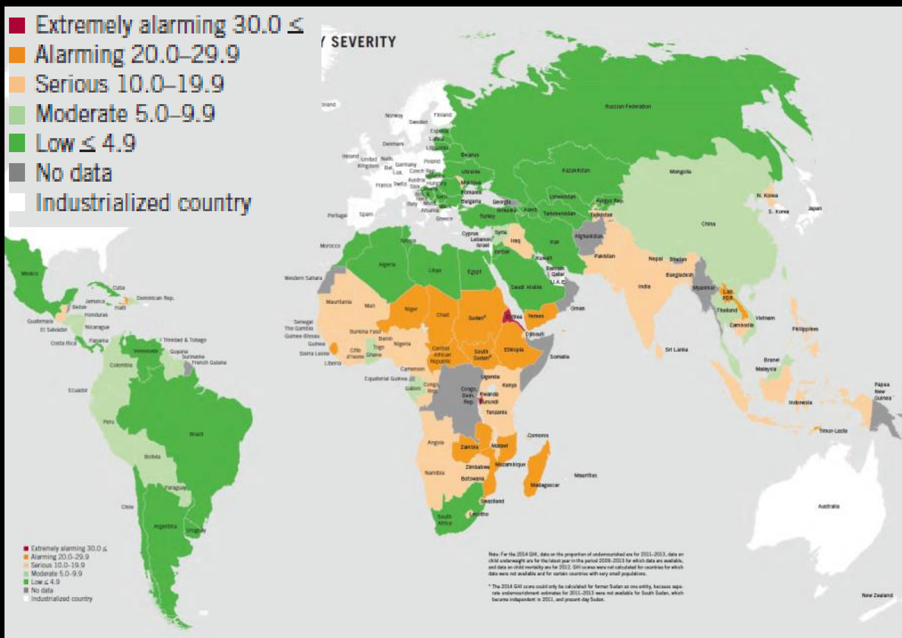
There are FEW resources for human.

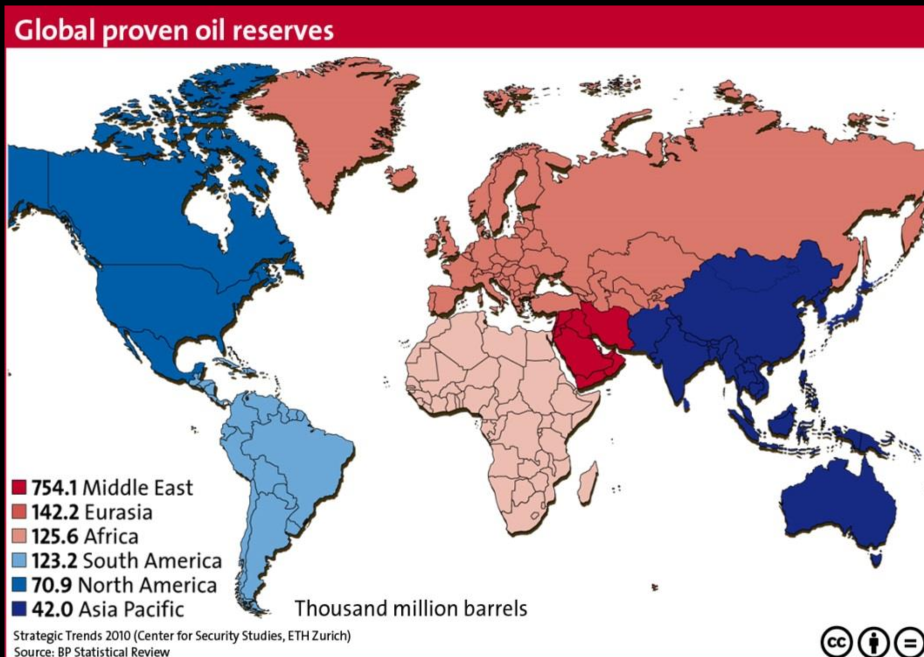
Crisis of Food Demands

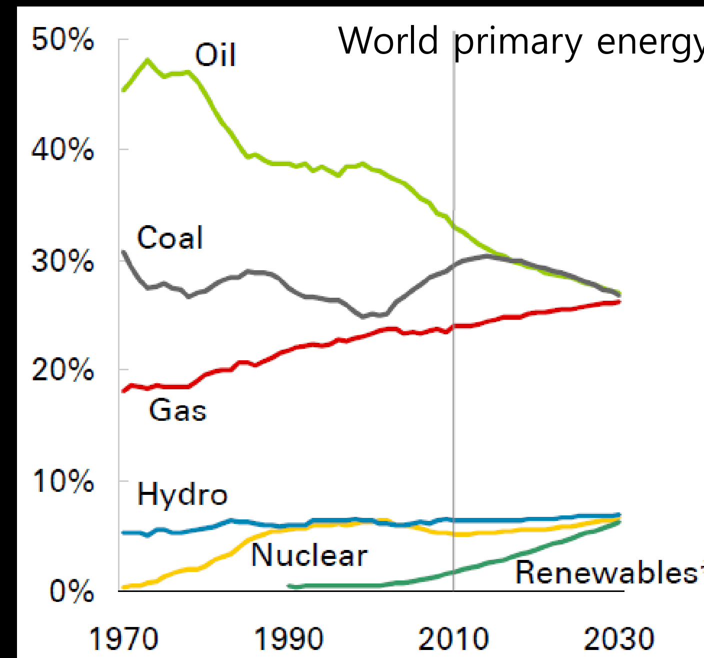


- ❖ 805 million people: worldwide chronically undernourished
- ❖ 162 million chronically undernourished people are young children
- ❖ Central Africa and South Asia are experiencing the most hunger

Source: Global Hunger Index report, 2014

Crisis of Energy Demands



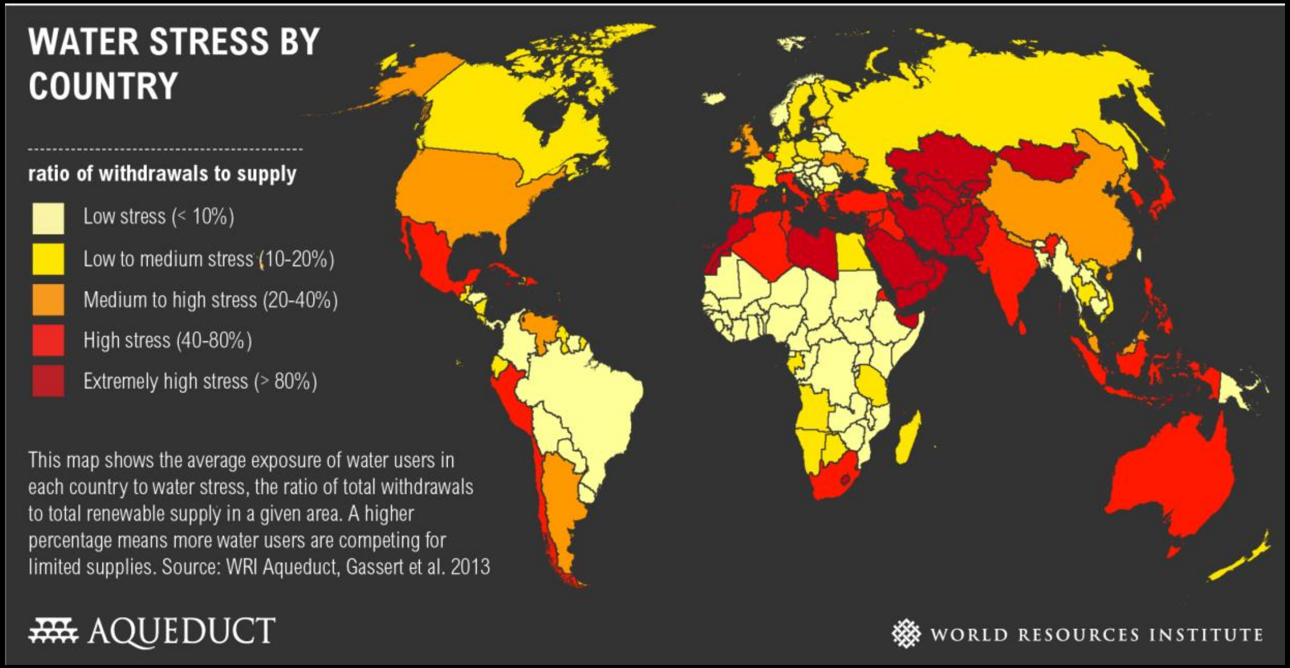


❖ Limited energy resources

→ As petroleum resources are running out of, the renewable energy must be exploited.

Source: International Energy Outlook,2011 / BP Energy Outlook 2030, 2011

Crisis of Water Demands



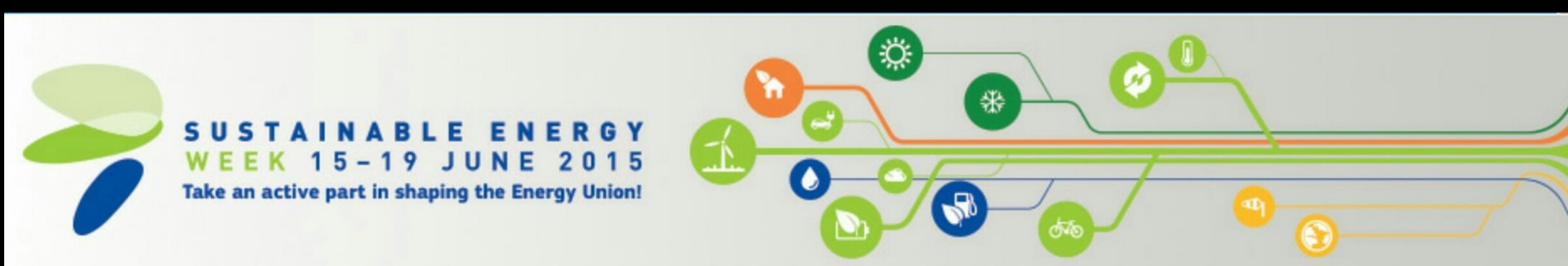
- ❖ Limited water resources

→ 40% of the world's population lives in severe water-stressed areas; by 2050, 2.3 billion more people than today.

Source: World Resources Institute, The UN World Water Development Report 2014

Without the Sun, where can you get FEW ?

European Commission @ Brussels



Seawater

Seawater

The origin of all creature

We may be from the sea.

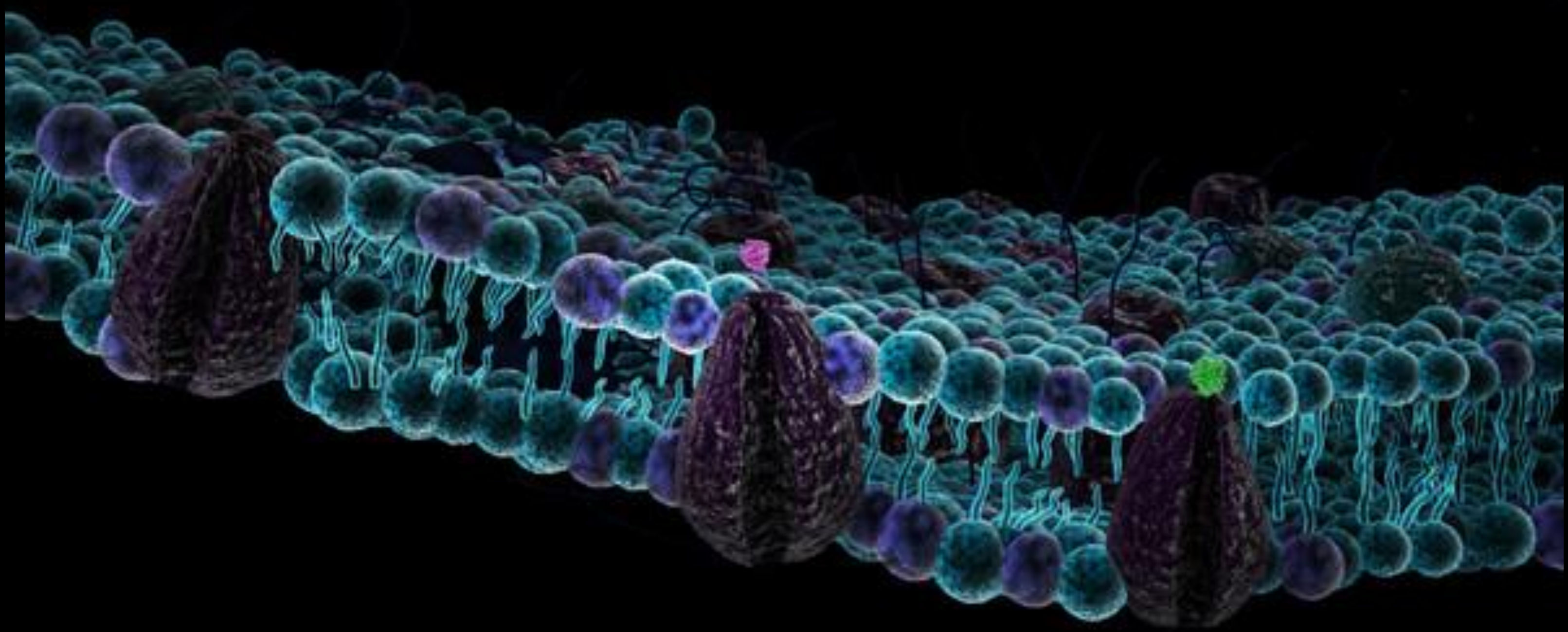
WE can be from the sea.

