Lawrence Livermore National Laboratory

Hydrogen and Water: Engineering, Economics and Environment

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Project ID # AN007

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Overview

- **Project Start:** October, 2007
- **Project End:** October, 2010
- **Percent Complete:** 98%[1]

Timeline

- **Systems Analysis Barrier A:**
  - Future Market Behavior
- **Systems Analysis Barrier E:**
  - Unplanned Analyses[2]
- **Production Barrier D:**
  - Feedstock Issues

Barriers

- **Total Funding:** **$640k + $200k**
- FY07 Funding: $200k
- FY08 Funding: $240k
- FY09 Funding: $200k
- FY10 Funding: $200k[2]

Budget

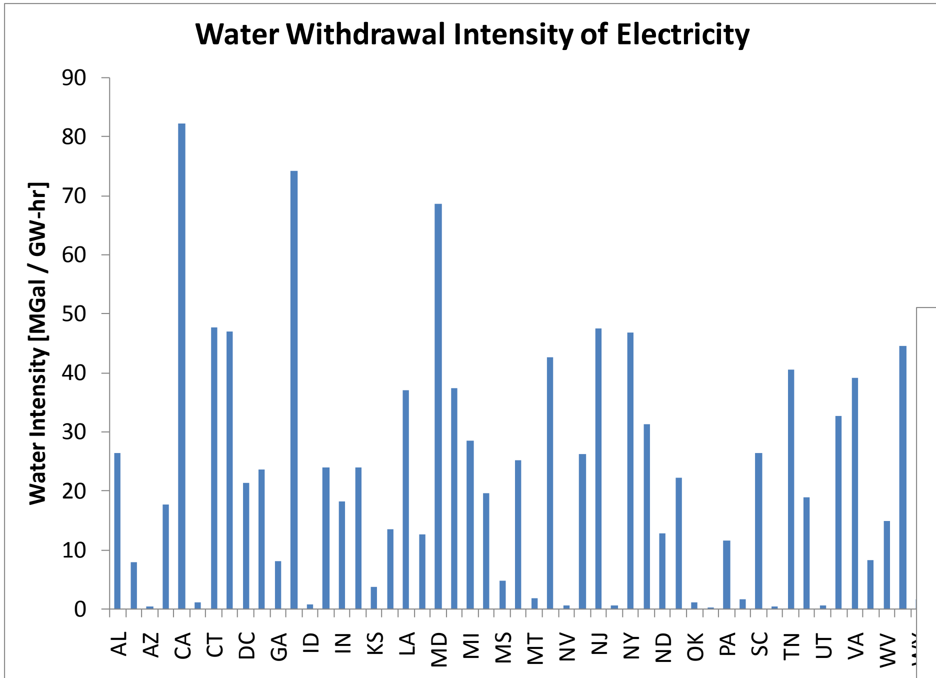
- NREL
  - HyDRA, MSM Coordination
- Sandia
  - MSM Interface, Water Model

Partners

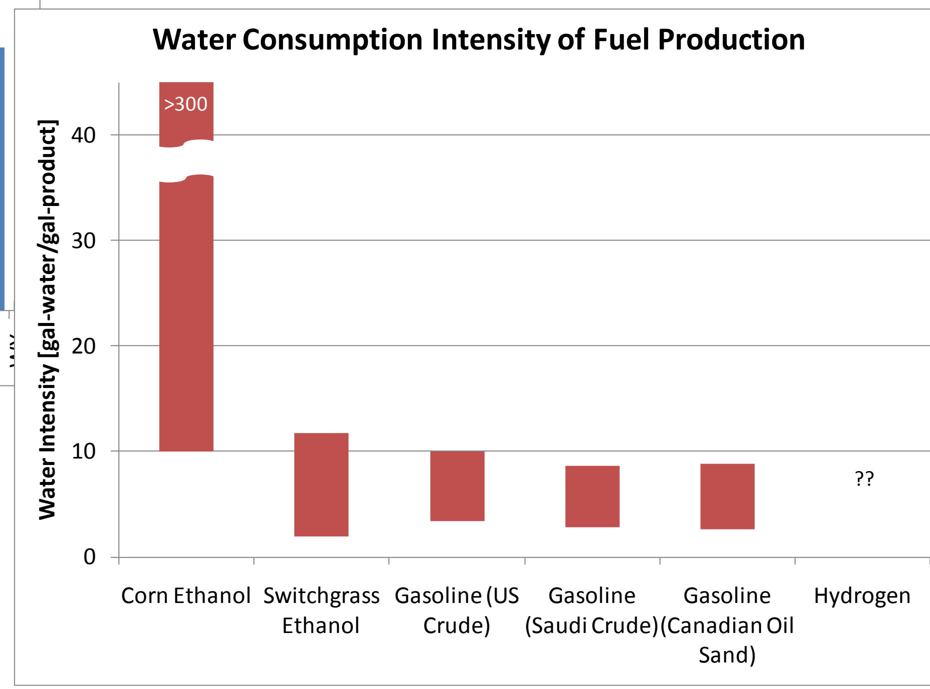
1. As of April 8, 2010, Final Report is undergoing Peer Review.

