Seawater Desalination

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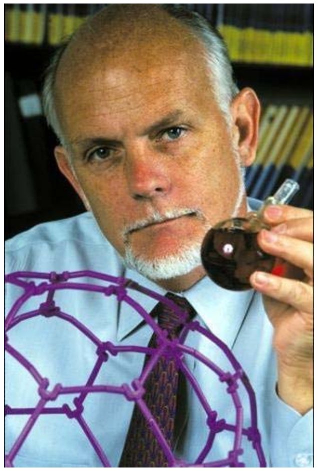
The “Top 10” Global Challenges for the New Millennium

1. **Energy**
2. **Water**
3. Food
4. Environment
5. Poverty
6. Terrorism and War
7. Disease
8. Education
9. Democracy
10. Population



Richard E. Smalley, Nobel Laureate, Chemistry, 1996, *MRS Bulletin*, June 2005

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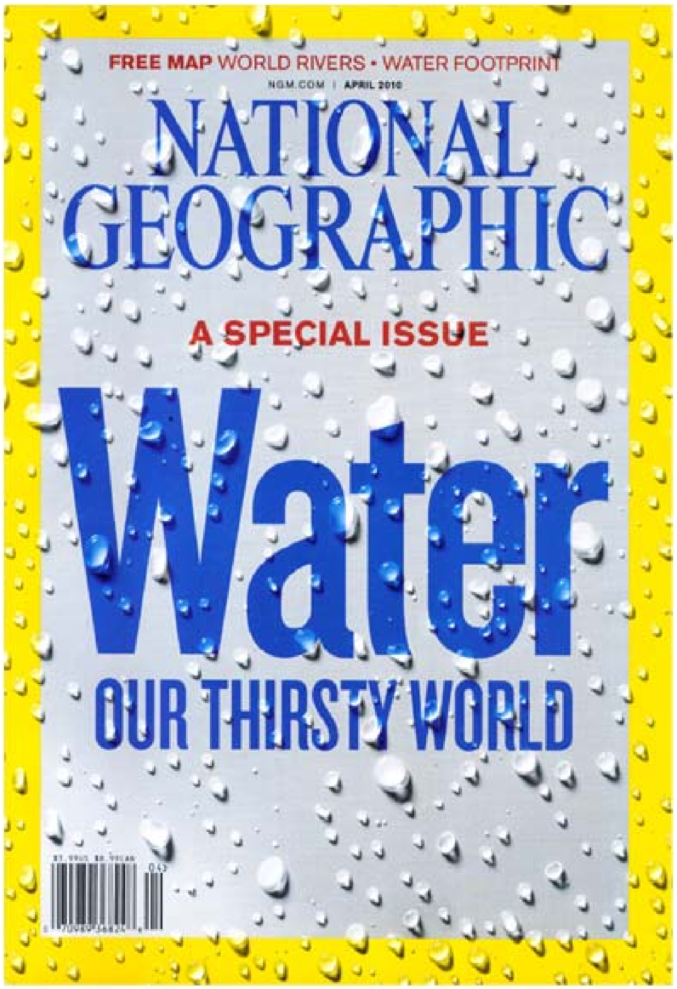
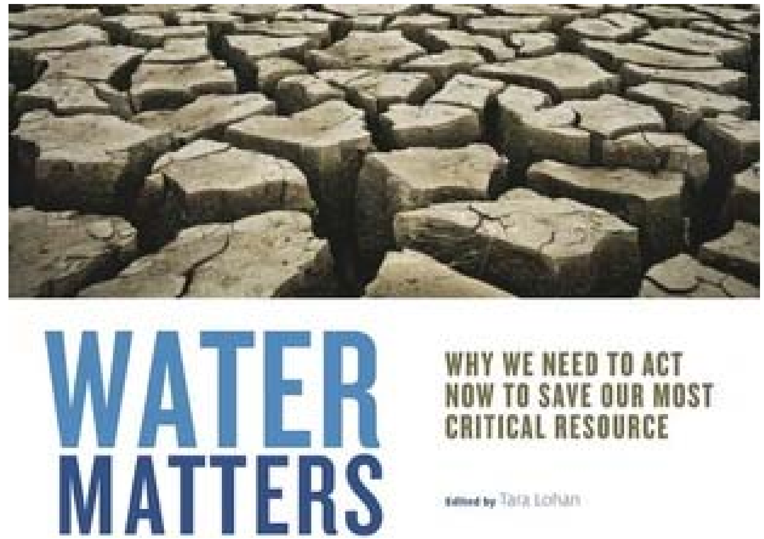
Water Scarcity is a Global and Regional Challenge





We Need New Water Sources

- Increasing water supply beyond what is achievable from the hydrologic cycle can only be achieved by:

  ✓ **Desalination** of seawater and brackish water

  ✓ Reuse of wastewater

- **Challenge:** Development of sustainable, energy-efficient technologies

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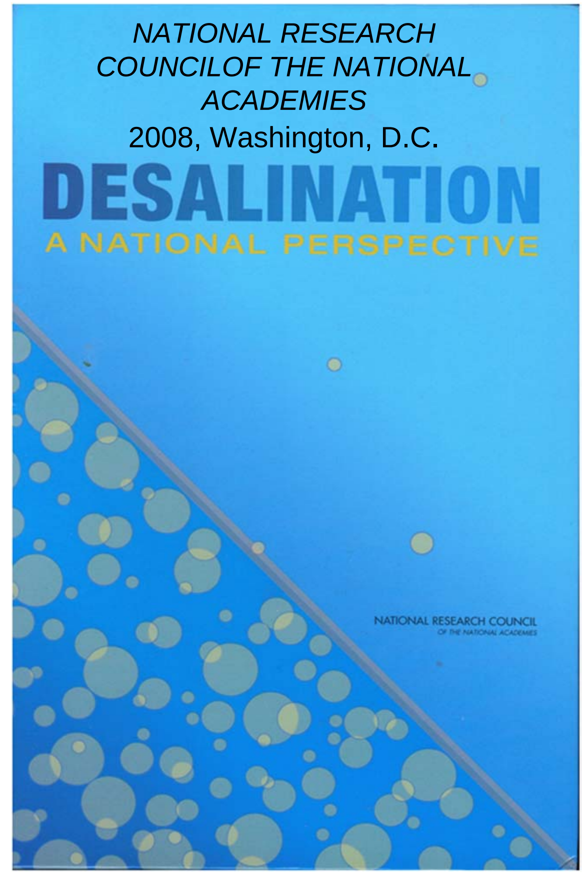
SCIENCE VOL 313 25 AUGUST 2006

INTRODUCTION

A Thirsty World



nature March 2008 **nature** Vol 452|20 March 2008

SPECIAL REPORT

Purification with a pinch of salt

Climate change, growing populations and political concerns are prompting governments and investors from California to China to take a fresh look at desalination. **Quirin Schiermeier** wades in.

