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Water Desalination Using Renewable Energy

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Module 1: Insights for Policymakers

Learning Objectives

By the end of this section, you will be able to:

- **Evaluate** the strategic role of renewable energy in addressing global freshwater scarcity.
- **Identify** the primary technological categories of desalination and their associated energy requirements.
- **Analyze** the economic and logistical benefits of integrating renewable energy with desalination in remote or arid regions.

Executive Summary: Increasing global water demand and climate change impacts are driving the need for desalination, particularly in semi-arid and coastal areas. While traditional desalination is energy-intensive and fossil-fuel dependent, the declining costs of renewable technologies make renewable energy-powered desalination a sustainable and viable solution for long-term water security and economic investment.

Global Water Demand and Scarcity

The global demand for water is steadily rising while freshwater sources become increasingly scarce. This crisis is driven by the growing demand for natural resources and the multifaceted impacts of **climate change**, with the most significant effects observed in semi-arid, coastal, and island regions.

Desalination Fundamentals

Desalination of seawater and brackish water serves as a critical method to augment freshwater supplies. However, the process remains historically tied to high energy consumption.

Current Energy Constraints

- **Energy Intensity:** Desalination is a very energy-intensive process.
- **Fossil Fuel Dependency:** Most existing plants rely on fossil fuels, which are susceptible to volatile market prices and logistical supply chain disruptions.
- **Sustainability Gap:** Current fossil-fuel-based systems are not sustainable, particularly for remote and island communities.
- **Market Status:** Only **1%** of total desalinated water currently originates from renewable energy sources.

Technology Categories

Policy decisions regarding desalination must be informed by the specific energy requirements of the two primary technology types.

- **Thermal Desalination:** Utilizes **heat** to vaporize fresh water.

- **Membrane Desalination (Reverse Osmosis):** Employs **high-pressure electrically-powered pumps** to separate fresh water from saline sources using a membrane.

💡 **Design Tip:** Engineers and policymakers should base technology selection on the **locally available** renewable energy sources to maximize efficiency and reduce costs.

Strategic Integration of Renewables

Renewable energy has become a mainstream and viable option as technology prices continue to decline. This shift is particularly critical for energy-importing nations like India and China, as well as small island nations.

Regional Applications

- **Arid Regions (e.g., MENA):** Concentrated Solar Power (CSP) provides heat for thermal desalination, while Solar Photovoltaic (PV) and CSP provide electricity for membrane processes.
- **Coastal and Island Communities:** Wind energy is a primary interest for membrane-based projects.
- **Remote Regions:** Renewable desalination is ideal for areas with poor infrastructure for freshwater and electricity distribution.

⚠️ **Safety Constraint:** While declining costs are promising, desalination remains costly; strategic mapping of water needs against renewable energy potential is a **mandatory** step for planning sustainable infrastructure.

Economic and Social Impact

Investing in renewable energy for water production should be viewed as a **valuable economic investment**. This approach reduces several key cost factors:

- External and social costs.
- Environmental impacts.
- Operational expenses related to fuel volatility.

Renewable energy-powered desalination acts as a **key enabler for growth**, sustaining local communities and supporting productive uses like irrigation.

Checkpoint Quiz

1. Which technology category primarily relies on heat to separate fresh water from salt?

- a) Reverse Osmosis
- b) Thermal Desalination
- c) Membrane Desalination
- d) Electrically-powered pumping

Answer: (b). Thermal desalination uses heat to vaporize fresh water, whereas membrane desalination (like reverse osmosis) uses electrical power to drive high-pressure pumps.

2. Why is fossil-fuel-based desalination considered unsustainable for remote island communities?

- a) The technology is too complex for remote operation.
- b) Renewable energy is the only technology that works on islands.
- c) Fossil fuels are vulnerable to volatile prices and logistical supply problems.
- d) Islands do not have enough water to justify the cost.

Answer: (c). Remote areas often lack the infrastructure for reliable fuel delivery and are hit hardest by global market price fluctuations.

3. What is the current market share of renewable energy in global desalinated water production?

- a) 1%
- b) 10%
- c) 25%
- d) 50%

Answer: (a). Despite the potential, current data shows that only 1% of the world's desalinated water is produced using renewable energy.

Module 2: Highlights

Learning Objectives

By the end of this section, you will be able to:

- **Analyze** global water withdrawal trends and the specific market share of desalination in water-scarce regions.
- **Compare** the energy consumption and production costs of major desalination technologies, including Reverse Osmosis and Multi-Stage Flash.
- **Evaluate** the economic feasibility of renewable desalination in remote regions compared to conventional fossil-fuel systems.

Executive Summary: Global water demand is driving a rapid expansion in desalination, with the MENA region leading at 38% of global capacity. While Reverse Osmosis remains the dominant technology due to lower energy requirements, the rising energy demand—projected to triple in some regions by 2030—is pushing the industry toward renewable energy integration, which is already becoming competitive in remote areas.

Process and Technology Status

This brief focuses primarily on **renewable desalination**, which utilizes renewable energy sources to produce fresh water. Globally, water withdrawals total approximately **4,000 billion m³ per year**. In regions like the Middle East and Northern Africa (MENA), desalination has become the primary source of water for both drinking and agriculture.

Global Market Indicators

- **Daily Production:** About 65.2 million m³ per day (24 billion m³ per year).
- **Global Supply Share:** Desalination accounts for 0.6% of the total global water supply.
- **Regional Leader:** The MENA region holds 38% of global capacity; Saudi Arabia is the world's largest desalinating country.
- **Plant Scale:** Large-scale facilities can exceed a capacity of **800,000 m³ per day**.


Technology Dominance

- **Reverse Osmosis (RO):** 60% of global capacity.
- **Multi-Stage Flash (MSF):** 26.8% share.

Renewable Suitability

- **Solar Thermal/CSP:** Produces high volumes of heat suitable for thermal desalination.

- **Solar PV and Wind:** Ideally combined with membrane units like RO or electrodialysis.
- **Geothermal:** Suited for integration into various desalination processes.

 **Design Tip:** Combining power generation with desalination can serve as a cost-effective **electricity storage** option when renewable generation exceeds immediate demand.

Performance and Costs


Desalination requires significant energy inputs, and the specific consumption depends heavily on the chosen technology.


Energy Consumption Benchmarks

- **MSF (Seawater):** Typically consumes **80.6 kWh of heat energy** plus 2.5 to 3.5 kWh of electricity per m³.
- **Large-scale RO:** Requires only **3.5 to 5.0 kWh of electricity** per m³.
- **Global Impact:** Desalination currently uses at least 75.2 TWh per year, roughly 0.4% of global electricity consumption.

Cost Analysis

- **Production Cost:** Has decreased to as low as **USD 0.5/m³** in some areas.
- **Market Price:** Typically ranges between USD 1/m³ and USD 2/m³.
- **Affordability:** Currently viable for middle-income regions but remains prohibitive for the poorest countries.

 **Calculation Note:** The economics of renewable desalination are almost entirely determined by the cost of the renewable energy technology itself. While currently higher than fossil-fuel systems, renewable costs are decreasing rapidly.

 **Design Tip:** Renewable desalination can already compete with conventional systems in **remote regions** where energy transmission and distribution costs exceed the cost of distributed generation.

Potential and Barriers

The demand for desalination is projected to grow by **9% per year** globally between 2010 and 2016, representing a cumulative investment of USD 88 billion.

Regional Growth Projections

- **MENA Region:** Water demand is expected to rise from 9 billion m³ (2010) to 13.3 billion m³ by 2030.



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