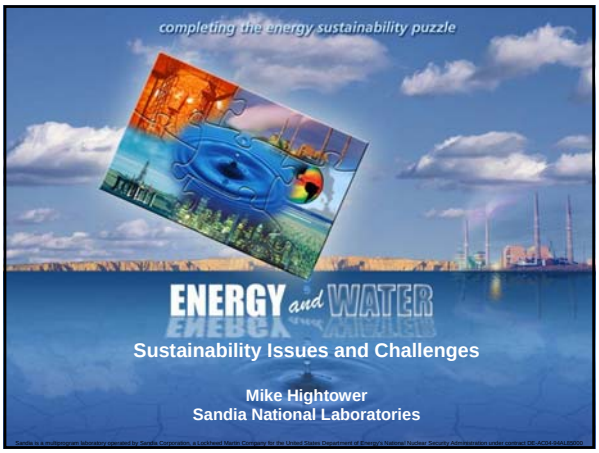


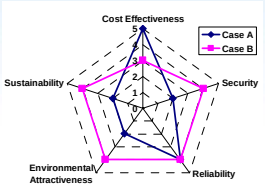
What is Sustainability? A Systems-level Concept

Fuel Cell Vehicle : $CH_4 + 2H_2O = 4H_2 + CO_2$

Sustainability Requires Multi-faceted System Considerations

Greenhouse Earth Example

- CO2 Emissions
  - 25% Electricity and heat
  - 18% Land use change
  - 14% Agriculture
  - 14% Transportation
  - 13% Industry and processes
  - 9% Other combustion
  - 4% Landfills and sewage
- Water vapor (i.e clouds) is the largest green house gas



Optimization Example

Sustainability is Balancing Resource Demands with Availability

Energy and Water are … Interdependent

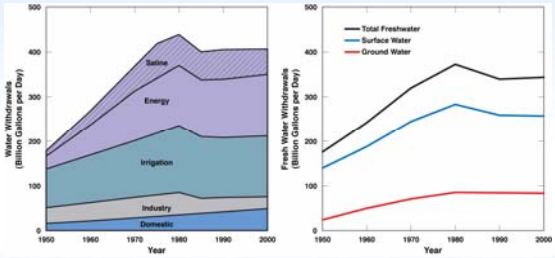
Water for Energy and ***Energy for Water***

Energy and power production require water:
- Thermoelectric cooling
- Hydropower
- Energy minerals extraction/mining
- Fuel Production (fossil fuels, H_2, biofuels)
- Emission control

Water production, processing, distribution, and end-use require energy:
- Pumping
- Conveyance and Transport
- Treatment
- Use conditioning
- Surface and Ground water

ENERGY and WATER

Water Withdrawal Trends by Sector

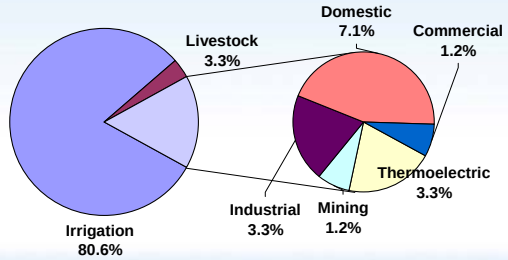


[USGS, 2004]

ENERGY and WATER

Water Consumption by Sector

U.S. Freshwater Consumption, 100 Bgal/day

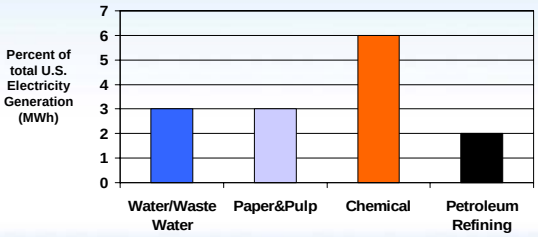


[USGS, 1998]

Energy accounts for 27 percent of non-agricultural fresh water consumption

ENERGY and WATER

As Much Energy is Used for Water/Wastewater as for Other Major Sectors of the U.S. Economy



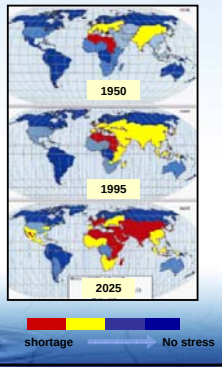
[DOE, 2004]

US Energy Sustainability

Over half the world's population will face severe water shortage in the next 50 years.

