Integrating Brackish Groundwater Desalination with Renewable Power

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Gary M. Gold

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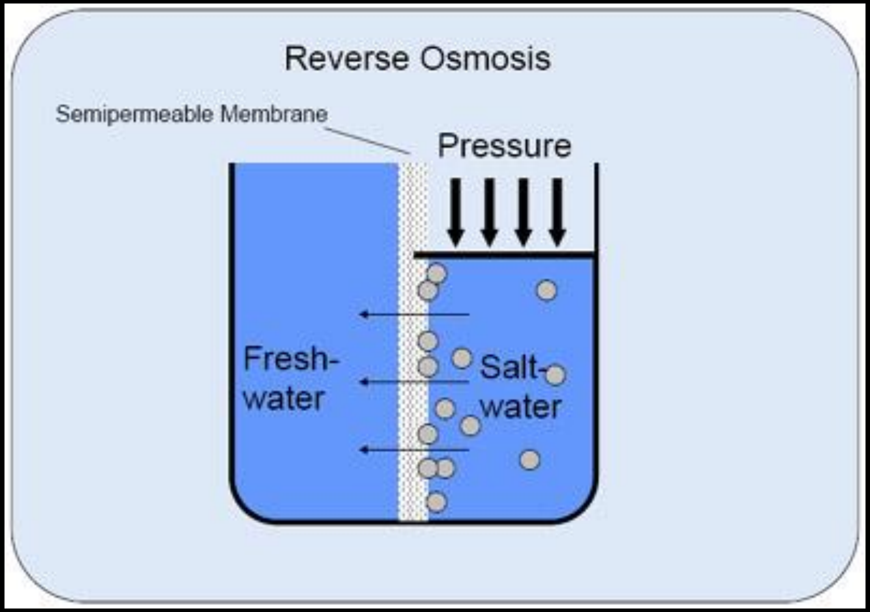
THE UNIVERSITY OF TEXAS AT AUSTIN

Desalination, wind power, and solar power are growing technologies, but have limitations prohibiting their development.

Integrating these technologies can potentially alleviate these limitations.

Relying on desalination could significantly increase energy use in the water sector

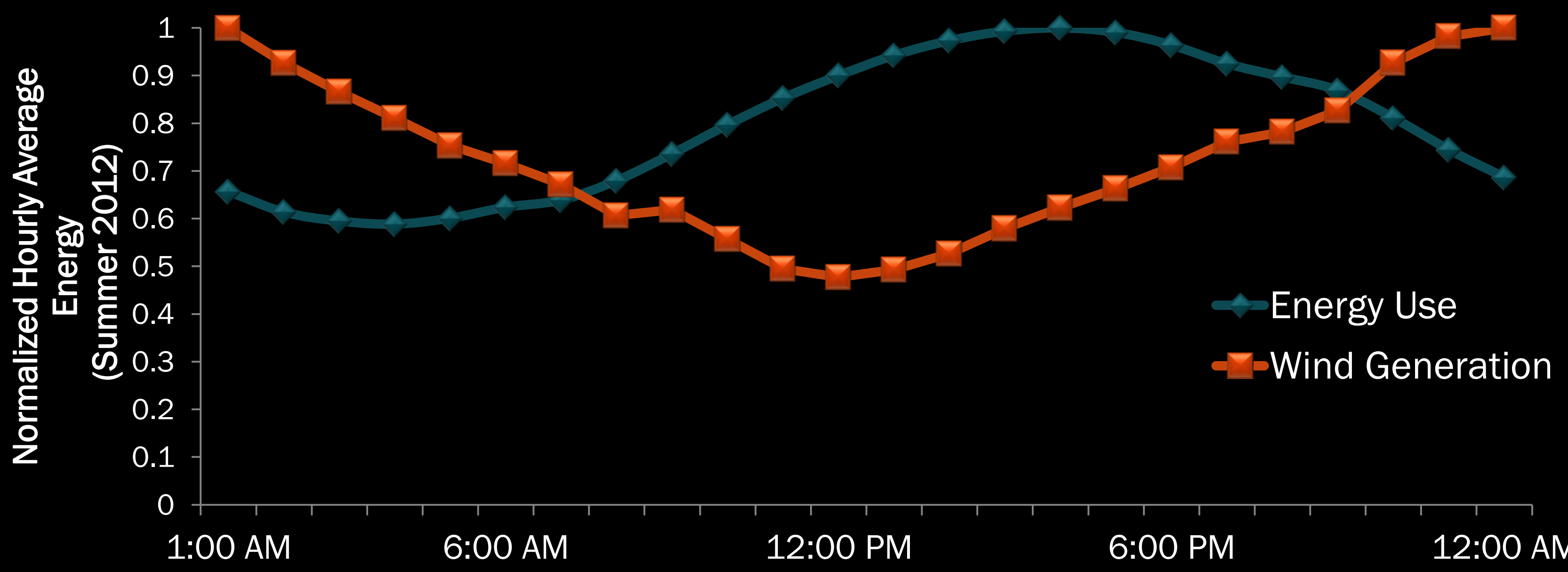
Reverse osmosis (RO) desalination is an energy intensive process, consuming approximately 10 times as much energy as typical surface water treatment [NRC].



