conventional distillation)**
  - **Can be coupled with waste heat or solar energy**
  - **Challenges**
    - Better (Hydrophobic) Membrane
    - Management of Temperature Polarization (Spacers)

Impaired Quality Feed to Drive FO Desalination (FO-RO Hybrid)

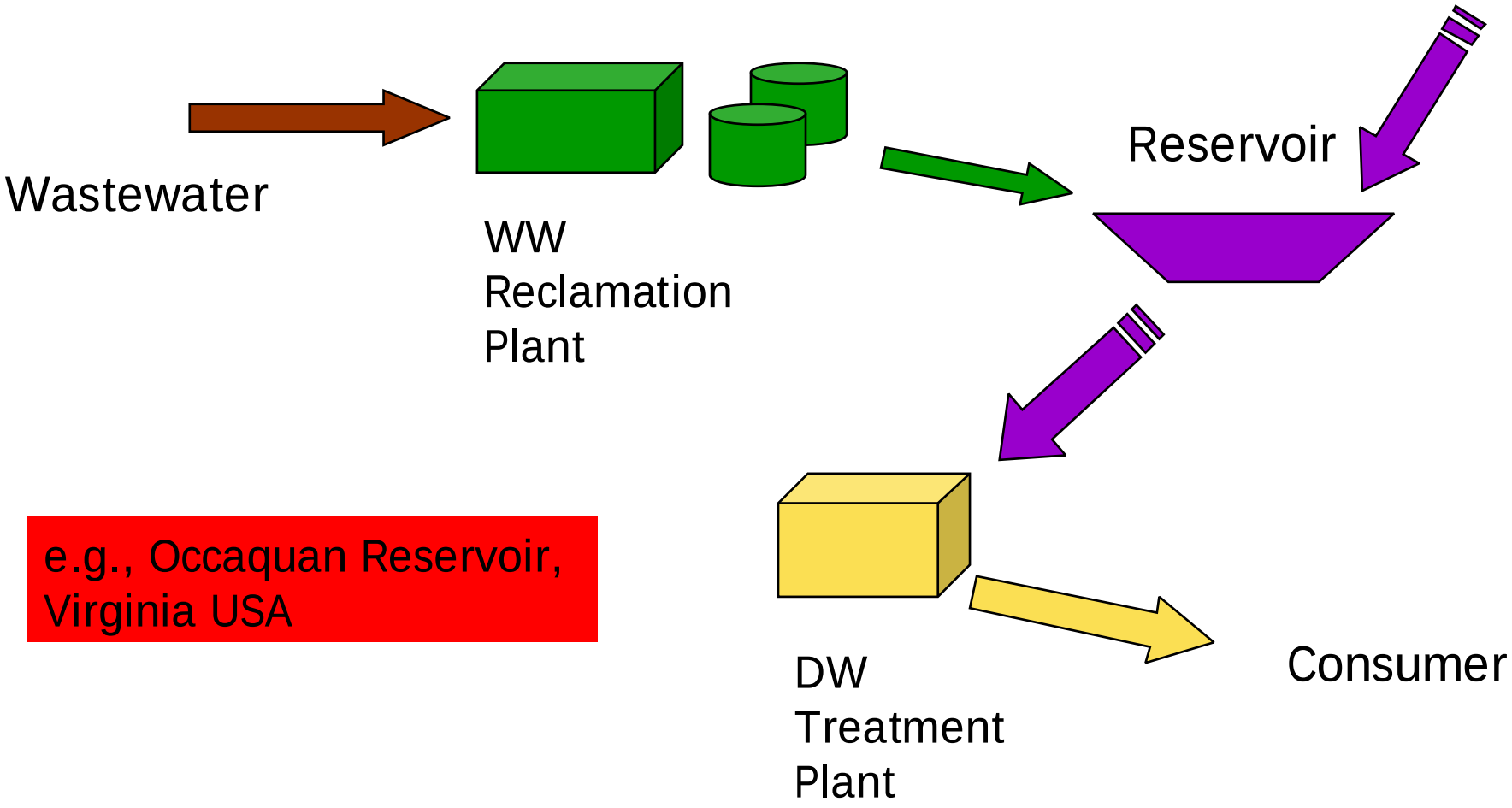


towards…
Potable Reuse
and Other Reuse Opportunities

Direct Potable Reuse X

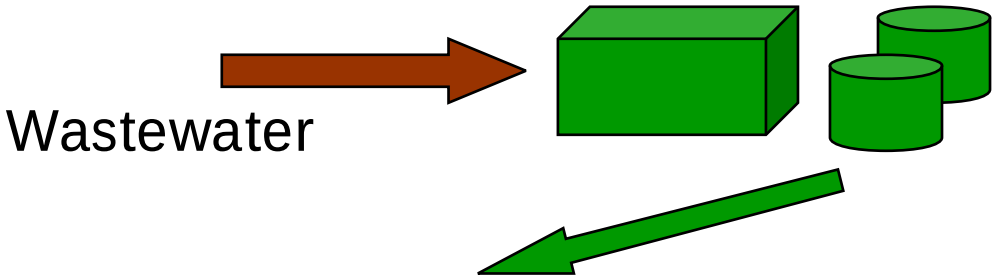


Indirect Potable Reuse

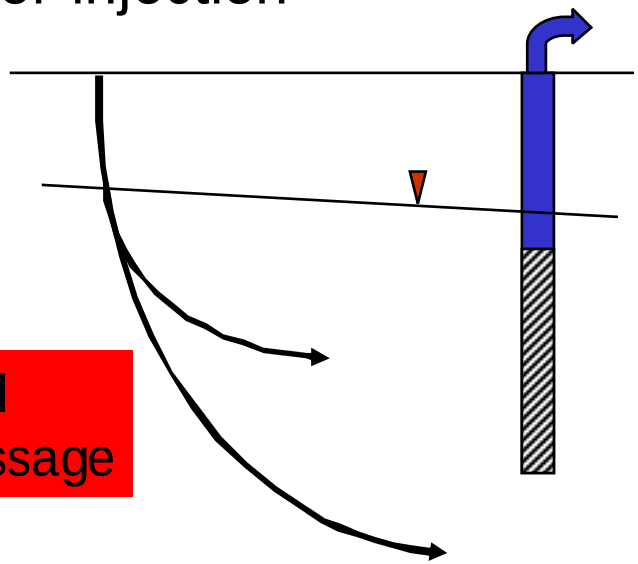


e.g., Occaquan Reservoir, Virginia USA

Indirect Potable Reuse