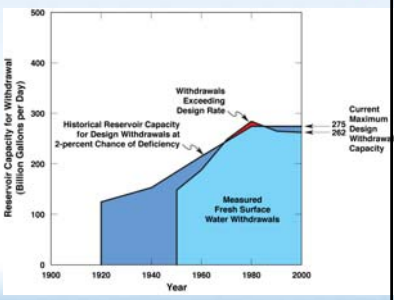
- In 1990, poor water supply and sanitation was the 2nd leading cause of death and disability worldwide.
- Over 50% of world's major rivers are dry or heavily polluted.
- By 2025, 20% more fresh water will be needed for irrigation and 40% more for cities to maintain current per capita water levels.
- NONTRADITIONAL water resources will need to be used to address these shortages.

"Water promises to be to the 21st century what oil was to the 20th century: the precious commodity that determines the wealth of nations."
Fortune Magazine, May 15, 2000



Current Trends in Fresh Surface Water Availability

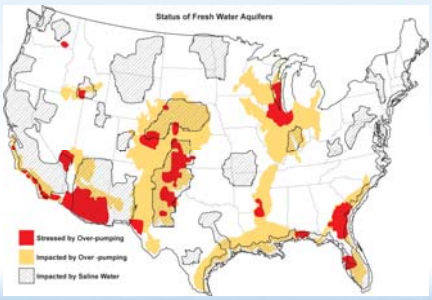
- Large surface water capacity increases from major dam construction
- Few dams built since 1980
- Climate issues and dam removal will reduce future surface water availability



ENERGY and WATER

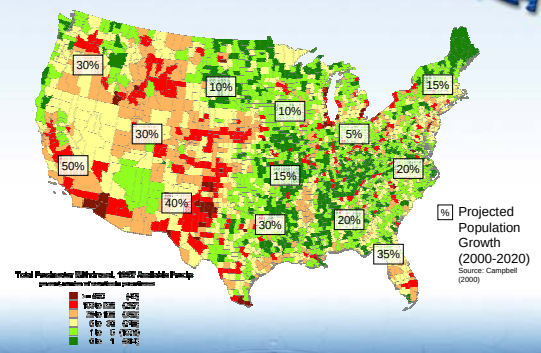
Current Trends in Fresh Ground Water Availability

- Many major aquifers have reduced yields from past over pumping
- Significant ground water quality issues also



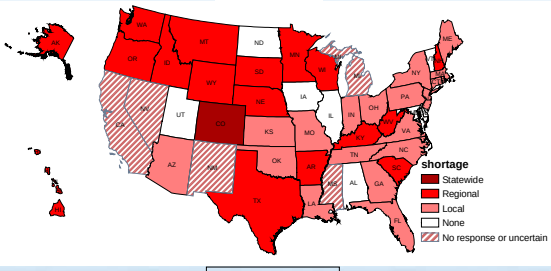
ENERGY and WATER

Water challenges are nationwide



ENERGY and WATER

Most State Water Managers Expect Shortages Over The Next Decade Under Average Conditions



Source: GAO 2003

ENERGY and WATER

2003 Heat Wave Impact on French Electric Power Generation

- Loss of 7 to 15% of nuclear generation capacity for 5 weeks
- Loss of 20% of hydro generation capacity
- Large-scale load shedding and shut off transmission to Italy
- Sharp increase of spot-market prices: 1000 to 1500 $ / MWh for most critical days

