

Energy Efficient Strategies and Renewable Energy Utilization for Desalination

Joe Jacangelo, WateReuse Research Foundation



Dr. Jacangelo is a Vice President and Director of Research for MWH. He has 27 years of experience in the field of environmental health engineering, and has specialized in the areas of water quality and treatment, water and wastewater disinfection, membrane technology, renewable energy and public health. He has served as Technical Director, Principal Investigator, Project Manager or Engineer for over 80 water and wastewater projects. He has published over 100 technical papers and holds various positions within professional organizations such as American Water Works Association and the International Water Association. Dr. Jacangelo is also an adjunct faculty member at the Johns Hopkins University Bloomberg School of Public Health. In addition, he is the Chair of the Board of Directors for the WateReuse Research Foundation and a past board member of the American Water Works Association. Dr. Jacangelo served three years as a Peace Corps Volunteer in the Republic of the Congo.

PowerPoint Presentation

<http://wrri.nmsu.edu/publish/watcon/proc56/Jacangelo.pdf>

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WateReuse Research Foundation
To conduct and promote applied research on the reclamation, recycling, reuse and desalination of water.

Reclaimed Water Utilization by Flow, FDEP 2010

2

water reuse & desalination

Applied research key to water crisis solutions

Research Funding

Research has made many of the gains that are permitting water reuse and desalination to flourish, including widespread public programs, according to **Joe Jacangelo**, executive director of the WateReuse Foundation. In the following article, he explains the importance of funding water research and how it addresses some of the public programs of water reuse and other issues regarding desalination and its high energy costs and environmental impact.

Applied research key to addressing water scarcity crisis

Research has made many of the gains that are permitting water reuse and desalination to flourish, including widespread public programs, according to Joe Jacangelo, executive director of the WateReuse Foundation. In the following article, he explains the importance of funding water research and how it addresses some of the public programs of water reuse and other issues regarding desalination and its high energy costs and environmental impact.

Other water-challenged countries such as Singapore and Israel are expending much greater sums on applied research in water than in the US. There is little doubt that the US will need to expend substantially more if we are to deal effectively with the coming water crisis.

Research & Innovation 2005

WateReuse Foundation

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Commitment to Research \$42 Million since 2001



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Study Goals

- To develop a comprehensive knowledge-base with the most updated developments in energy minimization and renewable energy techniques.
- Prepare a guidebook based on the relevant practical lessons learned by global researchers, organizations and utilities.

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Energy Efficient Strategies and Renewable Energy Utilization for Desalination

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Project Summary

Literature Review

- Collect information on energy minimization strategies, technological advancements and economic analyses (*Water Research* 45: 1907, 2011).

Utility Survey/
Case Studies

- Document information on process, implementation strategies, regulation and policy.

Guidebook Development

- Provide information to utility and policy makers.

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Background

- The generation of energy is the single largest source of green house gas (GHG) emissions.
- Optimizing the energy of desalination and reuse processes has become a critical component in addressing energy consumption.
- Increasing renewable energy resource (RES) utilization and reducing GHG emissions has become an important goal for water utilities and agencies.

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Promising New Desalination Technologies

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Nanocomposite RO

www.nano2o.com

Up to 20%
Less Energy

Up to 70%
More Water

Up to 40%
Smaller Plant

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In Situ Desalination (ISD)

www.desain8.com

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Nanotubes

Carbon nanotubes

www.nanocslinc.com

Boron Nitride Nanotubes

Hilder et al., Small, 2009.

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Closed Circuit Desalination (CCD)

Stover and Ertay, IDA, 2011

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Biomimetic Membranes

- Saves 70% on specific power consumption!
- Increases production efficiency >5 times!
- Robust and scalable

www.aquaz.dk

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Electrodialysis (ED)-Continuous Electrodeionization (CEDi)

http://www.siemens.com/sustainability/pool/en/current-reporting/sr2010_singapore.pdf

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Ion Concentration Polarization

- **Ion concentration polarization:**
 - Absence of membrane and applied pressure.
 - Specific energy consumption similar to RO ~ 3.5 kWh/m³ (Kim et al., *Nature Nanotechnology*, 2010).
 - 1,600 units fabricated on 8-inch wafer – 15 LPH of desalted water.