2. New emphasis on Flow Charts for 2010

Relevance: feedstock - the energy-water nexus



- Water use for electricity varies by a factor of 100 from region to region.
- Electricity production accounts for almost half of all water withdrawals.



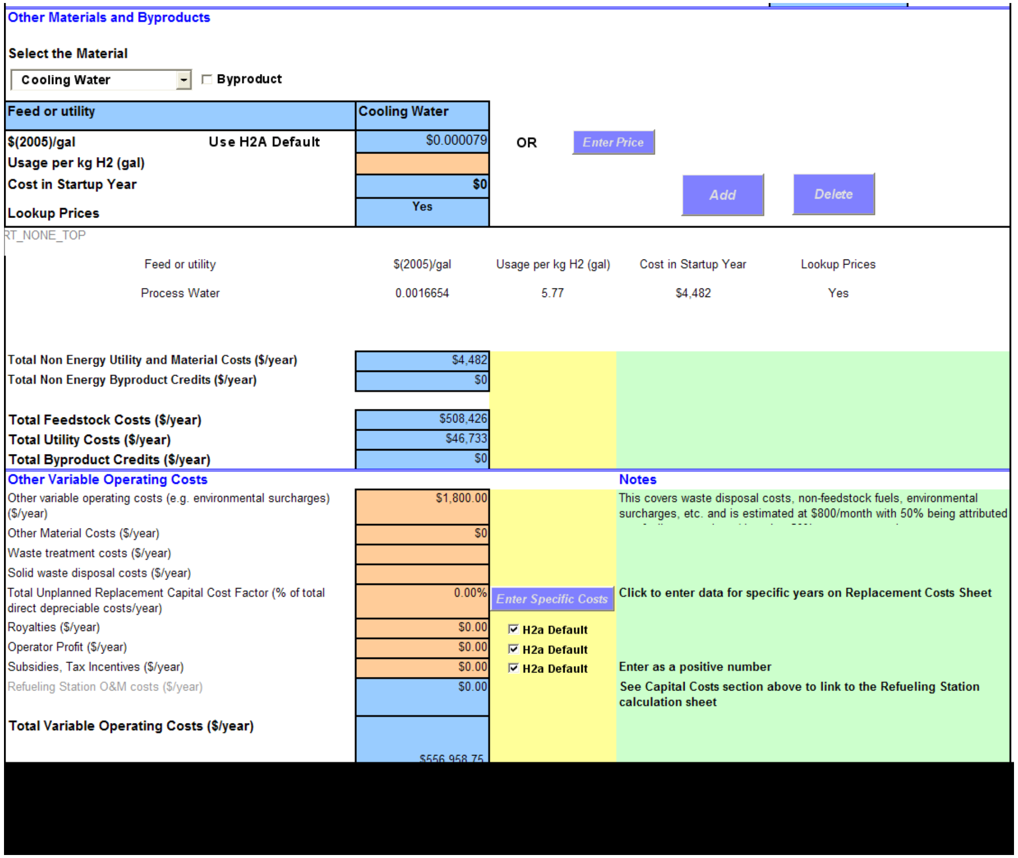
- Water use for liquid fuels varies by feedstock and process
- How does hydrogen compare?