[Fumatech]

Electricity generated from wind power does not typically match demand

- Wind-generated electricity is intermittent and does not typically match energy demand.
- Using wind power for desalination essentially allows water to act as a storage proxy for wind-generated electricity.

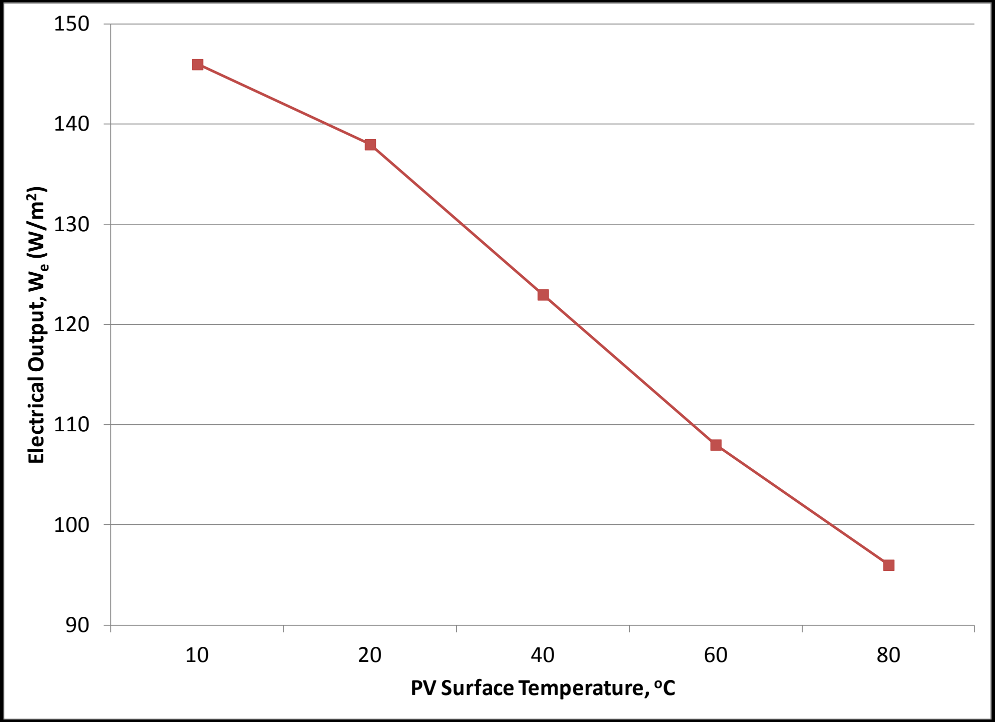


[Clayton]

The efficiency of solar power production declines as the temperature of solar panels rises

As the temperature of traditional solar panels rises, the efficiency of converting solar radiation to electricity declines due to energy lost as "waste heat" [Skoplaki].

