Can we Eat, Drink AND Turn on the Lights?

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Energy/Water/Food Nexus

• Water required to produce energy
  ✓ High withdrawals, limited consumption

• Energy required to treat, transport water
  ✓ We don’t pay for water, we pay to move it around
  ✓ Advanced treatment largely defined by energy requirements
  ✓ Substantial energy demand to heat water

• Water/Energy required to produce food
  ✓ Irrigation central to increased agricultural productivity
The Water / Energy Nexus

Water use and availability will limit our energy choices without substantial efficiency improvements.
Texas generation: 430 terawatt-hours in 2012
Cooling water consumption: ~ 0.4-0.5 Mac-ft/yr
(< 4% Texas total consumption per TWDB demand)

Dry Cooling Incentivized $1000-$2000 acre-ft
Water Requirements for Biofuel

It takes an average of 2,500 liters of water to produce 1 liter of liquid biofuel.

Water consumption for energy production in the US will jump two thirds between 2005 and 2030, and about half of the increase is due to growing biofuels (Service, 2000).

Replacing 10% of global energy consumption with 1st generation biofuel would double agricultural water withdrawals in the world (Source: The World Economic Forum: Water Initiative).

### WATER REQUIREMENTS FOR ENERGY PRODUCTION (Liters per megawatt hour)

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Water Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petroleum Extraction</td>
<td>10-40</td>
</tr>
<tr>
<td>Oil Refining</td>
<td>80-150</td>
</tr>
<tr>
<td>Oil shale surface retort</td>
<td>170-681</td>
</tr>
<tr>
<td>NGCC* power plant, closed loop cooling</td>
<td>230-30,300</td>
</tr>
<tr>
<td>Coal integrated gasification combined-cycle</td>
<td>~900</td>
</tr>
<tr>
<td>Nuclear power plant, closed loop cooling</td>
<td>~950</td>
</tr>
<tr>
<td>Geothermal power plant, closed loop tower</td>
<td>1900-4200</td>
</tr>
<tr>
<td>Enhanced oil recovery</td>
<td>~7600</td>
</tr>
<tr>
<td>NGCC*, open loop cooling</td>
<td>28,400-75,700</td>
</tr>
<tr>
<td>Nuclear power plant, open loop cooling</td>
<td>94,600-227,100</td>
</tr>
<tr>
<td>Corn ethanol irrigation</td>
<td>2,270,000-8,670,000</td>
</tr>
<tr>
<td>Soybean biodiesel irrigation</td>
<td>13,900,000-27,900,000</td>
</tr>
</tbody>
</table>

(Source: Service, 2009, Sci.)

Bioenergy is the biggest water consumer compared to other energies.

Cai, 2014
Hydraulic Fracturing: World Shale Plays and Water Availability

Mauter et al., 2014
US Shale Plays and Availability

Legend
- Shale Plays

Baseline Water Stress
1. Low (<10%)
2. Low to medium (10-20%)
3. Medium to high (20-40%)
4. High (40-80%)
5. Extremely high (>80%)

Arid & low water use
Water Savior?

Natural gas uses far less water overall than coal, nuclear, geothermal or concentrated solar power (CSP)

Save Water – Frac more?
Energy consumption for water

12% of US Energy Demand for Water
## Water for Food

### Water for Production

<table>
<thead>
<tr>
<th>Item</th>
<th>Water Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 apple</td>
<td>700 liters</td>
</tr>
<tr>
<td>1 cup of coffee</td>
<td>1120 liters</td>
</tr>
<tr>
<td>1 kg chicken</td>
<td>3500 – 5700 liters</td>
</tr>
<tr>
<td>1 kg beef</td>
<td>15,000 – 17,000 liters</td>
</tr>
</tbody>
</table>

Schuster, 2013
Water Imports and Exports

Figure 4. Virtual water balance per country and direction of gross virtual water flows related to trade in agricultural and industrial products over the period 1996-2005. Only the biggest gross flows (> 15 Gm³/yr) are shown; the fatter the arrow, the bigger the virtual water flow.
Water is exported at low cost!
Product Value / Water Consumed

Agriculture
- 57-113 $/acre-ft marginal value (Michelsen, 2014)
- Total Value/Total Water -$2,000/acre-ft (King, 2014)

Power Generation
- $20,000-40,000/acre-ft (King, 2014)

Hydraulic fracturing for oil and gas
- $115,000 / acre-ft (Michelsen, 2014)

Of course, its hard to eat oil and gas… but we don’t have to grow water intensive crops in water-stressed areas either
Case Study - Texas

This is a map of annual precipitation averaged over the period 1961-1990. Station observations were collected from the NOAA Cooperative and USDA-NRCS SpoTel networks, plus other state and local networks. The PRISM modeling system was used to create the gridded estimates from which this map was made. The size of each grid pixel is approximately 4x4 km. Support was provided by the NRCS Water and Climate Center.

Average Annual Precipitation
Texas

Copyright 2000 by Spatial Climate Analysis Service, Oregon State University

For information on the PRISM modeling system, visit the SCAS web site at http://www.ccs.orst.edu/prism

The latest PRISM digital data sets created by the SCAS can be obtained from the Climate Source at http://www.climatesource.com
Water Allocation and Demand

Figure 4. Existing (as of 2010) and future (2060) water demands for each water use category in each water planning region (TWDB 2012).