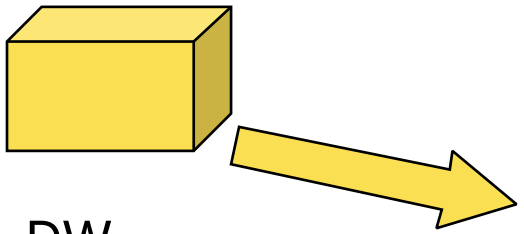


Surface spreading
or injection



Soil
Passage

e.g., California and
Arizona Sites USA



DW
Treatment
Plant

Consumer

Other Reuse Opportunities

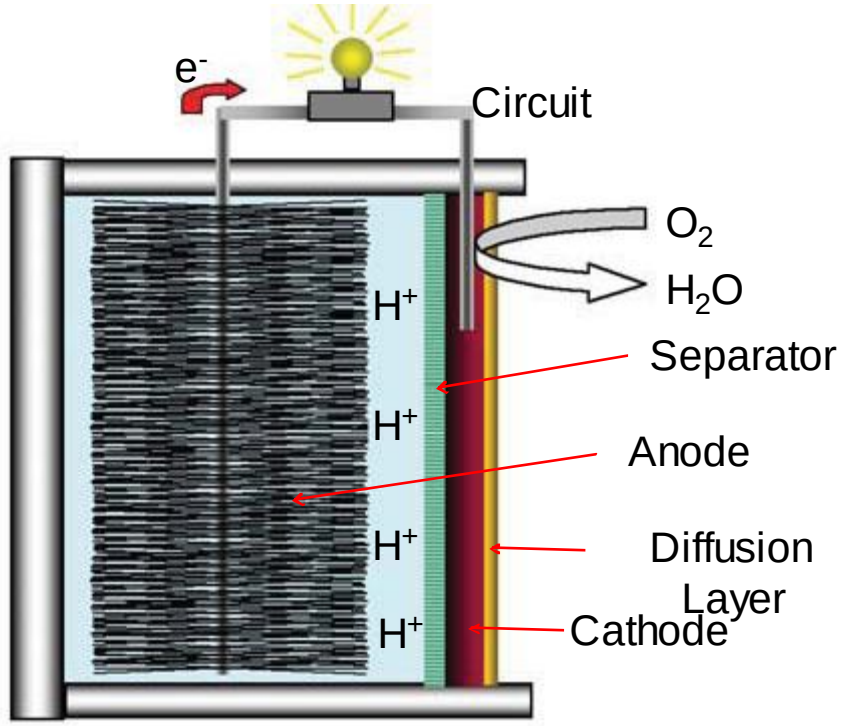
- Cascading Water Use
- Grey Water Segregation and Reuse
- Urine Diversion and Nutrient Recovery
- Dual Piping Systems (smaller demand for high quality water)
- Market(s) Developing for Reclaimed Water

and back to…
the Energy-Water Nexus

Energy Usage by Wastewater Treatment and Desalination Processes (Logan, 2009)