Water

Energy

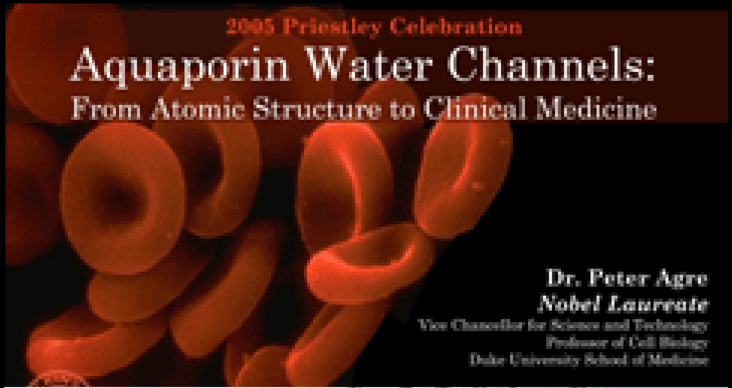
Membrane

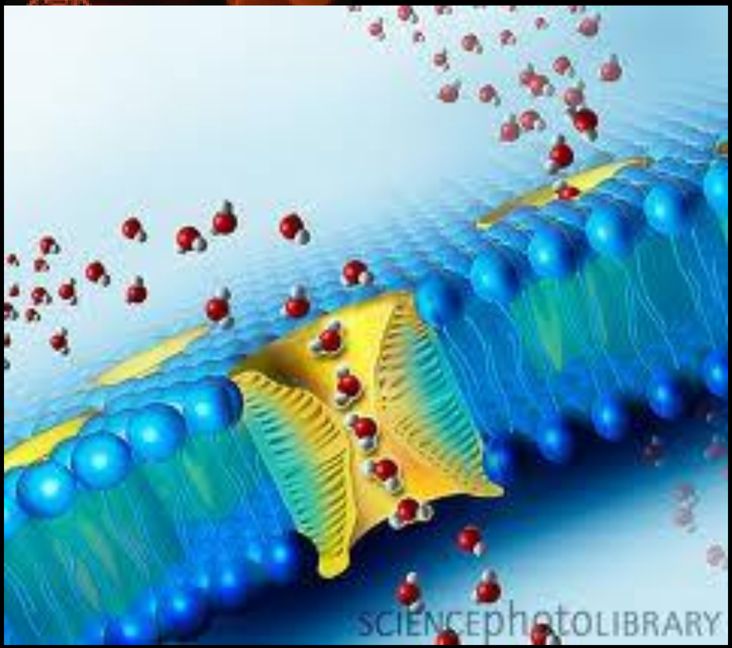
Water & Energy transport for all creature

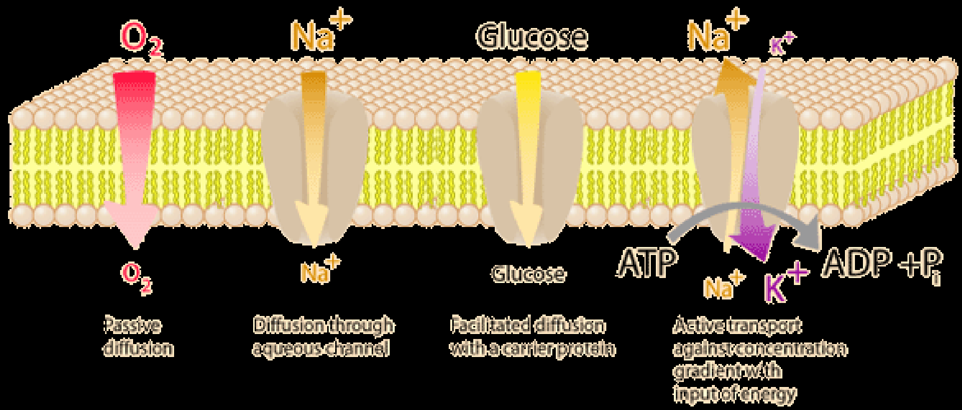


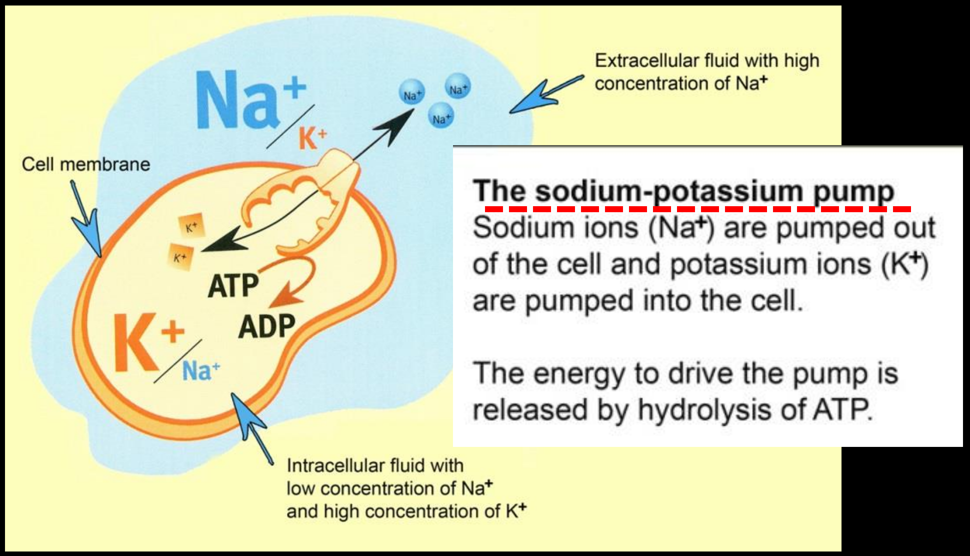
Membrane

Water & Energy transport for all creature









Technology

Technology
should be green…

&

- FEW resources for human
- Sustainable

- Seawater…
- Membrane…
- Technology…

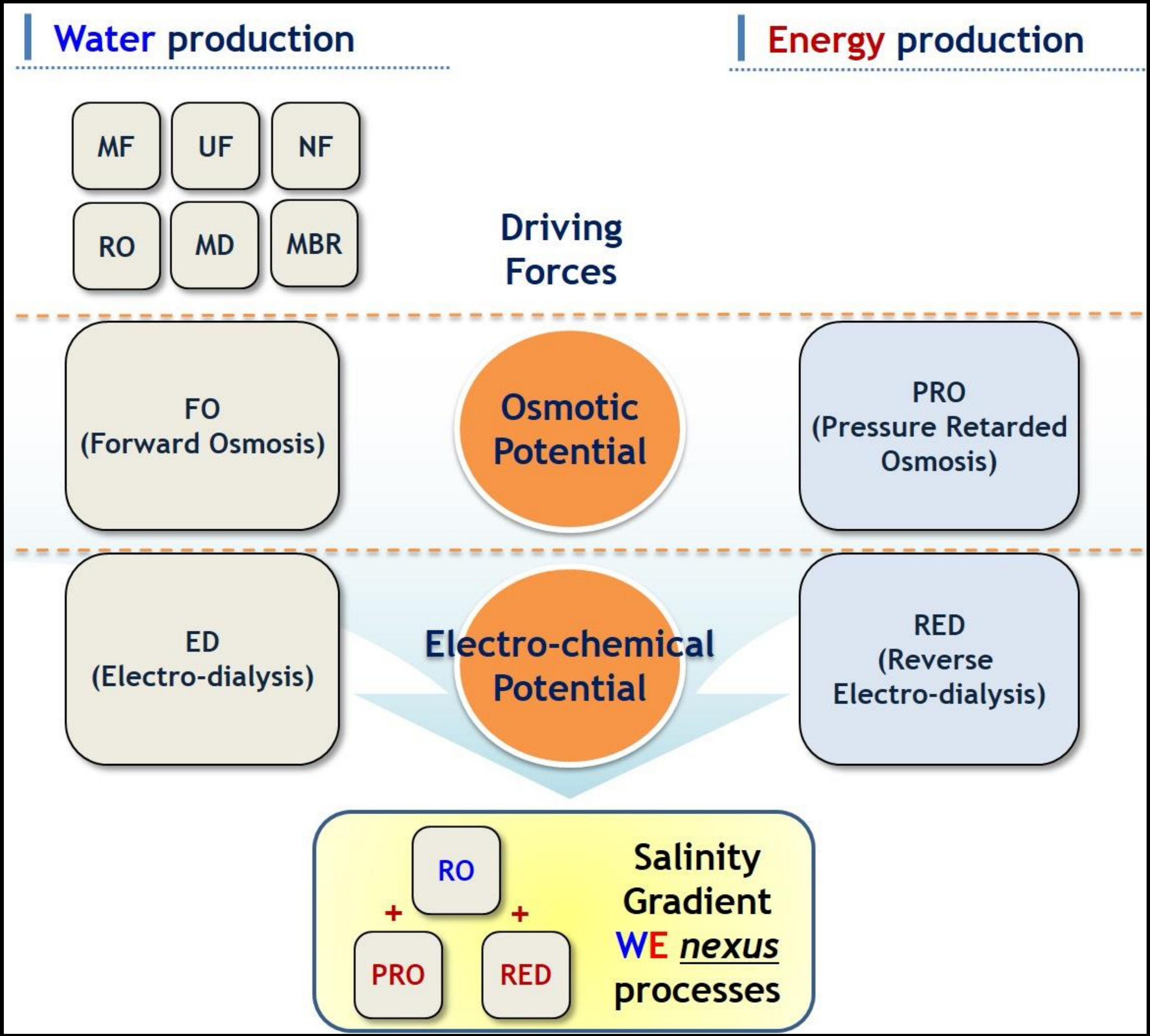
Green membrane technology to produce water & energy from seawater.

Membrane-based Desalination Technology in Water-Energy *nexus* Industry

Joon Ha Kim

Gwangju Institute of Science and Technology (GIST)

Outline


Water production
Energy production
MF
UF
NF
RO
MD
MBR
Driving Forces
FO (Forward Osmosis)
Osmotic Potential
PRO (Pressure Retarded Osmosis)
ED (Electro-dialysis)
Electro-chemical Potential
RED (Reverse Electro-dialysis)
RO
+
+
PRO
RED
Salinity Gradient WE nexus processes

Infrastructures…

- **4 main infrastructures :**

  Transportation, Telecommunication, Electricity, Water

- **Investment rank (2011~2030):**

  Water>Electricity>Telecommunication> Transportation

❖ **Prospect of Worldwide Investment for Infrastructure**

(Unit: US$ billion)

Infrastructure	2001 to 2010 (annual average)	2011 to 2020 (annual average)	2021 to 2030 (annual average)
Roads/Railways	269	299	350
Telecommunications	654	646	171
Electricity	**270**	**383**	**513**
Water	**576**	**772**	**1,037**
Total	1,769	2,100	2,071

Report from Organization for Economic Cooperation and Development (OECD, 2008)

Water & Energy production

using membrane technology

Membrane

Membrane Technology can be an alternative solution for Water & Energy problems at the same time, and for the need of co-generation infrastructure

Membrane-based Desalination R&D Roadmap in Korea

(Korea Agency for Infrastructure Technology Advancement In the Ministry of Land, Infrastructure, and Transport, MoLIT)

Phase I

- **SWRO** : 2007-2014 [150 million USD]

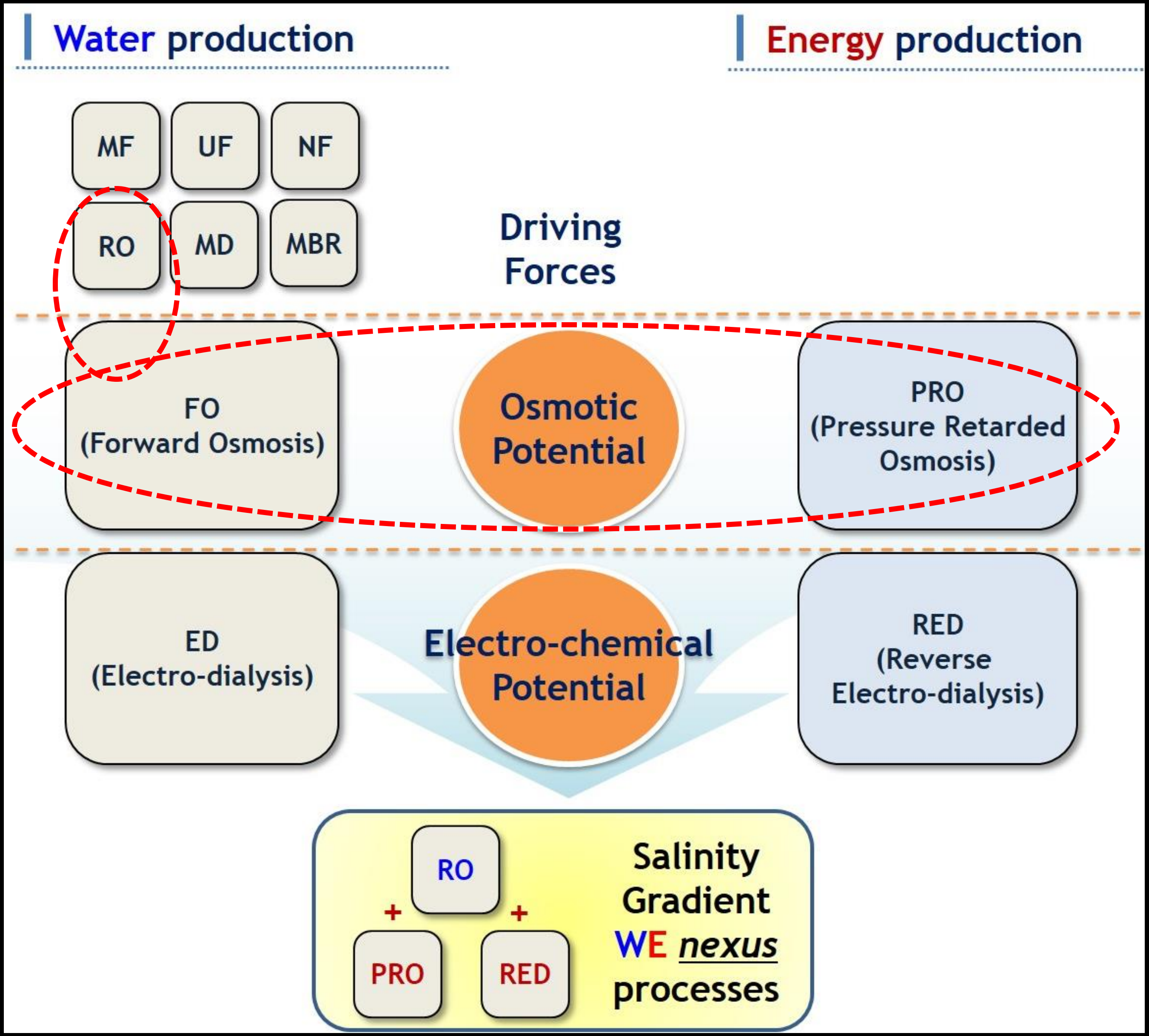
Phase II

- **MD-PRO** : 2013-2018 [25 million USD]
- **FO hybrid** : 2014-2019 [25 million USD]