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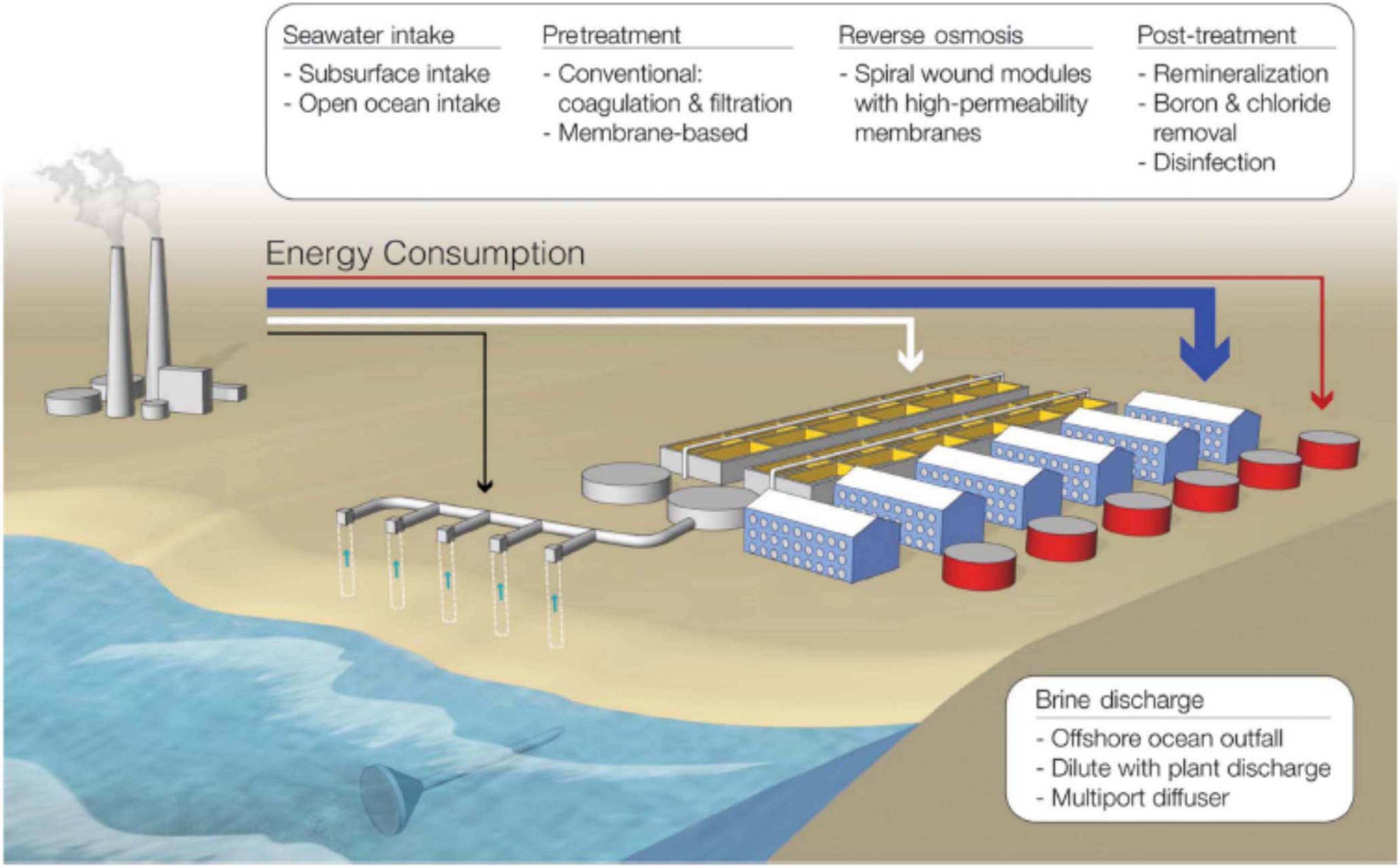
Seawater Reverse Osmosis (SWRO): The State-of-the-Art Technology



Seawater Desalination

- Offers a seemingly unlimited, steady supply of high-quality water
- Production of fresh water without impairing natural fresh water ecosystems
- More energy intensive (~ 3 to 4 times) compared to conventional technologies for the treatment of fresh water
- Concerns about the potential environmental impacts of large-scale SWRO plants

REVIEW

Science

The Future of Seawater Desalination: Energy, Technology, and the Environment

Menachem Elimelech* and William A. Phillip†

In recent years, numerous large-scale seawater desalination plants have been built in water-stressed countries to augment available water resources, and construction of new desalination plants is expected to increase in the near future. Despite major advancements in desalination technologies, seawater desalination is still more energy intensive compared to conventional technologies for the treatment of fresh water. There are also concerns about the potential environmental impacts of large-scale seawater desalination plants. Here, we review the possible reductions in energy demand by state-of-the-art seawater desalination technologies, the potential role of advanced materials and innovative technologies in improving performance, and the sustainability of desalination as a technological solution to global water shortages.

5 AUGUST 2011 VOL 333 **SCIENCE**

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Address Four Major Questions

- What is the Current Energy Efficiency of Desalination and Can it be Improved?
- Can Novel Materials Reduce Energy Consumption?
- Are There Innovative Systems and Technologies that can Reduce Energy Demand?
- Is Seawater Desalination a Sustainable Technological Solution to Global Water Shortages?

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What is the Current Energy Efficiency of Desalination and Can it be Improved?

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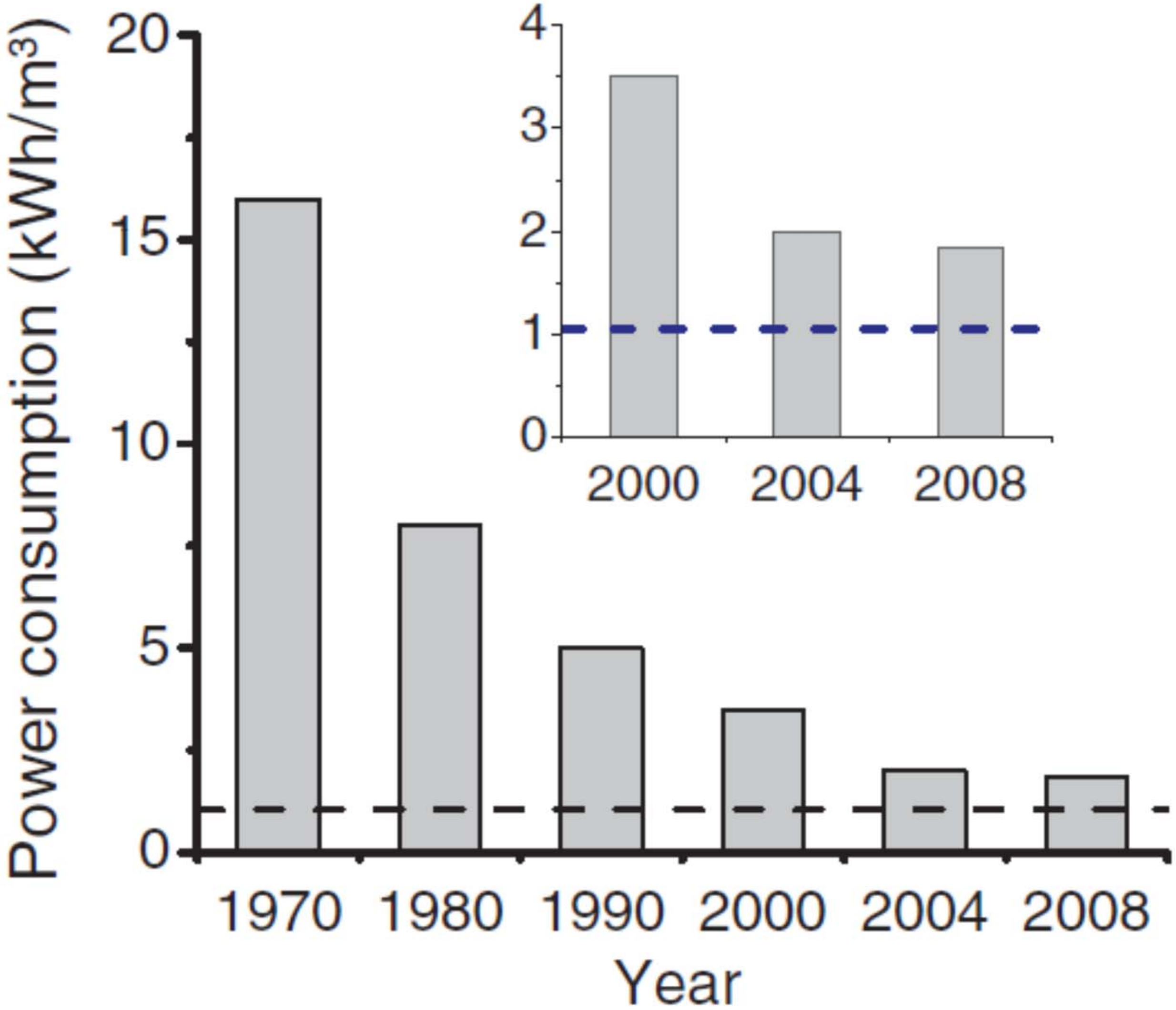
Major Reductions in Energy Use by SWRO in the Past 20 Years