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Benefits of Renewable Energy Sources

- Renewable energy is carbon neutral
- Abundant resources
- Underutilized
- Decentralized facilities
- Ability to create new employment

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FO/RO Hybrid: Osmotic Dilution of Seawater

Cath et al., WaterReuse Research Foundation, 2009.

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Challenges of Renewable Energy Sources

- High capital costs
- Local/region dependent
- Often require new infrastructure
- Requires funding and incentives
- Large footprint requirement
- Return-on-investment (ROI)

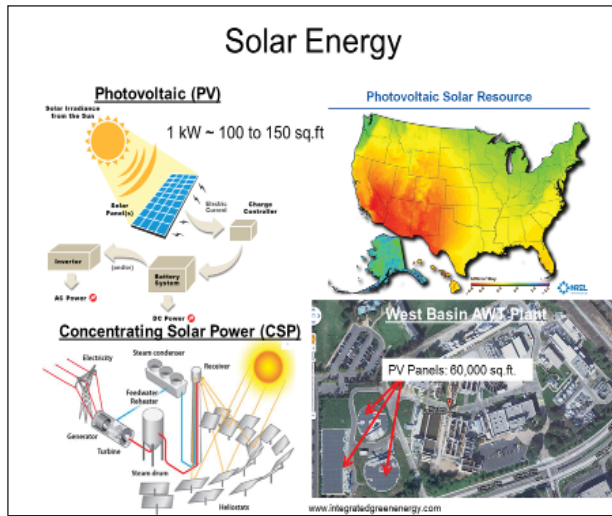
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Renewable Energy Utilization

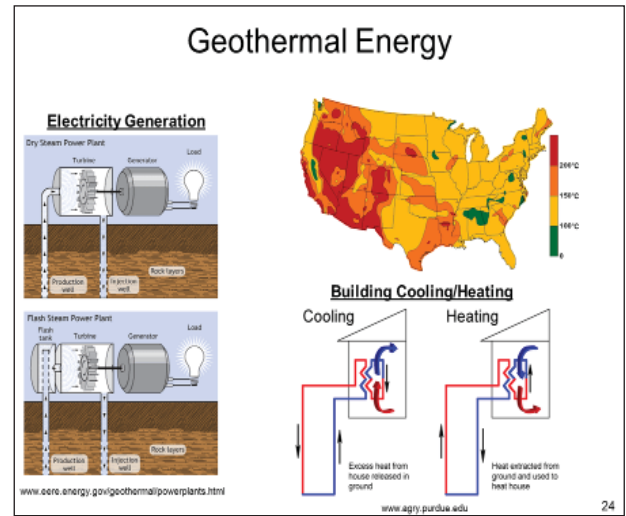
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Established Renewable Energy Technologies

