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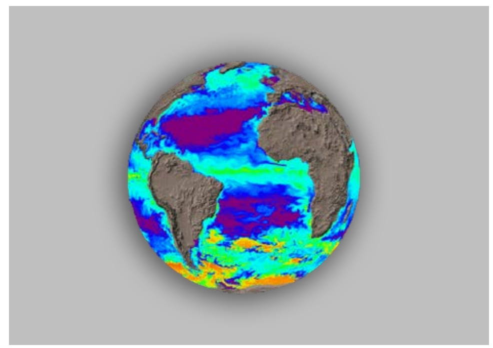


Natural Resource Sustainability Considerations in Future Energy Development

Mike Hightower
Sandia National Laboratories – Albuquerque, NM USA
Woodrow Wilson Canada Institute – May 3, 2013

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Energy's Impacts on Natural Resources are Often not System Focused

Hydrogen Supply for Fuel Cells:

$$CH_4 + 2H_2O + heat \rightarrow 4H_2 + CO_2$$

Energy Generation and Delivery – Becoming More and More Complex

Resource Dependencies

- Air shed
- Fuel
- Land
- Water
- Capital

Infrastructure Dependencies

- Transmission and distribution
- Fuel/resource needs and transportation
- Water
- Telecommunications
- Government

Natural Resource Issues in Energy Development

- As nations try to balance the demands and availability of water resources to support human health and economic development in the coming decades, it is clear that the water footprint, like the carbon footprint, will become an increasingly critical factor to consider in addressing reliable and sustainable energy development worldwide.

Hightower, ASME Mechanical Engineering July 2011

- "Water and watersheds is where the climate change rubber meets the road"

Bernie Zak Sr. Scientist, Sandia, April 2013

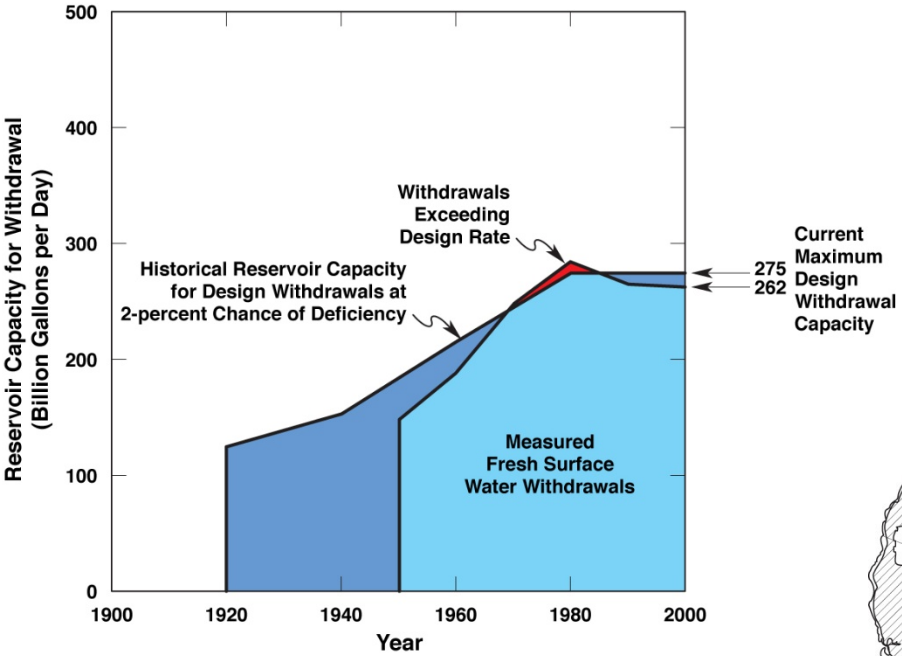
- There is no doubt that applying integrated resource-management principles could help provide the framework needed to meet future global energy and water needs in a more systematic and sustainable way.

Hightower, Nature, March 2008

Energy-Water Interdependency Examples and General Issues and Trends

- Energy sector accounts for 8% of worldwide fresh water withdrawals
  - 40% of withdrawals in developed countries – 40% US, 64% Canada
- Energy sector contributes to water quality issues
  - Traditional oil and gas produced water; biofuels, oil sands, oil shale, gas shale, and coal bed methane ; water drainage from coal and uranium mines; power plant emissions and power plant impacts on surface water quality
- Water and waste water sector energy use is expected to grow substantially
  - Growth in water treatment, new disinfection technologies, increased water transportation needs, etc. will increase energy intensity
  - Water and waste water sector energy use could grow from 3% to 10% of total U.S. energy demand by 2030
  - 30% of India’s energy use is for ground water pumping