Objectives

- Quantify the *impact of water* on a future hydrogen economy
  - Economic impact of water prices on hydrogen production
  - Regional impact of hydrogen production on regional water resources
- Production Barrier D: Feedstock Issues
  - Energy-Water Nexus
- Systems Analysis Barrier A: Future Market Behavior
  - Timing and magnitude of H_2-Water stresses
- Systems Analysis Barrier E: Unplanned Analyses

Approach: H2A/MSM Integration

- Process water
  - Vendor information
- Cooling load
  - Calculate from energy balance
- Electricity demand
  - Direct from H2A spreadsheet
- Feedstock/fuel
  - Direct from H2A spreadsheet

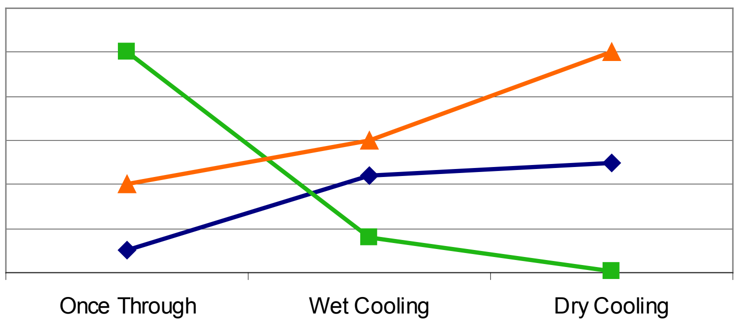


DOE Hydrogen Program, 2008

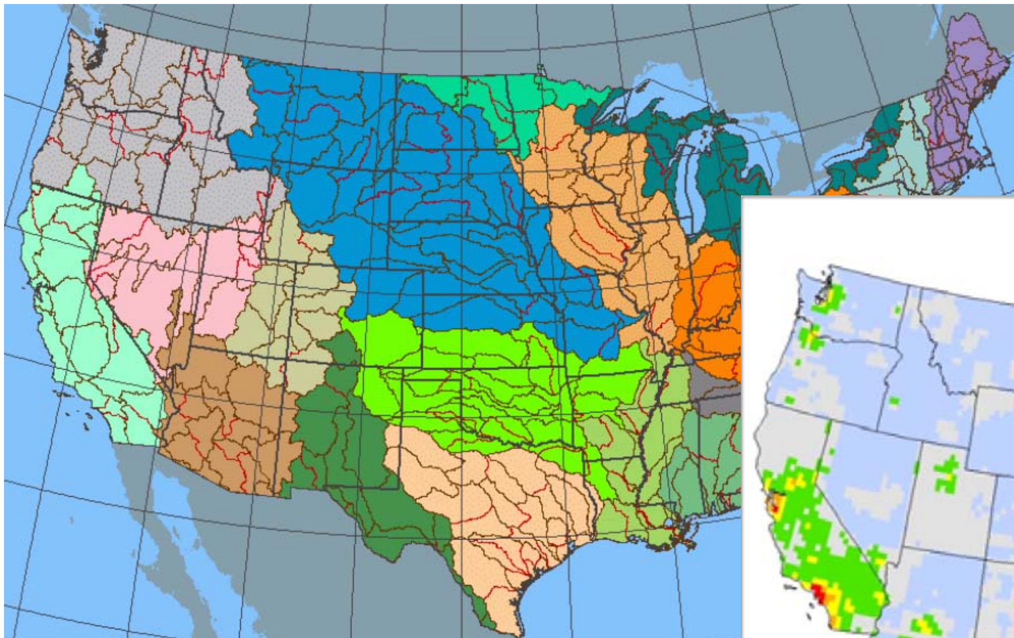
Approach: Economic optimization

- Different water treatment and cooling technologies have different capital vs. O+M (water and electricity purchase) tradeoffs.
- Find the plant-gate water price cutoffs that mark the transition between increasingly water-conserving technologies.
- Perform sensitivity analysis to:
  - plant gate water quality
  - electricity price