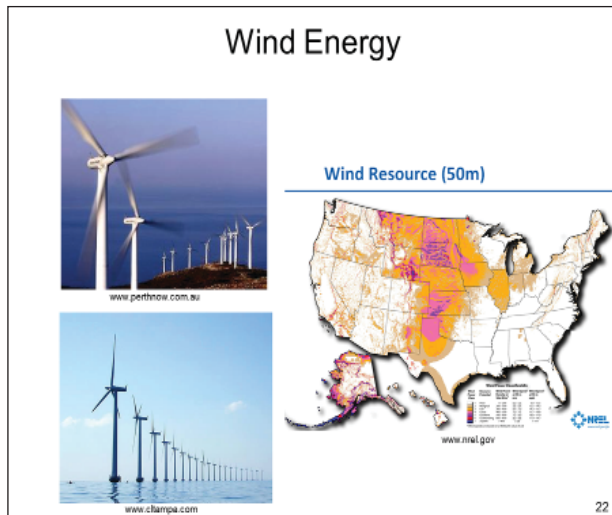
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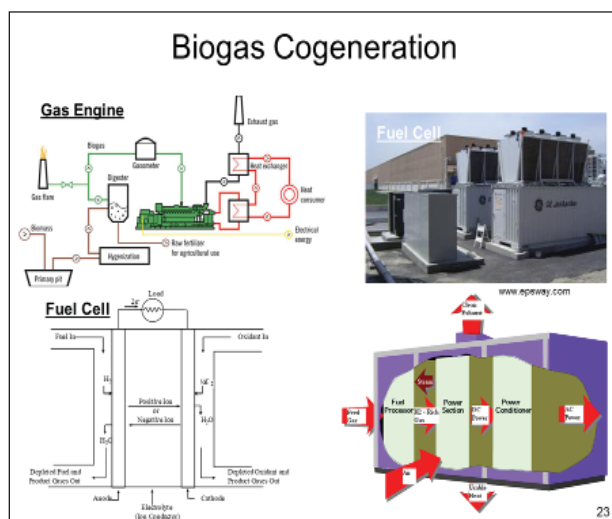
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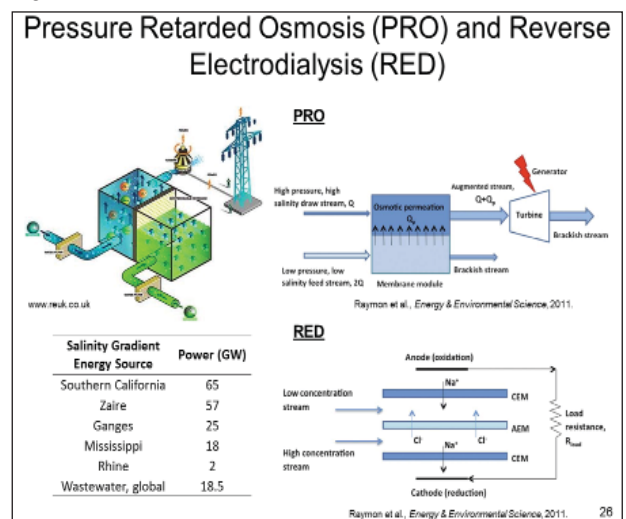
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Promising Renewable Energy Technologies

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Wave Energy

Wave Energy Levels (KWh/m of Wave Front)
www.oceanpowertechnologies.com

Carnegie Water Energy Limited

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Questionnaire Objectives

- Treatment process description
- Energy consumption for utilities using conventional energy source
- Energy consumption for utilities using renewable energy
- GHG emissions and tools used for quantification
- Economic evaluation for integrating renewable energy and implementation of energy efficient strategies
- Regulation and policy for energy management

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Utility Case Studies

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Utilities Participating in Study

Type of Plant	Capacity MGD	End Use	Feed TDS, mg/L	Permeate TDS, mg/L	Energy Consumption, kWh/m ³
Reuse 1	30	GWR, IPR	850	30	NA
Reuse 2	11	IPR, Industrial	552	26	0.98
Seawater Desalination 1	38	DW	37,000 - 40,000	< 200	3.6
Seawater Desalination 2	66	DW	36,700	275	3.3
Seawater Desalination 3	88	DW	40,500	< 80	3.5
Seawater Desalination 4	36	DW	35,000	< 270	3.5 - 3.9
Seawater Desalination 5	25	DW	< 28,500	< 360	3.9
Brackish Desalination 1	3.5	DW	2,300	< 320	0.94
Brackish Desalination 2	8	DW	2,000	< 150	1