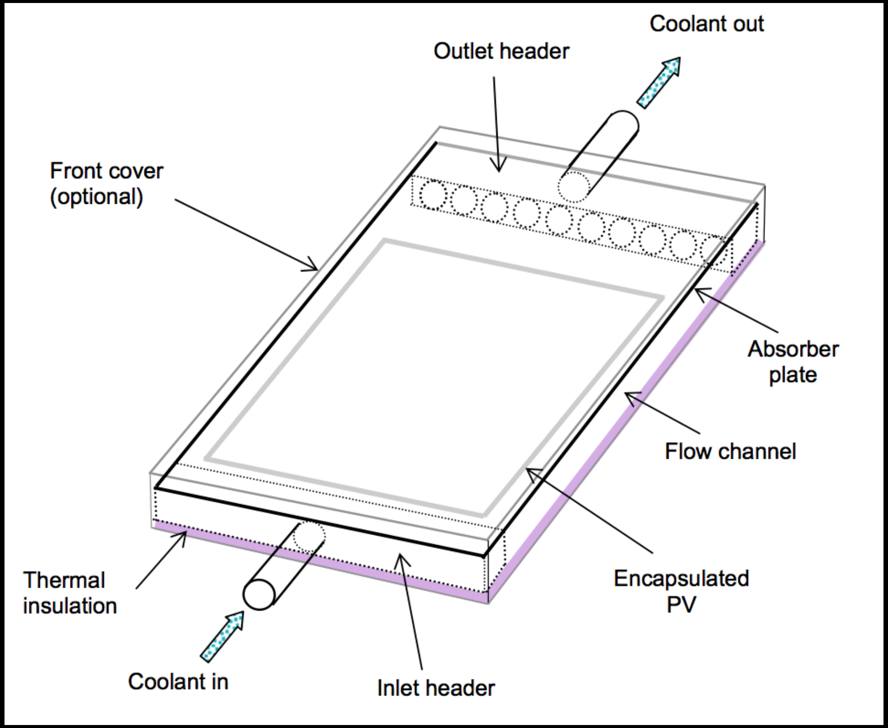
- Power output from cooled solar arrays is expected to be as much as 20% higher than that from non-cooled arrays during periods of highest insolation [Davis].



[Solimpeks]

Brackish groundwater can be used to cool solar panels using PVT modules.

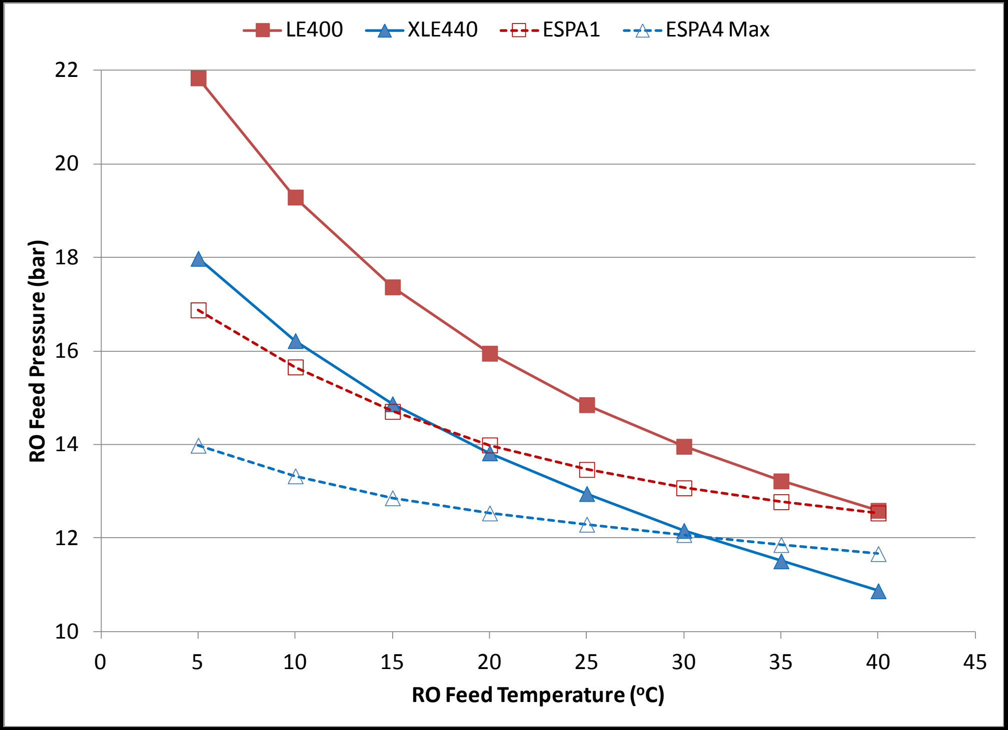
- Photovoltaic thermal (PVT) solar modules exchange heat between solar panels and a working fluid (typically water or air), generating electricity and transferring thermal energy to the fluid.
- The modules could act as a heat exchanger to to cool the solar panels and improve the efficiency of solar power production.