Phase III

- **Renewable energy hybrid w/ SWRO** : 2016-2020 [TBD: apprx. 30 million USD]

Outline



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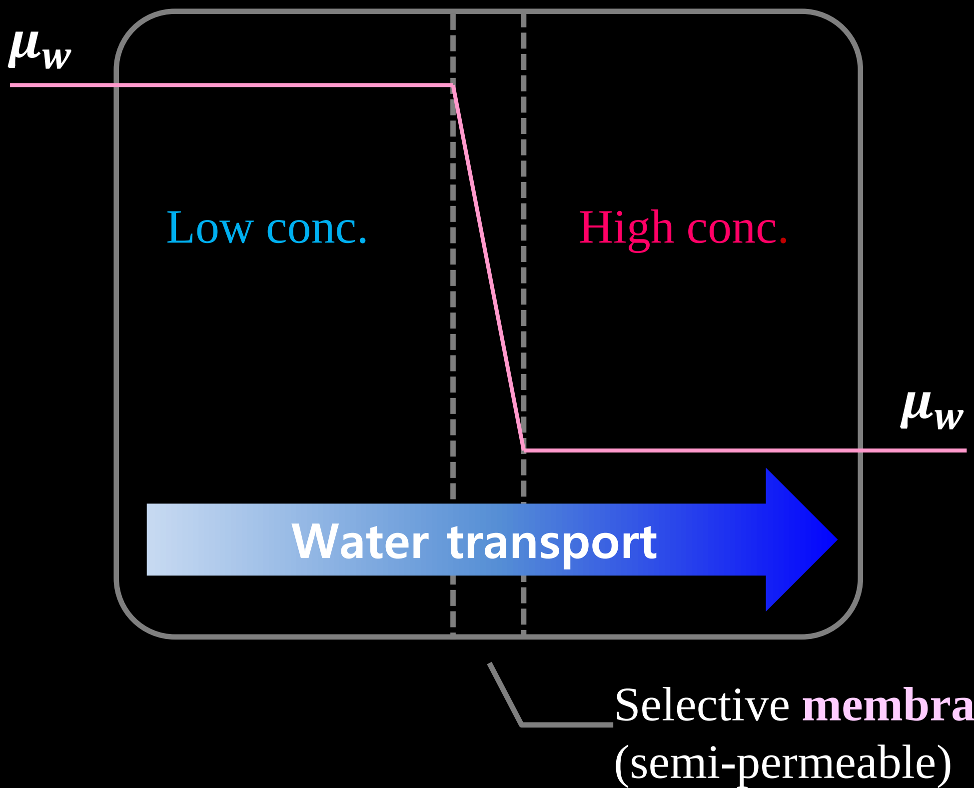
Osmotic Potentials

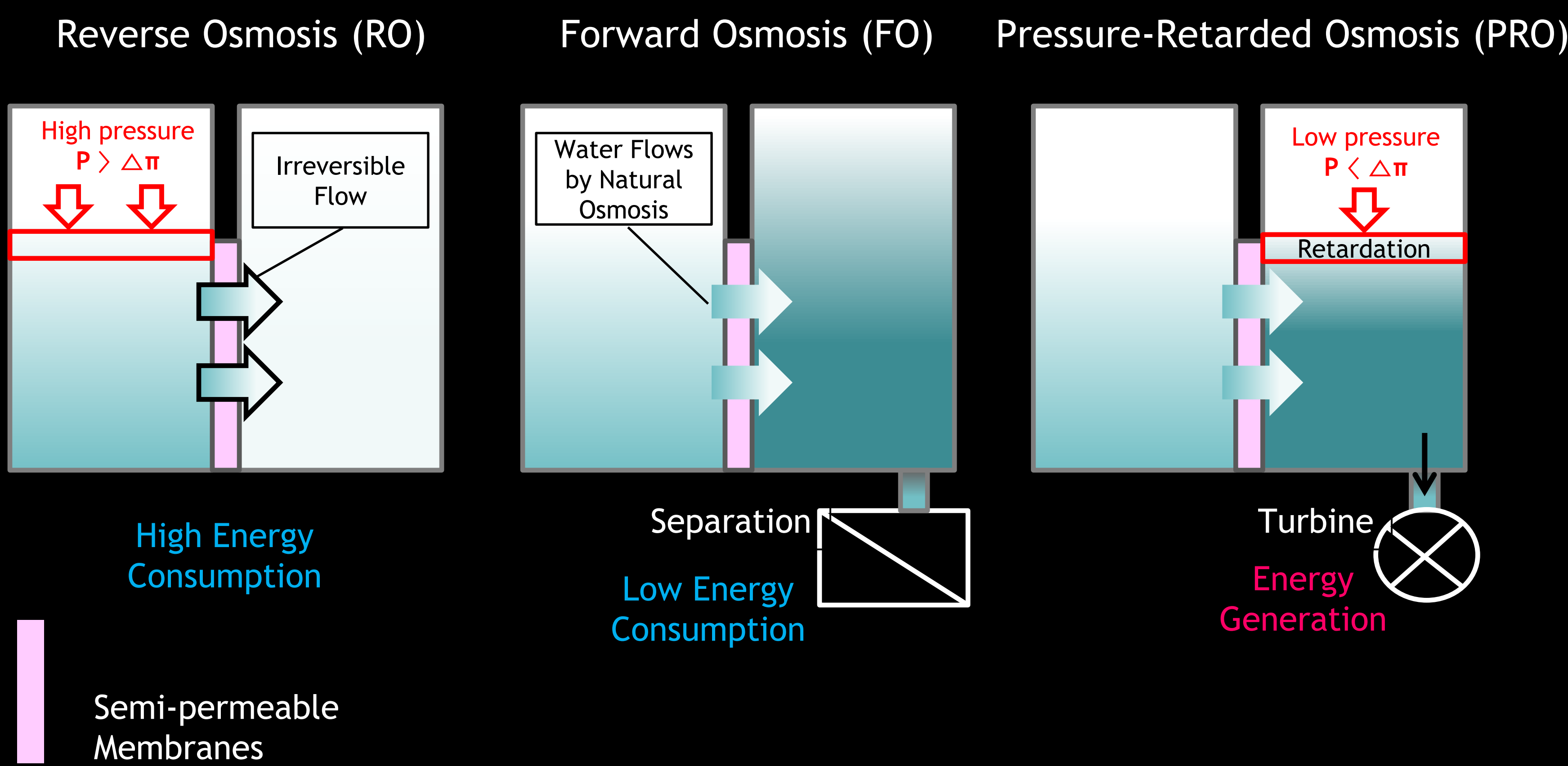
(RO, FO, & PRO)

Driving force: Chemical potential (Osmosis)



- Driven by chemical potential (Osmosis) difference
- Water passes through membrane

Principle of Osmosis Membrane



RO Membrane Technology

RO Membrane Technology becomes economically feasible…..

But, competition for reducing energy consumption just begins.

Features of seawater RO (SWRO) process

- Membrane material: **cellulose acetate, polyamide**
- Membrane module configuration: spiral wound type / hallow fiber type

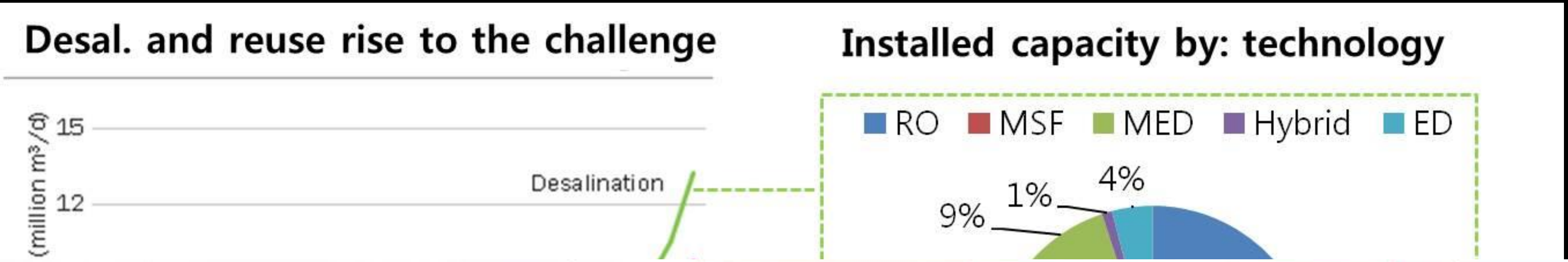
Advantages

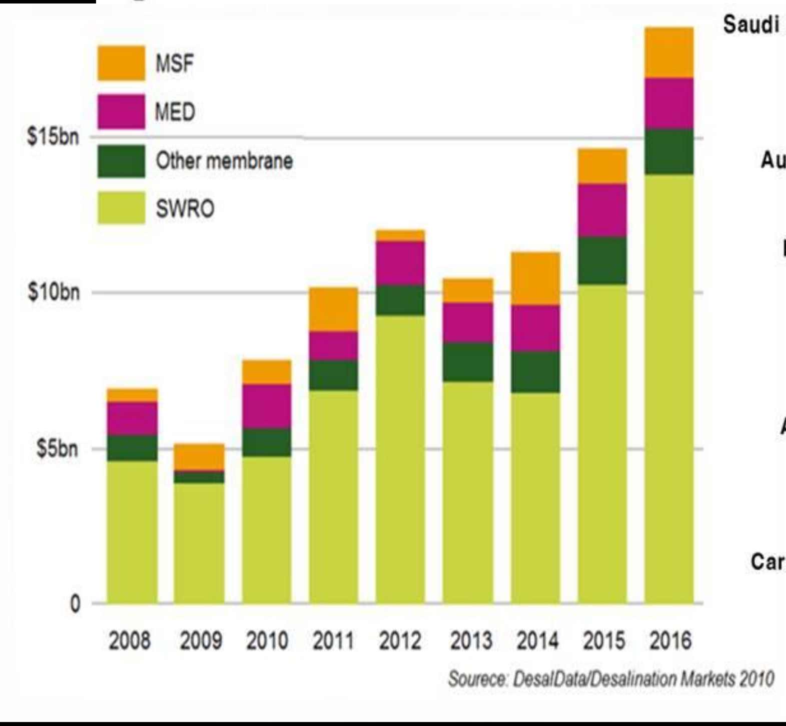
- **Lower energy consumption (3~4 kWh/m3) compared to distillation (10~16 kWh/m3)**
- Well systematic process among the desalination processes
- **Production of high quality freshwater (Na+ < 80~300 ppm)**