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Survey Questionnaire

RENEWABLE ENERGY TECHNOLOGIES AND ENERGY EFFICIENCY STRATEGIES
GUIDELINES FOR WATER DESALINATION AND REUSE SYSTEMS TO OPTIMIZE
ENERGY USE AND IMPROVE CARBON-FOOTPRINT CALCULATIONS (WRF 00-11)

WATER REUSE FOUNDATION | MWH

PROJECT BACKGROUND AND SURVEY REQUEST

The objective of the project is to develop a guideline on the application of energy conservation and renewable energy technologies for water reuse and desalination facilities. The guideline will be designed to answer the following questions in relation to energy minimization and renewable energy adoption:

- What are the contemporary public policies in their aspects?
 - What are the drivers of integrating these technologies?
 - What are the implementation and operational benefits and challenges?
 - What are the barriers to use and how can they be overcome?
 - What are the factors that are critical to success in order to support these approaches in their existing management plan?

Do believe that your participation in this process of developing a benchmark guideline will benefit your energy savings with maximum financial information that might be critical in developing policies/procedure that may provide economic benefits through reducing energy consumption.

As a participating utility, you will also be acknowledged in any permit/contract plans, contracts, plans, operations, website generated from this project. Furthermore, a final copy of the guideline will be provided to you free of charge for your future energy management activities.

Should you have any questions regarding this program, please feel free to contact Dr. Joseph Jacangelo (jjacangelo@waterreuse.org).

Thank you!

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Energy Consumption of Various Components of a Seawater Desalination Plant Participating in Study

Component	Energy Consumption, kWh/m ³
Raw Water Pumping	0.39
Pretreatment & Desalination	2.865
Post Treatment	0.012
High service pump station	0.3
General (Buildings, heating, cooling)	0.04
Total Energy Consumption	3.607

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Reported Energy Minimization Strategies

- Energy efficiency of pumps monitored (pump efficiency curves) to determine if the pumps and motors are operating close to the best efficiency point (BEP).
- Older pumps and motors replaced with newer premium efficiency models.
- VFDs installed to control motor speed.
- Smaller RO trains and larger high pressure pumps utilized for seawater desalination.
- ERDs (pelton wheel, pressure exchangers) for seawater desalination were installed in the first pass.
- ERDs (turbochargers) for brackish water desalination were installed between the first and second stage to operate as a booster pump.

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Reported Renewable Energy Utilization Lessons

- Feasibility study essential before implementation at the utility scale.
- Footprint requirements for installation of solar PV reduced by installing solar panels on existing concrete tanks.
- Grid integration for solar PV panels improved by utilizing several inverters in parallel to provide continuous power supply.
- Government funding and support from utility board was key in the implementation of renewable energy resources.
- Risk shared in delivery of renewable energy: third party utilized to provide independent risk assessment.
- Specialized staff required within utility during the design and implementation phase.

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Renewable Energy Employed by Utility Participants

Type of Plant	Renewable Energy	% Use of Renewable	Onsite/Offsite	Funding/Incentives
Reuse 1	Solar PV	20%	Onsite - Grid Connected	Southern California Edison
Reuse 2	Cogeneration	20%	Onsite - Grid Connected	Energy Saving Fund (NSW Dept. of Env. and Climate Change)
Seawater Desalination 1	Wind	100%	Offsite - Grid Connected	Government
Seawater Desalination 2	Wind	100%	Offsite - Grid Connected	Energy Saving Fund (NSW Dept. of Env. and Climate Change)
Seawater Desalination 3	None	0%	-	-
Seawater Desalination 4	None	0%	-	-
Seawater Desalination 5	None	0%	-	-
Brackish Desalination 1	Future Consideration	0%	Considering Onsite Solar PV/CSP	Not Determined
Brackish Desalination 2	Future Consideration	0%	Considering Onsite Solar PV	Not Determined

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Guidebook

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Challenges for Utility Participants

Plant Type	ROI	Funding	Footprint	Integration	Permitting
Reuse 1	-	+	-	-	+
Reuse 2	-	+	+	-	+
Seawater Desalination 1	-	+	+	+	+
Seawater Desalination 2	-	+	+	+	+
Seawater Desalination 3	NO RENEWABLES UTILIZED				
Seawater Desalination 4	NO RENEWABLES UTILIZED				
Seawater Desalination 5	NO RENEWABLES UTILIZED				
Brackish Desalination 1	-	?	?	?	-
Brackish Desalination 2	-	-	+	?	?