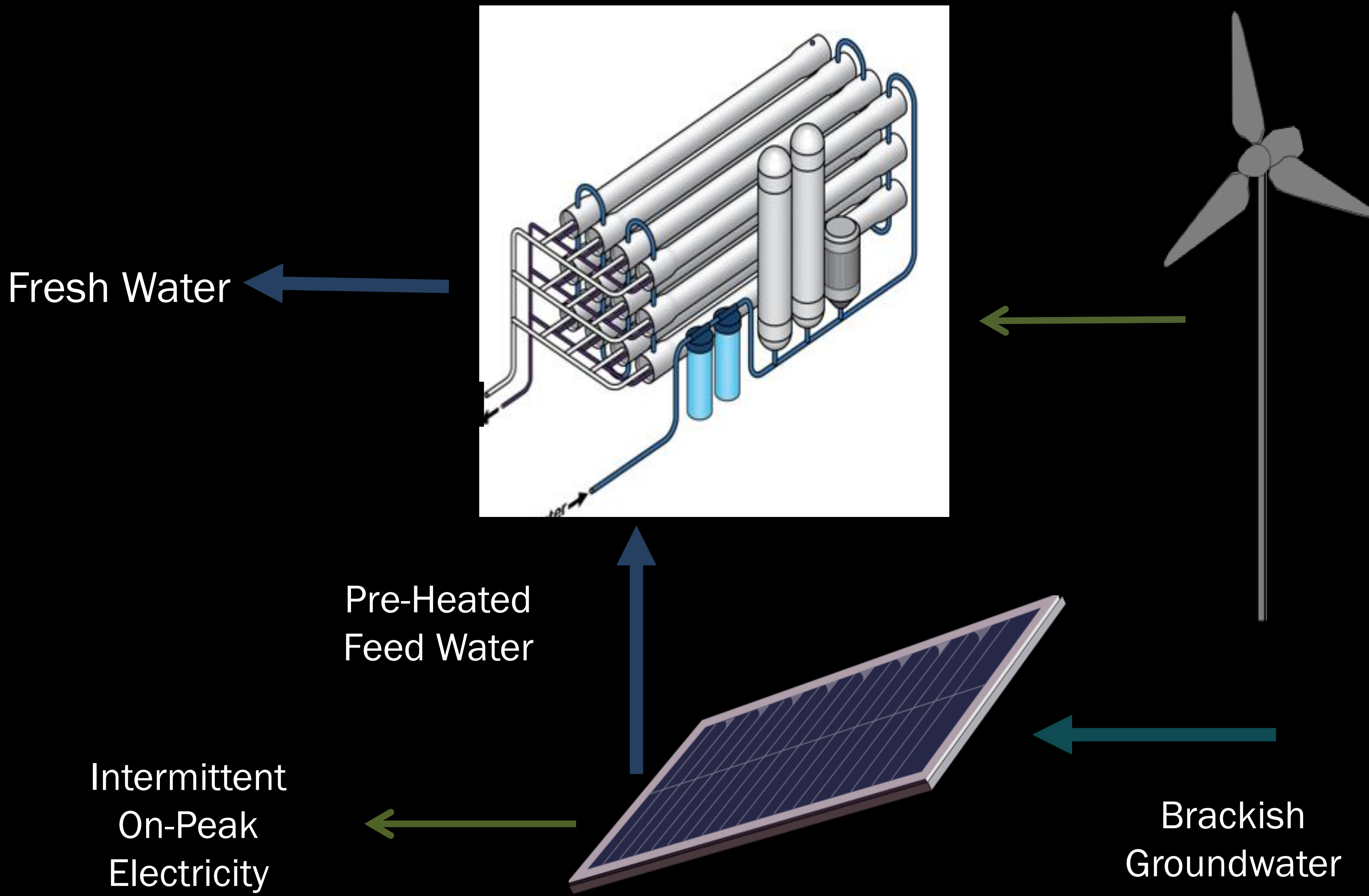
[Chow]