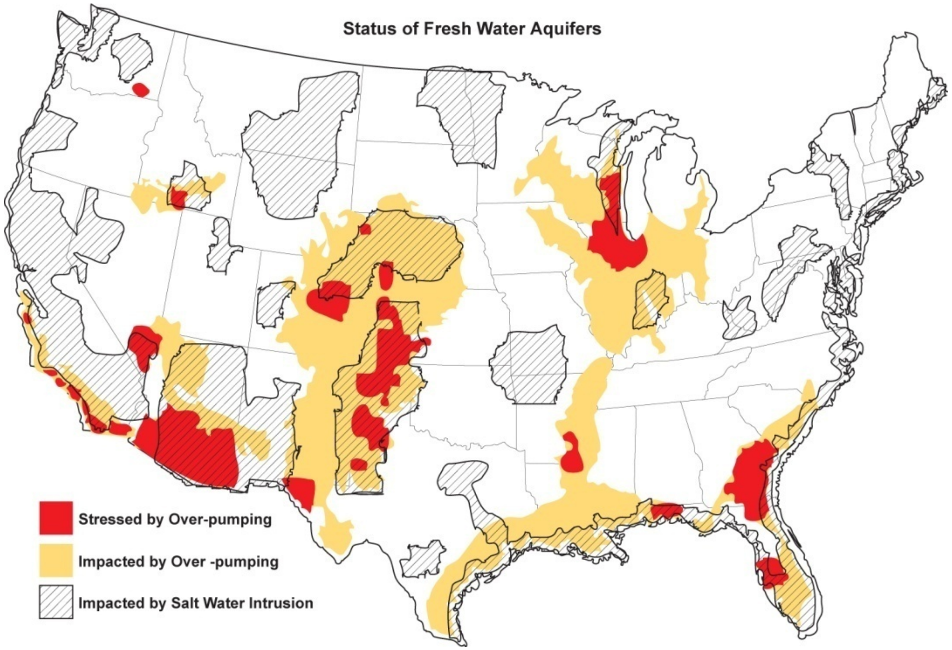
Growing Limitations on Fresh Surface and Ground Water Availability in the U.S.



(Based on USGS WSP-2250 1984 and Alley 2007)

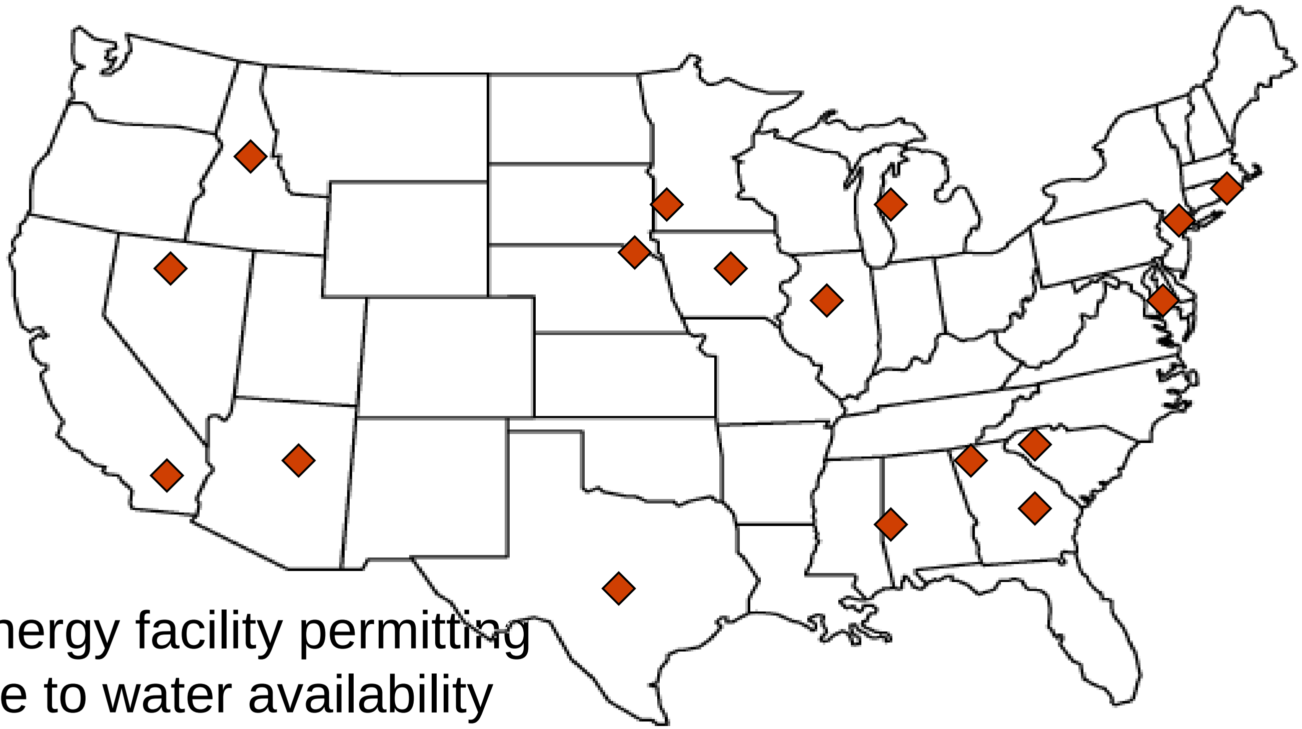
- Little increase in surface water storage capacity since 1980
- Concerns over climate impacts on surface water supplies