*+ * indicates "favorable condition"
 *- * indicates "NOT favorable condition"
 ? indicates "NOT evaluated"

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The Purpose of the Guidebook is to Answer the Following Questions

- What resources are available as a utility manager to reduce energy consumption and implement renewable energy resources?
- What are the strategies available to reduce energy consumption in an existing or newly proposed plant?
- How are energy efficiency and GHG emissions monitored?
- What are the steps required for implementing renewable energy?
- What are the renewable energy technologies available for implementation at a large scale?
- What are the funding options available?
- What are the challenges involved during implementation of renewable energy resources?

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Components of the Guidebook

- Chapter 1: Introduction
- Chapter 2: Planning
- Chapter 3: Implementation of Efficient Energy Strategies
- Chapter 4: Utilization of Renewable Resources
- Appendices – Utility Surveys and Literature Review



Important information



Further resources and tools

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Implementation of Renewable Energy Resources (Contents of Chapter 4)

- Determination of resource availability.
- Available options for financing and incentives.
- Commercial technologies available.
- Leading renewable energy providers.
- Integration challenges and methods, consideration for grid integration.
- Handling resource variability.
- Permitting approach and requirements.

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Implementation of Energy Efficient Strategies (Contents of Chapter 3)

- Distribution of energy consumption through treatment processes.
- Design strategies for energy minimization during design of seawater/brackish water/advanced water treatment processes.
- Pumping strategies for energy efficiency.
- Selection of energy minimization components for treatment processes.
- Strategies to reduce energy consumption with HVAC and lighting.
- Implementation of energy efficient strategies.

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Example: What you need to know while selecting solar PV cells (Contents of Chapter 4)

Parameter	Description
Cell efficiency	Percentage of solar energy falling on PV cells that is converted into electrical energy
Module efficiency	Combination of cell efficiency placed into a module
Energy yield	Output in kilowatt hours (kWh) over time
Typical module size	175 – 200 Watt: 3 feet by 5 feet
Common types of modules	Poly Crystalline, Mono Crystalline, Amorphous Silicon (thin film)
Module lifetime	Poly Crystalline ~ 40 years; Mono Crystalline ~ 50 years; Amorphous Silicon ~ 20 years

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Example: What you need to know while selecting ERDs (Contents of Chapter 3)

Criterion/Device	Pelton Wheel Turbine	Reverse Running Turbine Pump	Turbo Booster Pump	Pressure or Work Exchanger
Commercial Availability	Yes	Yes	Yes	Yes
Proven technology for high salinity applications	Yes	Yes	Yes	Yes
Potential Energy Savings (Relative to each other)	Medium	Low to Medium	Low	High
Capital Cost (Relative to each other)	Low to Medium	Low to Medium	Low	High
O&M Costs (Relative to each other)	Low	Low	Low	Medium to High
Efficiency (Relative to each other)	Medium (84% to 90%)	Low to Medium (75% to 85%)	Low (55% to 60%)	High (95% to 97%)
Efficiency Curve Shape	Varies	Varies	Slopes downward at low flows	Flat
Efficiency at Changing Process Conditions (Effect of deviation from design point)	Efficiency reduces when flow rate changes from design point	Efficiency reduces when flow rate changes from design point	Efficiency reduces when flow rate changes from design point	Moderate impact on performance
Braze Mixing with Feed Water	None	None	None	About 2 - 3%
System Complexity	Low	Low	Low	High