Preheating RO feed water can reduce the energy intensity of desalination

- Preheating brackish groundwater before treatment reduces the pressure required to force water through desalination membranes.
  - Specific energy required to operate reverse osmosis units is expected to drop 3.4% if feed water is heated 5 degrees Celsius [Davis].



[Davis]


Fresh Water
Pre-Heated
Feed Water
Intermittent
On-Peak
Electricity
Brackish
Groundwater

Research objective

Develop a water treatment model and an energy model to produce potential daily operation profiles for a desalination facility powered by a wind-generated electricity and collocated with a solar farm

A water treatment was developed to estimate the energetic requirement of brackish groundwater desalination

Total power

$$P = P_P + P_D$$

Power for pumping

$$P_P[kW] = \left(\frac{\rho[\frac{kg}{m^3}] * g[\frac{m}{s^2}] * q[\frac{m^3}{s}]}{1000 * \eta_P * CF_D}\right) * \left(z[m] + \frac{\left(\frac{4*q[\frac{m^3}{s}]}{\pi*(d[m])^2}\right)^2}{2 * g[\frac{m}{s^2}]} * \frac{f}{d[m]} * (z[m] + l[m])\right)$$

Power for desalination

$$P_D[kW] = \frac{E_D[\frac{kWh}{m^3}] * q[\frac{m^3}{s}]}{CF_D}$$

An energy model was developed to estimate the required size for a solar farm to preheat feedwater

Mass flow rate of water

$$\dot{m}[\frac{kg}{s}] = \frac{G_D[\frac{m^3}{day}]}{\nu[\frac{m^3}{kg}] * R_D} * \frac{1}{86400}[\frac{day}{sec}]$$

Thermal energy required to preheat feedwater

$$\dot{Q}[kW] = \dot{m} * (h_{out}[\frac{kJ}{kg}] - h_{in}[\frac{kJ}{kg}])$$

Solar array capacity

$$C_{SOLAR,C}[kW] = \frac{\dot{Q}[kW]}{\eta_{PVT}}$$

An energy model was developed to estimate the required size for a wind farm to power water production

Wind farm capacity

$$C_{WIND,B}[kW] = \frac{P[kW]}{CF_{WIND}}$$

An integrated optimization model was developed using results from the water treatment and energy models

Revenue from water production

$$R_{DESAL}[\frac{\$}{day}] = Pr_{WATER}[\frac{\$}{m^3}] * \sum_{t=1}^{96} G_{D,t}[\frac{m^3}{:15}]$$

Cost of brine disposal

$$C_{BRINE}[\frac{\$}{day}] = Pr_{BRINE}[\frac{\$}{m^3}] * \sum_{t=1}^{96} G_{D,t}[\frac{m^3}{:15}]$$

Cost of electricity purchased from the grid

$$C_{ELECTRICITY}[\frac{\$}{day}] = P_{ELECTRICITY}[\frac{\$}{kWh}] * \sum_{t=1}^{96} E_{GRID}[\frac{kWh}{:15}]$$

An integrated optimization model was developed using results from the water treatment and energy models

Wind-generated electricity sold to the grid

$$E_{WIND-GRID_{C},t}[\frac{kWh}{:15}] = E_{WIND_{C},t}[\frac{kWh}{:15}] - E_{DESAL_{C},t}[\frac{kWh}{:15}]$$

Revenue from selling wind-generated electricity

$$R_{WIND_{C},t}[\frac{\$}{:15}] = E_{WIND-GRID_{C},t}[\frac{kWh}{:15}] * Pr_{ELECTRICITY}[\frac{\$}{:kWh}]$$