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Minimum Theoretical Energy of Desalination

- Reversible thermodynamic process
- Independent of the technology or mechanism of desalination

Minimum theoretical energy (typical seawater, 35,000 ppm):

- 0% recovery: **0.76 kWh/m^3**
- 50% recovery: **1.06 kWh/m^3**

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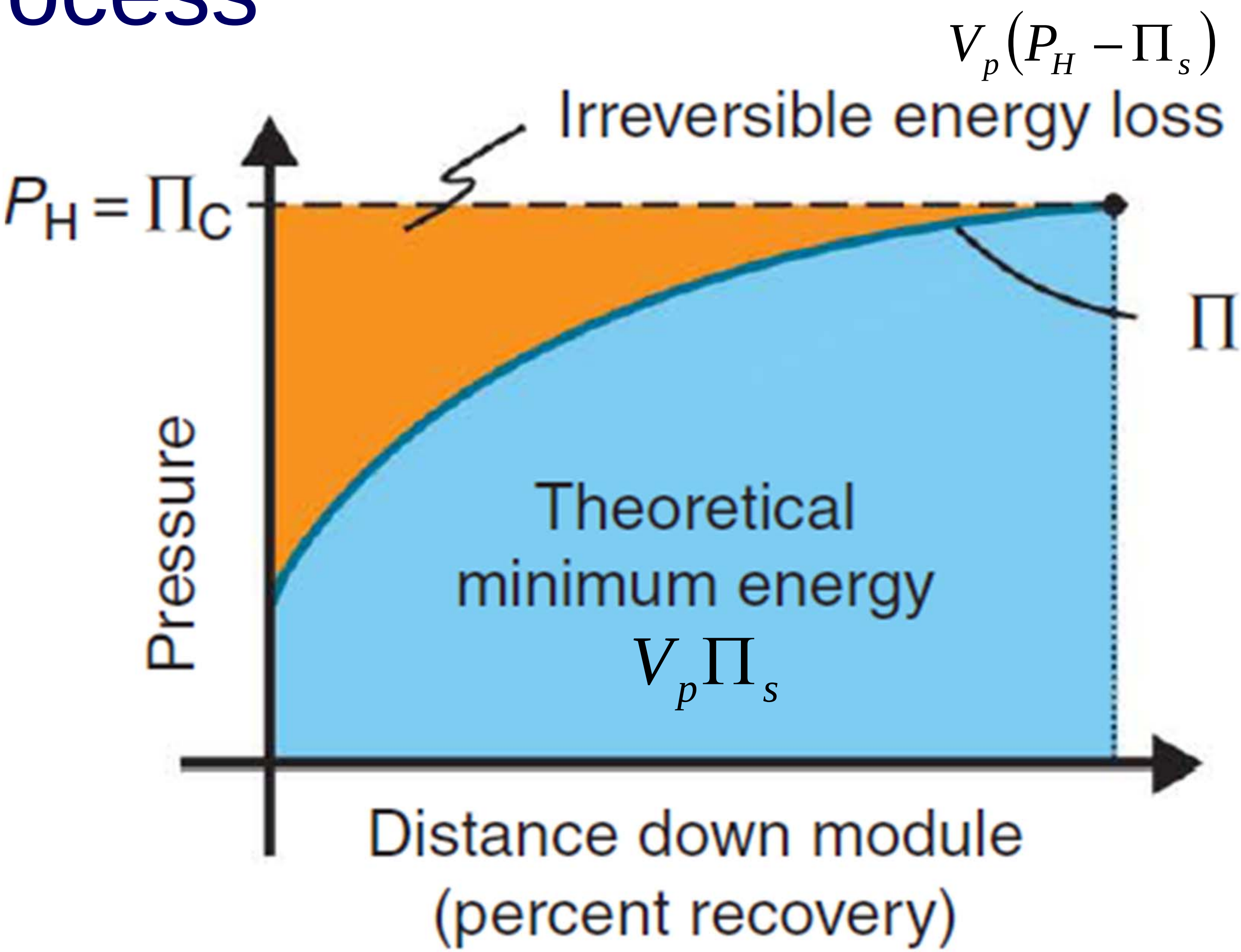
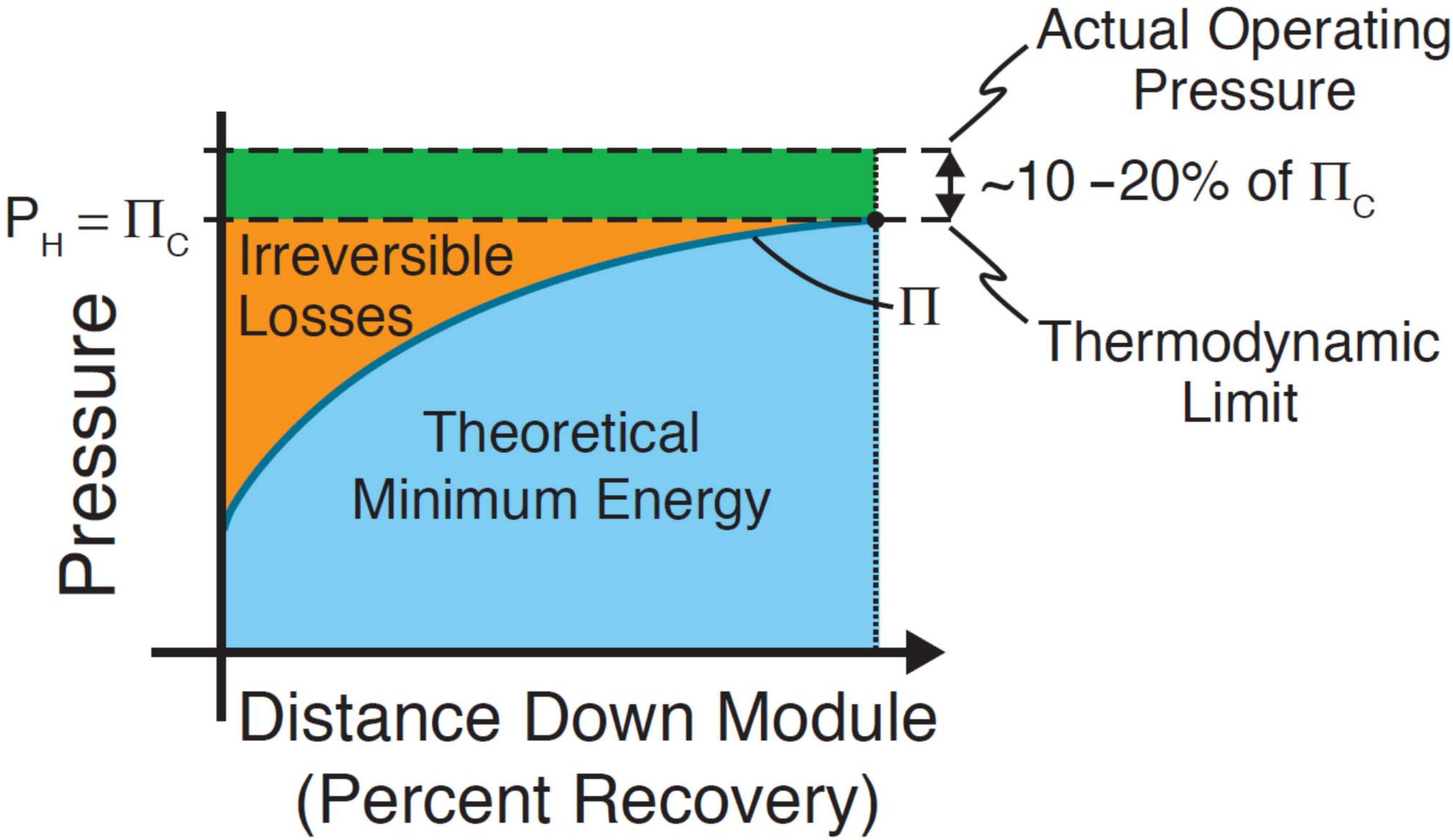
Energy Consumption in the RO Process