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Example: What you need to know about financing options available (Contents of Chapter 4)

- Third-party ownership with a power purchase agreement (PPA):
 - Provides utilities with the ability to benefit from renewable energy service contracts while avoiding the risks associated with ownership.
 - The utility enters into a contract with the vendor/electric company to install a renewable energy system.
 - The vendor/electric company deliver a set amount of power at an agreed price.
 - The third-party (vendor/electric company) is responsible for operation and maintenance of renewable energy system.

www.epa.gov/greenpower/buypp/solarpower.htm

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Resources Provided in the Guidebook

Web links

You will find information on:

- Performing energy audits.
- Best practices for energy efficiency.
- Software/Modeling tools for energy optimization and renewable energy implementation.
- GHG emissions monitoring and management tools.
- Financing options available for renewable energy implementation.
- Information on vendors providing state-of-the-art energy reducing technologies and renewable energy equipment.

Additional Resources

[Handbook for energy efficiency: http://www.energy.ca.gov/reports/efficiency_guidebook/index.html](http://www.energy.ca.gov/reports/efficiency_guidebook/index.html). Last accessed: July 11, 2011.

Information on energy accounting, financing public sector energy projects, energy auditing, guidelines for hiring an energy service company and guidelines for hiring a construction manager can be found in the above web link.

[Energy management guidebook for wastewater and wastewater utilities: http://www.epa.gov/epaosdp/water/energy/water_energy_guidebook_water.pdf](http://www.epa.gov/epaosdp/water/energy/water_energy_guidebook_water.pdf). Last accessed: July 11, 2011.

The guidebook provides a plan, do, check and act method for energy monitoring, energy minimization and energy improvement for public utilities. A copy of the guidebook can be found in the above web link.

[Energy best practices guidebook for water and wastewater utilities: http://www.epa.gov/epaosdp/water/energy/water_energy_guidebook_wastewater.pdf](http://www.epa.gov/epaosdp/water/energy/water_energy_guidebook_wastewater.pdf). Last accessed: July 11, 2011.

The guidebook provides guidelines on energy use estimation, energy baseline calculation, management and technical best practices for water treatment, wastewater treatment, collection and distribution systems. A copy of the guidebook can be found in the above web link.

[Software tools for energy efficiency best practices: http://www1.eere.energy.gov/buildings/energy_efficiency/best_practices/](http://www1.eere.energy.gov/buildings/energy_efficiency/best_practices/). Last accessed: July 12, 2011.

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Energy Usage-Reuse

Energy Use by Equipment

Energy Use by Process

- Pumps consume the most energy.

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Summary

- The evolution of renewable energy sources and development of novel processes and materials will continue to impact energy usage and production of GHG emissions.
- There are many common drivers, operational techniques and challenges for energy optimization or use of renewable energy sources irrespective of source water and end use.
- A guidebook was developed to provide information to utilities, designers and policymakers interested in implementing energy optimization strategies and renewable energy technologies.

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Energy Recovery-Brackish Water Desalination

www.energyrecovery.com

- Energy recovery/interstage booster pump in one device.
- Low Pressure TurboCharger (LPT) reduces the required boost to the high-pressure pump.
- Zero energy cost for interstage pumping.

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Acknowledgements

WaterReuse Research Foundation (Project # 08-13)
California Energy Commission
Project Managers – Caroline Sherony (WaterReuse Research Foundation), Paul Roggensack – California Energy Commission (CEC)

PAC Members

- Martin Vorum – National Renewable Energy Laboratory (NREL)
- David Yates – National Center for Atomic Research (NCAR)
- Stephen Fok – Pacific Gas & Electric (PG&E)
- Shahid Chaudhry – California Energy Commission (CEC)
- Andrew Tiffenbach – Bureau of Reclamation (USBR)