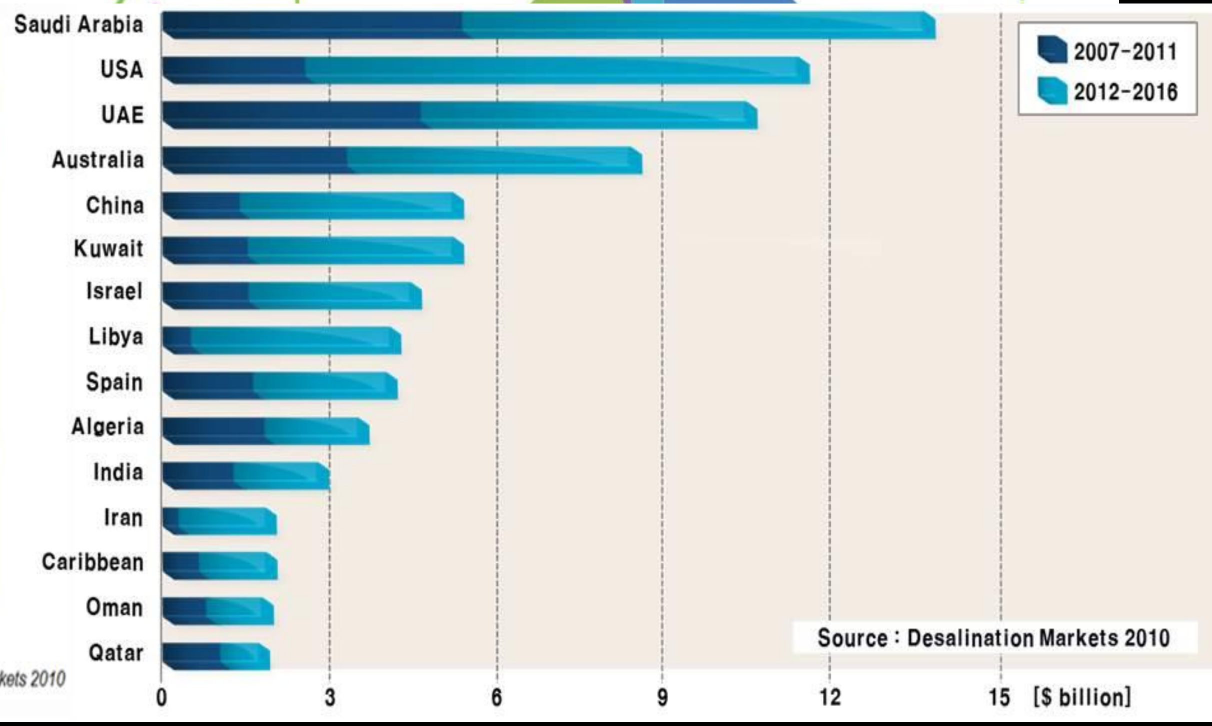
Disadvantages

- **Membrane fouling**
- Membrane cleaning/replacement
- **Requirement of pretreatment system (MF, UF, DAF, DMF, and anti-scalant)**
- Increase in cost to produce freshwater

SWRO process market







Future forecasts of SWRO desalination plant

Ref: **From Various Sources**

Parameter	Today	Within 5 years	Within 20 years
Cost o (2011 U			
Construc (US$/n			
* Power use of SWRO system (kWh/m³)	2.5 ~ 2.8	2.0 ~ 2.3	1.4 ~ 1.8
Membrane productivity (m³/day/SWRO membrane)	28 ~ 47	35 ~ 55	95 ~ 120
Membrane useful life (years)	5 ~ 7	7 ~ 10	10 ~ 15
Water recovery ratio (%)	45 ~ 50	50 ~ 55	55 ~ 65

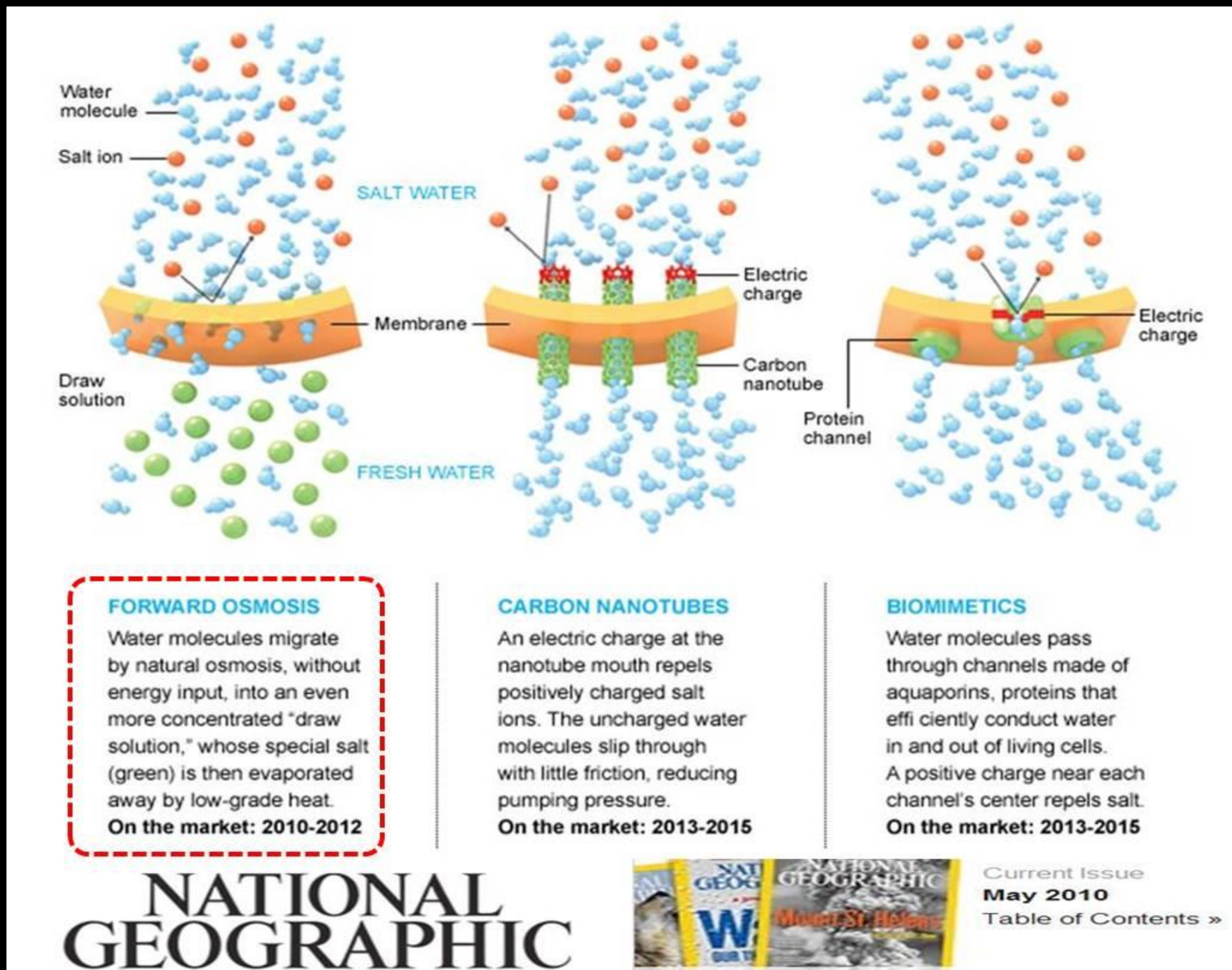
Membrane 2-D modification →
Still promising for next 20 yrs !

* Minimum theoretical energy for desalination at 50% recovery: **1 kWh/m³**

* Practical limitations: No less than **1.5 kWh/m³**

* Achievable goal: **1.5 – 2 kWh/m³**

Future technology of water treatment using **membrane**



Principle of FO membrane process

Principle

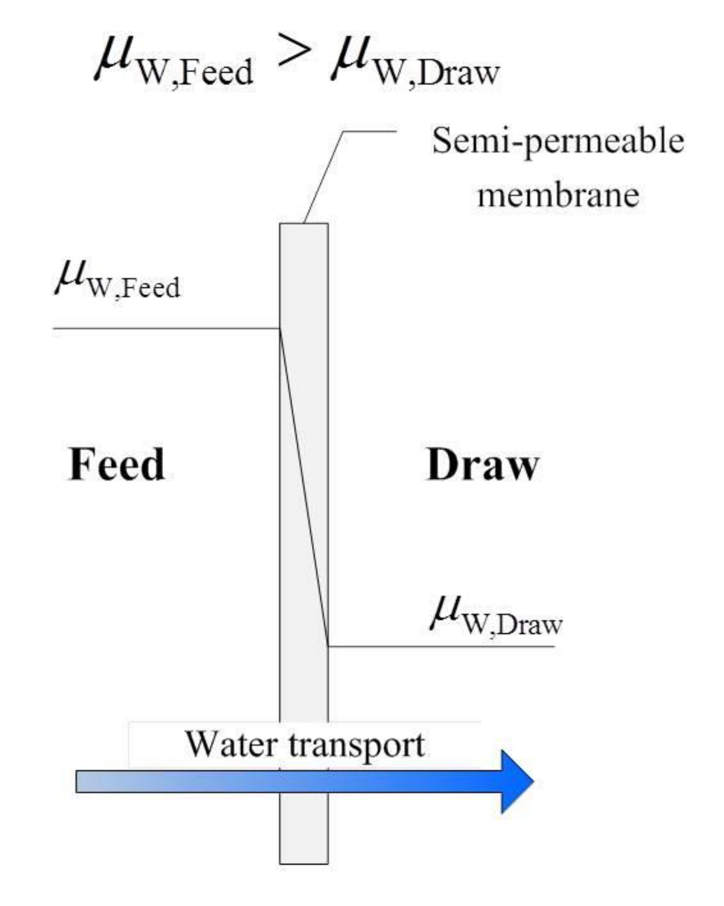
- Naturally driven process without hydraulic pressure
- Run by chemical potential difference (i.e., concentration difference)
- Thermodynamically, reversible process

Advantages

- Low energy consumption
- Theoretically, No energy is required for membrane process

Limitations

- Lack of suitable membrane for FO
- Lack of appropriate draw solution

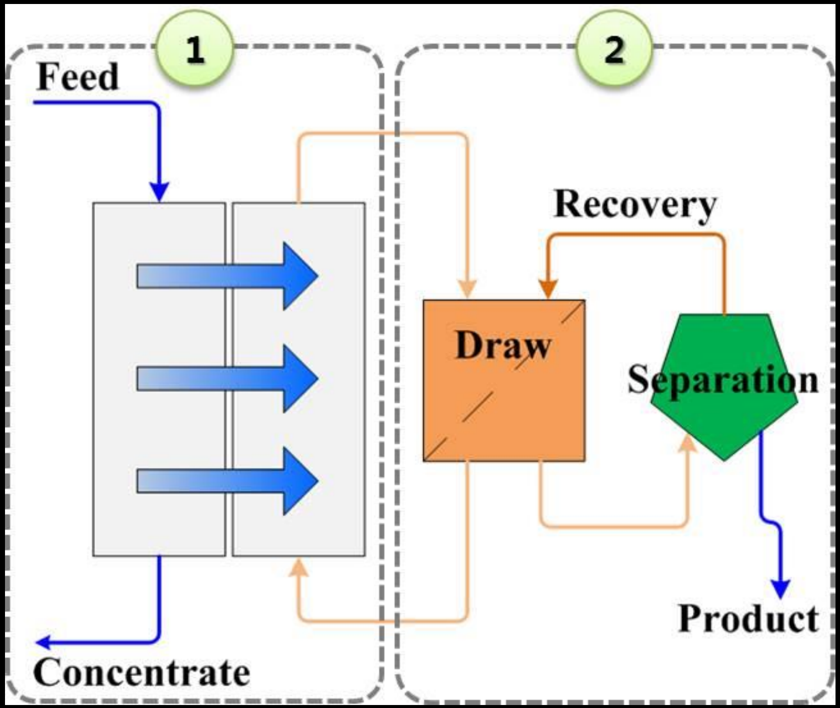


< Schematic of FO processes >

Features of FO process

Membrane process

- Water transports through membrane toward draw side
- Draw solution is diluted



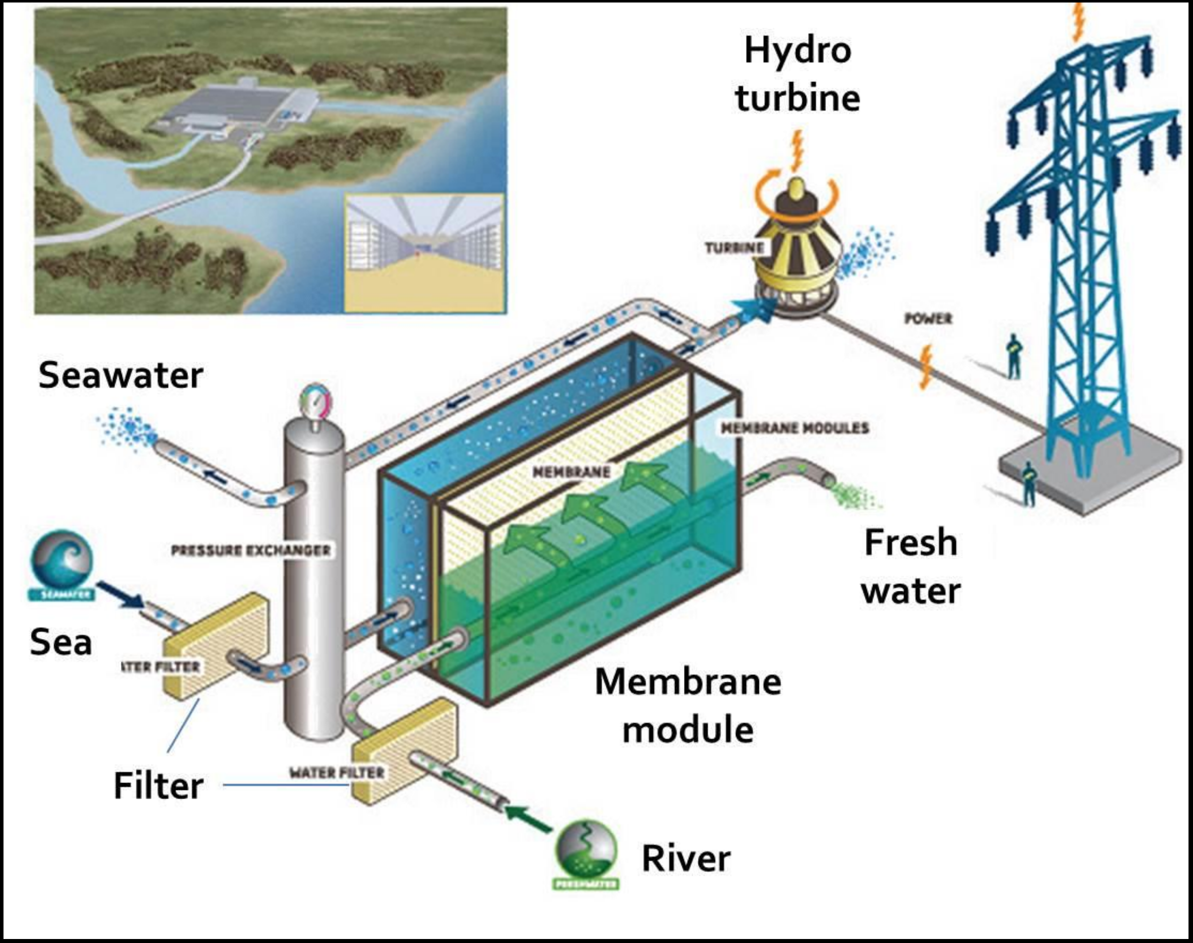
Separation and recovery process

- Pure water is separated out from diluted draw solution
- Draw solution is recovered to be sent back into membrane process

