Renewables and Brackish Groundwater Desalination in Texas

Texas Water Development Board

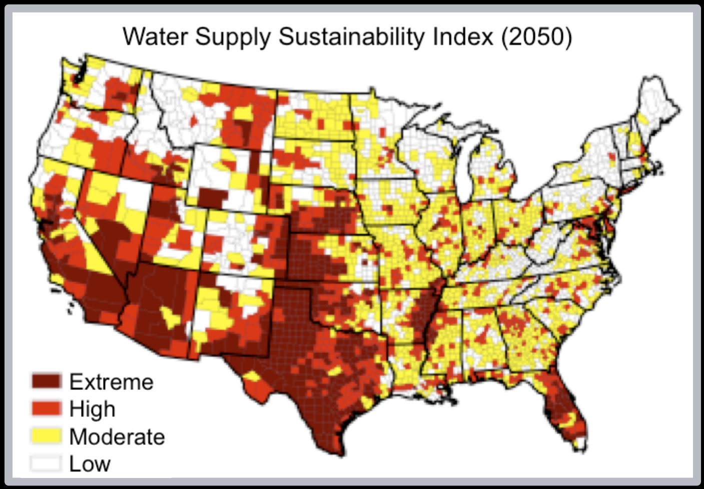
Mary Clayton, Jill Kjellsson and Michael E. Webber

February 28, 2013

We Have A Water Problem and An Energy Problem: Integrating Renewables With Brackish Groundwater Desalination Might Mitigate Both

In Light Of Concerns About Water Scarcity, More Cities Are Considering Desalination

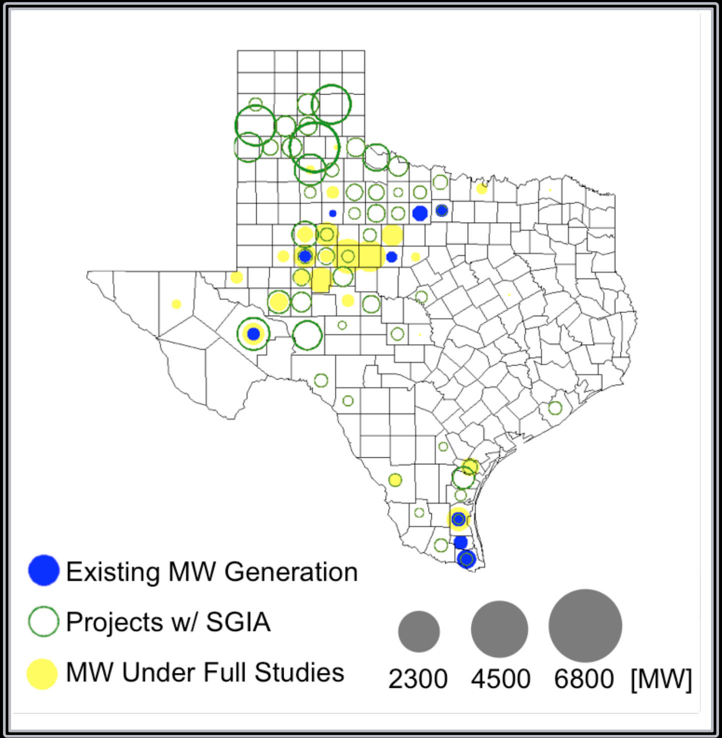
- **Many areas in the US face water sustainability risks due to increasing demands and decreasing existing water supplies**
- **TWDB estimates a need for an additional 9 million ac-ft per year by 2060 in Texas [TWDB]**
- **Brackish groundwater treatment consumes 20-40 times more energy than surface water treatment [EPRI, CEC]**



[NRDC]

Implementation Of Wind Power Is Desirable But Faces Challenges

- **Diurnal and season variations are mismatched with demand (for continental wind)**
- **Intermittency presents challenges for integration into the grid**
- **Requires expensive infrastructure for transmission**

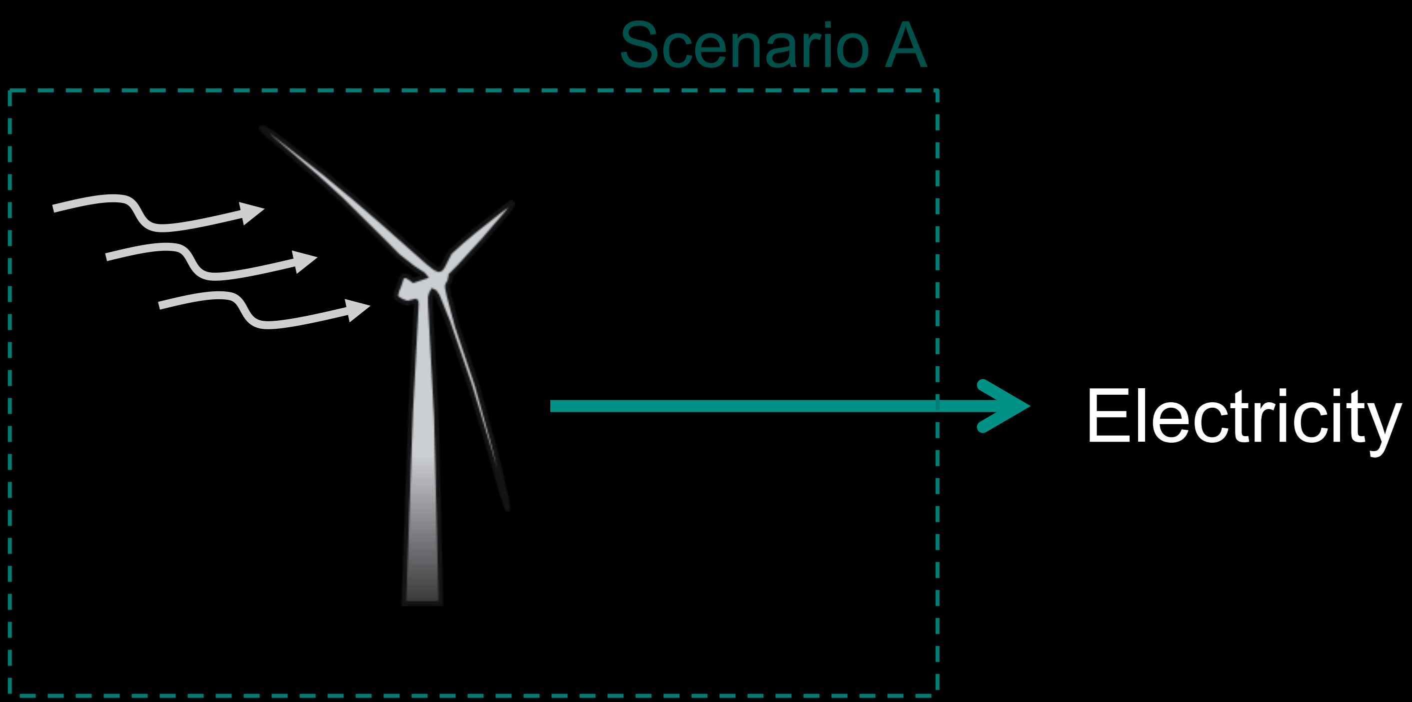


[ERCOT]

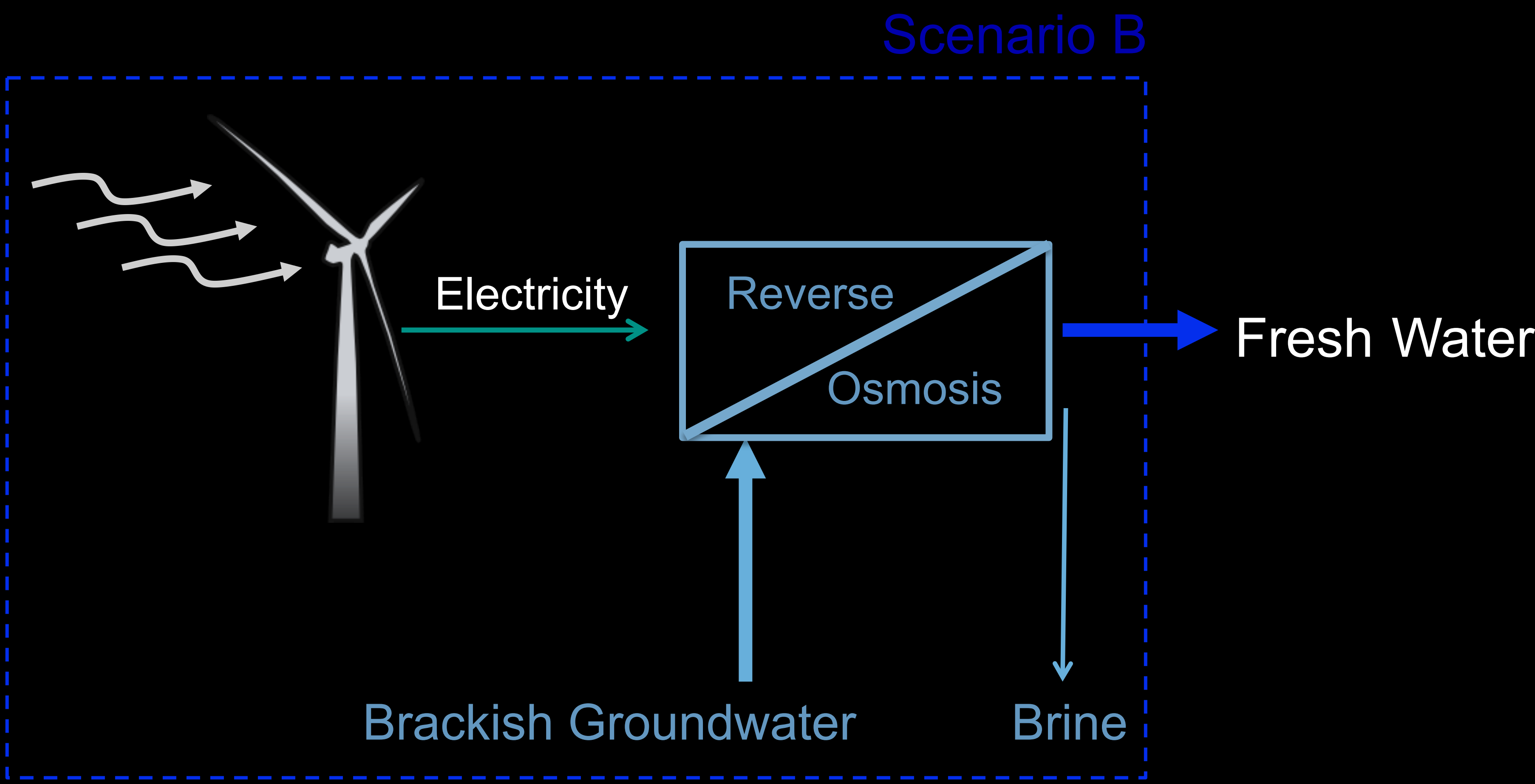
Integrating Wind Power With Brackish Desalination Solves Several Problems Simultaneously