- Many major ground water aquifers seeing reductions in water quality and yield



(Shannon 2007)

Water Limitations Have Already Impacted Energy Development in the U.S.



◆ Recent energy facility permitting issues due to water availability

Climate Impacts on the Energy Sector

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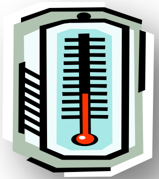
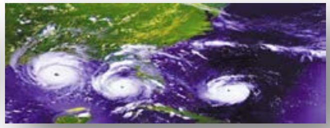


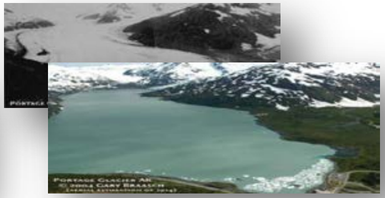
Temp Increase

Droughts & Floods



More Frequent Bigger Storm Events

Rising Sea Level



Snow Cover Shrinking

Impacts on…

Resource Production

- Competition for access to water
- Increased production interruptions
- Early season delays
- Pad damage
- Precipitation impact on biofuels

Transport & Terminals

- Damage to shore-line facilities
- Increased shipment interruptions
- Increased ice-load variation
- Reduced barge and other shipping seasons

Refining

- Reduced access to water
- Increased flooding
- Loss of peak cooling capacity

Pipelines

- Thaw subsidence and frost jacking
- Increased setbacks
- Loss of capacity in existing pipelines

Electricity Generation

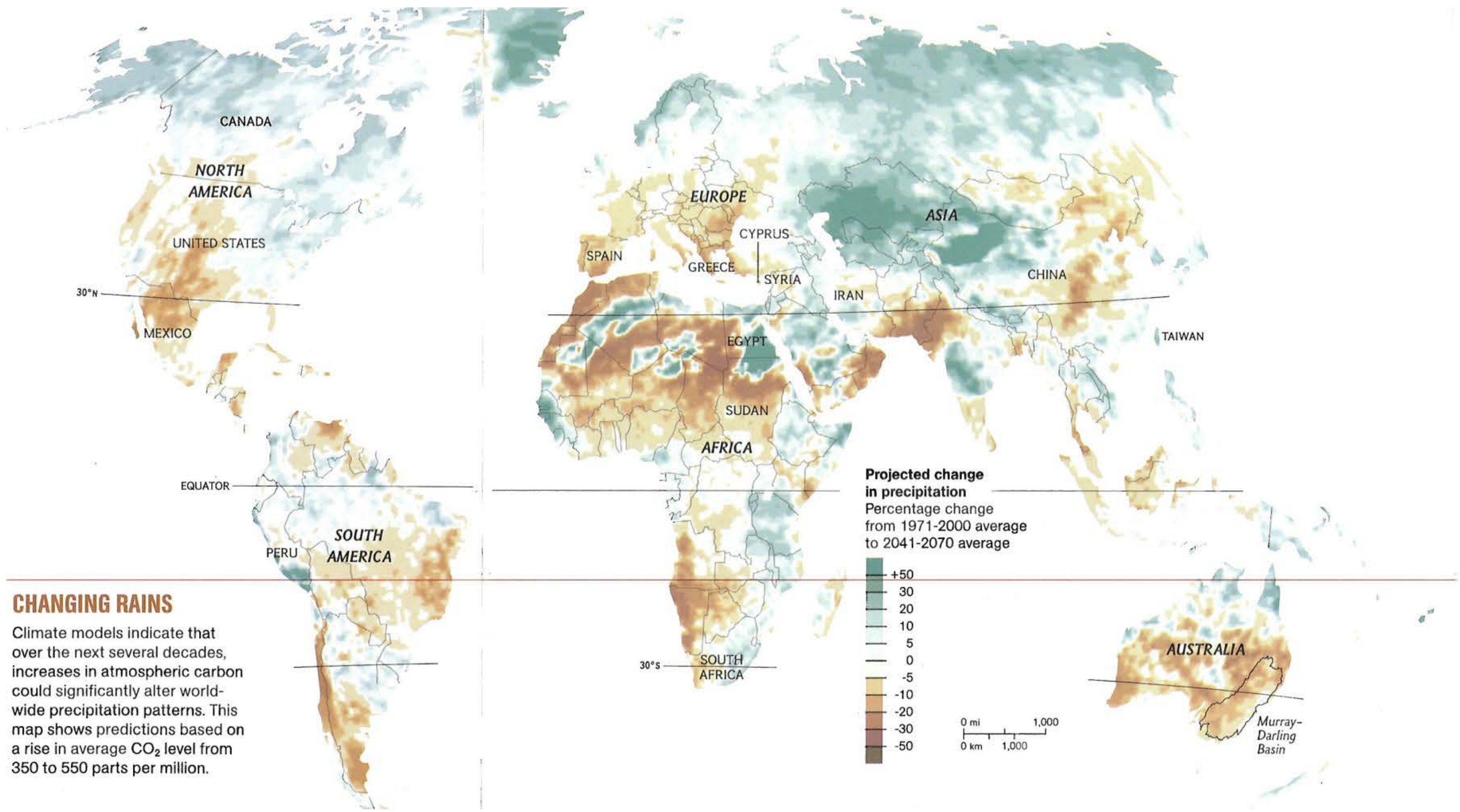
- Competition for access to water
- Increased peak demand and loss of peak cooling capacity
- Increased flooding
- Increased wind and solar variability