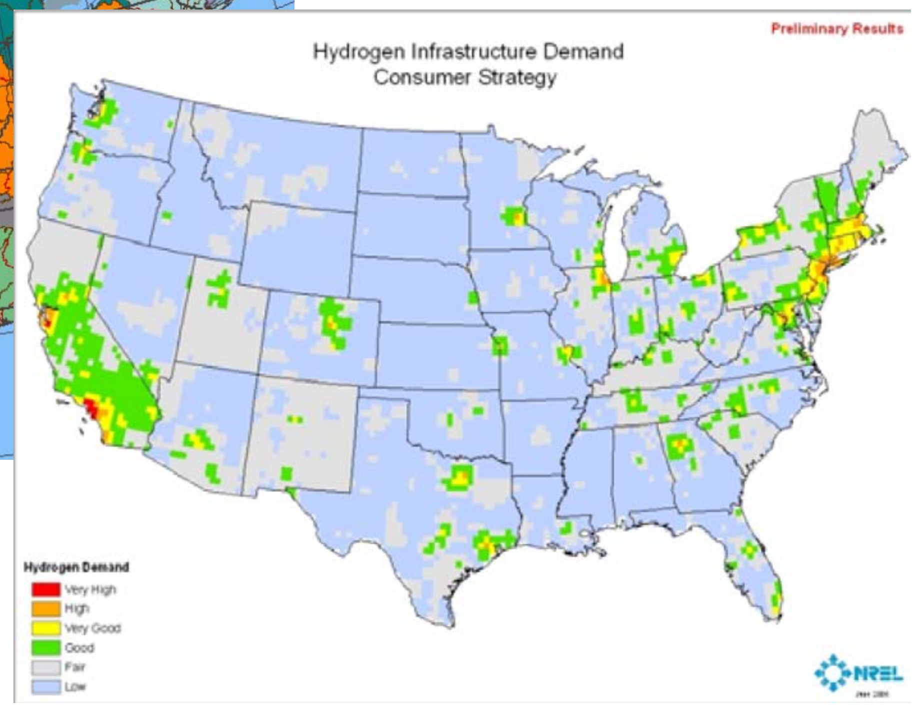
Tradeoffs for cooling technologies



Approach: regional watersheds and demand



Dept. of Interior 2009



NREL, 2008

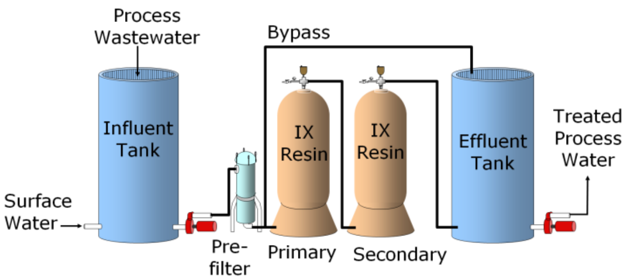
Accomplishments: Technology Analysis

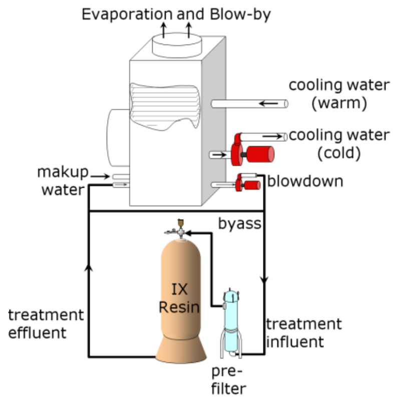
Central SMR Water Treatment and Cooling Options: 379,387 kg hydrogen per day, no CCS					
Cooling Method		Tower	Tower	Dry	Dry
Cooling Water Treatment		Ion Exchange	none	n/a	n/a
Process Water Treatment		Ion Exchange	Reverse Osmosis	Ion Exchange	Reverse Osmosis
Zero Discharge?		Yes	No	Yes	No
Water Resource (TDS, ppm)		Surface (800)	Surface (800)	Surface (800)	Surface (800)
Water Withdrawal	gpm	1202	2235	441	706
Water Discharge	gpm	0	1033	0	265
Power Draw	kW	1460	1146	3093	3227
Capital Cost	$	117,100,000	5,066,000	63,4245,000	14,100,000
Fixed O+M	$/yr	582,000	567,000	314,000	327,000
Treatment Variable O+M	$/kg-H2	0.84	0.03	0.38	0.01

Forecourt Electrolysis Water Treatment and Cooling Options: 1500 kg hydrogen per day					
Cooling Method		Cooling Tower	Cooling Tower	Dry Cooling	Dry Cooling
Cooling Water Treatment		none	none	none	none
Process Water Treatment		Ion Exchange	Reverse Osmosis	Ion Exchange	Reverse Osmosis
Zero Discharge?		No	No	Yes	No
Water Resource (TDS, ppm)		Municipal (400)	Municipal (400)	Municipal (400)	Municipal (400)
Water Withdrawal	gpm	8.0	8.8	2.1	2.9
Water Discharge	gpm	0.9	1.74	0	0.84
Power Draw	kW	7.0	8.6	18.8	20.4
Capital Cost	$	162,000	58,000	328,000	224,000
Fixed O+M	$/yr	22,000	22,000	111,000	111,000
Treatment Variable O+M	$/kg-H2	0.22	0.02	0.21	0.01