- Transform low-value products (brackish groundwater and intermittent electricity) into a high-value product (treated drinking water)
- Alternative use of a carbon-free, domestic, renewable source of energy with low marginal costs
- Provide an alternative source of water for water-strained areas
- Provide solutions to challenges of each technology
  - Desalination addresses intermittent, off-peak nature of wind power
  - Wind power addresses high energy requirements of desalination

Traditionally, wind generated electricity is sold to the grid at market clearing or purchase power agreement prices



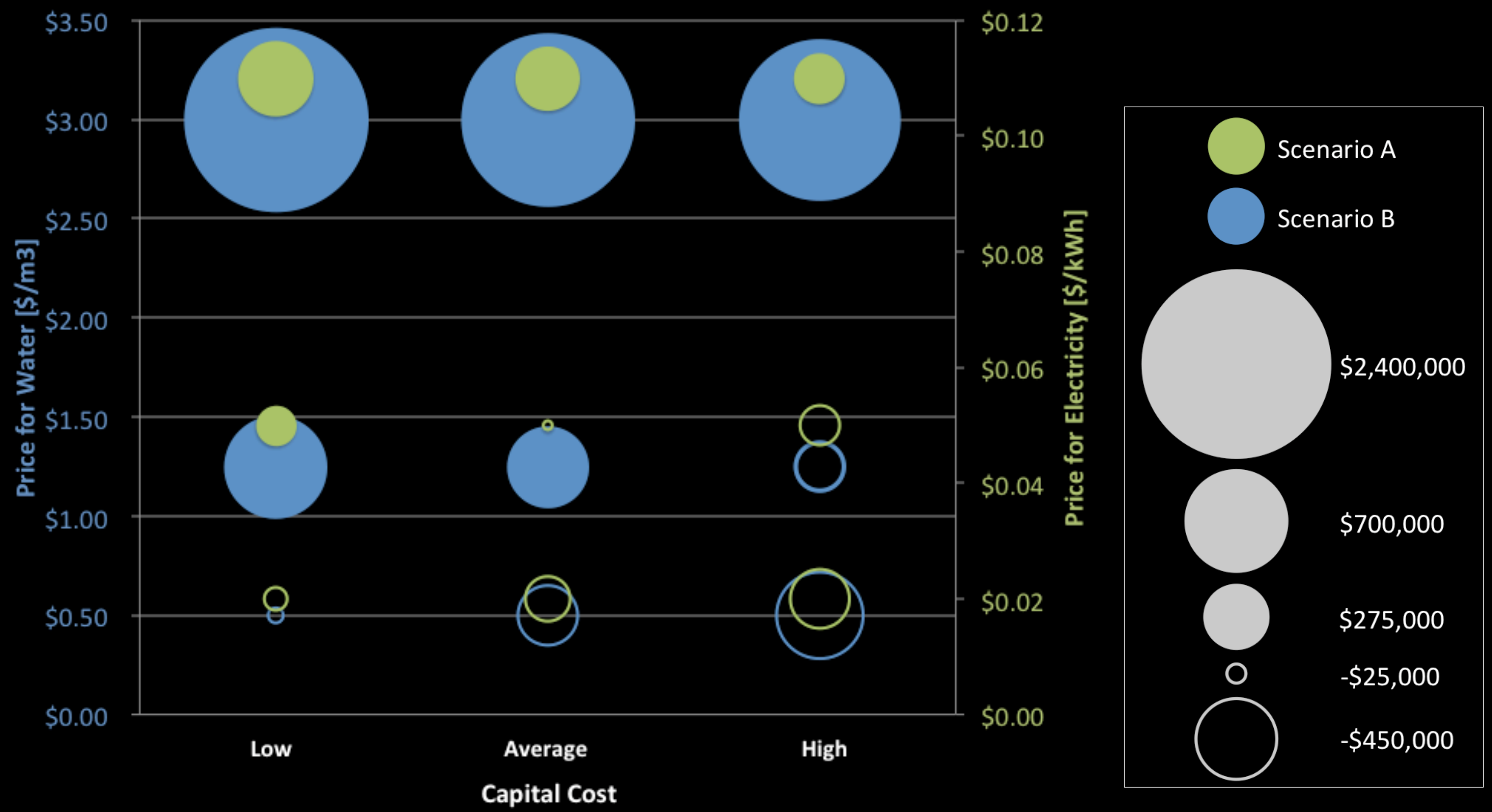
Inclusion of a brackish groundwater RO desalination plant could utilize the electricity to produce fresh water



Economic analysis is based on both fixed and variable costs reported in literature

	Reported Costs			Source
Wind turbine capital	1,500	2,700	[$/kW]	DOE
Wind turbine operational	5	15	[$/MWh]	DOE
Reverse osmosis desalination capital	500	950	[$/m^3/d]	Arroyo, TWDB
Groundwater well capital	70	250	[$/m^3/d]	TWDB
Concentrate disposal capital	200	2,100	[$/m^3/d]	USBR
Reverse osmosis operational	0.09	0.18	[$/m^3]	Arroyo, TWDB
Concentrate disposal operational	0.02	3.90	[$/m^3]	USBR

Integrated wind power with desalination presents greater profitability potential for most scenarios



A range of project parameters are considered to determine sensitivity of profitability

Project Parameter	Unfavorable	Favorable
Wind turbine capacity factor	0.25	0.40
Reverse osmosis recovery	0.6	0.8
Reverse osmosis energy intensity [kWh/m^3]	2.6	1.0
Depth to brackish groundwater [m]	250	50

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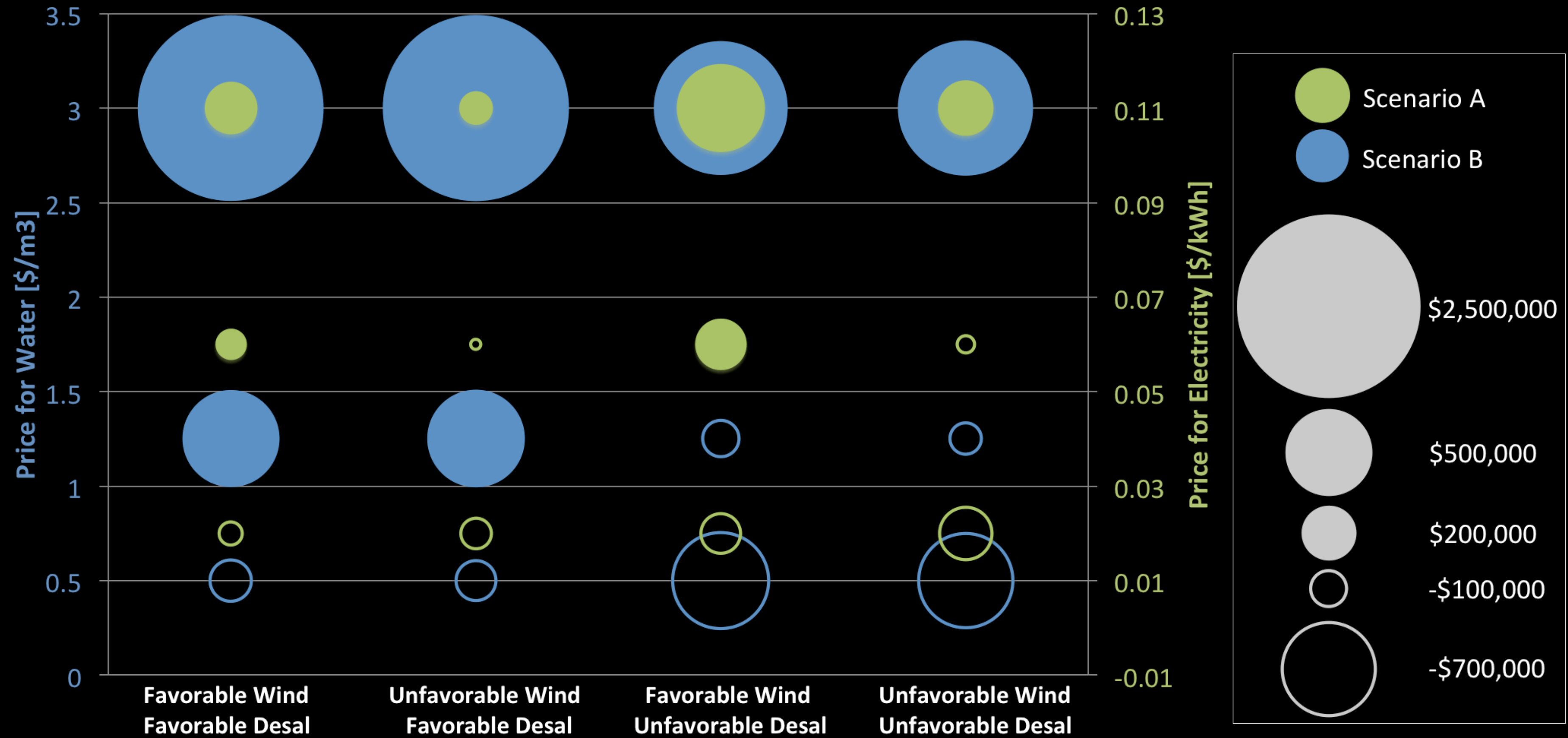