- Naturally driven process by osmosis
- Theoretically, no energy is required for water production
- Contrary to RO, energy requirement is very low

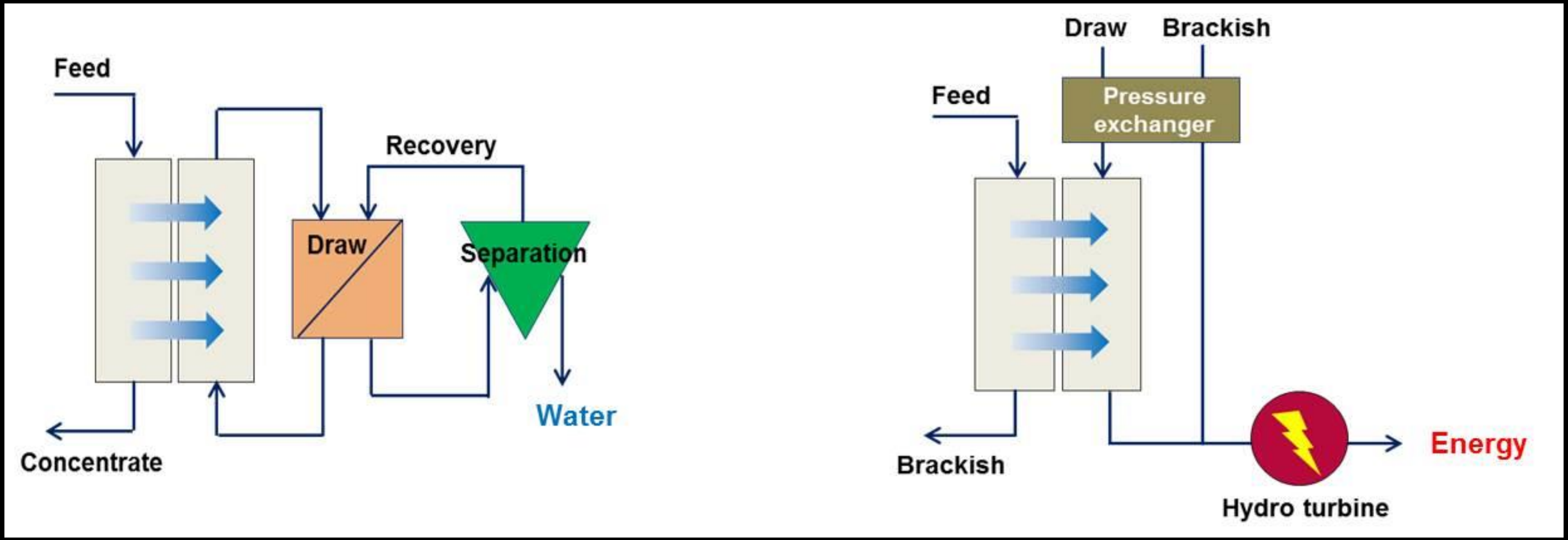
Principle of PRO membrane process

(pressure-retarded osmosis)



- Chemical potential difference between feed and draw solution
- Depressurizing the permeate through hydro-turbine → **Energy**

Comparison of FO & PRO processes



Similarity

- **Two flows** (feed solution, draw solution)
- Utilization of osmotic pressure

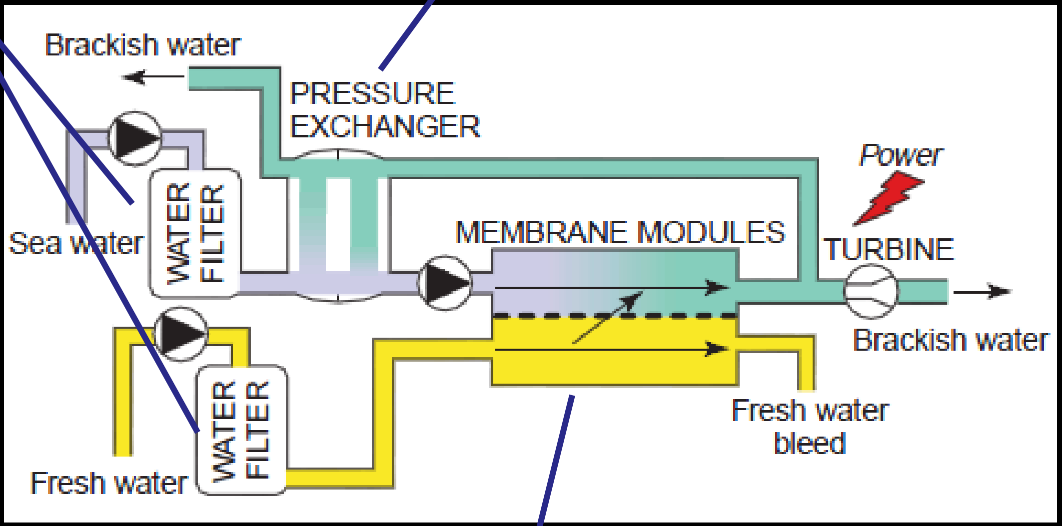
Difference

- **Membrane orientation**
- **FO** : Draw solution recovery

  PRO : Pressure exchanger

Features of PRO process

- **<u>Two pre-treatments</u>**
- **<u>Energy recovery</u>** for initial energy input

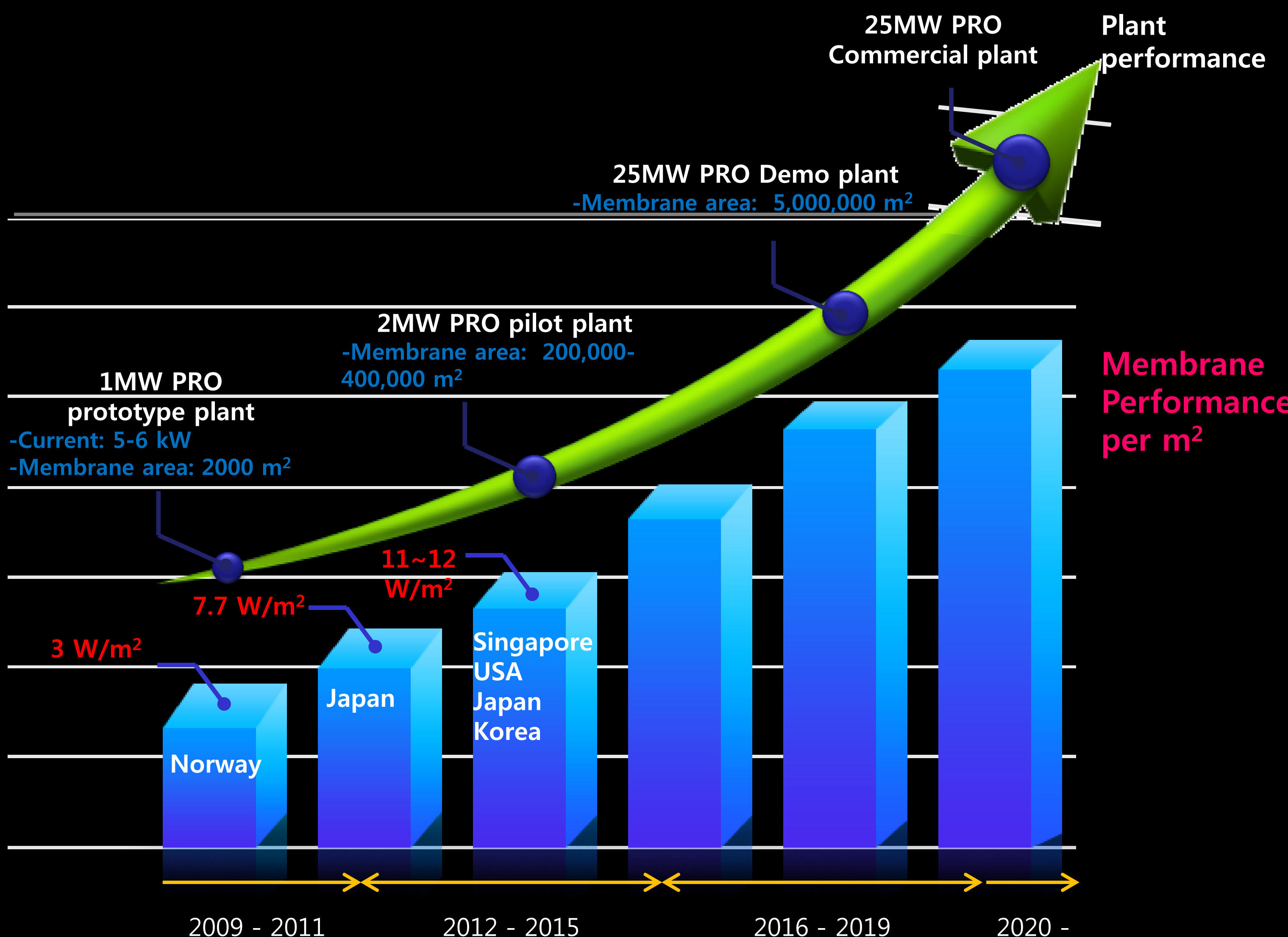


<u>Membrane</u>

- Concentration polarization (ICP, ECP), reverse draw salt flux
- Negative effect of coupling between ICP and reverse salt flux

Ref) Rolf Jarle Aaberg, “Osmotic power: a new and powerful renewable energy source? ”, Refocus (2003)

Future forecasts of PRO power plant



Benefits of PRO power plant

Challenging !

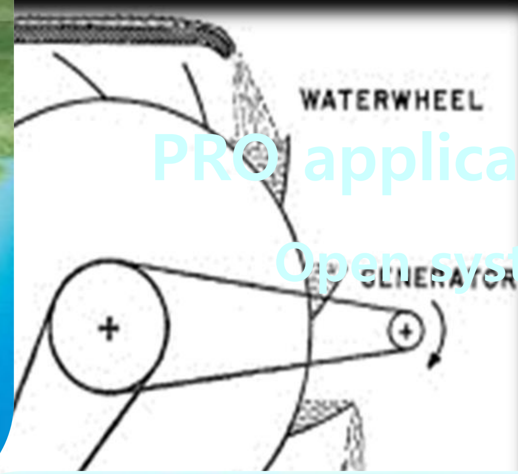
	PRO (Seawater)	PRO (Brine)	Solar Power	Wind Power	Waste Power	Fuel Cell
Generation cost ($/kWh)	0.21	0.16	0.86	0.19 – 0.28	0.13 – 0.26	0.26
Years of operation	17	17	20	17	20	15
Utilization Factor	>85	>85	12	20	65	91

- Recoverable energy from ocean
  → **2,000 TWh** (IEAIOES, 2004)

  ** provides energy to the 40 million household
- Abundant marine resources → **sustainable**
- **No thermal pollution**
- **No CO_2 emission**

Ref) Akihiko Tanioka, "Power generation by PRO using concentrated brine from seawater desalination system and treated sewage; Review of experience with pilot plant in Japan ", 3rd Osmosis Membrane Summit (2012)