Transmission

- Damage to lines from storm events, temperature increases, and floods
- Increased congestion

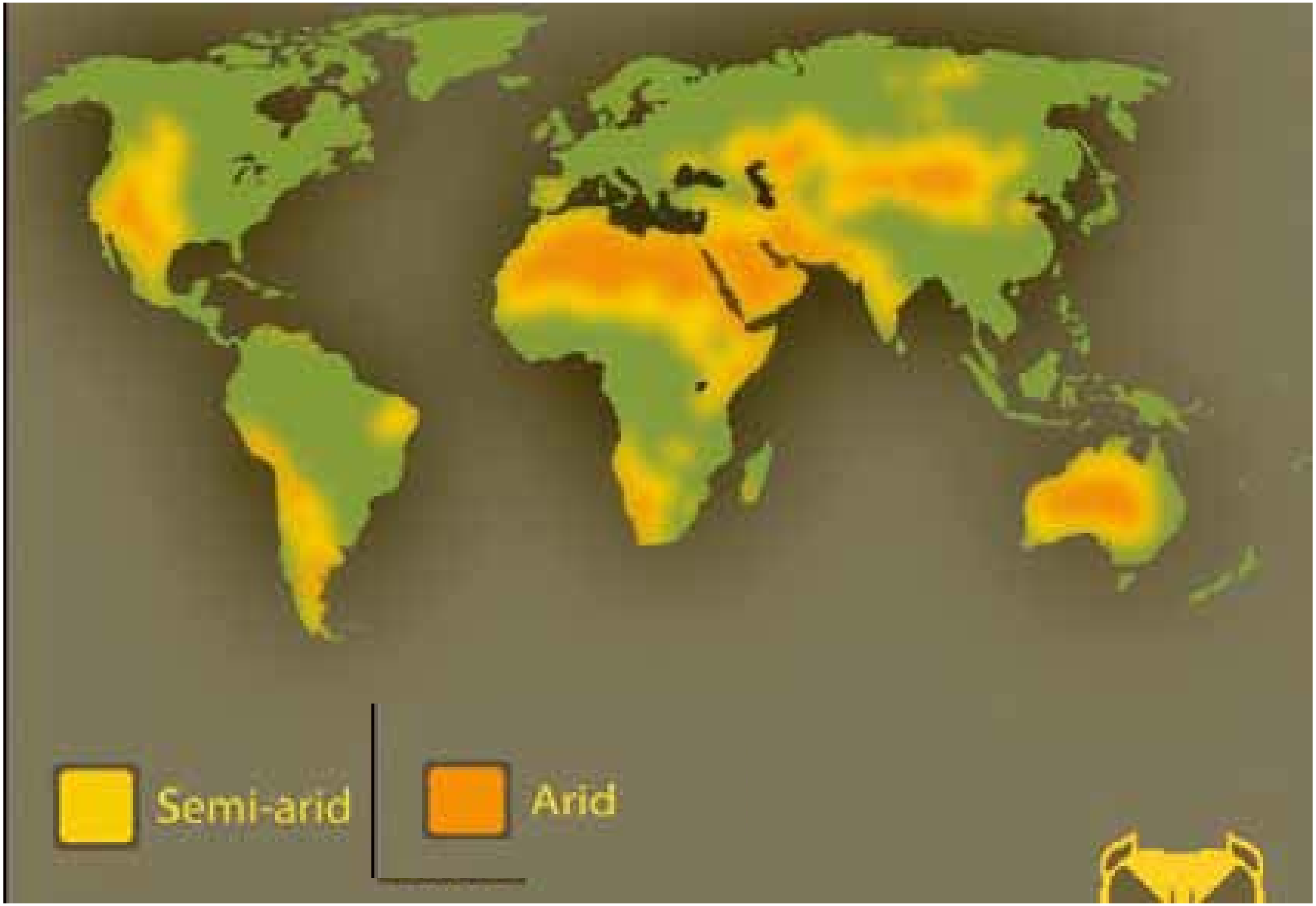
From Jan Dell, CH2MHill

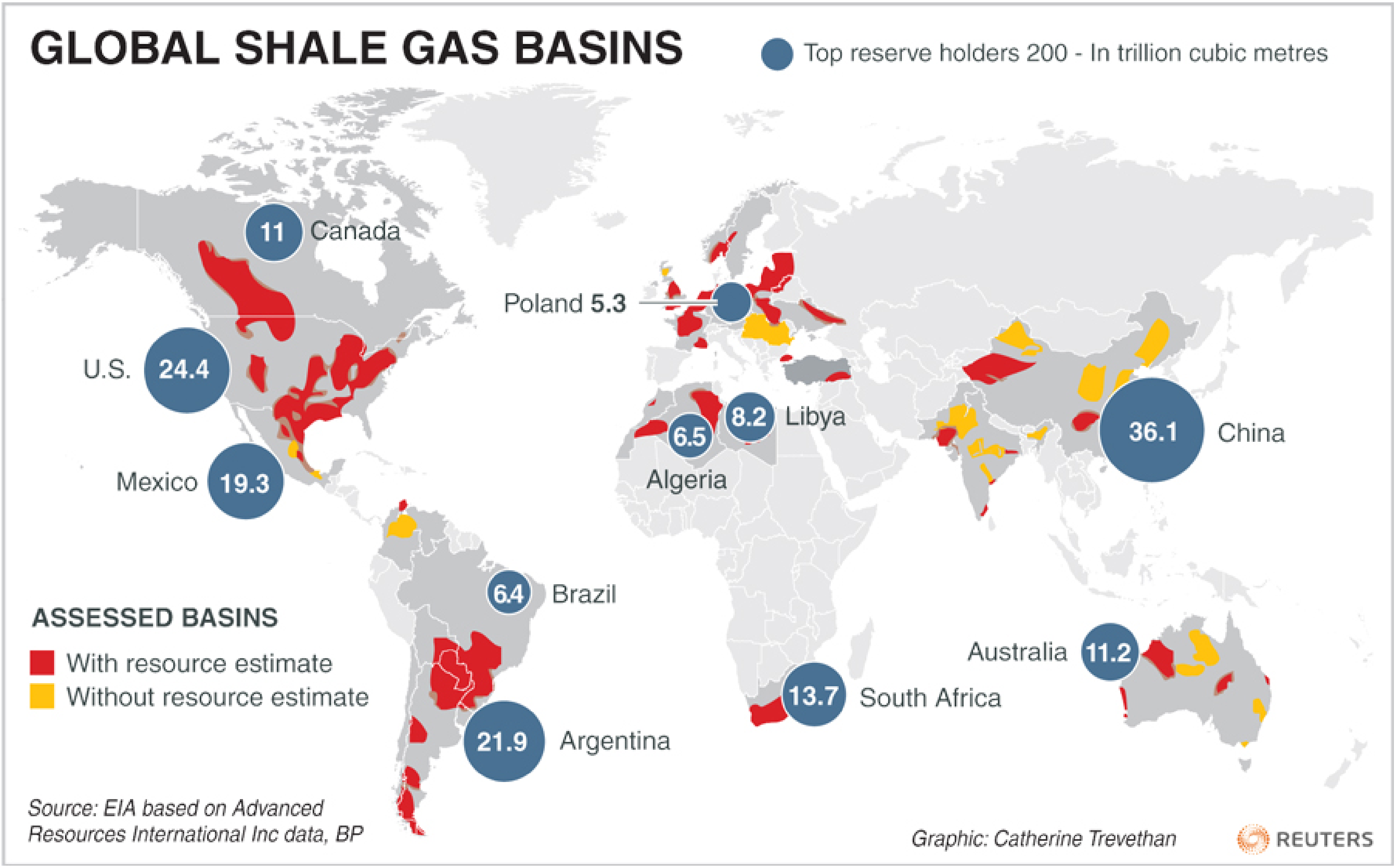
Climate Changes will Impact Precipitation and Regional Water Supplies and Resources