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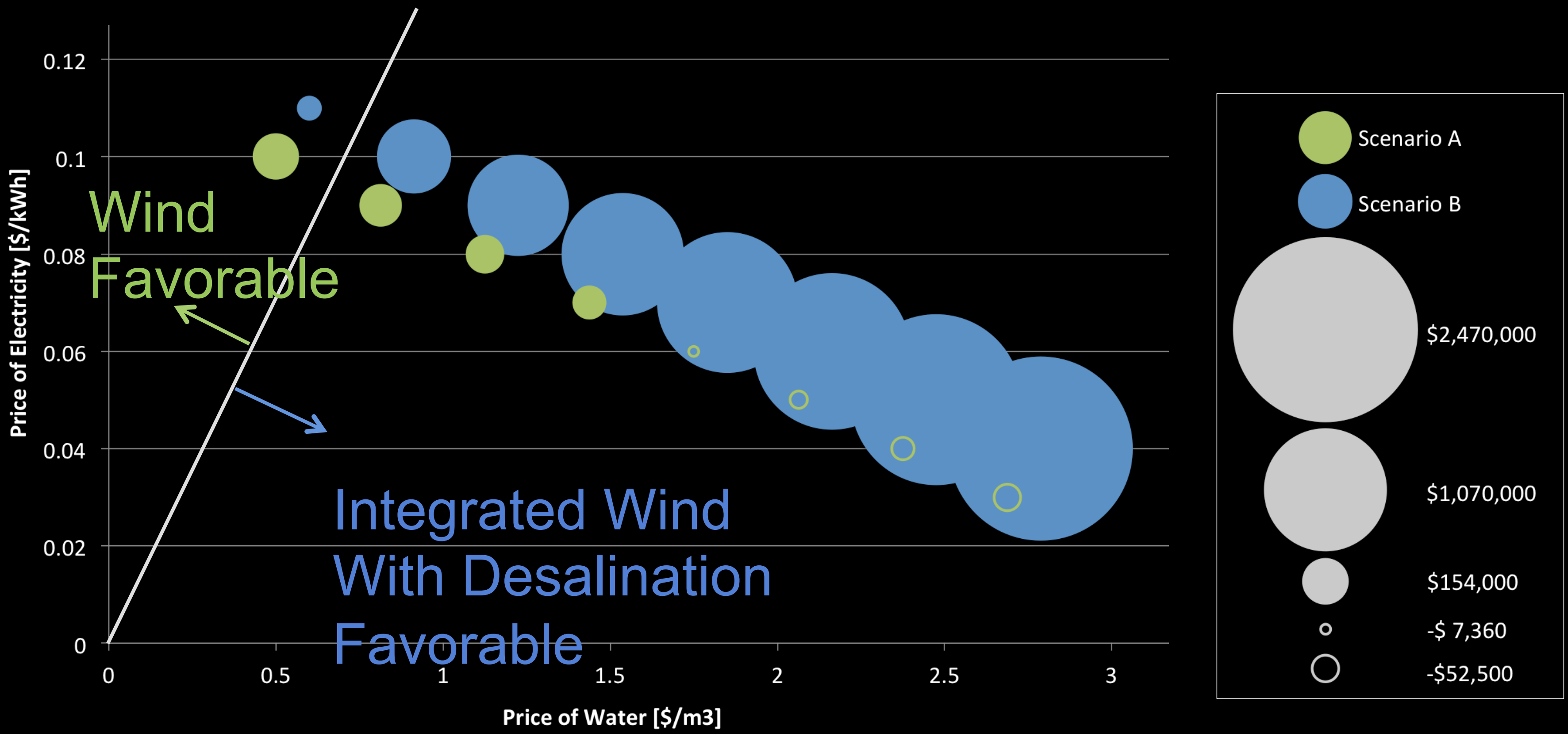
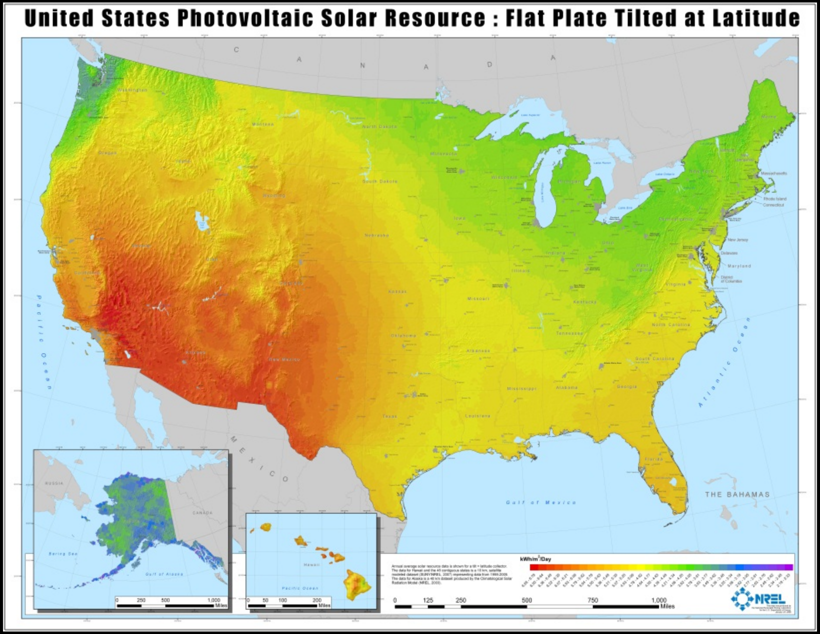


Solar Resources Can Also Be Integrated for Desalination

There is a Wealth of Solar Radiation in Texas

- **Solar Energy Potential**
  - **900-1,300 kWh/m²/year (Winter)**
  - **2,150-2,900 kWh/m²/year (Summer)**



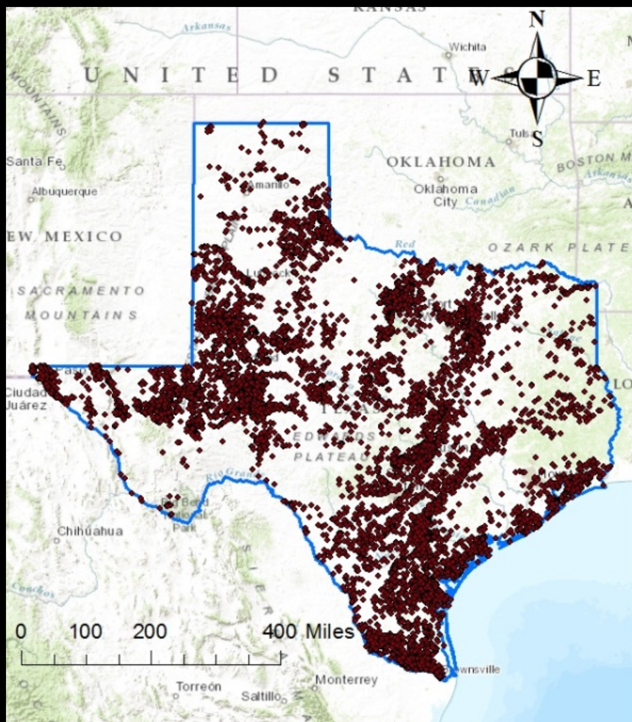
- **Drawbacks:**
  - **Intermittent**
  - **Difficult/expensive to store**

Stored, treated water can act as a proxy for energy storage!