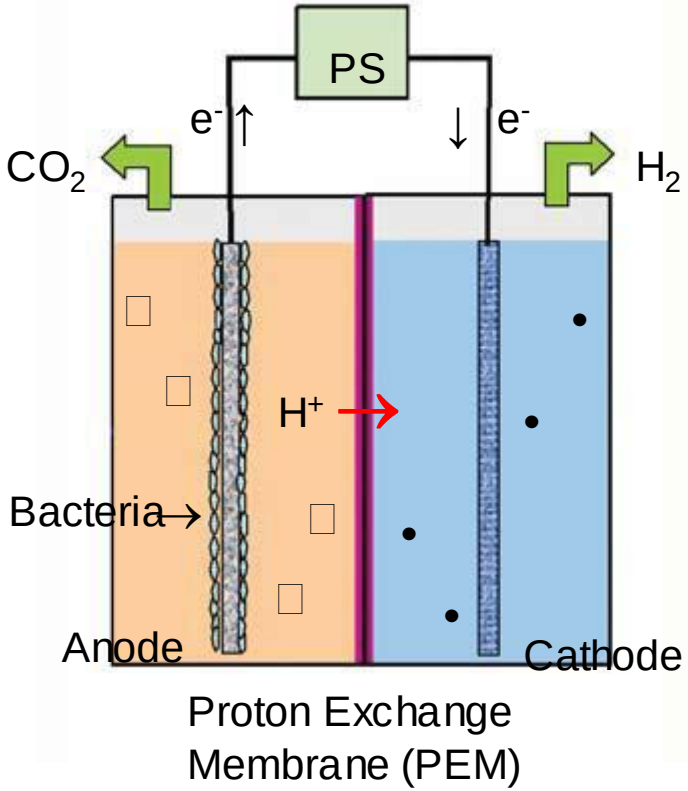
Process	Energy Requirement (kWh/m^3)
Trickling Filter	0.12
Activated Sludge	0.28 – 0.71
Membrane Bioreactor	2.4
SWRO	3.0

Microbial Fuel Cell (MFC): Wastewater Treatment While Producing Energy (Bioelectricity) (Logan, 2009)



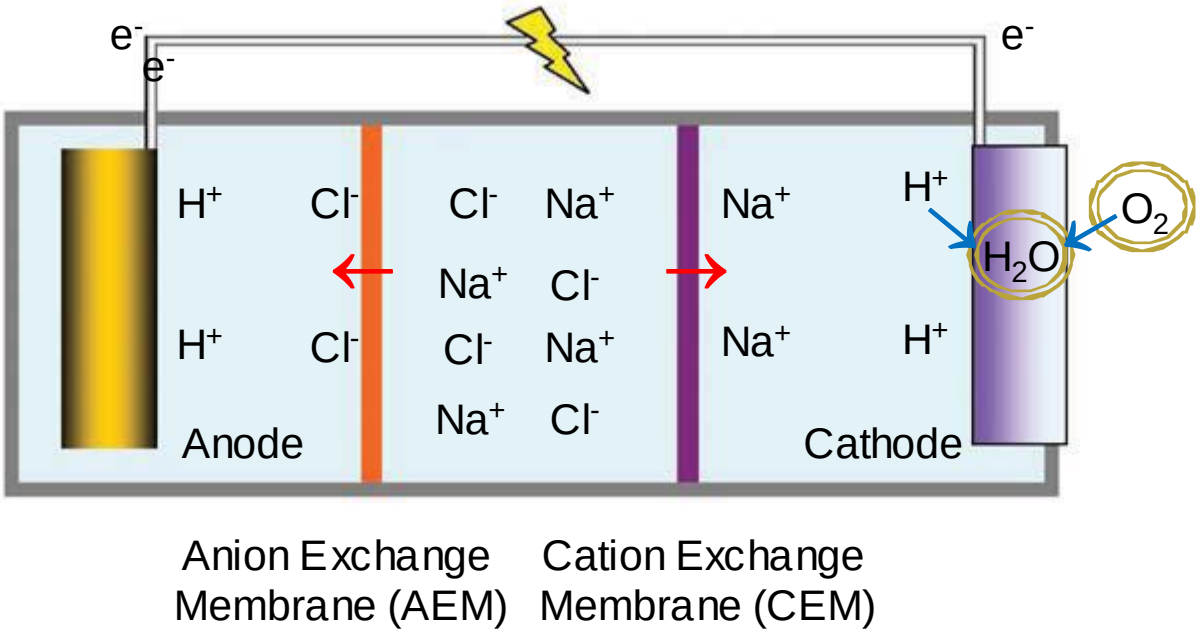
- Certain Bacteria Directly Produce Electrical Current While Degrading WW
- New Low-Energy (Self Sufficient) Opportunity for WW Reclamation/Reuse
- Removal of Sulfide, Nitrate, Halogenated Organic Demonstrated

Microbial Electrolysis Cell (MEC): Wastewater Treatment While Producing Energy (Hydrogen Gas) (Logan, 2009)



- Further Modification of a MFC (excluding oxygen)
- New Low-Energy Opportunity (H_2 Production) for WW Reclamation/Reuse

Microbial Desalination Cell (MDC): Desalination While Producing Energy (Logan, 2009)



- Further modification of MFC (ion exchange membranes)
- New Low-Energy Opportunity for Desalination (up to 99 % demonstrated)
- Research Needs: Metter Membranes and Module Configuration


Thank you…