Energy Consumption in the RO Process



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Energy Consumption in SWRO Desalination

For 50% recovery:

- Theoretical minimum energy (thermodynamics): **1.06 kWh/m³**
- Practical minimum energy (when operating at the thermodynamic limit, $P_H = \Pi_C$: **1.56 kWh/m³**
- For best SWRO, RO consumes: ~ **2 kWh/m³**
- Overall energy consumption for the entire SWRO plant for recently constructed plants: **3 - 4 kWh/m³**

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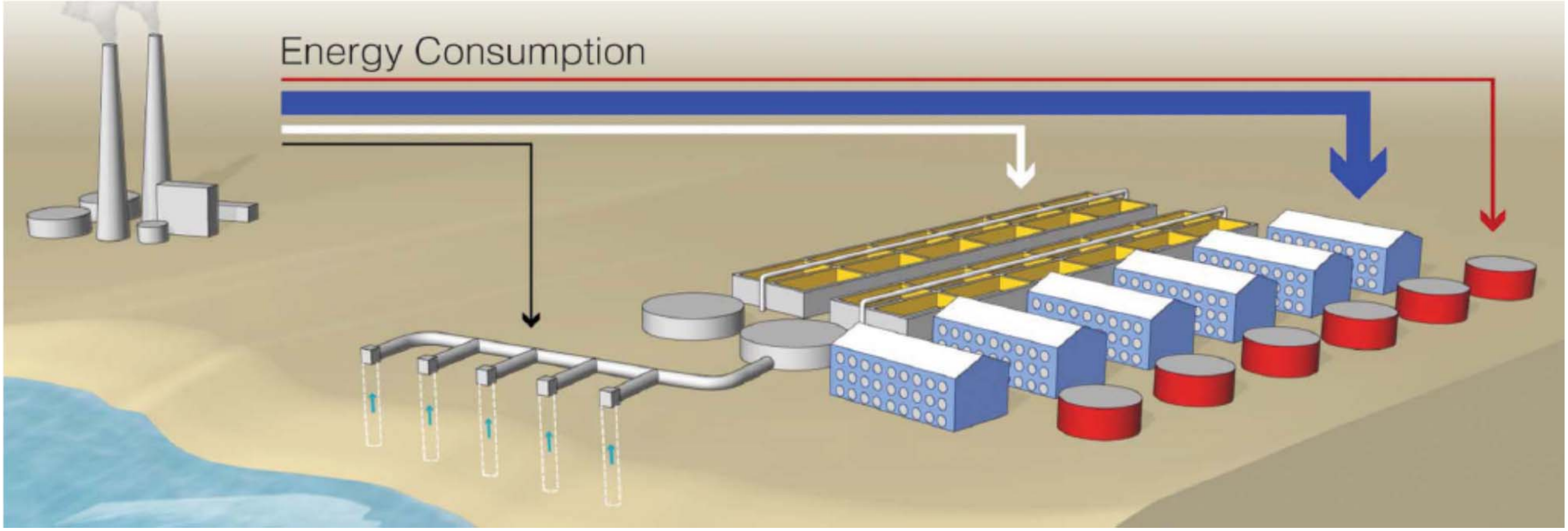
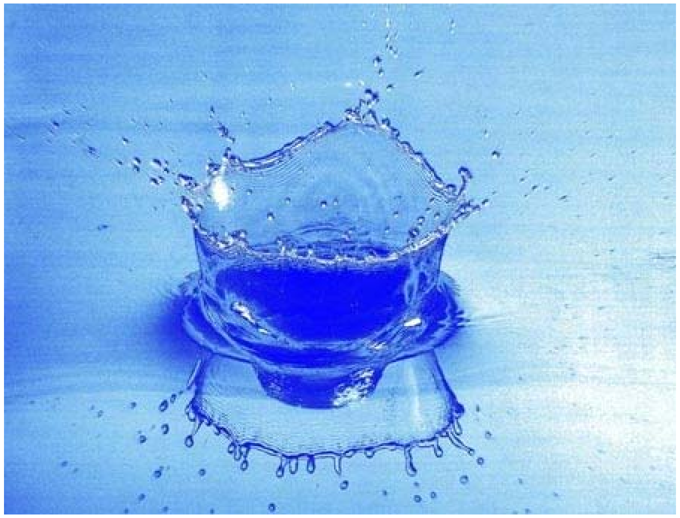
RO Consumes ~ **2 kWh/m³**: Where is the Rest of Energy Expended?



- Pre-treatment (will decrease with increased recovery)
- Increased pressure to compensate for fouling
- Post-treatment (boron and chloride removal for agricultural water)
- Intake, discharge

Can Novel Materials Reduce Energy Consumption?



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How Can We Reduce the Energy Use in the RO Stage?