Estimation of Desalination Capacity

- **Research Focus: PV-Powered Reverse Osmosis**
- **Steps:**
  - **Spatial variability of solar radiation**
  - **Spatial variability of brackish well characteristics**
    - **Depth, Total Dissolved Solids (TDS)**
  - **Estimation of desalination capacity**

The TWDB Groundwater Database and NREL Solar Radiation Database Provide Data to Determine Desalination Capacity

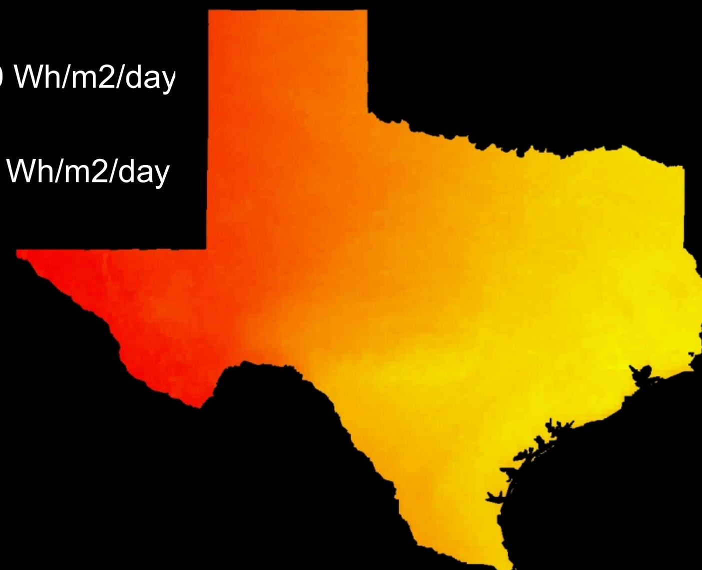


Legend

GlobalTilt

High : 6,600 Wh/m2/day

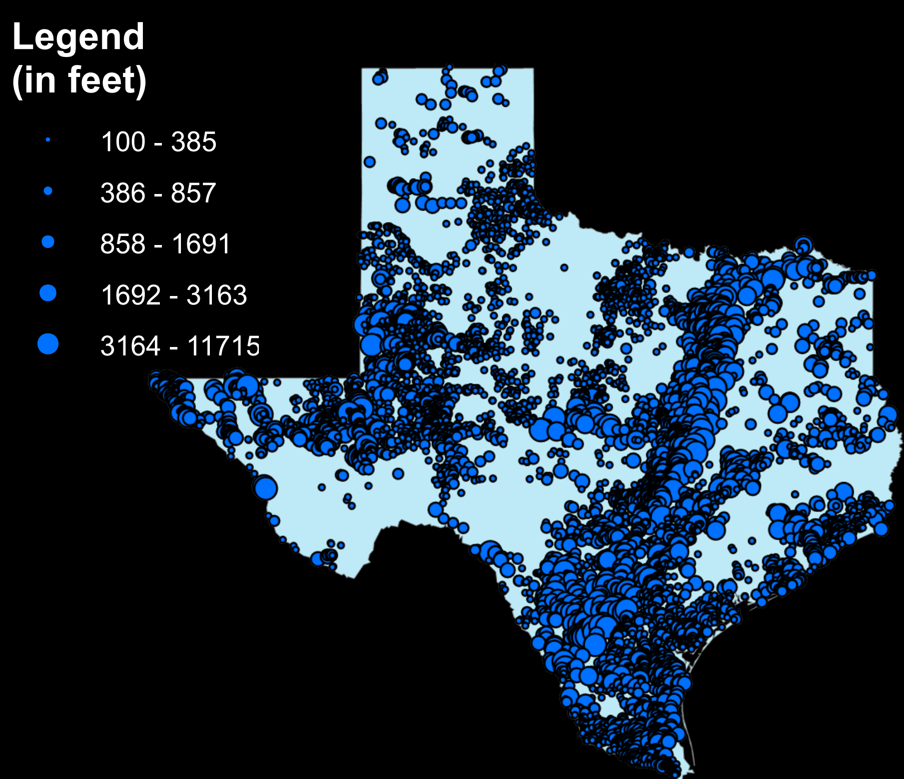
Low : 4,700 Wh/m2/day

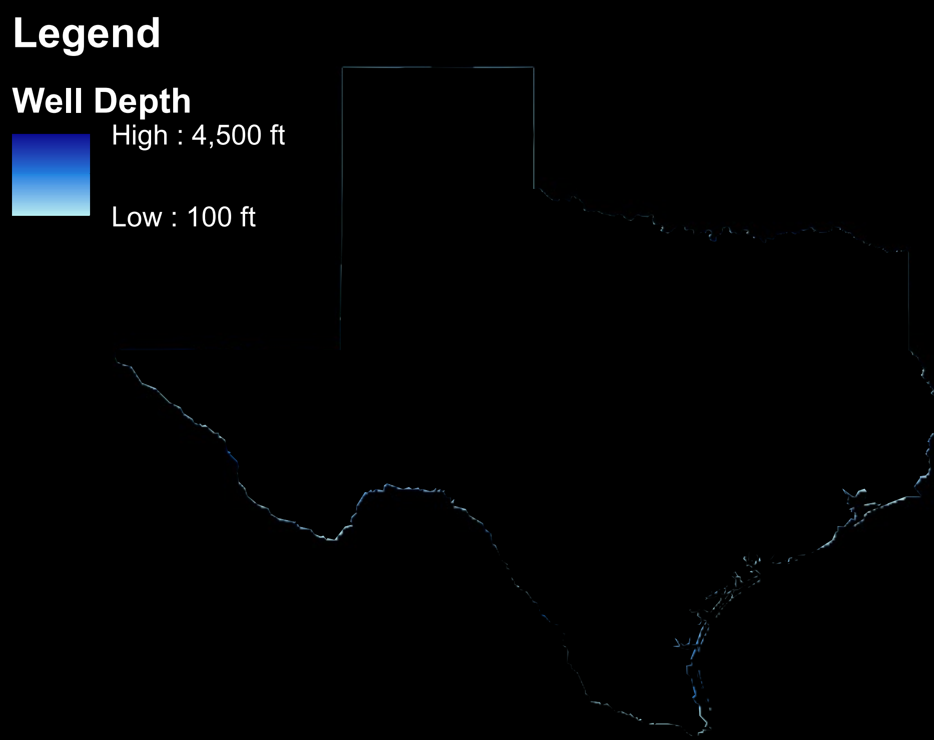


Well Depth Range: 100-12,000 feet
TDS Range: 1,000-30,000 mg/L

Well Depth is Greatest along the Balcones Fault Zone

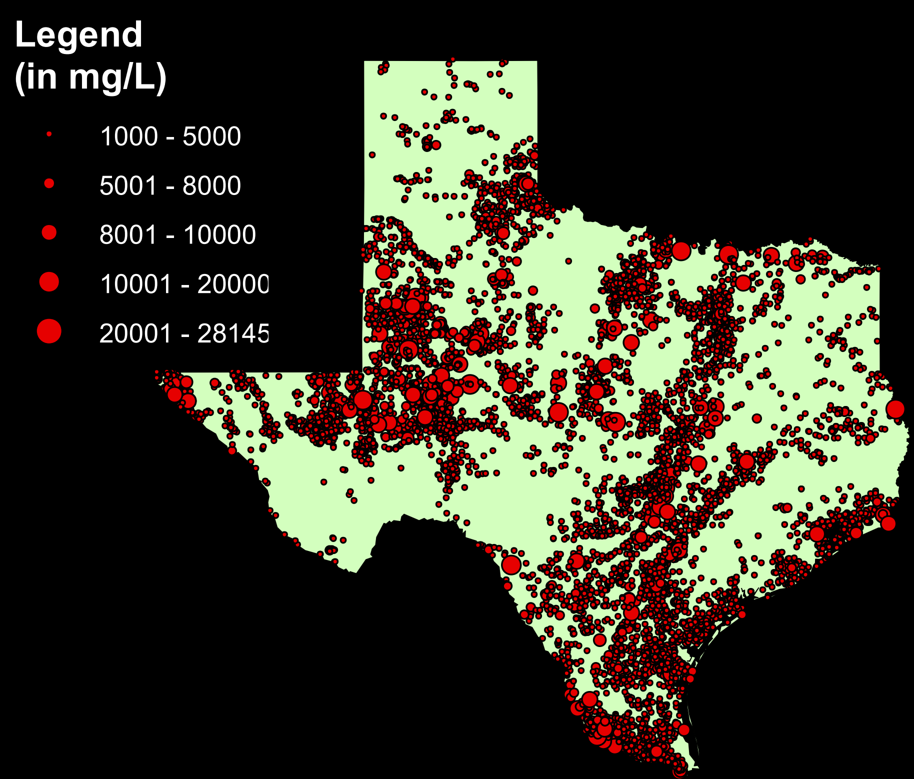
Well Depth

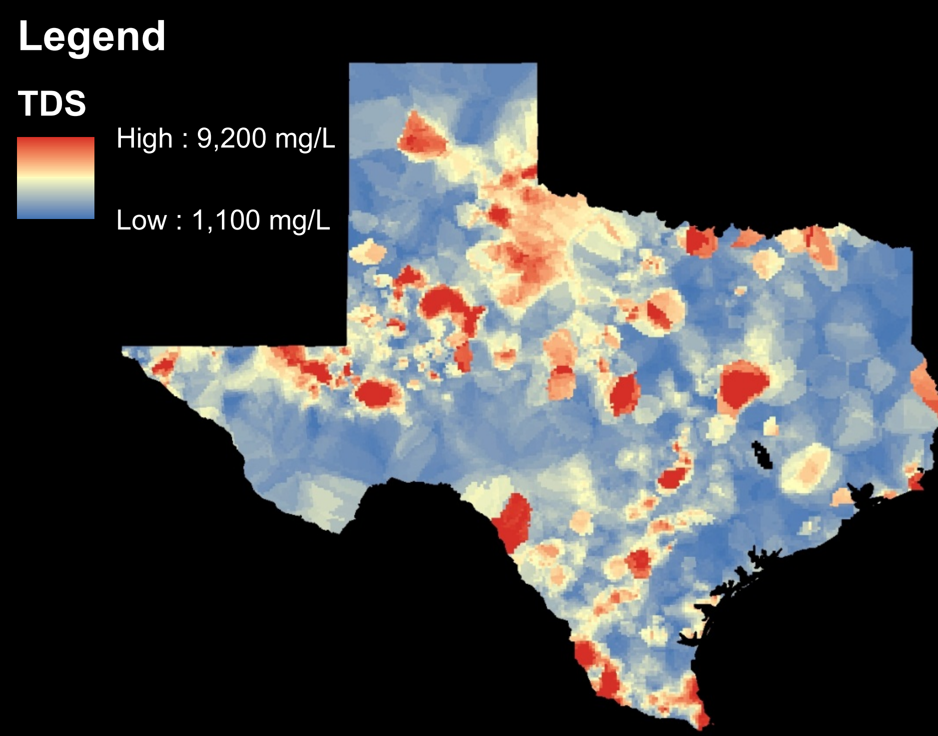




Areas of High Total Dissolved Solids Concentrations are Scattered

Total Dissolved Solids





Desalination Capacity is Estimated using GIS

- **To determine desalination capacity, the power generation from PV was set equal to the power required for RO desalination**