Legend
- Mining
- County-other
- Steam Electric
- Manufacturing
- Livestock
- Municipal
- Irrigation

Acre feet

Scale: acre-feet (million)
Texas Water Demand and Value

Water Demand

- Irrigated Agriculture
- Livestock
- Mining
- Manufacturing
- Power
- Municipal

Economic value

- Irrigated Agriculture
- Livestock
- Mining
- Manufacturing, Trade
- Services
- Government

Sources:
Texas Water Development Board
Office of State Comptroller
What are the Options?
Cumulative Water Management Strategies by 2060 - TWDB

- Conservation: 24.9%
- Surface Water: 33.8%
- New Reservoirs: 16.7%
- Groundwater: 8.9%
- Groundwater Desalination: 2%
- Seawater Desalination: 1.4%
- Water Reuse: 10.2%
- Conjunctive Use: 3.4%
- ASR: 1.7%
- Other: 1.4%

Developed by Regional Water Management Districts: Cost - $53 Billion

Research Opportunities
Agricultural Irrigation Conservation

Approaches

- Appropriate crop selection
- Efficient hybrids
- Efficient Irrigation Systems
  - Drip irrigation
- Efficient scheduling
  - Canopy Temperature Control
  - Satellite Soil Moisture Sensing
- Target ~80% of crop evapotranspiration needs

West, 2014
# Economic Impact of Dry Farming

GDP of Lubbock $9,424,000,000

## Table 3. Total Dollar Impact for the Texas High Plains

<table>
<thead>
<tr>
<th>Gross Output</th>
<th>All Irrigated</th>
<th>Dryland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct</td>
<td>1,678,383,596</td>
<td>608,648,330</td>
</tr>
<tr>
<td>Indirect</td>
<td>426,243,712</td>
<td>165,896,341</td>
</tr>
<tr>
<td>Induced</td>
<td>233,177,309</td>
<td>91,171,091</td>
</tr>
<tr>
<td>Total</td>
<td>2,337,804,640</td>
<td>865,715,761</td>
</tr>
</tbody>
</table>

[Map of Texas High Plains with districts highlighted]
Municipal Conservation

San Antonio
1984-2009

Customers ↑ 67%

Water ↑ 0%

Puente, 2012

SAWS Total Production (1984 vs. 2009)

- Customers: 1984 - 800,627; 2009 - 1,342,730
- Water: 1984 - 191,431 acre-feet; 2009 - 186,112 acre-feet
- Population: 1984 - 800,627; 2009 - 1,342,730
Water Demand
Hydraulic Fracturing

• 3-10 MM gal (11-44 MM L) per well

• 1000 gal (3700L) /lateral ft of horizontal well

• Enormous growth in last 5 years (2-4 times more water)
  ✓ Less than 1% of total water use in TX
  ✓ But...new consumer in time of drought!

Expected to peak at 125,000 Acre-ft/yr

Similar to evaporation from Highland Lakes
What are our Alternatives to Freshwater for Hydraulic Fracturing?

- Reuse Flowback and Produced Water
- Reuse Municipal Effluents
  - Treated wastewater
  - RO reject water
- Employ brackish waters
- Disincentives common to each of these
  - Transportation to point of use
  - Appropriate chemistry (precipitation and fouling, corrosion)
  - Treatment to achieve appropriate chemistry
Reuse Produced Water?
### Challenge: Cost/Disposal Options

<table>
<thead>
<tr>
<th></th>
<th>PA Marcellus</th>
<th>TX Barnett</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water availability</td>
<td>Abundant</td>
<td>Limited</td>
</tr>
<tr>
<td>Drilling water, MM gal</td>
<td>0.085</td>
<td>0.25</td>
</tr>
<tr>
<td>Hydraulic fracturing, MM gal</td>
<td>5.5</td>
<td>3.8</td>
</tr>
<tr>
<td>New unconventional wells 2012</td>
<td>1365</td>
<td>660</td>
</tr>
<tr>
<td>Wells completed 2012 (est)</td>
<td>540</td>
<td>500</td>
</tr>
<tr>
<td>Active horizontal wells 2012</td>
<td>3680</td>
<td>&gt;10,000</td>
</tr>
<tr>
<td>Salt water disposal wells</td>
<td>7-8</td>
<td>980 (12,000 in TX)</td>
</tr>
<tr>
<td>Flowback + produced (WW), MGD (est)</td>
<td>3.1</td>
<td>2</td>
</tr>
<tr>
<td>Fraction WW recovered</td>
<td>~0</td>
<td>~0</td>
</tr>
<tr>
<td>Fraction WW Reused</td>
<td>0.87</td>
<td>0.13</td>
</tr>
<tr>
<td>Fraction WW deep-well injected</td>
<td>0.13</td>
<td>0.87</td>
</tr>
</tbody>
</table>

Silva et al. 2013
CRMWD System Map

Use of wastewater effluent

Use of RO Reject Water
Can we Eat, Drink AND Turn on the Lights?

Turn on the Lights? √
Drink? √
Eat? ?