Participating Utilities

- El Paso Water Utilities Public Service Board
- Eastern Municipal Water District
- West Basin Municipal Water District
- Tampa Bay Water
- Sydney Water Corporation
- Water Corporation of Western Australia (Perth)
- Public Utilities Board, Singapore
- Ashkelon Desalination Facility

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Components and Steps for Renewable Energy Utilization

Steps:

- Determine: Energy usage, Energy costs, Renewable resource availability
- Evaluate: Financing options, Incentives, Ownership options
- Select: Technology, Infrastructure Requirements, System size, Integration type
- Determine: Budget, Return on Investment (ROI), Permits, Regulations
- Bid: Engineering, Procurement, Construction, Ownership, and Operation

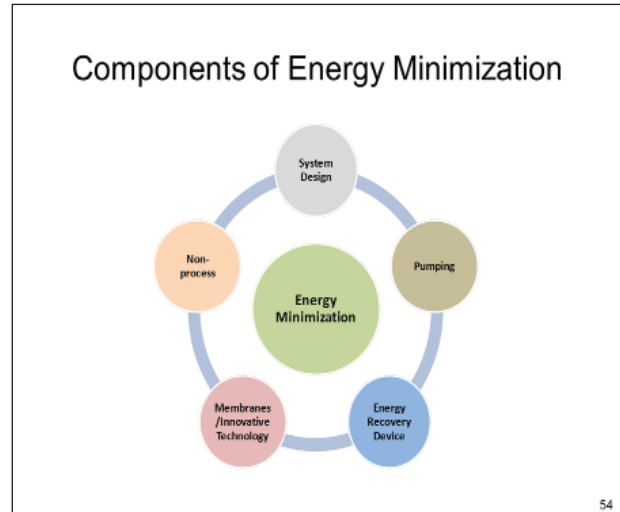
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Energy Usage and Minimization Strategies

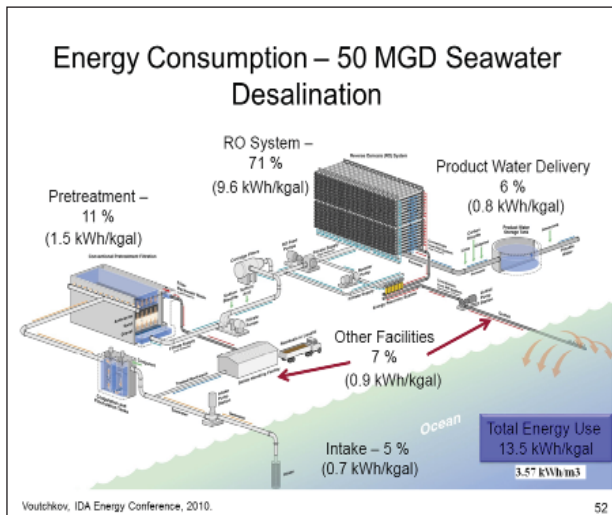
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Established Energy Minimization Techniques

- Enhanced system design:** Use of hybrid elements (nanofiltration, brackish, seawater), interstage boosting, use of permeate from front-end elements to feed second pass. Reduced energy consumption ~ 5 – 12%.

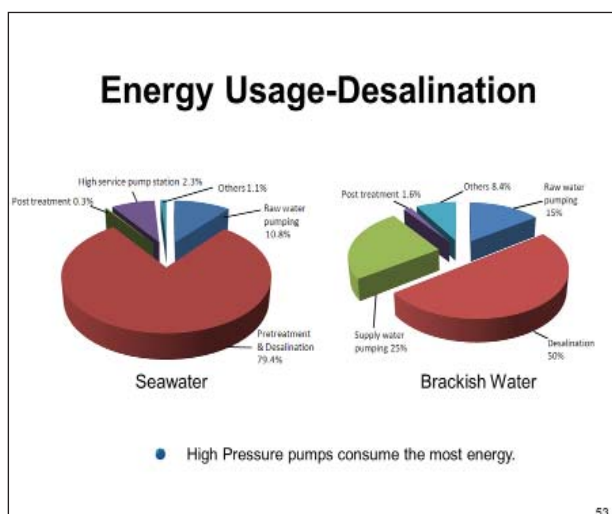
Voutchkov, IDA Energy Conference, 2010
- High efficiency pumping:** Use of variable frequency drive (VFD), premium efficiency motor, larger capacity pumps, operation at BEP, regular energy monitoring and maintenance.