Accomplishments: System Economic Analysis

Treatment Systems Analyzed			
	Cooling Technology	Water Treatment Technology	Water Discharge
A	Cooling Tower	Ion Exchange	Zero
B	Cooling Tower	Reverse Osmosis	Minimal
C	Cooling Tower	Ion Exchange	Conventional
D	Cooling Tower	Reverse Osmosis	Conventional
E	Air Cooling	Ion Exchange	Zero
F	Air Cooling	Reverse Osmosis	Minimal
G	Air Cooling	Ion Exchange	Conventional
H	Air Cooling	Reverse Osmosis	Conventional





Assumptions

- H2A Current Central SMR Default Values
  - 28-May-08 Version
  - Non-water capital, O+M, Tax, etc.
  - *Electricity Price*

Variables

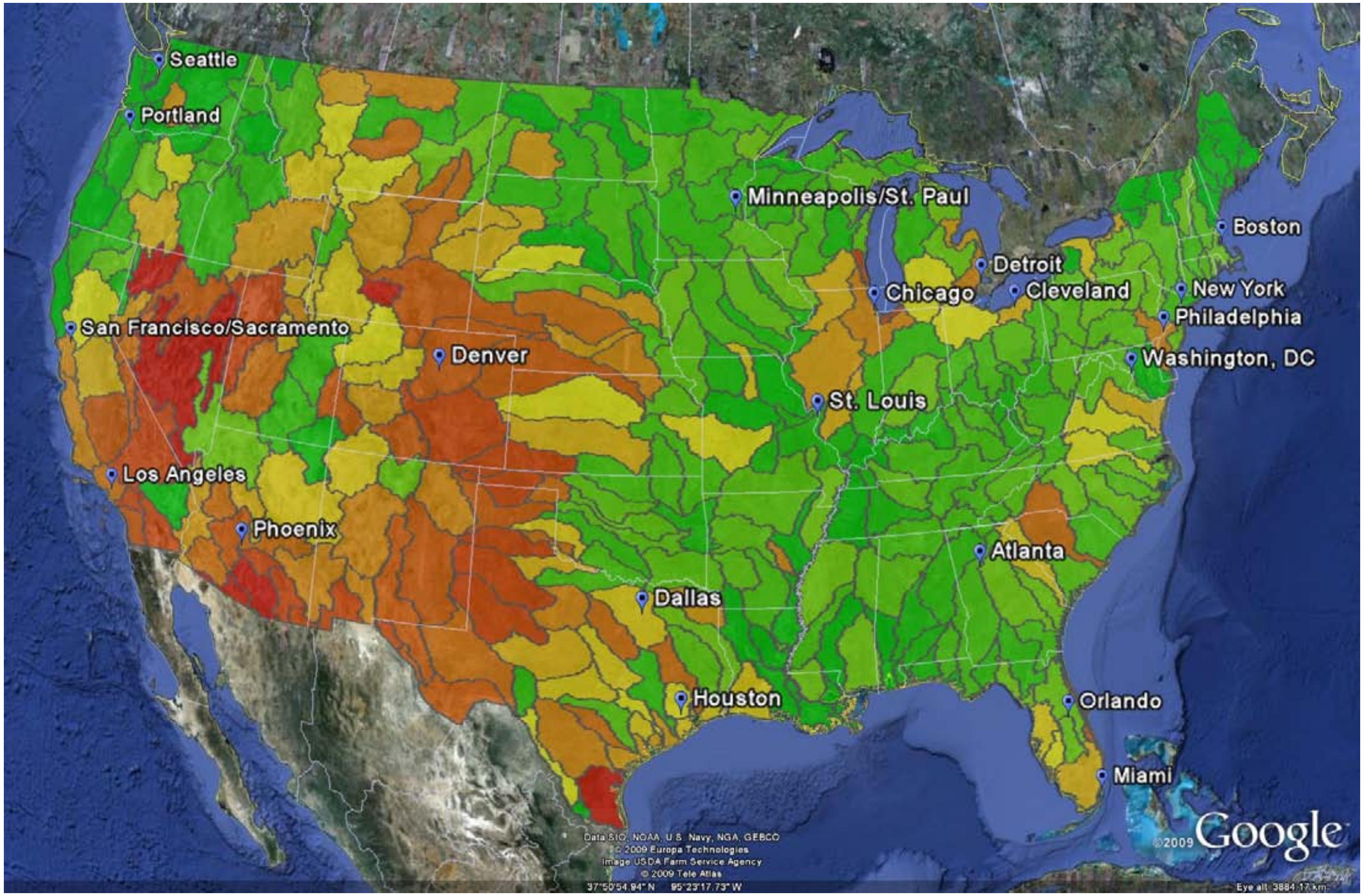
- Water
  - Withdrawal amount and price
  - Discharge amount and price (implemented through “byproduct”)
- Treatment and Cooling Costs
  - Capital, Fixed and Variable O+M
- Treatment and Cooling Energy Use