- Hot Area of Research: High Permeability (Flux) RO Membranes..... "Quantum Leap In Desalination"

  Rationale: High permeability membranes would reduce the required applied pressure and hence red

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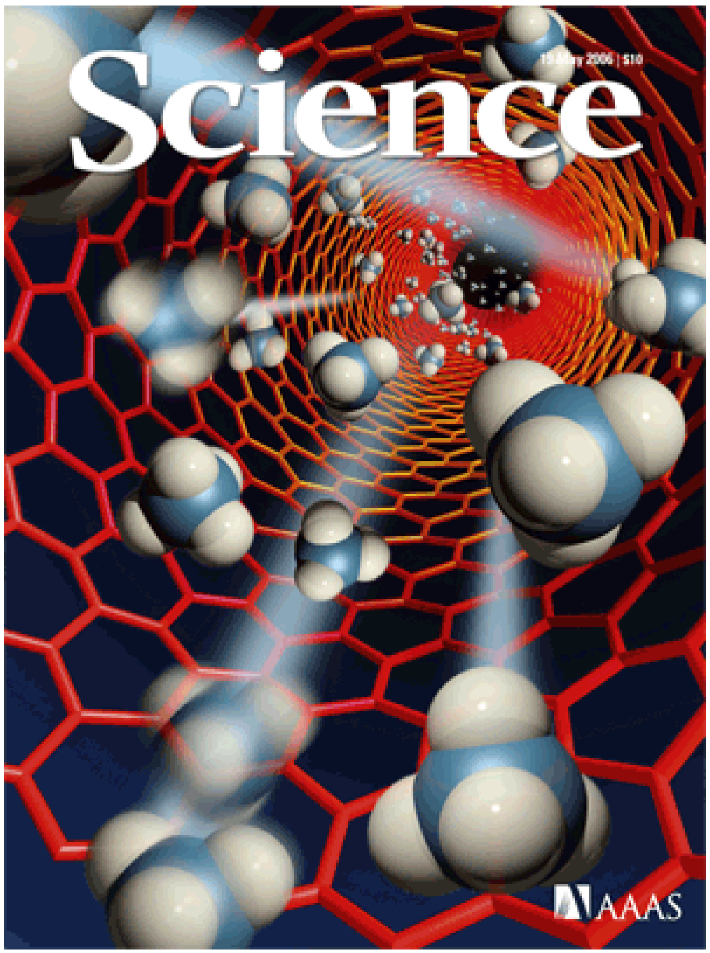
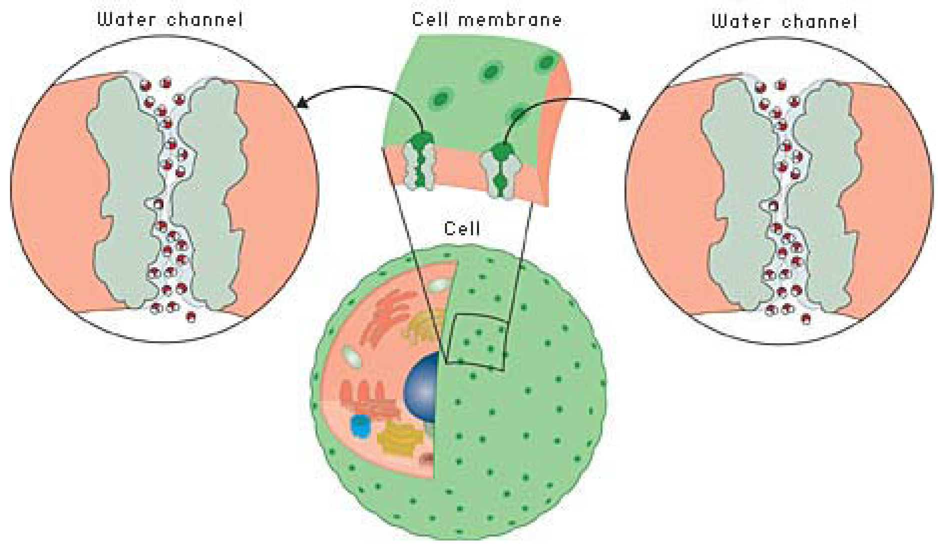
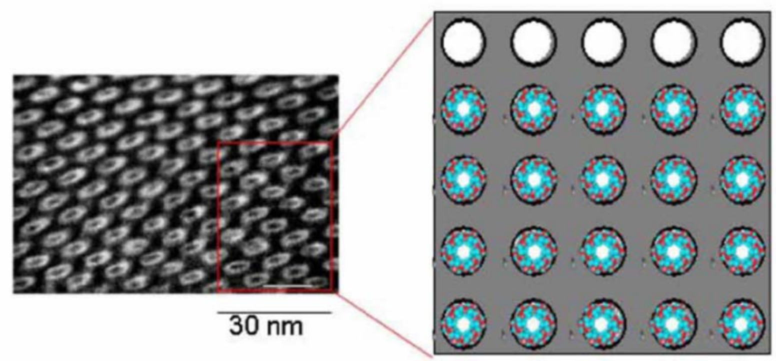
Aligned Nanotubes as High Flux Membranes for Desalination



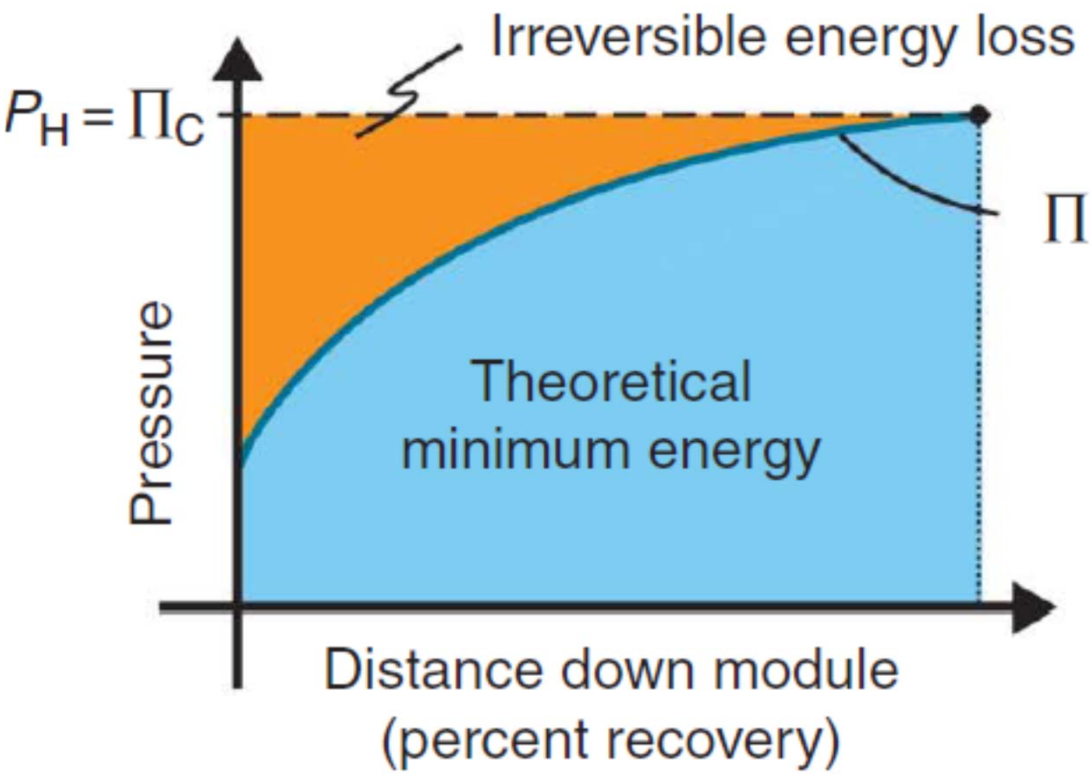
Bio-inspired (Aquaporin) High Flux Membranes for Desalination