Nat. Geo. April 2009 from IPCC

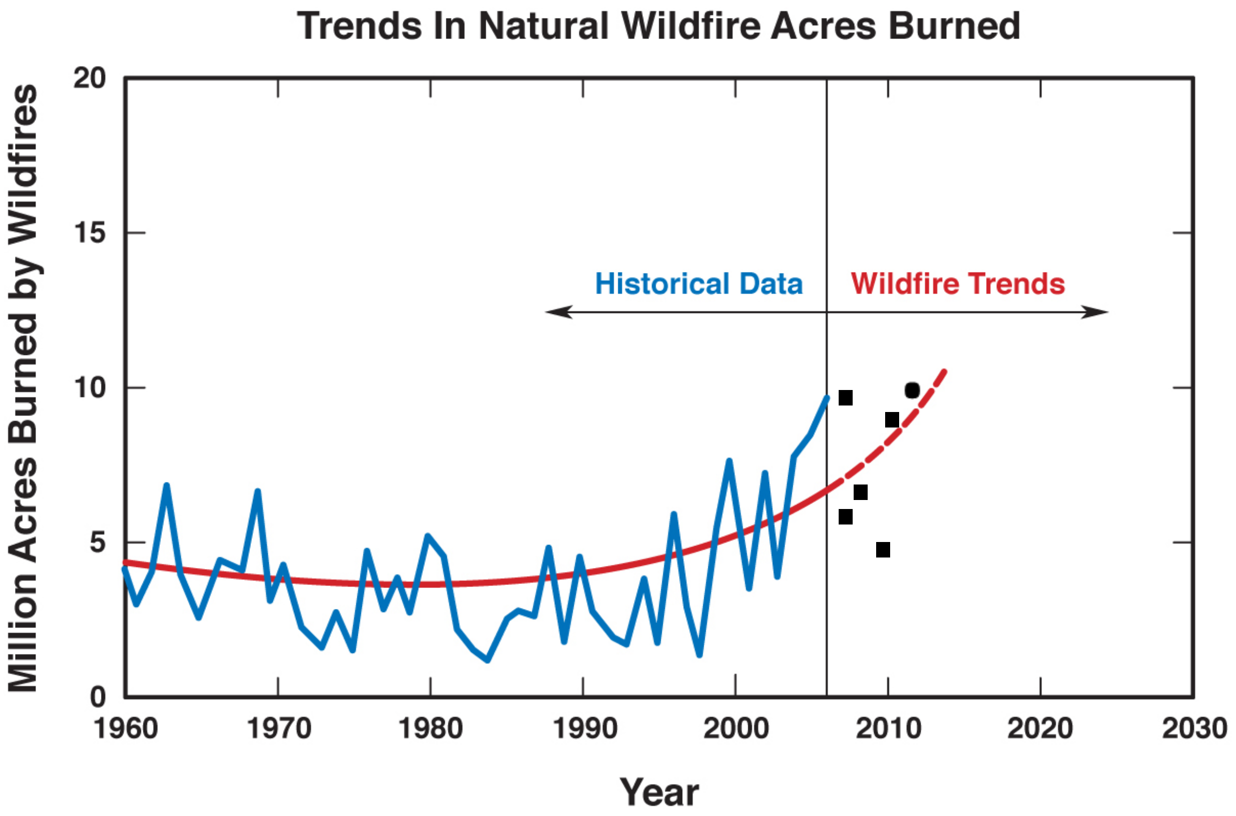
Many Energy Development Regions are where Climate Change Water Issues could be Significant




GLOBAL SHALE GAS BASINS
Top reserve holders 200 - In trillion cubic metres
11 Canada
Poland 5.3
U.S. 24.4
Mexico 19.3
8.2 Libya
6.5
Algeria
36.1 China
6.4 Brazil
ASSESSED BASINS
With resource estimate
Without resource estimate
Australia 11.2
13.7 South Africa
21.9 Argentina
Source: EIA based on Advanced Resources International Inc data, BP
Graphic: Catherine Trevethan
REUTERS

Changes in Water Availability are Impacting Watersheds, Ecosystems, and Services

Current trends show that the number, size, and severity of wildland fires in the U.S. has grown significantly over the past four decades



U.S. Oil and Gas Production Estimates

Figure 1. U.S. domestic crude oil production by source, 1990-2040
millions barrels per day