Accomplishments: H2A Analysis (Central SMR)[1]

		Water Purchase Price [$/gal]					
		$0.0001	$0.001	$0.01	$0.10	$1.00	
Water Discharge Price [$/gal]	$0.0001	1.356993	1.362263	1.414953	1.941862	7.21095	Cooling Tower, Reverse Osmosis
	$0.001	1.35815	1.363419	1.41611	1.943019	7.212107	
	$0.01	1.369715	1.374985	1.427675	1.954584	7.223672	
	$0.10	1.48537	1.490639	1.54333	2.070238	7.339326	
	$1.00	2.641911	2.64718	2.699871	3.22678	8.495868	
	$0.0001	1.955287	1.956871	1.97271	2.131106	3.715065	Dry Cooling, Deionization Zero Discharge
	$0.001	1.955287	1.956871	1.97271	2.131106	3.715065	
	$0.01	1.955287	1.956871	1.97271	2.131106	3.715065	
	$0.10	1.955287	1.956871	1.97271	2.131106	3.715065	
	$1.00	1.955287	1.956871	1.97271	2.131106	3.715065	
	$0.0001	1.384619	1.387154	1.412512	1.666089	4.20186	Dry Cooling, Reverse Osmosis Treatment
	$0.001	1.38557	1.388106	1.413464	1.667041	4.202812	
	$0.01	1.395089	1.397624	1.422982	1.676559	4.21233	
	$0.10	1.49027	1.492806	1.518163	1.77174	4.307511	
	$1.00	2.442082	2.444618	2.469975	2.723552	5.259323	

1. Cells with a red background represent the lowest cost hydrogen under a specific purchase/discharge price regime

Accomplishments: Watershed-Level Water Stress Analysis



Water Stress Definition:

Total withdrawals within the watershed divided by the total influx (precipitation and river flow) into the watershed.

Upstream withdrawals are accounted for.

Green: Stress < 1

Yellow: Stress ~ 1

Red: Stress >1

Water Stress > 1 is not necessarily unsustainable because ~3/4 of water may be returned to surface flows

Accomplishments: Hydrogen Roll-Out Regional Analysis[1]

Metro Area	Water Stress	Water used for Hydrogen (MGal/day)	% of supply used for hydrogen	% increase in industrial water usage
New York	0.04	15.6	0.02%	16.1%
Los Angeles	2.01	12.3	1.14%	7.1%
Chicago	1.17	8.9	0.08%	0.8%
Washington	0.09	7.5	0.02%	6.8%
San Francisco/ Sacramento	0.18	5.1	0.01%	2.8%
Philadelphia	0.81	3.9	0.09%	1.6%
Boston	0.05	8.4	0.05%	20.6%
Detroit	1.13	5.9	0.16%	0.8%
Dallas	0.34	5.7	0.08%	14.0%
Houston	0.27	5.4	0.08%	2.5%
Atlanta	0.09	4.9	0.01%	1.5%
Miami	0.44	1.4	0.02%	5.5%
Seattle	0.00	1.8	0.00%	2.2%
Phoenix	4.88	2.8	0.44%	44.0%
Minneapolis/St. Paul	0.06	2.8	0.01%	6.4%
Cleveland	0.33	2.3	0.04%	1.5%
Denver	8.75	2.5	0.66%	5.0%
St. Louis	0.01	2.4	0.00%	6.2%
Portland	0.01	1.6	0.00%	0.3%
Orlando	0.15	1.0	0.01%	1.0%

Water Supply Definition:

Total influx (precipitation and river flow) into the watershed(s) that feed the metro area.