PRO power plant applications

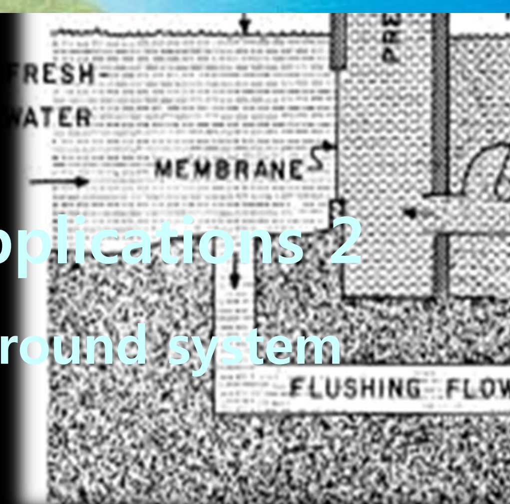


PRO applications 1

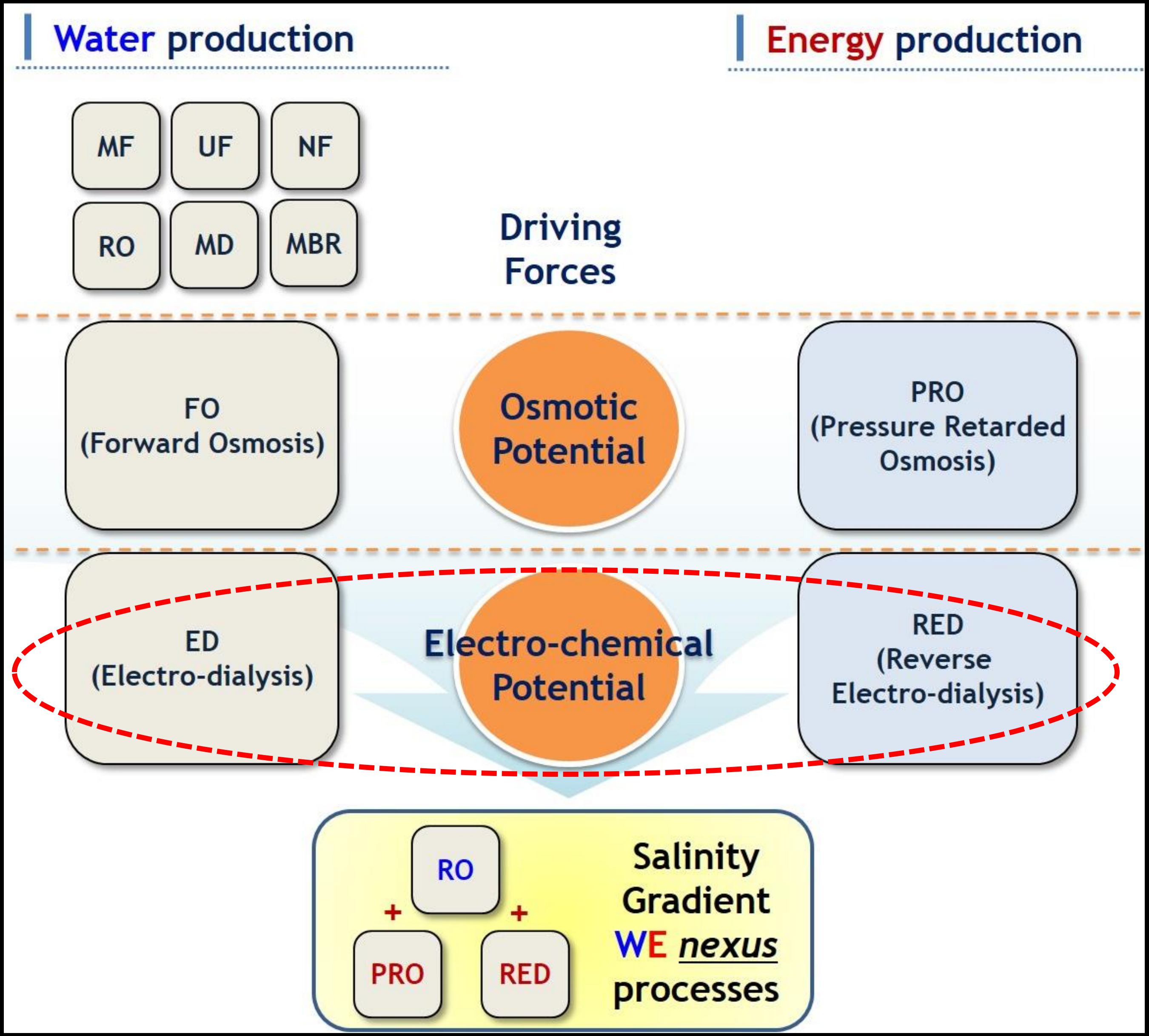
Open system

PRO applications 2

Underground system



Outline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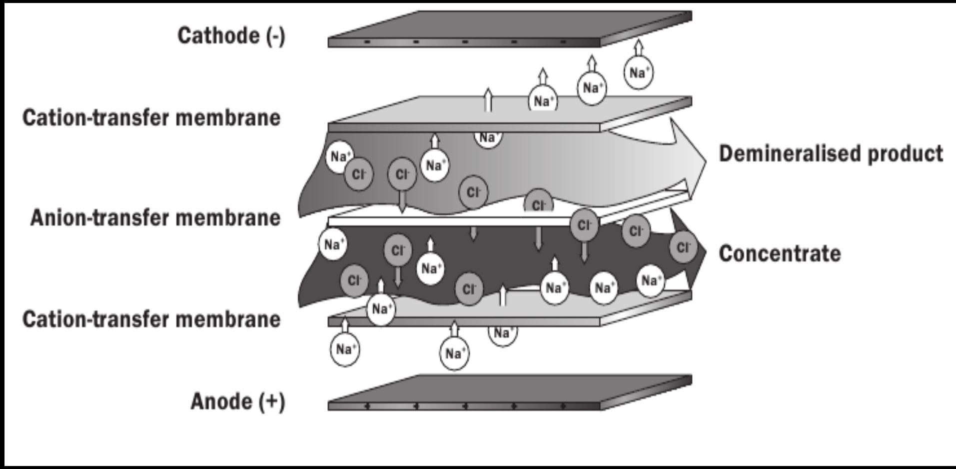
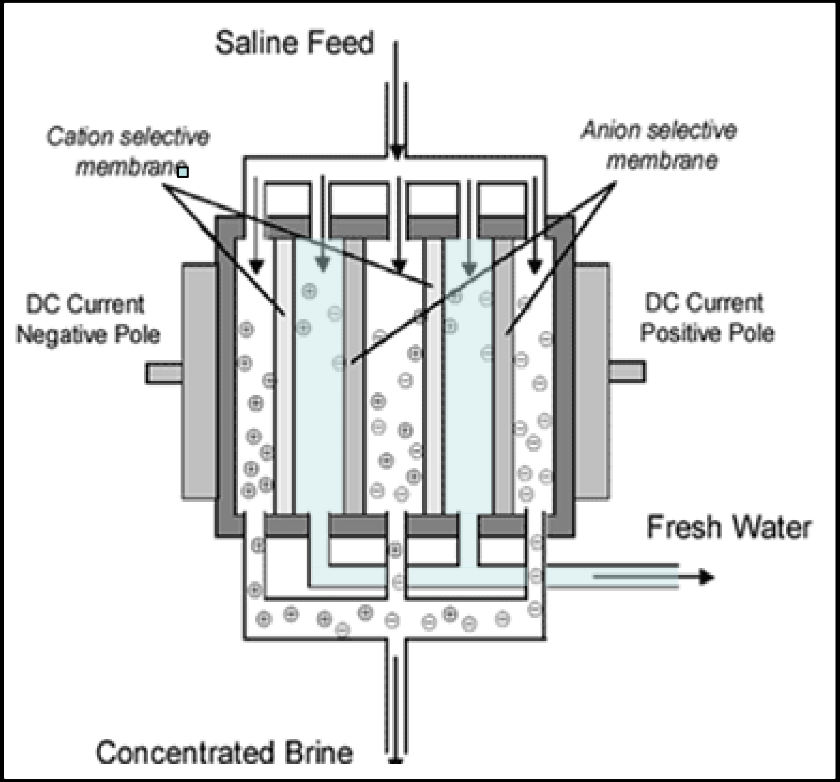
Electro-chemical Potentials

(ED & RED)

Principle of Electro-dialysis (ED)

- Principle of Electro-dialysis (ED)
  - Voltage-driven membrane process
  - Electro-chemical potential difference used to move salt through an ion-exchange membrane
  - Styrene-Divinylbenzene copolymers





Ref. Desaldata.com, TheWaterTreatmentPlant.com

Features of ED process

Advantages

- Without phase change
- **Relatively low energy consumption**
- **Particularly suitable for separating non-ionized from ionized components**
- Not affected by osmotic pressure
- Lower O&M cost

Disadvantages

- **Not remove organic matter, colloids** and SiO_2
- **Only limited in low salinity (BWRO)**
- Feed water pre-treatment is necessary
- Elaborate controls are required, the optimum operation can be difficult
- Selection of materials of membrane is important to ensure compatibility with the feed stream

ED Applications

REDUCE
Electrolyte Content

- **Potable water**
- Food products
- Nitrate from drinking water
- Cooling tower water
- Boiler feed water
- Rinse water
- Effluent streams
- Sugar and molasses

  ……

RECOVER
Electrolyte Content

- **Pure NaCl salt**
- Al(ll) salts
- Ni (ll)
- Zn (ll)
- Salts of organic acids
- **Amino acides**
- HCl

  ……

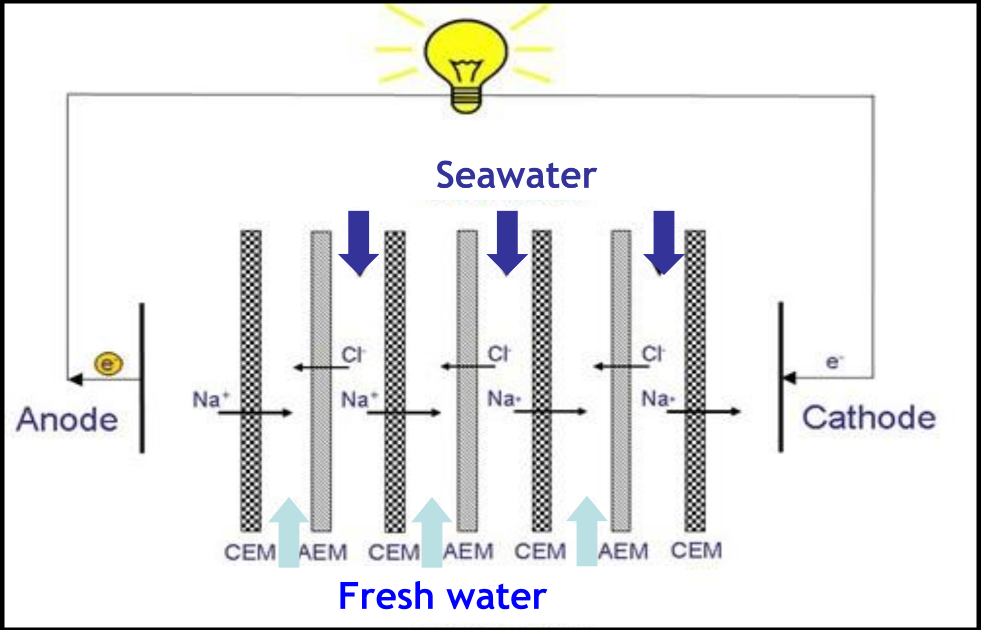
Miscellaneous
Applications

- Salt splitting
- Metathesis
- Concentrate RO brines
- Ion substitution

  ……

Principle of RED process

(Reversed Electro-dialysis)



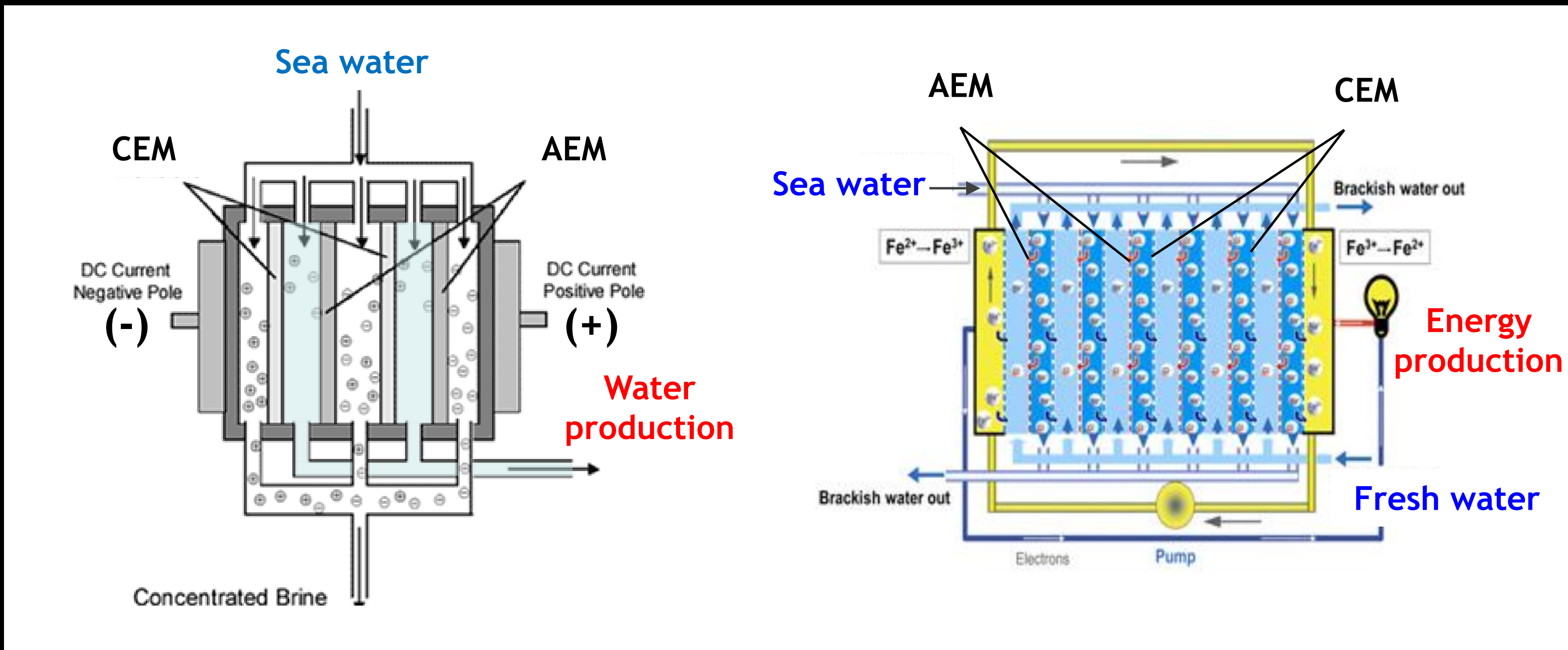
CEM (Cation-exchange membrane)

AEM (Anion-exchange membrane)

- Electro-chemical potential difference between brine and dilute → driving force
- Two membrane types: CEM and AEM
- Electrical current and the potential difference → Energy