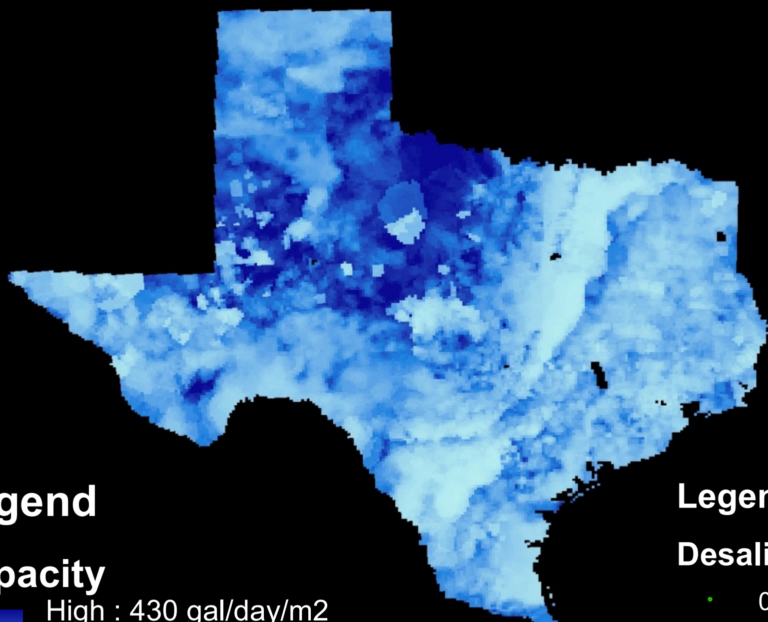
- $P_{desal} = P_{RO} + P_{pumping}$

- $P_{desal} = \left(\frac{Q \times \gamma \times WD}{\eta_{pump}}\right) + \left(Q \times 0.08 \times (TDS_{in} - TDS_{out})\right)$

- $P_{PV} = \eta_{PV} \times Global\ Tilt\ Radiation \times A_{PV} \times 365$

Solar PV Powered Desalination Capacity is Highest in Northern Texas

Desalination Capacity across Texas



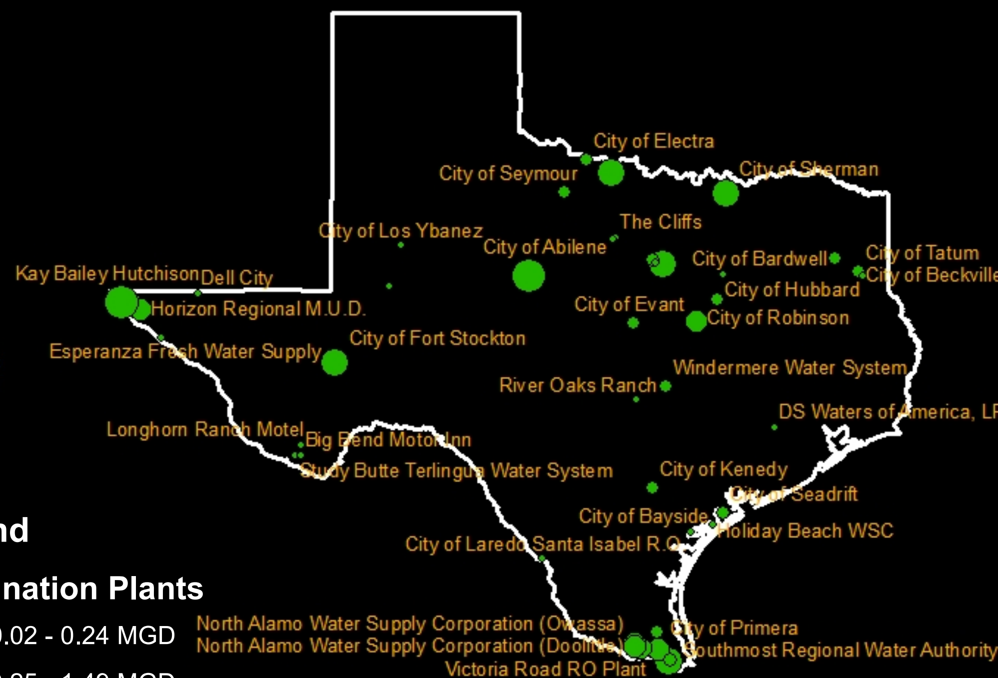
Legend

Capacity

High : 430 gal/day/m2

Low : 9 gal/day/m2

Desalination Plants in Texas



Legend

Desalination Plants

- 0.02 - 0.24 MGD
- 0.25 - 1.49 MGD
- 1.50 - 3.99 MGD
- 4.00 - 7.99 MGD
- 8.00 - 21.25 MGD

Jill B. Kjellsson
Webber Group Symposium 2013
Michael E. Webber, Ph.D.
TXWDB Desal Roundtable
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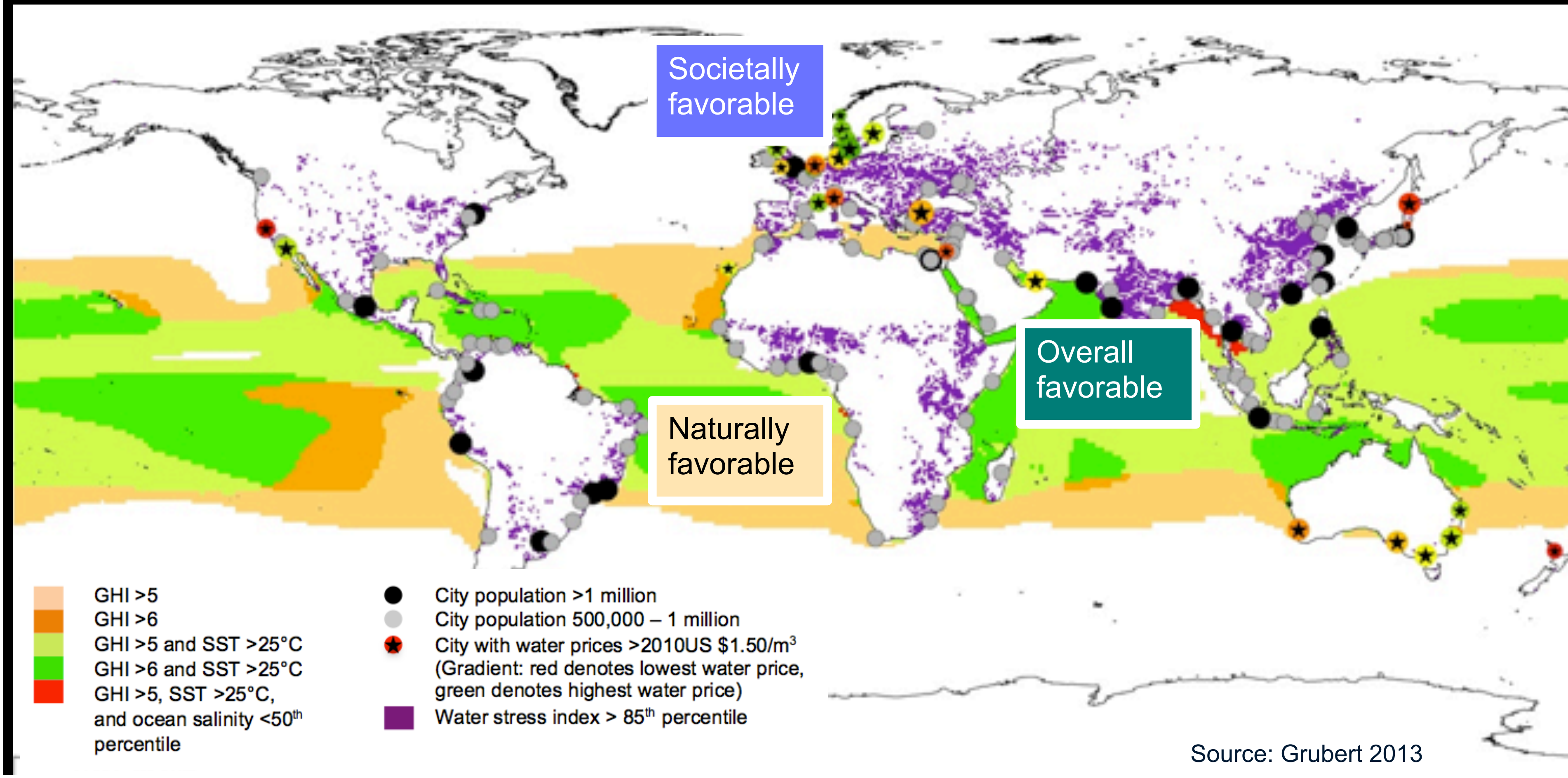
There Are a Few Locations Where Solar PV Desalination Makes Sense: high water stress, low salinity, high water temp, high solar radiation, and high water prices



Source: Grubert 2013

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http://www.webberenergygroup.com

Sources

[1] United States. Texas Water Development Board. “Water For Texas 2012 State Water Plan.” Jan. 2012. Web. <http://www.twdb.state.tx.us/publications/state_water_plan/2012/2012_SWP.pdf>.