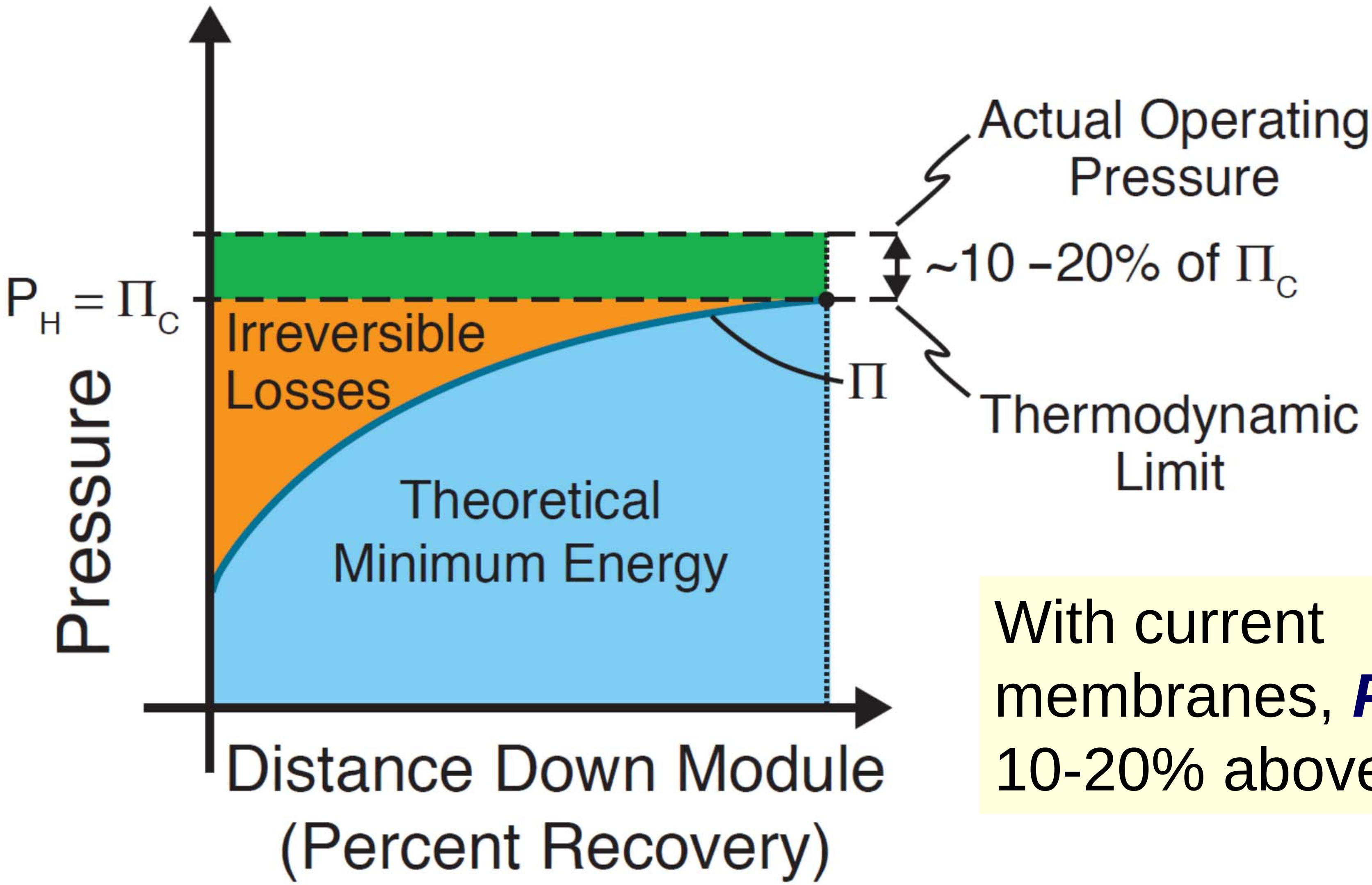
Synthetic water channel

But…Energy is Governed by the Osmotic Pressure of the Concentrate



Must operate at
$P_H > \Pi_C$

High Permeability Membranes will Have a Negligible Effect



With current membranes, $\boldsymbol{P_H}$ is 10-20% above Π_C

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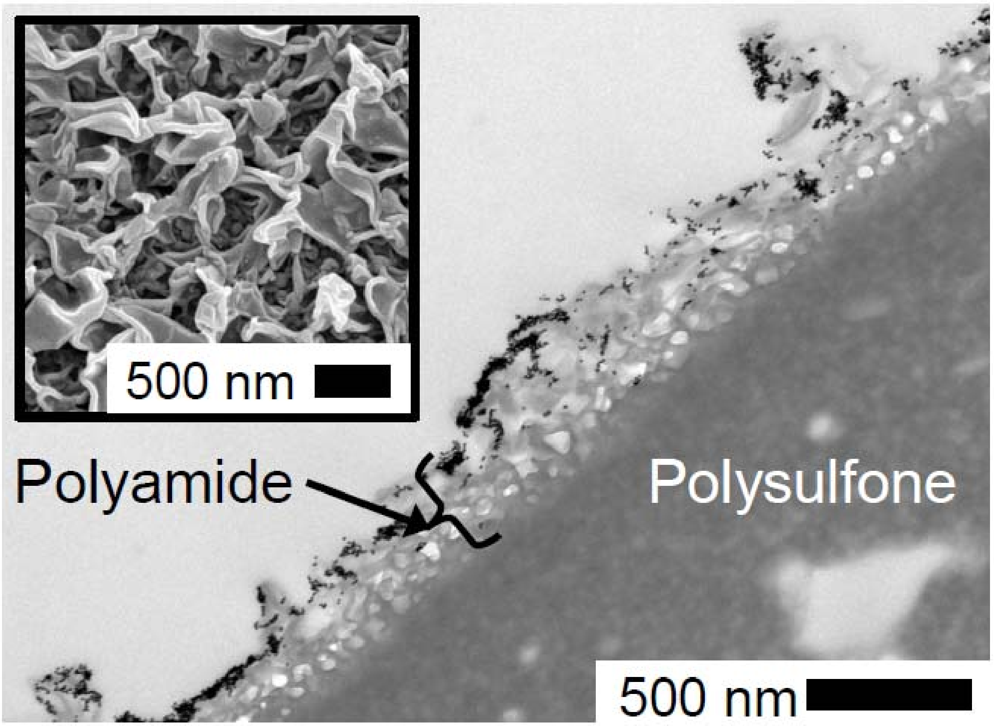
Thin-Film Composite Polyamide Membranes are Prone to Fouling



- Relatively hydrophobic
- Rough surface
- Contain carboxyl groups
- Hence, **prone to fouling**

- Also sensitive to oxidants (like chlorine)
- Hence, **prone to biofouling**

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Reducing RO Membrane Fouling and Biofouling is the Key

- Fouling resistant membranes
- Chlorine (oxidant) resistant membranes
  - Improve reliability and energy efficiency of RO
  - Reduce the use of chemicals for cleaning
  - Reduce pretreatment energy and costs

Are There Innovative Systems and Technologies that can Reduce Energy Demand?