Ref. R. E. Lacey "Energy by reverse electodialysis", Ocean Engng. Vol. 7 (1980)

Comparison of ED & RED



Similarity

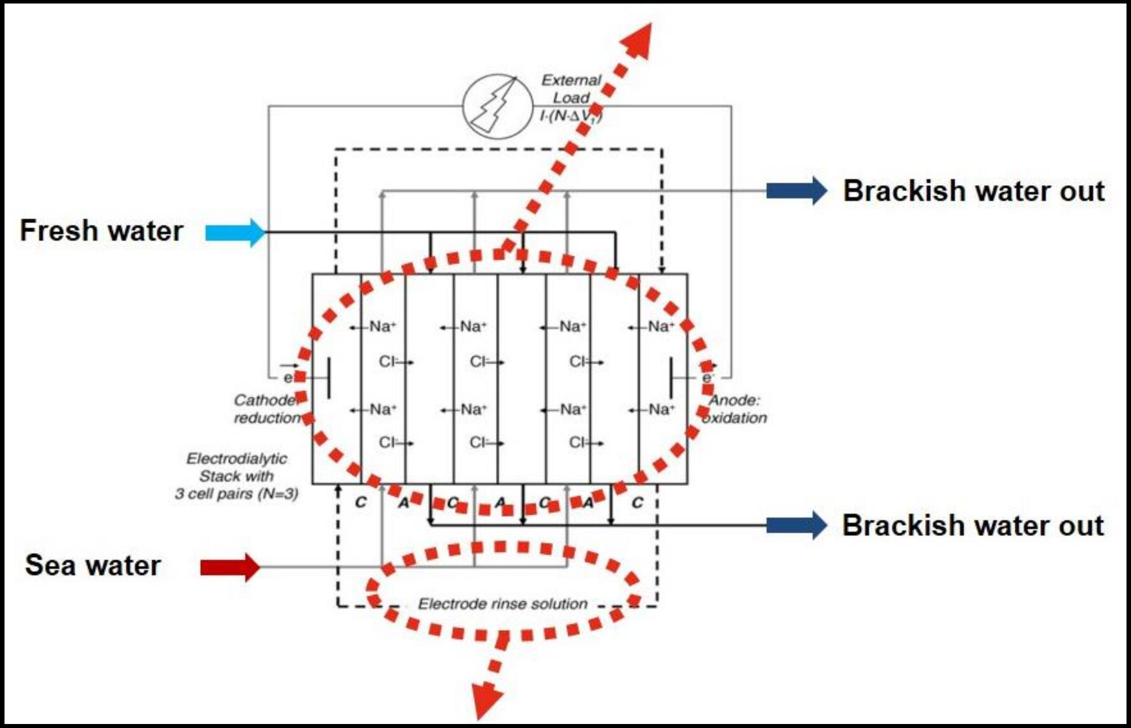
- cation-exchange membrane (CEM) and anion-exchange membrane (AEM)

Difference

- **ED** : Electrolyte cell, **one flow**
- **RED** : Galvanic cell, **two flows**

Features of RED process

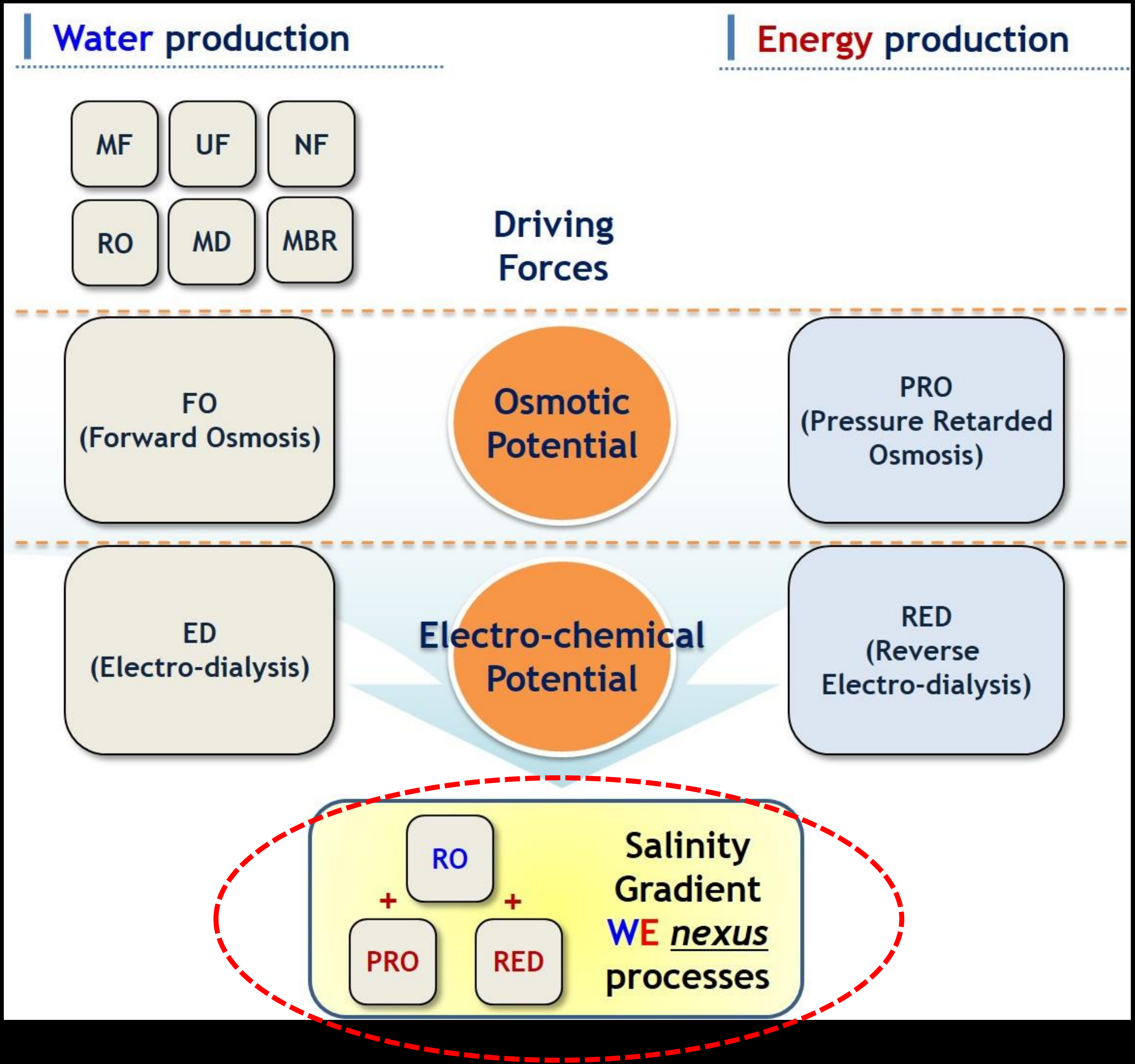
- Concentration polarization at membrane surface
- Not special RED membranes yet



- Possibility of membrane poisoning due to rinse solution

Ref) J. W. Post et al., “Salinity gradient power: Evaluation of pressure retarded osmosis and reverse electrodialysis”, JMS (2007)

Outline



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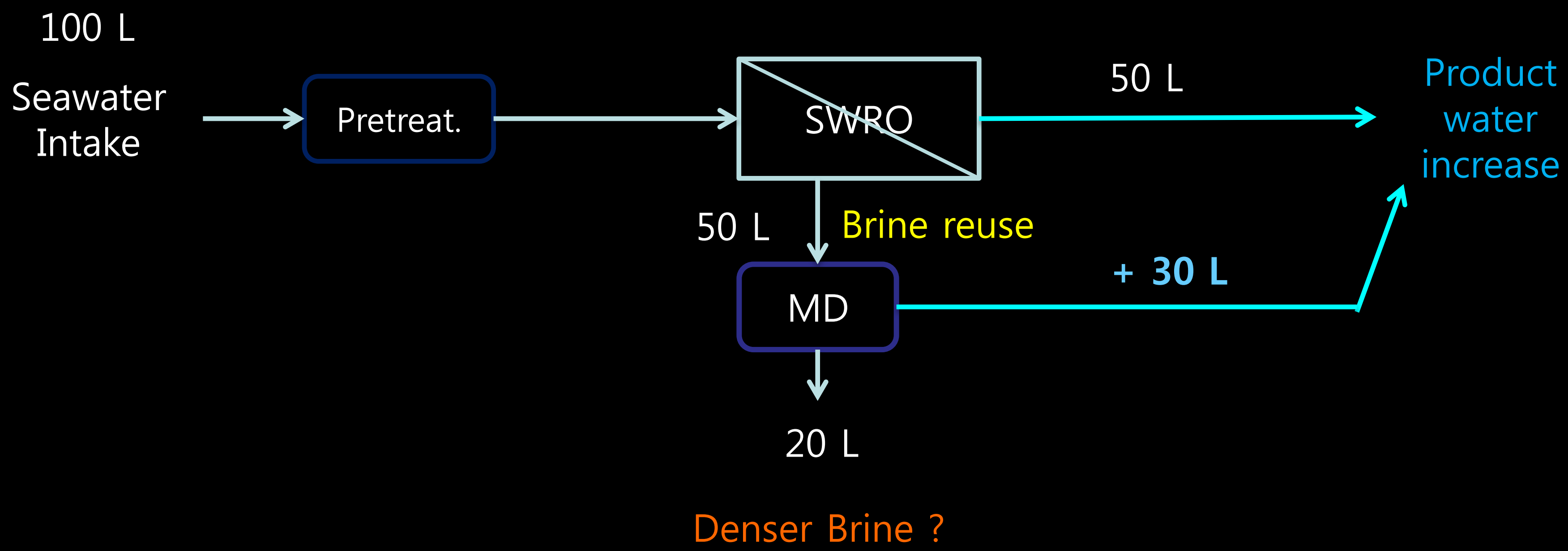
Salinity Gradient WE *nexus* processes