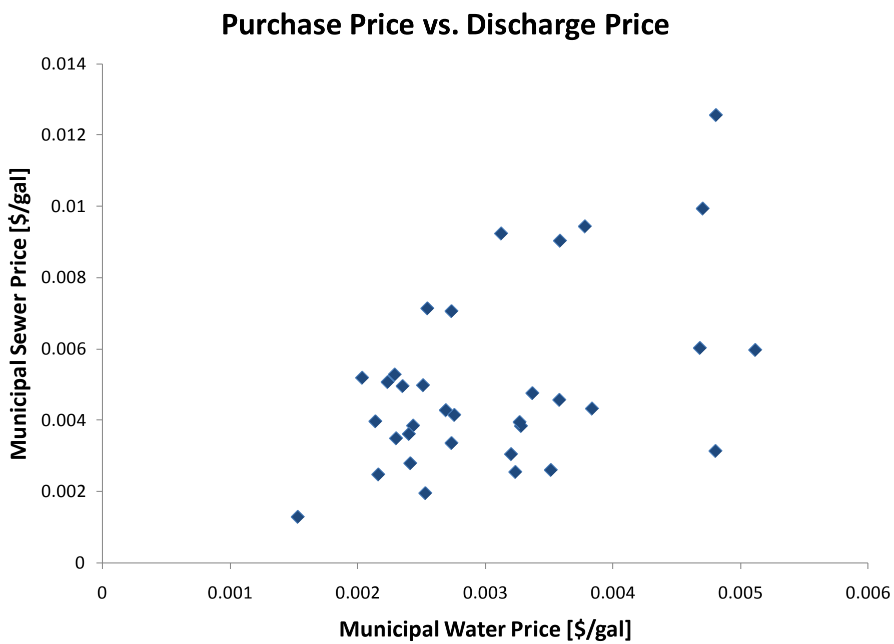
Upstream withdrawals are accounted for.

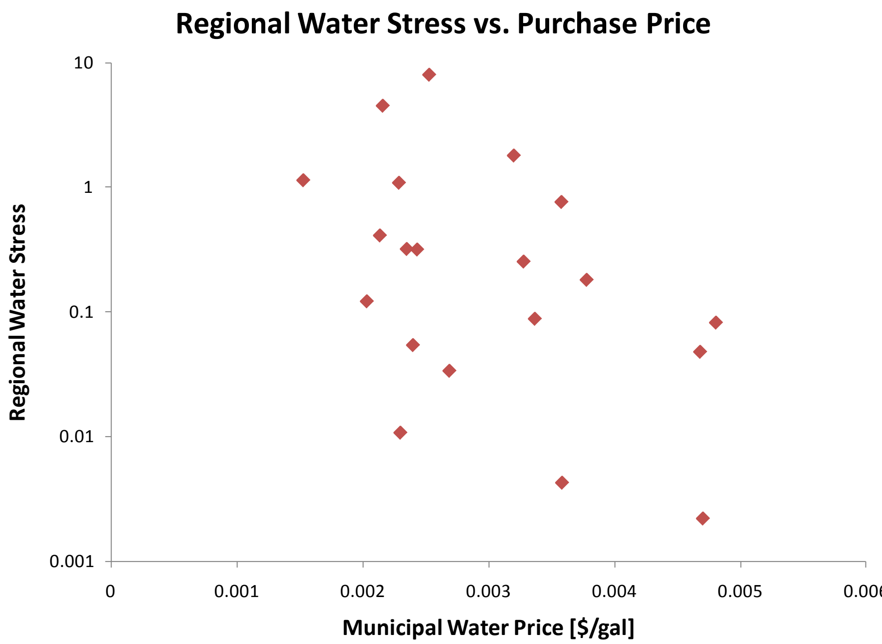
Industrial Usage:

Total withdrawals by industrial users within the metro area watershed(s).

1. These numbers are based on Green et. al (2008), and assume forecourt SMR hydrogen production with ~8 gal/kg-H_2 withdrawal.

Accomplishments: Regional Water Economic Analysis





Lessons Learned:

Water discharge is likely to be more expensive than water withdrawal.

Water price is not positively correlated with water stress.