[2] "Desalination: Brackish Groundwater." *Texas Water Development Board*. Water For Texas, Jan. 2012. Web. <http://www.twdb.state.tx.us/publications/shells/Desal_Brackish.pdf>.

[3] Wogan, David M.; Michael Webber; and Alexandre K. da Silva. "A Framework and Methodology for Reporting Geographically and Temporally Resolved Solar Data: A Case Study of Texas." *Journal of Renewable and Sustainable Energy* (2010). Rpt. in American Institute of Physics, 2010. Web.

Data:

Brackish Groundwater Database. TWDB. 2002. http://wiid.twdb.texas.gov/ims/wwm_drl/viewer.htm?DISCL=1&appno=2

National Solar Radiation Database. NREL. Oct. 2012. http://www.nrel.gov/gis/data_solar.html

The power rating of the wind turbine is based on pumping and desalination power requirements

Wind turbine capacity is a function of the power requirements for pumping and desalination

- **Pumping power requirement is a function of the flow rate, depth to aquifer, pump efficiency, pipe length, pipe diameter, friction factor, and desalination capacity factor**
- **Desalination power requirement is a function of the flow rate, the desalination capacity factor, and energy intensity of desalination**
  - **Energy intensity of desalination is modeled as a linear function of total dissolved solids and the national average electricity use for brackish groundwater treatment**

The power rating of the wind turbine is based on pumping and desalination power requirements

Wind turbine capacity

$$C_{WT}[kW] = P_P[kW] + P_D[kW]$$

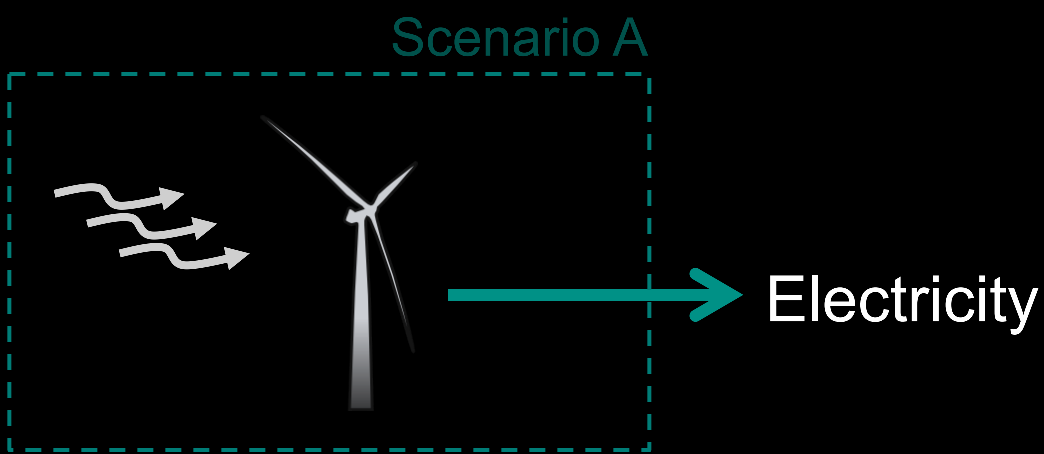
- **Pumping power requirement**

$$P_P[kW] = \frac{\rho\left[\frac{kg}{m^3}\right] g\left[\frac{m}{s^2}\right] q\left[\frac{m^3}{s}\right]}{1{,}000\eta_P CF_D}\left(z[m] + \frac{\left(\frac{4q\left[\frac{m^3}{s}\right]}{\pi(d[m])^2}\right)^2}{2g\left[\frac{m}{s^2}\right]}\frac{f}{d[m]}(z[m] + l[m])\right)$$

- **Desalination power requirement**

$$P_D[kW] = \frac{3{,}600\ EI_D\left[\frac{kWh}{m^3}\right] q\left[\frac{m^3}{s}\right]}{CF_D}$$

Profitability is determined for wind generated electricity based on capital costs, operational costs, and electricity sales



Profitability is a function of the price of electricity, PTC, capital expenses, turbine capacity, operational expenses, electricity generation, project life, and interest rate

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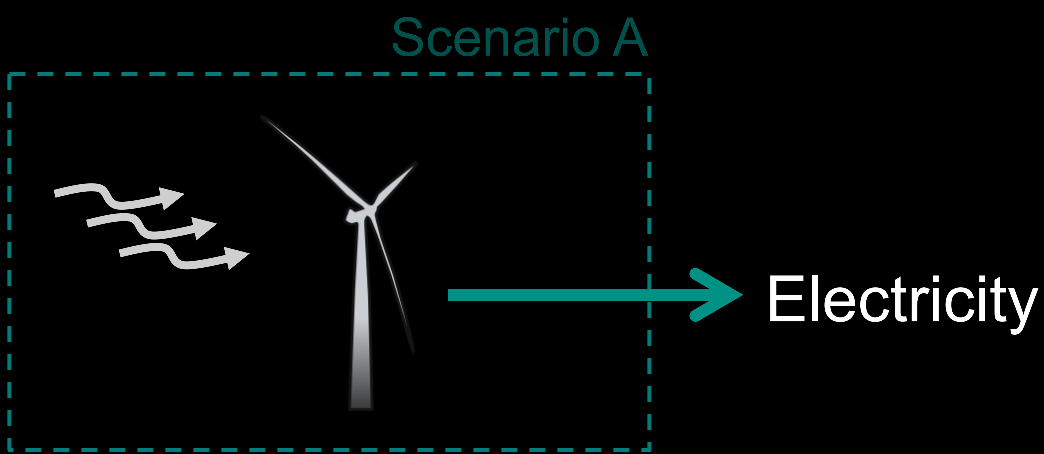
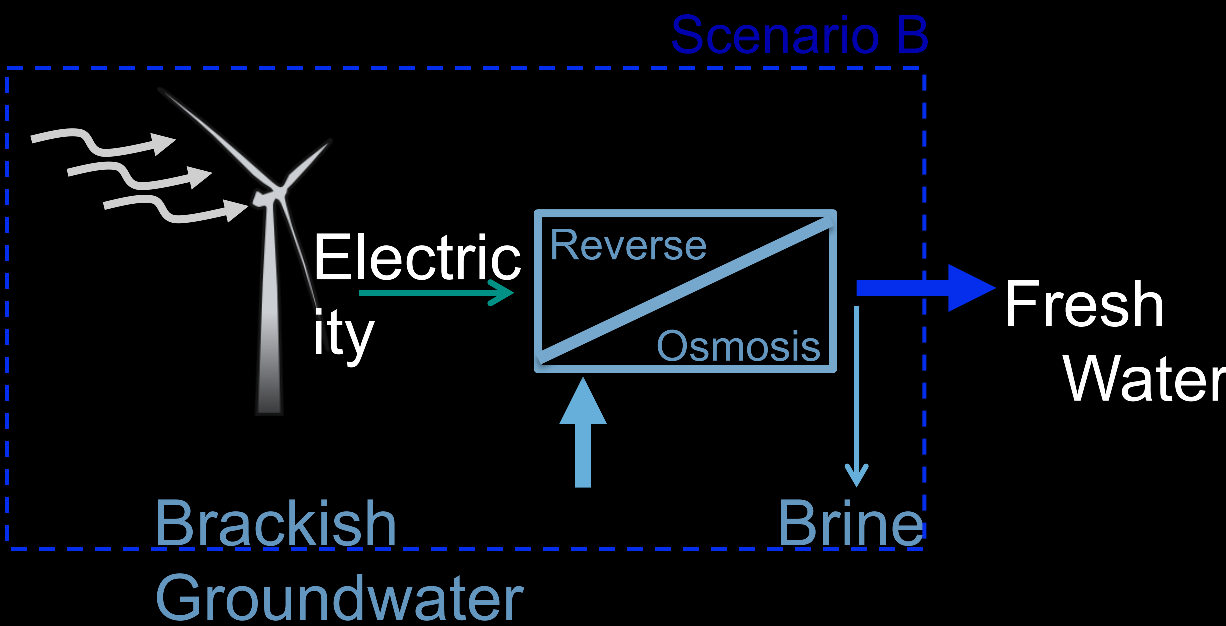


$$Profitability_A\left[\frac{\$}{yr}\right] = \left[\left\{P_e\left[\frac{\$}{kWh}\right] + PTC\left[\frac{\$}{kWh}\right]\right\} \times G_{WT}\left[\frac{kWh}{yr}\right]\right] - \left[\frac{CAPEX_{WT}\left[\frac{\$}{kW}\right] \times C_{WT}[kW]}{A[yr]}\right]$$

$$- \left[OPEX_{WT}\left[\frac{\$}{kWh}\right] \times G_{WT}\left[\frac{kWh}{yr}\right]\right]$$