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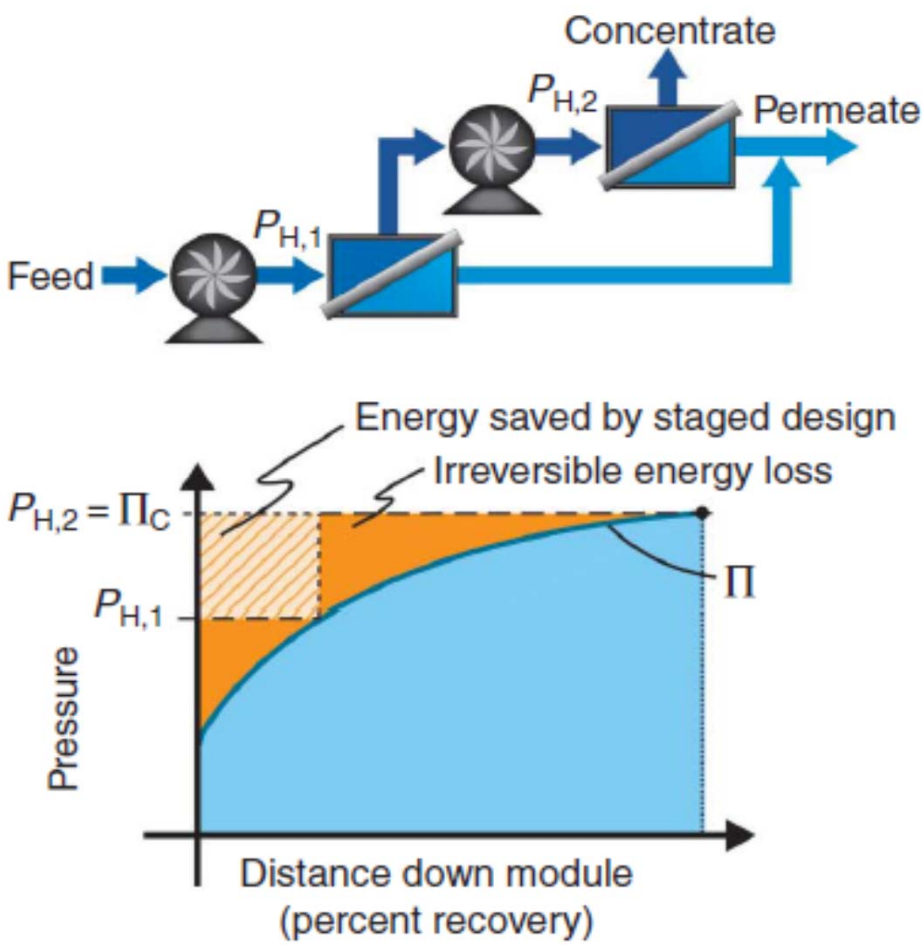
Two Stage-RO: Reduces Energy but Increases Capital Costs



Practical Minimum Energy

- 1 Stage: 1.56 kWh/m^3
- 2 Stages: 1.28 kWh/m^3
- ∞ stages: 1.06 kWh/m^3 (theoretical minimum energy)

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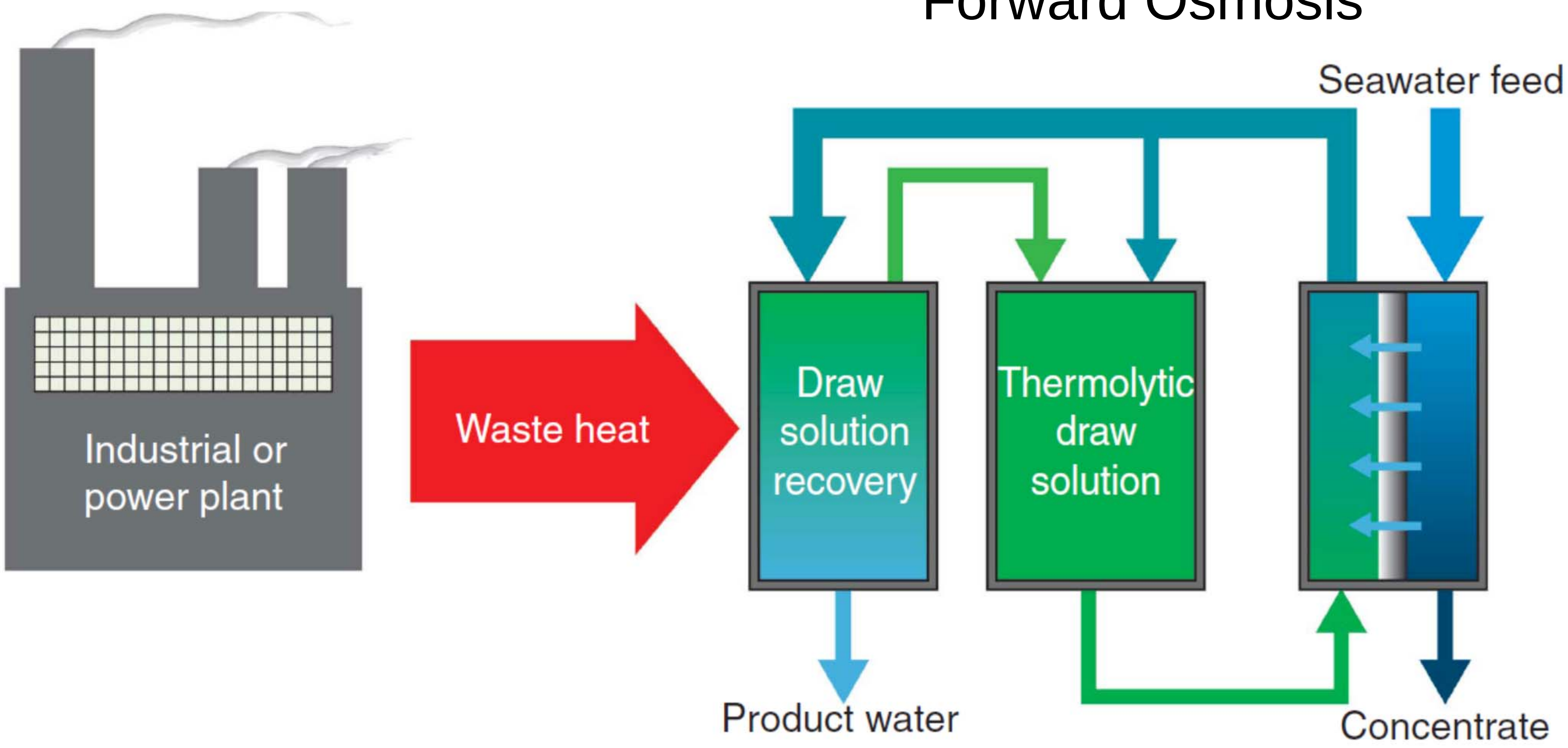
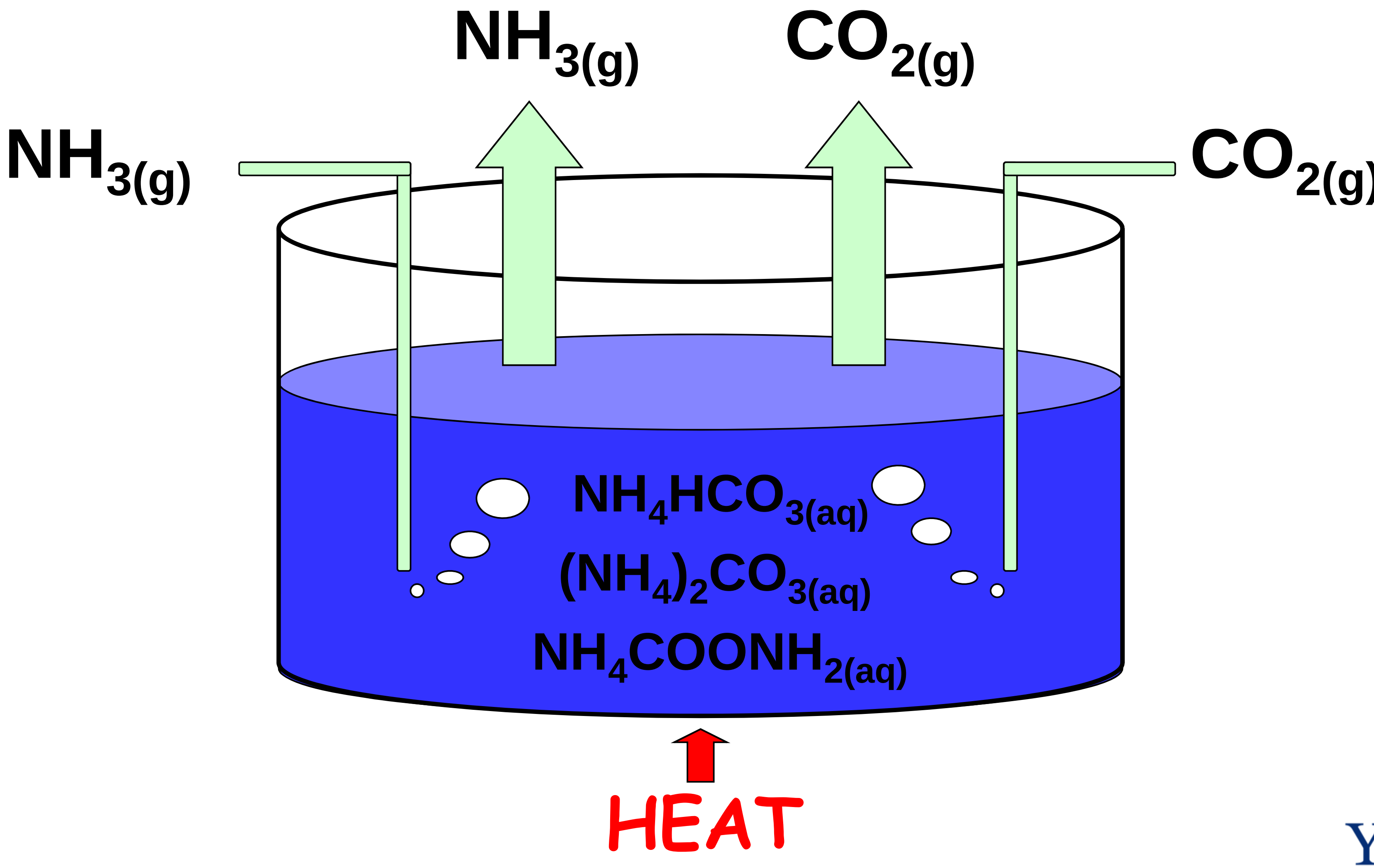
Utilize Waste Heat as the Main Energy Source for Desalination