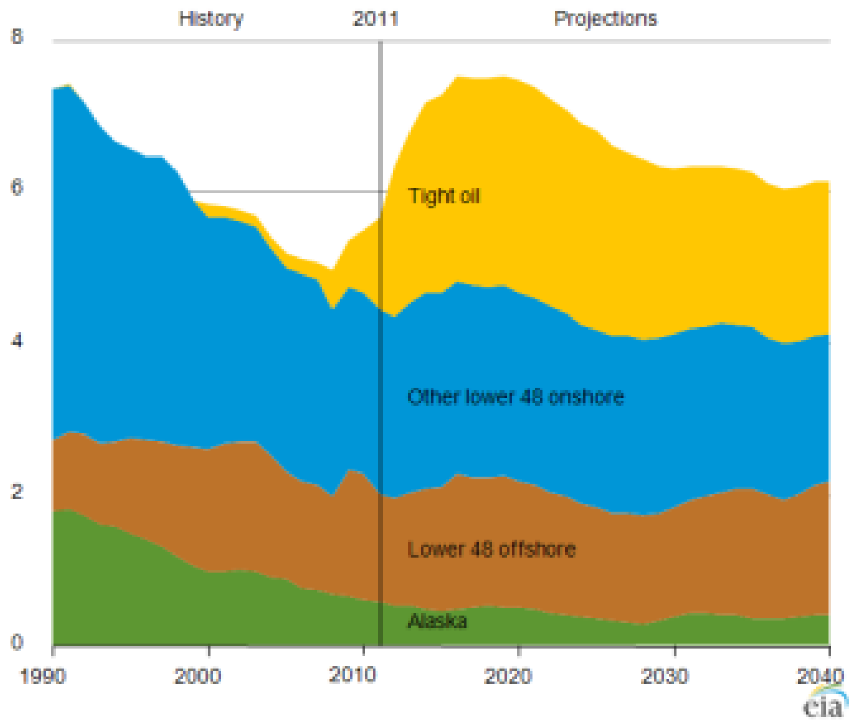
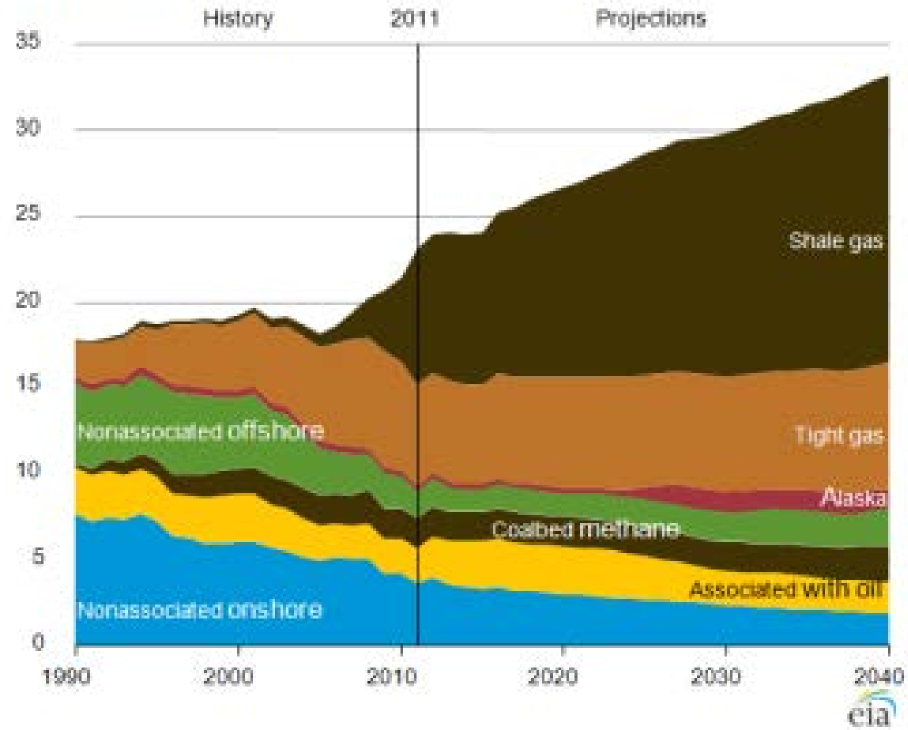