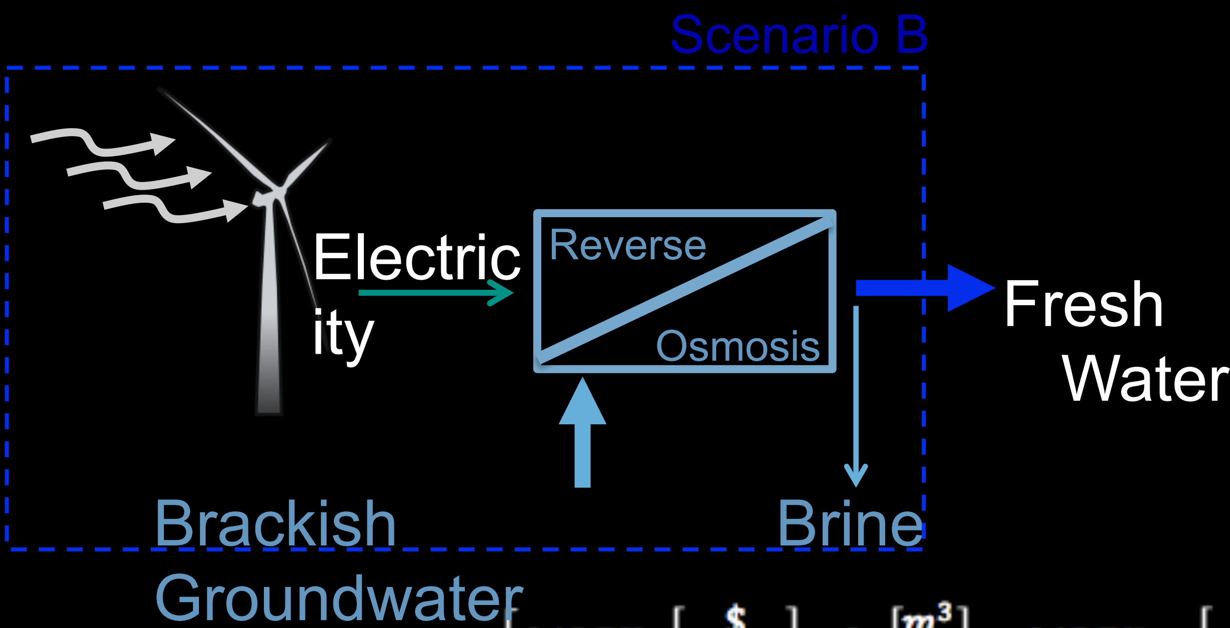
$$A[yr] = \frac{1-(1+i)^{-n}}{i}$$

Profitability is determined for integrated wind with desalination based on capital costs, operational costs, and water sales



Profitability is a function of the price of water, capital expenses, turbine capacity, desalination capacity, operational expenses, water production, electricity generation, project life, and interest rate

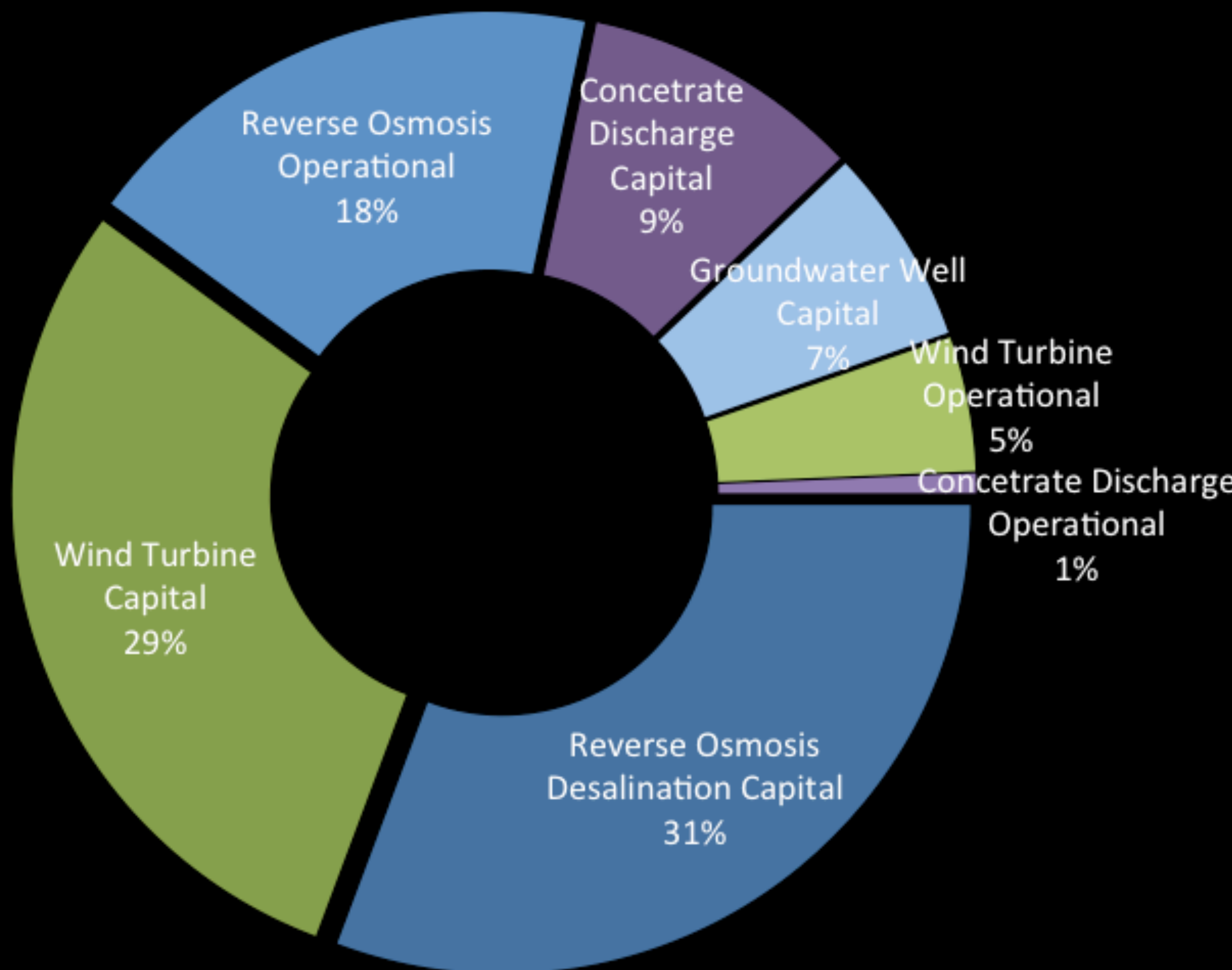
Profitability is determined for integrated wind with desalination based on capital costs, operational costs, and water sales



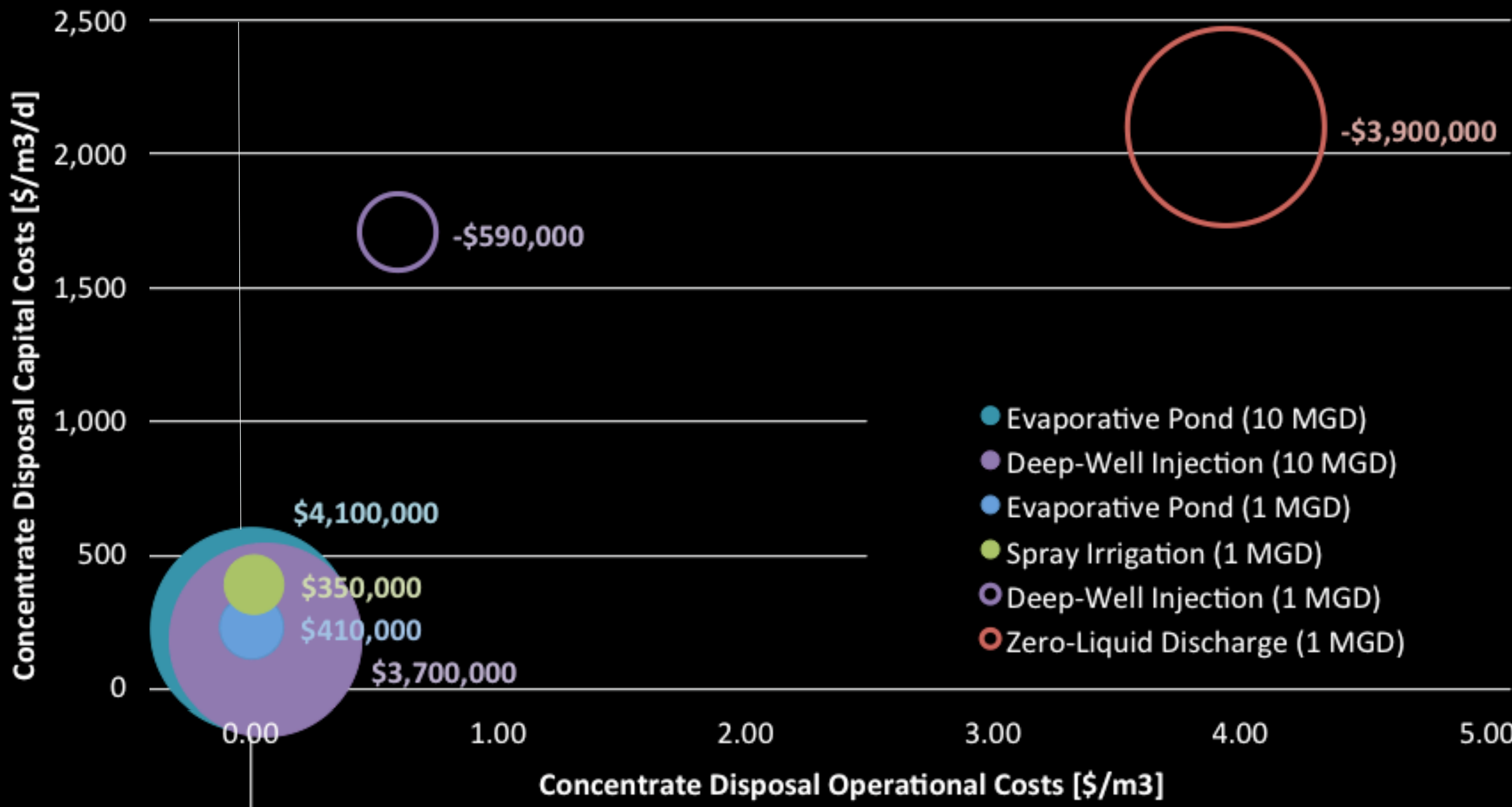
$$Profitability_B\left[\frac{\$}{yr}\right] = \left[P_w\left[\frac{\$}{m^3}\right]\times G_D\left[\frac{m^3}{yr}\right]\right] - \left|\frac{CAPEX_D\left[\frac{\$}{m^3/d}\right]\times C_D\left[\frac{m^3}{d}\right] + CAPEX_{WT}\left[\frac{\$}{kW}\right]\times C_{WT}[kW]}{A[yr]}\right|$$