Revenue from selling solar-generated electricity

$$R_{SOLAR_{C},t}[\frac{\$}{:15}] = E_{SOLAR-GRID_{C},t}[\frac{kWh}{:15}] * Pr_{ELECTRICITY}[\frac{\$}{:kWh}]$$

Optimization was performed to develop a daily operational schedule for the integrated facility

The model developed in GAMS maximizes total profit by optimizing optimizes the a criterion function:

$$R_C[\$] = R_{DESAL_C}[\$] + R_{SOLAR_C}[\$] + R_{WIND_C}[\$] - C_{ELECTRICITY_C}[\$] - C_{BRINE_C}[\$]$$

Decisions based on 15 minute intervals to determine if the facility should:

- Use wind-generated electricity for desalination
- Sell wind-generated electricity to the grid and purchase additional electricity for desalination
- Halt desalination

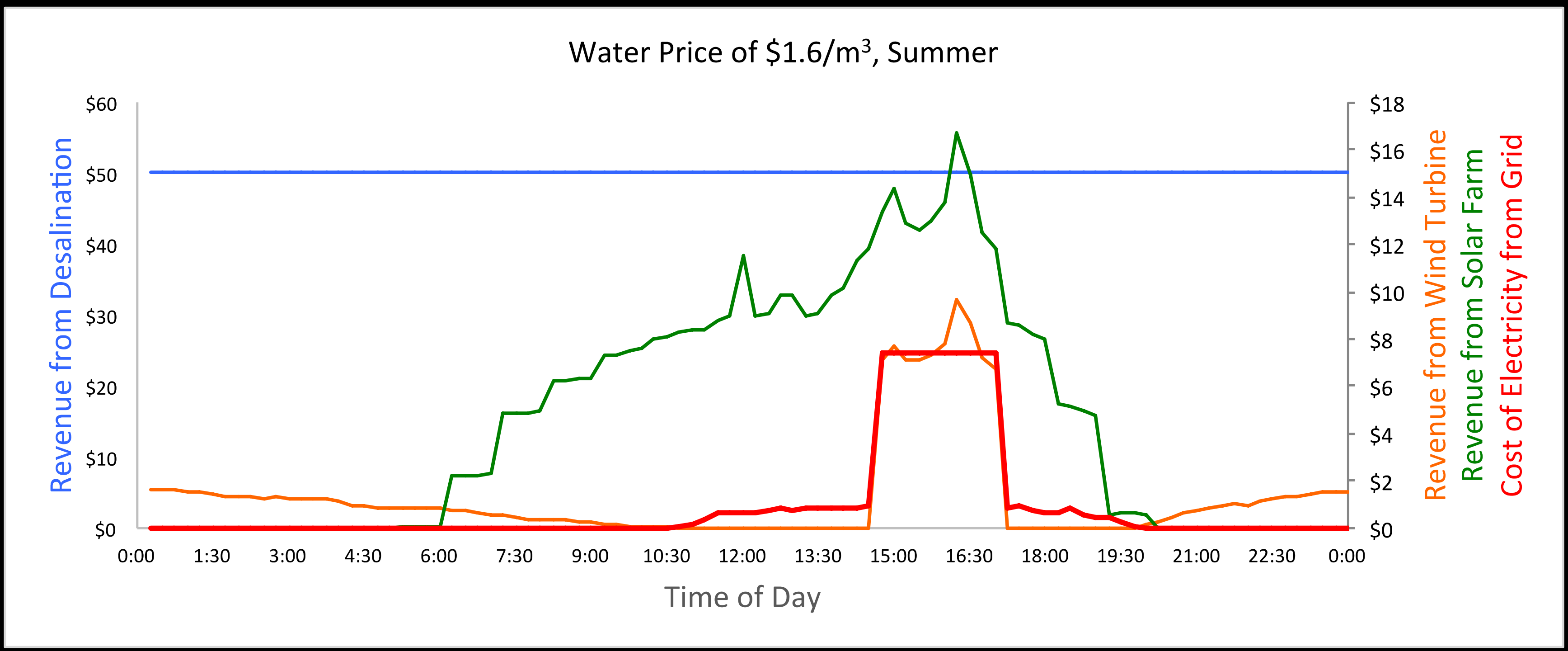
Output includes:

- Revenue from water production
- Revenue from wind- and solar-generated electricity
- Cost of grid-purchased electricity

Results

Operational profiles for a summer and winter day in Central Texas

The model can estimate the revenue from water, wind power, and solar power production during each 15-minute interval



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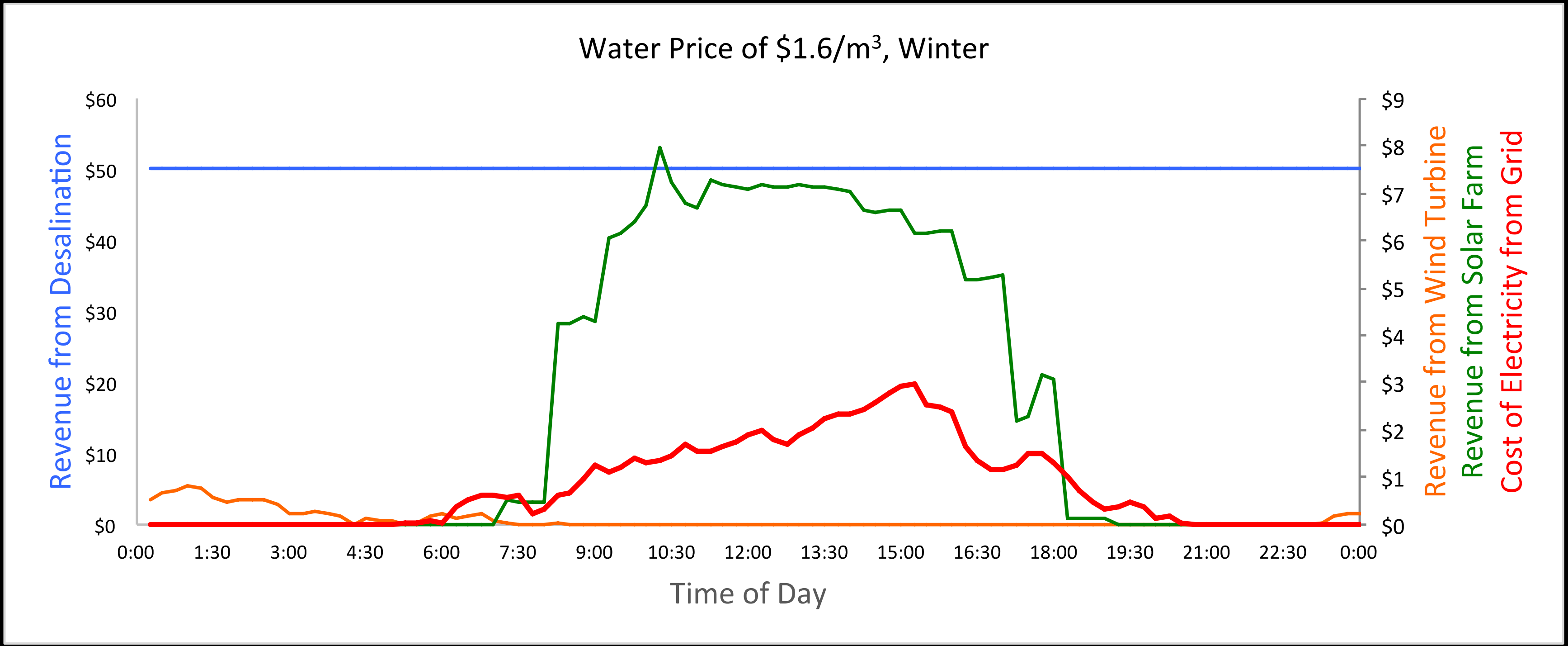
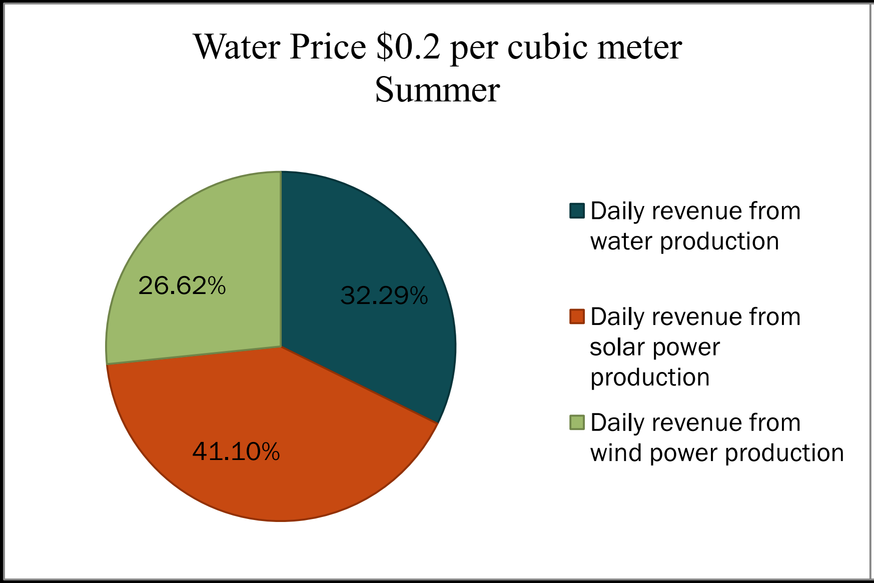
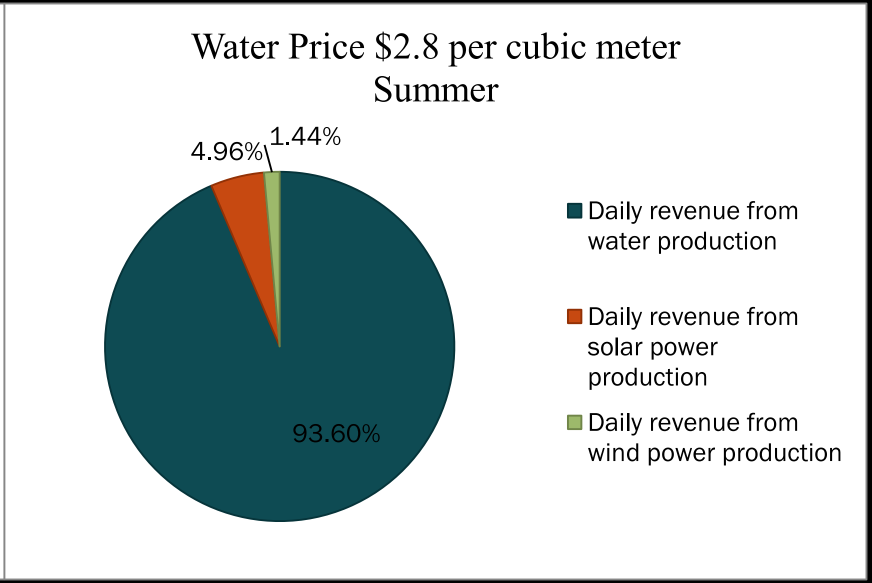


The model estimates percent of daily revenue from each source





Preliminary results indicate this configuration offers a number of advantages…

Using treated water as a storage proxy for wind-generated electricity offers a prudent use for this intermittent power source.

- The times when the model elects to “trade” electricity are scarce.

Revenue from solar power production offers a significant additional revenue stream in some cases.

- Revenue from solar-generated electricity could be comparable to that from water production in some cases.
- Sizing the solar farm for economic purposes could make sales from solar-generated electricity more significant.

However, there are a number of limitations to the proposed facility…

The capital and possibly operational costs of the integrated facility would likely be significantly greater than a traditional desalination powered by grid-purchased electricity.

Future work will quantify capital and operational costs to assess the economic feasibility of the integrated facility.

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Gary M. Gold

Graduate Research Assistant

Civil, Architectural, and Environmental Engineering

The University of Texas at Austin

garygold@utexas.edu

www.webberenergygroup.com

Webber Energy Group

THE UNIVERSITY OF TEXAS AT AUSTIN