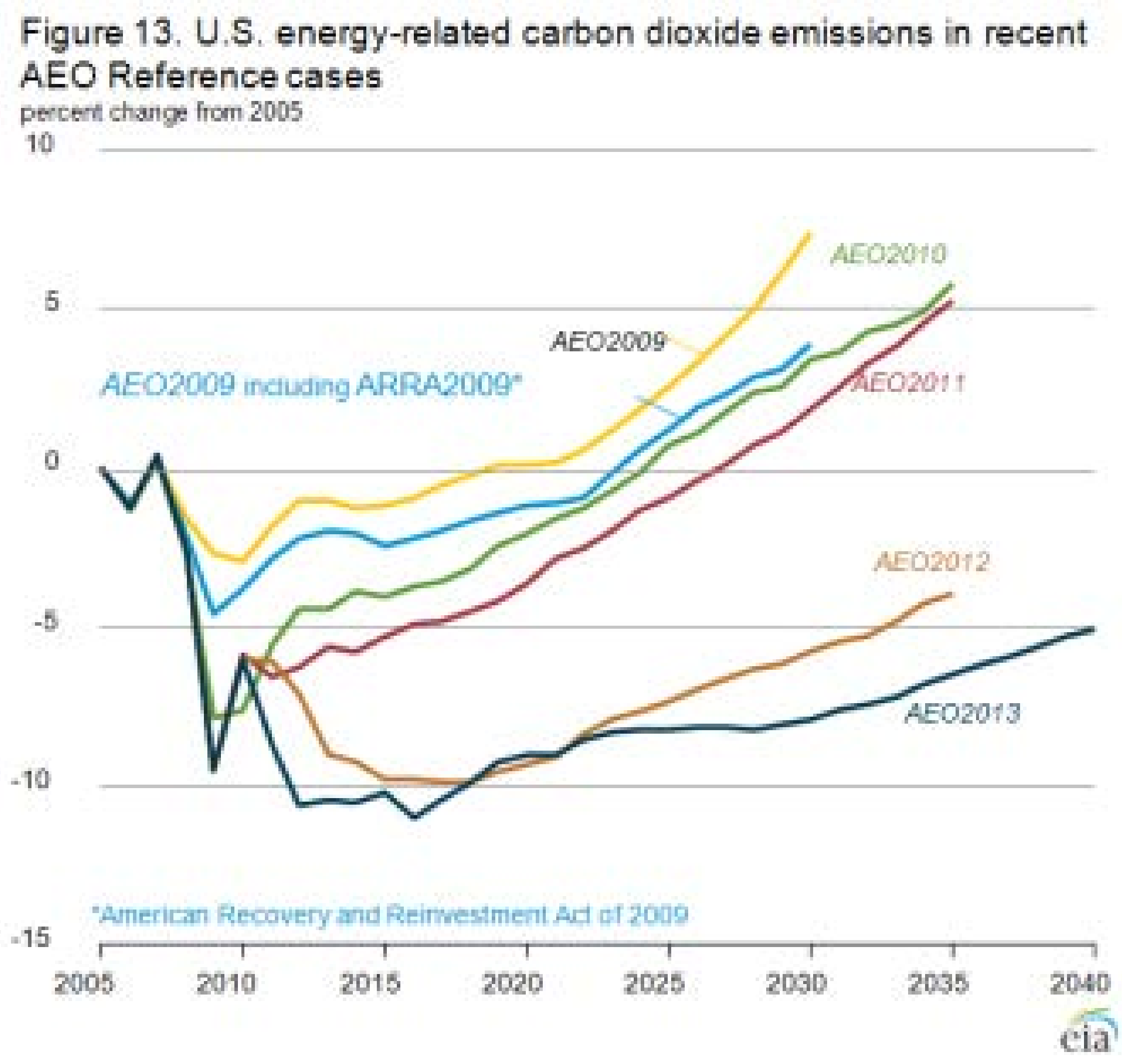