Forward Osmosis



Thermolytic Draw Solution: NH_3/CO_2



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Is Seawater Desalination a Sustainable Technological Solution to Global Water Shortages?

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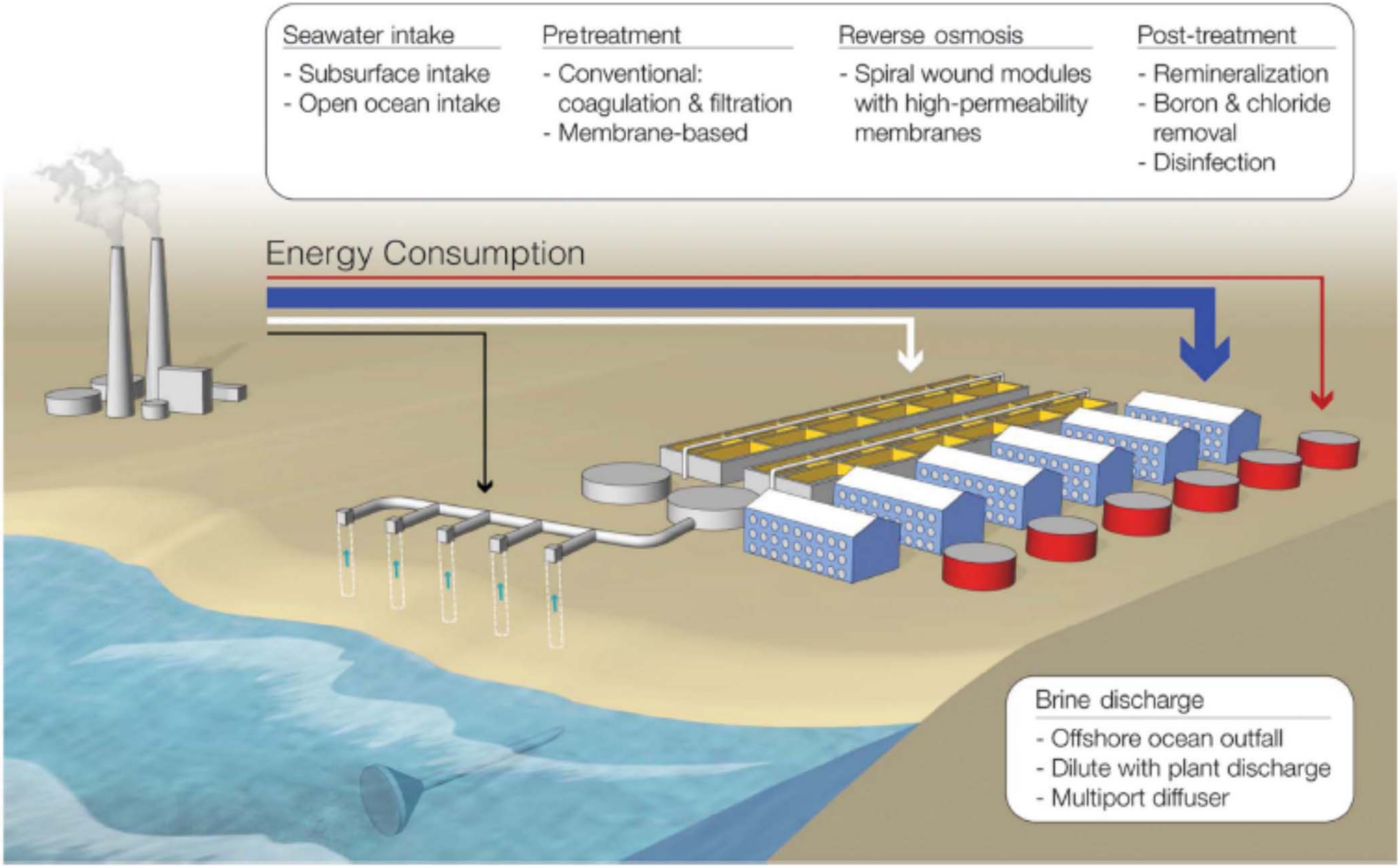
SWRO-Plant Interactions with the Environment



Major Concern: Greenhouse Gas Emissions

- Reverse Osmosis

  3.5 – 5.0 kWh per cubic meter of product water

- CO_2 Emission:

  ~ 1.6 kg CO_2 per cubic meter of fresh water

- Example, Spain:
  - 1 billion m^3 (ton) per year
  - 4,000 GWh per year
  - 1.6 billion kg CO_2 per year

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Recommendations

“Although several options currently exist to augment freshwater sources—including the treatment of low-quality local water sources, water recycling and reuse, and water conservation—these options alone will not be enough to meet this need.“

“While seawater desalination must be considered after all other options have been implemented, it should be viewed as a crucial component in the portfolio of water supply options.”

“For water-scarce countries that already implement all other measures for freshwater generation, desalination may serve as the only viable means to provide water supply.”

Elimelech and Phillip, *Science*, **333** (2011) 712-717.

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waterCAMPWS
Center of Advanced Materials
for Purification of Water with Systems

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