Normal conditions in August

Bort-les-Orgues Réservoir

August 27, 2003

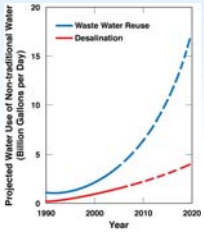
ENERGY and WATER

Water Availability Is Already Impacting New Energy Development

- Recent energy facility permitting issues due to water availability

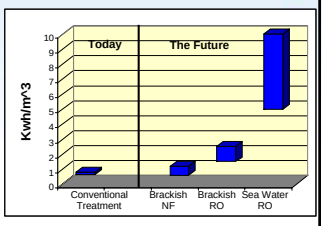
ENERGY and WATER

Growing Use of Non-traditional Water Resources



(From EPA 2004, Water Reuse 2007, Mickley 2003)

Power Requirements For Treating

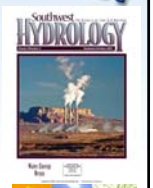


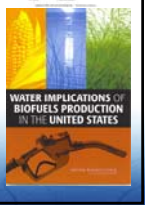
(Einfeld 2007)

- Desal growing at 10% per year, waste water reuse at 15% per year
- Reuse not accounted for in USGS assessments
- Non-traditional water use is energy intensive

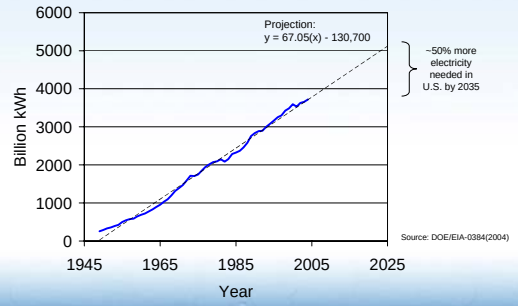
Emerging Interest in Energy and Water Issues and Challenges

- State and national water and energy groups
  - 30 invited presentations in FY07 and 08 on energy and water challenges
  - Research and regulatory groups considering future energy and water needs
- Increased media interest
  - NATURE, ECONOMIST
  - Technical magazines
- NSF/NRC interest in energy debate and interdependencies research
- Growing international concerns and challenges
  - Europe, Australia, Asia, Canada



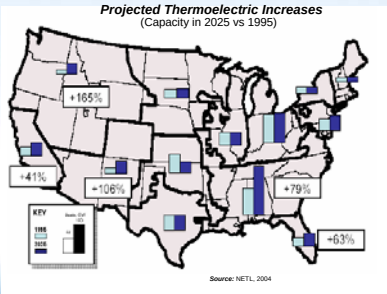


The U.S. will need 50% more electricity by 2035



Growth in Thermoelectric Power Generation

- Most growth in water stressed regions
- Most new plants expected to use evaporative cooling

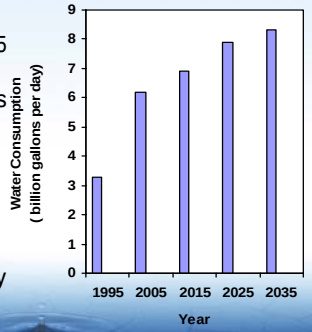


Water Use and Consumption for Electric Power Generation

Plant-type	Cooling Process	Water Use Intensity (gal/MWh$_e$)		
		Steam Condensing		Other Uses
		Withdrawal	Consumption	Consumption
Fossil/ biomass steam turbine	Open-loop	20,000–50,000	~200-300	~30
	Closed-loop	300–600	300–480	
Nuclear steam turbine	Open-loop	25,000–60,000	~400	~30
	Closed-loop	500–1,100	400–720	
Natural Gas Combined-Cycle	Open-loop	7,500–20,000	100	7–10
	Closed-loop	230	180	
Integrated Gasification Combined-Cycle	Closed-loop	200	180	150
Carbon sequestration for fossil energy generation	~25% increase in water withdrawal and consumption			
Geothermal Steam	Closed-loop	2000	1350	50
Concentrating Solar	Closed-loop	750	740	10
Wind and Solar Photovoltaic	N/A	0	0	1-2