$$-\left[OPEX_D\left[\frac{\$}{m^3}\right]\times G_D\left[\frac{m^3}{yr}\right] + OPEX_{WT}\left[\frac{\$}{kWh}\right]\times G_{WT}\left[\frac{kWh}{yr}\right]\right] + \left[PTC\left[\frac{\$}{kWh}\right]\times G_{WT}\left[\frac{kWh}{yr}\right]\right]$$

Wind Turbine Expenses Comprise Only 35 Percent of Integrated Project Expenses When Considering Average Expenses and Low Concentrate Discharge Expenses



Concentrate disposal methods range widely in capital and operational costs, largely influencing profitability



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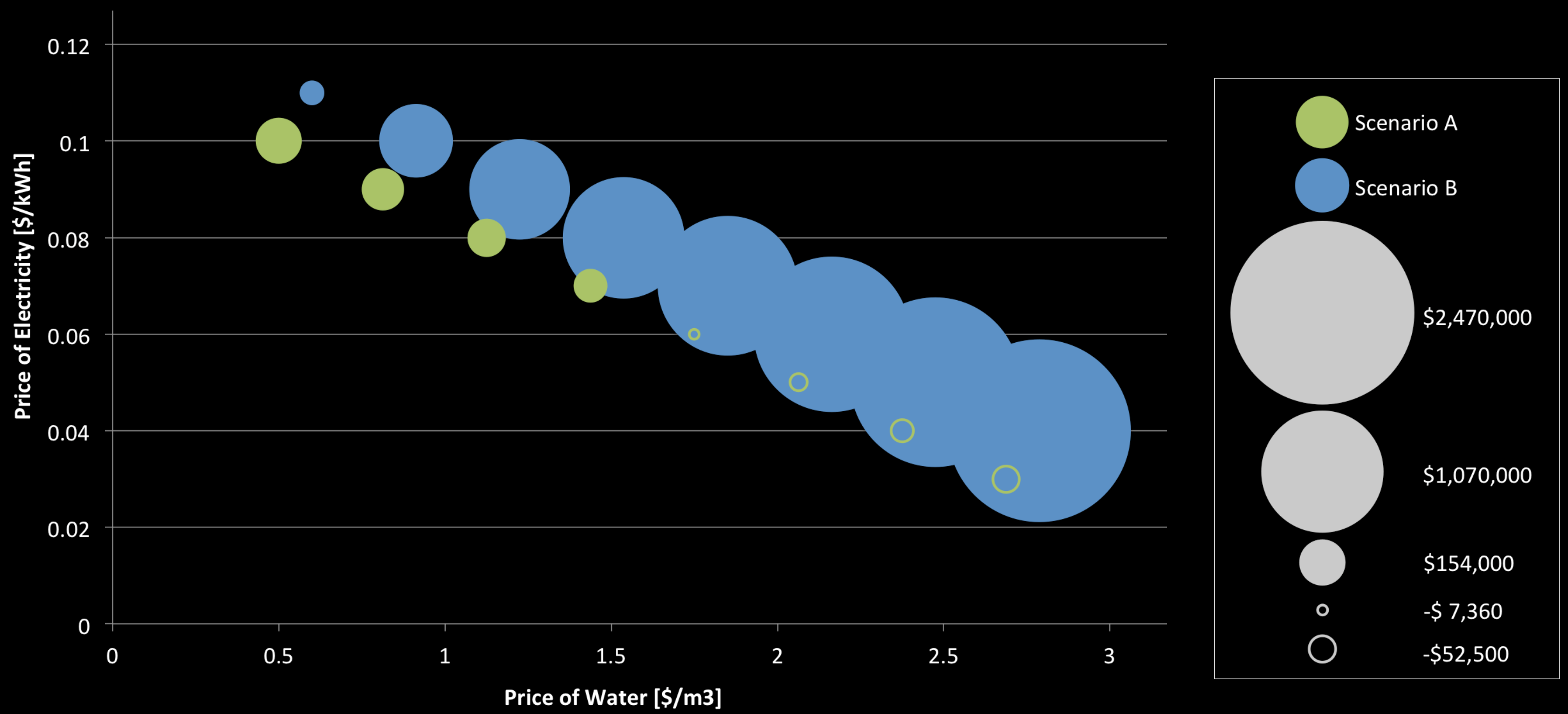


Conclusions

- Brackish groundwater desalination using wind power provides opportunity to address challenges of the intermittent and off-peak nature of wind resources and high energy requirements of desalination

- Brackish groundwater desalination using wind power is favorable for:
  - High reverse osmosis recovery
  - Low energy intensity of desalination
  - Shallow groundwater depths and low total dissolved solids
  - High water prices

- As cities continue to require more new water sources and wind turbine technologies advance, the profitability of this integration may increase

Where Does Desalination Make Sense?

Leveraging natural and societal conditions to improve sustainability

Emily Grubert

WEG Symposium 2013, Austin, TX

8 January 2013

We use data layers and mapping techniques to identify favorable sites for desalination

- Map global regions where local conditions could help seawater desalination make sense
  - Energy intensity: feedwater characteristics
  - Energy impact: fuel availability
  - Cost: market conditions
- Case study: global view of solar-aided seawater reverse osmosis desalination

Why focus on energy intensity?

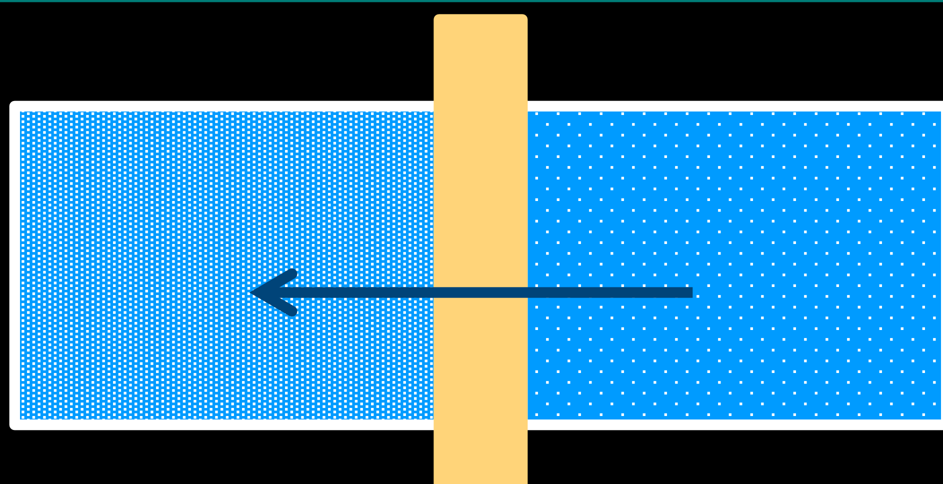
- Energy intensity **drives costs**
- Energy use contributes to **environmental and security risks**
- Site selection can **reduce overall energy use** and **enable alternative fuels**

Water Source	Energy intensity (kWh/m^3)
Surface water (typical)	0.06
Pumped groundwater (CA)	0.14-0.60
Direct potable reuse	<1.1
Colorado River Aqueduct (CA)	1.6
California State Water Project	2.4
Seawater desalination (CA)	3.6-4.5

What is desalination?

- Desalination typically takes one of two forms:
  - Evaporation (thermal desalination)
  - Filtration (membrane desalination)
- Filtration is more common for new plants
  - Mainly as reverse osmosis

The highly saline brine is a waste product that must be disposed



Plants use energy to force salts from less salty water into brine, overcoming osmotic pressure

Our case study considered solar-aided seawater reverse osmosis desalination

	Case study parameters	Reason
Energ y intensi ty	• Feedwater temperature • Feedwater salinity	• Higher temperatures increase flux • Lower salinity reduces osmotic pressure
Energ y impact	• Insolation	• Solar is available at regional levels and is unlikely to be fully utilized
Cost	• Water stress index • Water prices • Population	• Stress indicates demand for new supply • Existing prices indicate affordability • Density enables economies of scale