www.floserve.com
- Energy recovery device:** Use of turbo-chargers and pressure exchangers. Reduced energy consumption ~ 30 – 50% (combining with high efficiency pumping).

www.energyrecovery.com

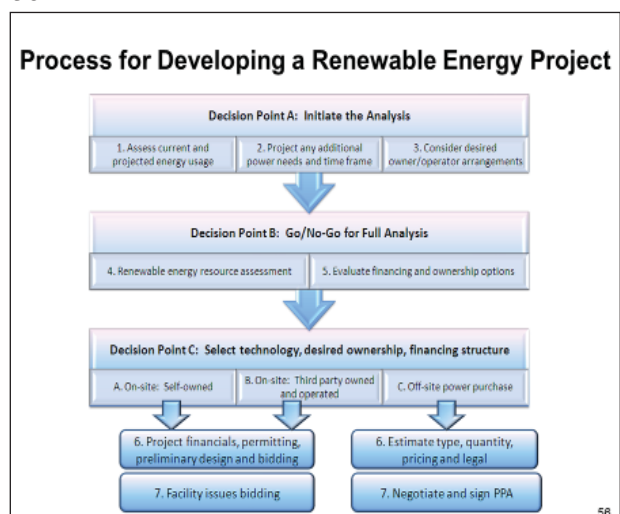
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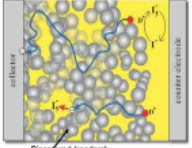


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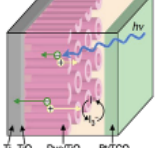
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Future PV Technology Highlights

Nanotubes: Improved electron transport = Better efficiency

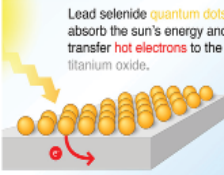


Disordered (randomly packed) nanotubes




TiO₂ Dye/TiO₂ PVTCO

Quantum Dots: Improved efficiency



Lead selenide quantum dots absorb the sun's energy and transfer hot electrons to the titanium oxide.

Organic PV: Ultra low-cost flexible modules




NREL, 2011
www.sciencemag.org

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Thermo-Ionic Desalination

Technology




SALT WATER → DESALTING DEVICE → PRODUCT

EVAPORATION → EVAPORATOR → HYPER-SALINE

HYPER-SALINE → DESALTING DEVICE → PRODUCT

DISCHARGE

Hybrid Operation



SALT WATER → REVERSE OSMOSIS → FRESH WATER

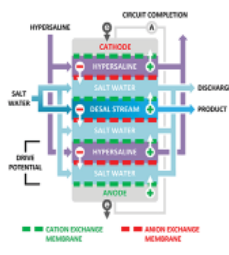
REVERSE OSMOSIS → THermo-IONIC™ → DISCHARGE

THermo-IONIC™ → EVAPORATION → HYPER-SALINE

HYPER-SALINE → SALT MAKER → SOLIDS

THermo-IONIC™ DESALINATED PRODUCT

Desalting Device



HYPER-SALINE

CATHODE

HYPER-SALINE

REVERSE OSMOSIS

SALT WATER

HYPER-SALINE

ANODE

DISCHARGE

PRODUCT

DRIVE POTENTIAL

— CATION EXCHANGE MEMBRANE — ANION EXCHANGE MEMBRANE

www.saltworkstech.com