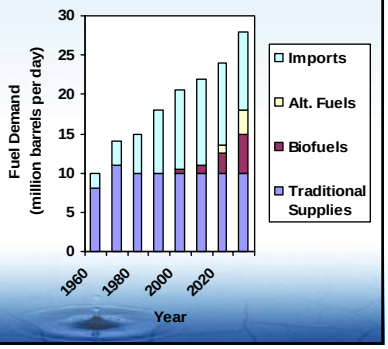
Water Demands for Future Electric Power Development

- Water demands could almost triple from 1995 consumption for projected mix of plants and cooling
- Carbon emission requirements will increase water consumption by an additional 1-2 Bgal/day



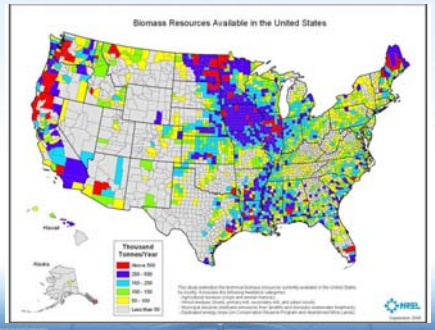
The U.S. will need 33% more Transportation Fuels by 2030

- Fuel use will increase despite gains in efficiency
- Current initiatives for domestic alternatives like oil shale and biofuels
- Major hydrogen use will be post 2030



ENERGY and WATER

Biomass and Water Use Impacts Will be Regional



ENERGY and WATER

Water Demand/Impact of Transportation Fuels

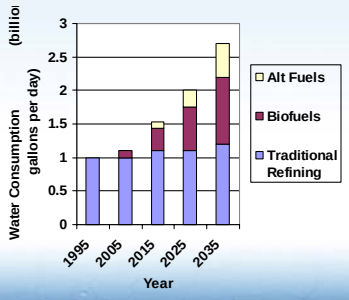
Fuel Type and Process	Relationship to Water Quantity	Relationship to Water Quality	Water Consumption	
			Water consumed per-unit-energy [gal / MMBTU] [1]	Average gal water consumed per gal fuel
Conventional Oil & Gas	Water needed to extract and refine; Water produced from extraction	Produced water generated from extraction; Wastewater generated from processing;		
Oil Refining			7 – 20	~ 1.5
NG extraction/Processing			2 – 3	~ 1.5
Biofuels	Water needed for growing feedstock and for fuel processing;	Wastewater generated from processing; Agricultural irrigation runoff and infiltration contaminated with fertilizer, herbicide, and pesticide compounds		
Grain Ethanol Processing			12 - 160	~ 4
Corn Irrigation for EtOH			2500 - 31600	~ 980*
Biodiesel Processing			4 – 5	~ 1
Soy Irrigation for Biodiesel			13800 – 60000	~ 6500*
Lignocellulosic Ethanol and other synthesized Biomass to Liquid (BTL) fuels	Water for processing; Energy crop impacts on hydrologic flows	Wastewater generated; Water quality benefits of perennial energy crops	24 – 150 [3] (ethanol)	~ 2 - 6 [3]
			14 – 90 [3] (diesel)	~ 2 - 6 [3]
Oil Shale	Water needed to Extract / Refine	Wastewater generated; In-situ impact uncertain; Surface leachate runoff		
- In situ retort			1 – 9 [2]	~ 2 [2]
- Ex situ retort			15 - 40 [2]	~ 3 [2]
Oil Sands	Water needed to Extract / Refine	Wastewater generated; Leachate runoff	20 - 50	~ 4 - 6
Synthetic Fuels	Water needed for synthesis and/or steam reforming of natural gas (NG)	Wastewater generated from coal mining and CTL processing		
- Coal to Liquid (CTL)			35 - 70	~ 4.5- 9.0
- Hydrogen RE Electrolysis			20 – 24 [2]	~ 3 [2]
- Hydrogen (NG Reforming)			40 – 50 [2]	~ 7 [2]

[1] Ranges of water use per unit energy largely based on data taken from the Energy-Water Report to Congress (DOE, 2007)
* Conservative estimates of water use intensity for irrigated feedstock production based on per-acre crop water demand and fuel yield
[2] Estimates based on unvalidated projections for commercial processing; [3] Assuming rain-fed biomass feedstock production