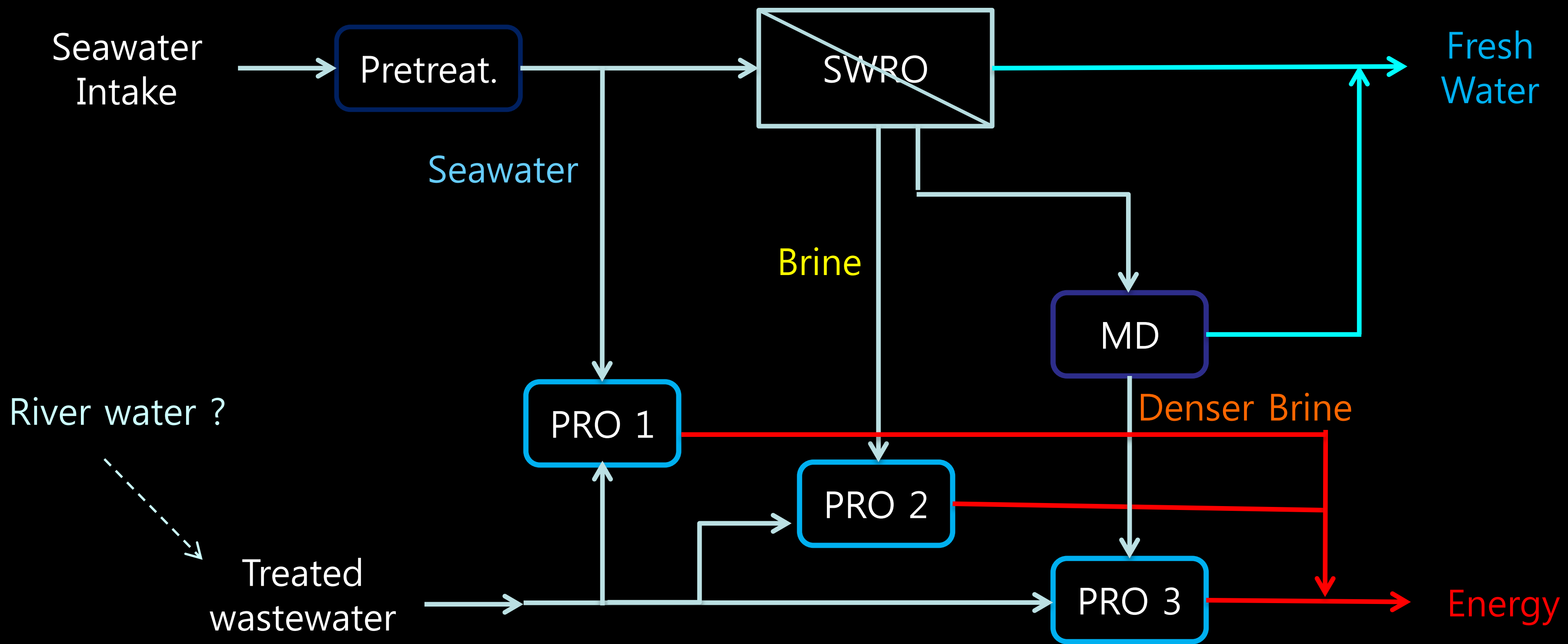
SWRO hybridization with MD

Increase of product water

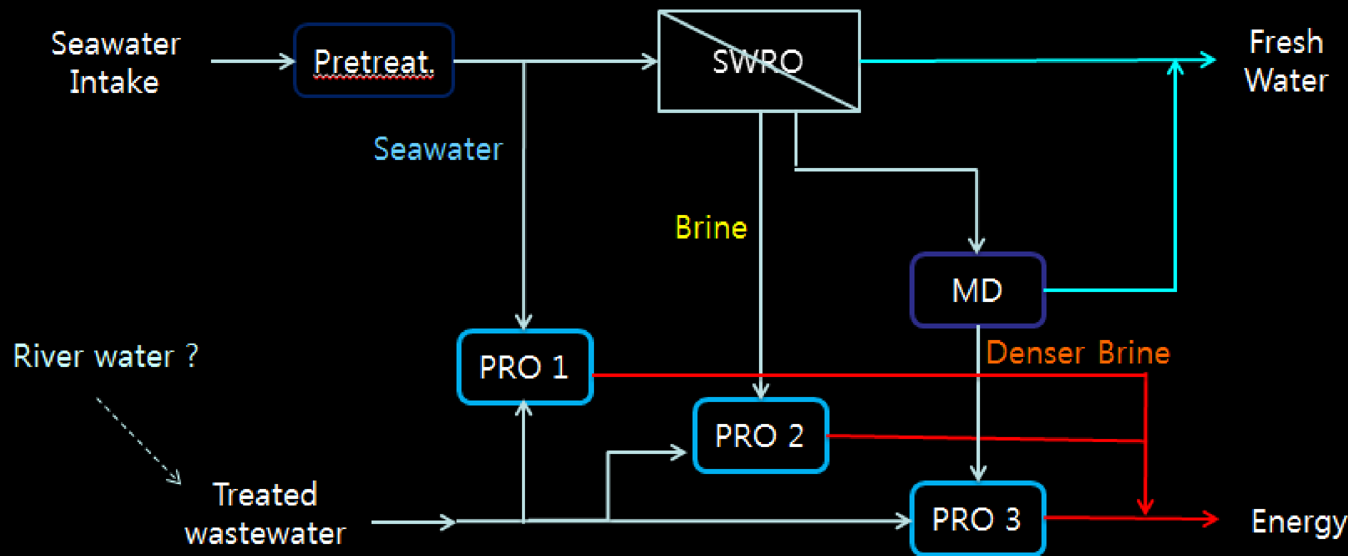


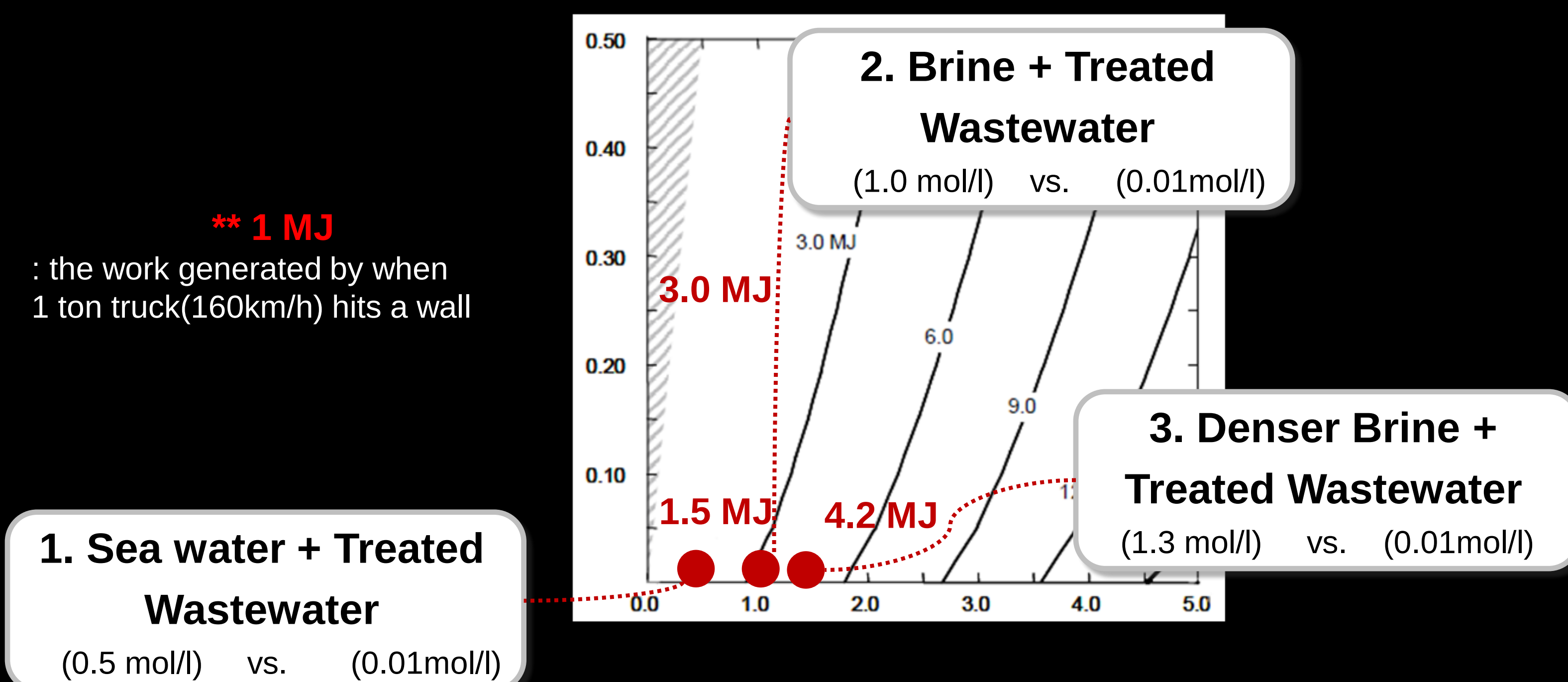
SWRO hybridization with MD & PRO

Increase of product water + energy



Increase of product water + energy

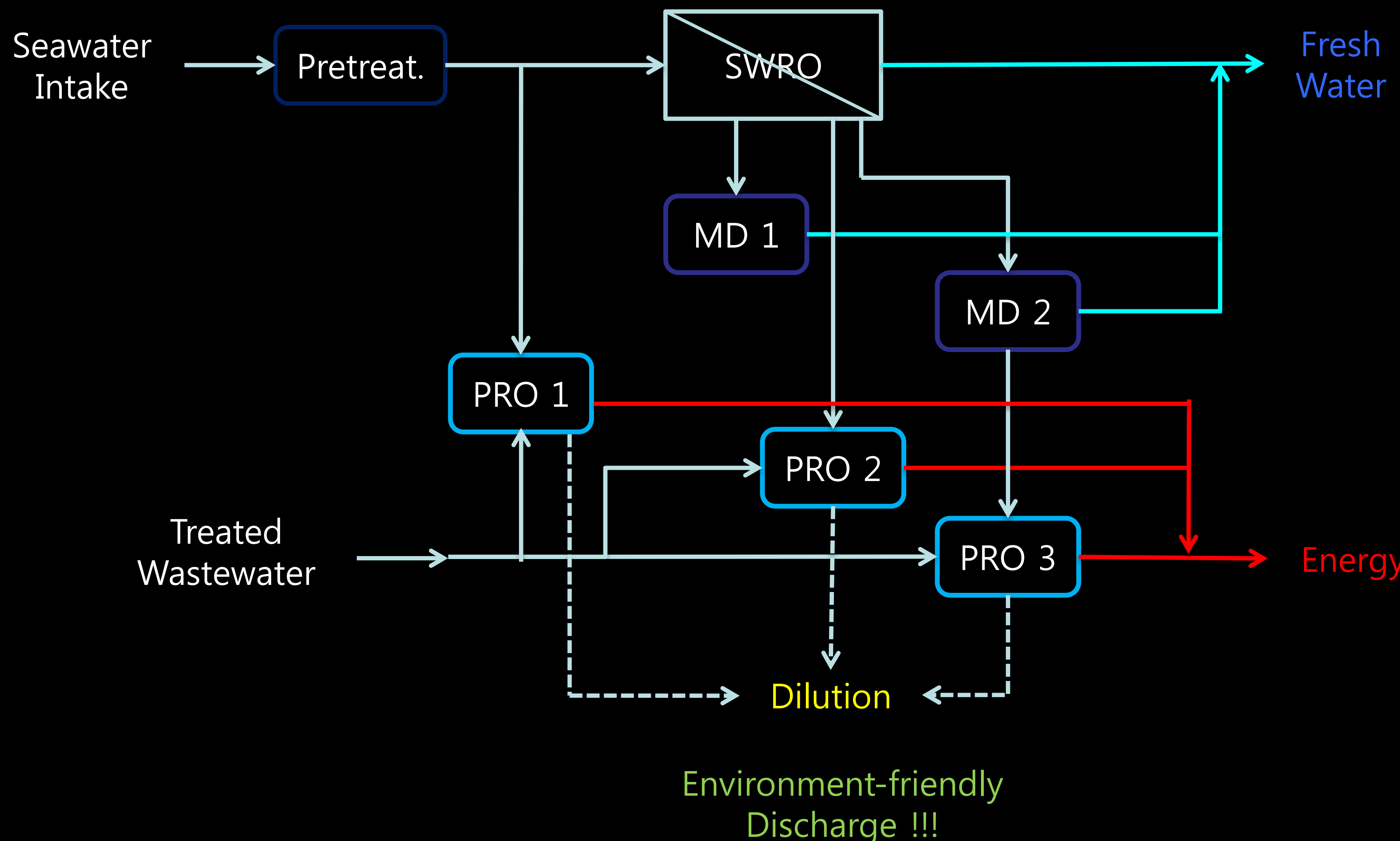




**** 1 MJ**

: the work generated by when
1 ton truck(160km/h) hits a wall

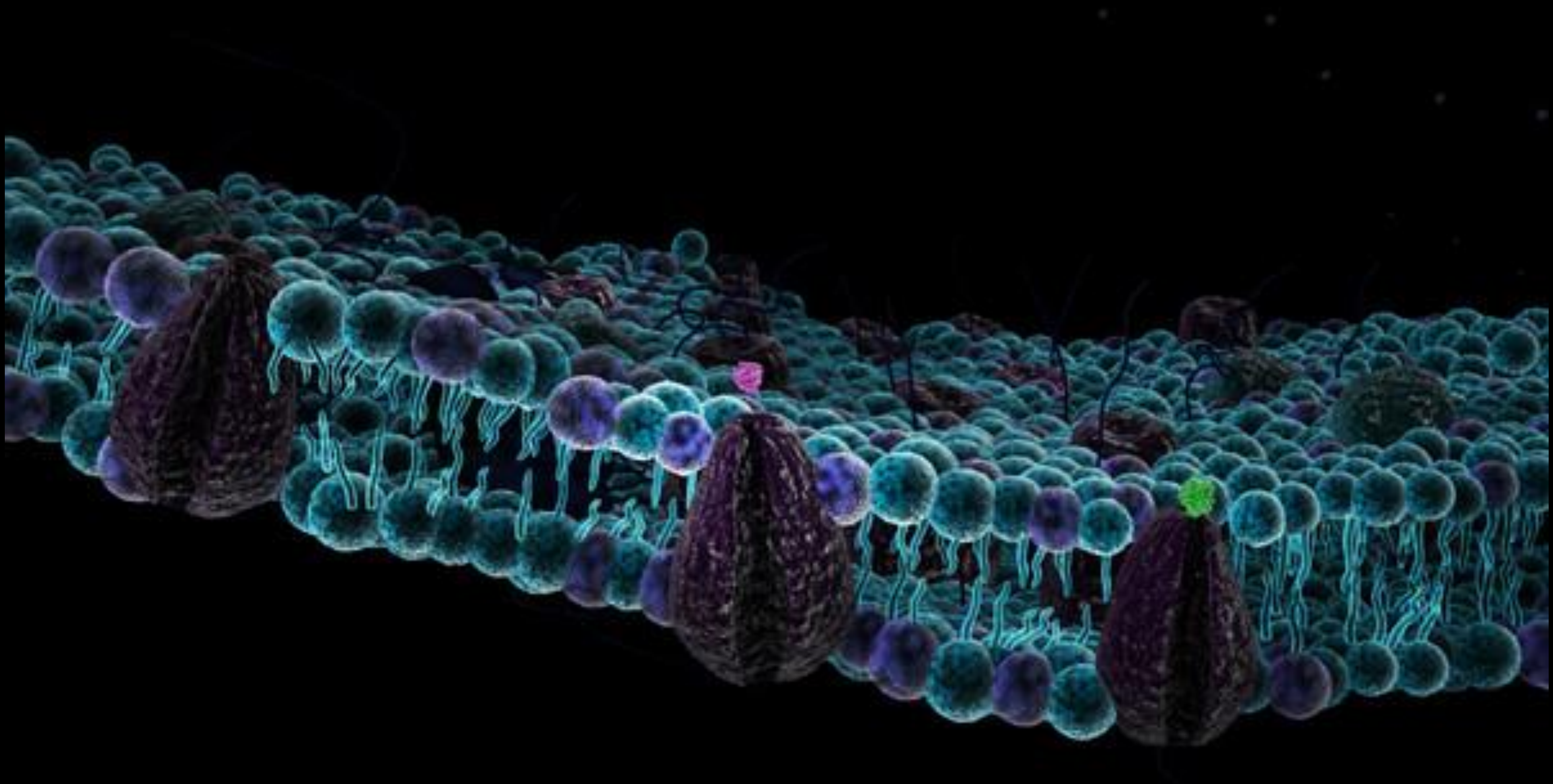
Increase of product water + energy + green discharge



Seawater

Unlimited resource for WE ,,,

Membrane



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- FEW resources for human
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- Seawater…
- Membrane…
- Technology…

Green membrane technology to produce water & energy from seawater.

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All WE may be from the sea.

Thanks for your attention!

Any question?