Collaborations

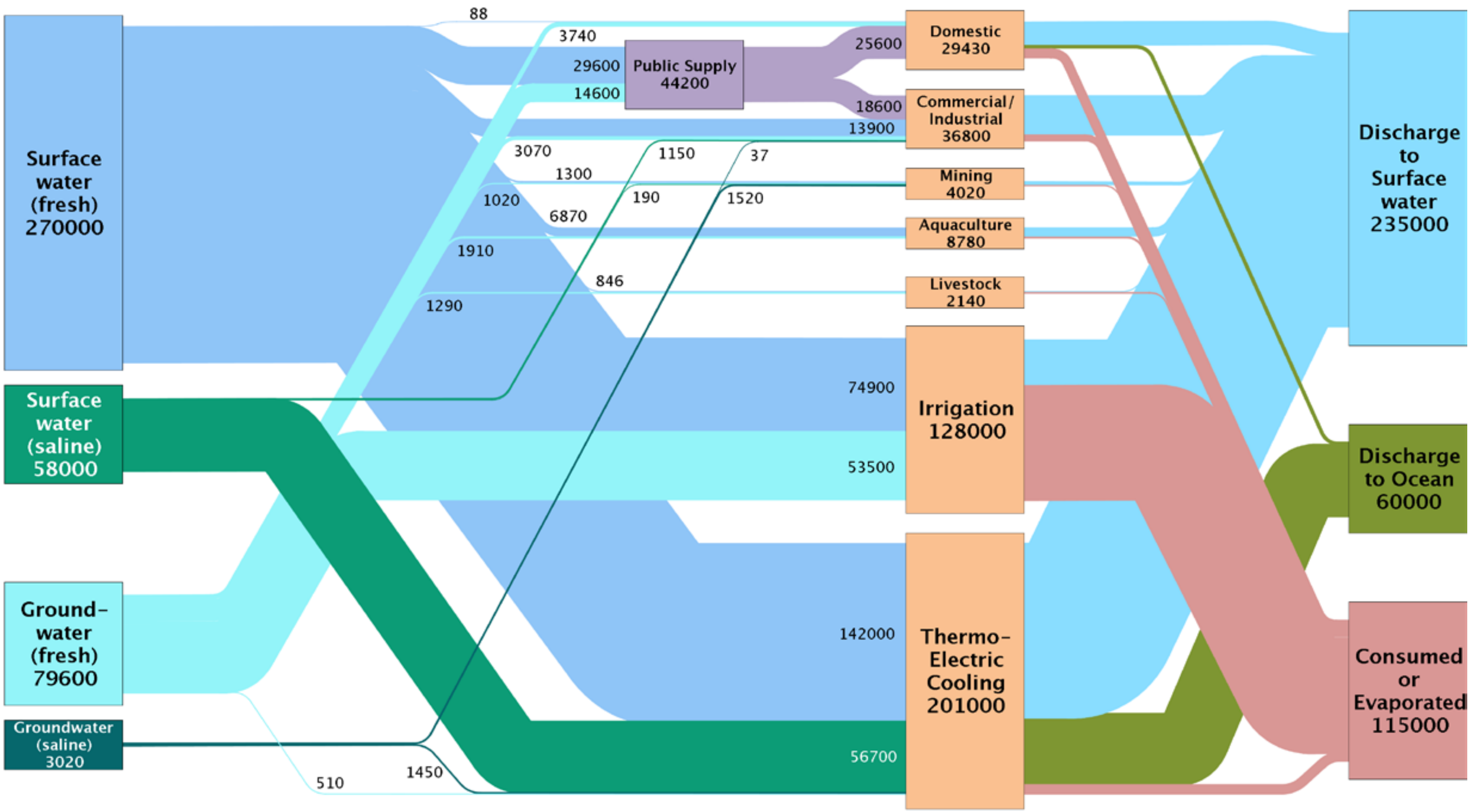
- Energy-Water nexus group
    - NETL
    - Sandia
- NREL
    - MSM team
    - RPM/HyDRA

Future Work

- Integrate with MSM, HyDRA
- Energy and Water Flow Charts
  - International
  - National
  - Regional
  - Sectoral

Future Work

Estimated U.S. Water Flow in 2005: 410000 Million Gallons/Day



LLNL 2009. Data is based on USGS Circular 1344, October 2009. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Commercial water use is not reported by USGS, it is estimated to be the fraction of municipal supply that is not delivered to residences and includes municipal water use and conveyance losses. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Discharge and Consumption fractions are estimated from 1995 data and will be updated soon.

Summary

- Water price does not currently "behave" according to traditional supply/demand relationships.
- The price of water and water treatment equipment is unlikely to affect the price of hydrogen by more than 5% (far less than \$0.10/kg-H_2).
- Water is abundant at the national level, but...
  - *Permitting/allocation will be problematic in regions with high water stress*
  - *Rapid expansion of "industrial" water use in some regions requires caution.*
- Energy-water nexus affects all future fuels
  - Hydrogen, Biofuels, EV/PHEV, GTL, CTL…