ENERGY and WATER

Emerging Water Demands for Alternative Fuels Development

- Irrigation of even small percentage of biofuel acreage will increase water consumption by an additional 5 Bgal/day



ENERGY and WATER

Energy Water Roadmap Overview

- Three regional needs assessment workshops: Nov 2005 through mid-January 2006
  - Kansas City, Baltimore, Salt Lake City
  - Almost 350 participants from 40 states involved
  - Focus on emerging user and stakeholder problems and challenges and science and technology role in effective solutions – captured high-level issues, needs, and directions
- Broad spectrum of regional, state, and local participation and input
  - Representatives from energy companies, electric utilities, water utilities, water managers, economic development groups, energy regulators, environmental groups, tribal nations, other water-use sectors
- Gaps and Technical Innovations Workshops to capture science and technology research and development priorities
  - Almost 150 researchers and technology developers involved

ENERGY and WATER

Summary of Major National Needs and Issues Identified in Regional Workshops

Better resources planning and management
- Integrated regional energy and water resource planning and decision support tools
- Infrastructure and regulatory and policy changes for improved energy/water efficiency
- Improved water supply and demand characterization, monitoring, and modeling

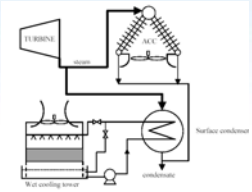
Improved water and energy use efficiency
- Improved water efficiency in thermoelectric power generation
- Improved biofuels/biomass water use efficiency
- Reduced water intensity for emerging energy resources

Development of alternative water resources and supplies
- Oil and gas produced water treatment for use
- Energy efficiency and assessment of impaired water treatment and use

www.sandia.gov/energy-water

ENERGY and WATER

Research Program for Electric Power Sector



Hybrid Wet-Dry Cooling System

- Improve dry and hybrid cooling system performance
- Improve ecological performance of intake structures for hydro and once-through cooling
- Improve materials and cooling approaches compatible with use of degraded water
- Electric grid infrastructure upgrades to improve low water use renewable technology integration

Research Program for Alternative Fuels Sector

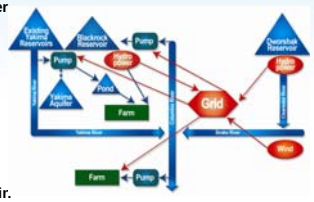
- Reduce water use for cooling in biofuels and alternative fuels production
- Reduce water use in processing
- Develop low fresh water use technologies such as algal biodiesel
- Assess non-traditional water use for fuels applications
- Assess hydrologic impacts of large cellulose biofuels scale up and oil shale

Research and Development Program for Integrated Resources Management

- **Accelerate water resources forecasting and management**
- **Evaluate impacts of climate variability and improve hydrological forecasting**
- **Improve common decision support tools**
- **Develop system analysis approaches for: Co-location of energy and water facilities, improved national transmission capabilities to support renewables, distributed generation of biofuels**

Columbia/Snake/Yakima River Basin Integrated Planning Pilot Results

- Looked at combining wind and hydro to meet agricultural energy and water demands
- Included BPA, BoR, Corps, power and ag sectors
- Showed huge benefits of hydro/wind integration and planning
  - $100M/yr savings in irrigation pumping costs
  - Reduction in water rationing for irrigation
  - End use can accommodate intermittency
- Climate forecasting and better streamflow data has huge value ir. improving system operations
- Additional hydro needed to provide system storage and capacitance



ENERGY and WATER

Summary of Energy and Water Considerations for the Far West

- Have hit 'peak fresh water'
  - Moving toward era of water management vs. fresh water development to meet future water needs
- Non-traditional water resources - waste water and saline water are potential new water resources
- Climate change in the Far West could reduce water availability and increase energy demands
- Long-range planning and integration of energy and water infrastructure is needed to conserve energy and fresh water and improve sustainability

ENERGY and WATER