Figure 3. U.S. dry natural gas production by source, 1990-2040
trillion cubic feet



Growth will be with hydraulic fracking and increased water use,
Currently 3-5 million gallons per frack, and 100,000 ppm TDS flowback water

Electric Power Water Consumption and CO_2 Emissions will be reduced with More Natural Gas



Water Use and Consumption for Electric Power Generation Technologies

Plant-type	Cooling Process	Water Use Intensity (l/MWh$_e$)		
		Steam Condensing		Other Uses
		Withdrawal	Consumption	Consumption
Fossil/ biomass steam turbine	Open-loop	80,000–200,000	~800-1200	~120
	Closed-loop	1200–2400	1200–2000	
Nuclear steam turbine	Open-loop	100,000–240,000	~1600	~120
	Closed-loop	2000–4400	1600–2900	
Natural Gas Combined-Cycle	Open-loop	30,000–80,000	400	40
	Closed-loop	900	700	
Integrated Gasification Combined-Cycle	Closed-loop	800	700	600
Carbon sequestration for fossil energy generation	~85% increase in water withdrawal and consumption			
Geothermal Steam	Closed-loop	8000	1000-5000	200
Concentrating Solar	Closed-loop	3000	2900	40
Wind and Solar Photovoltaic	N/A	0	0	10

Water Consumption for Different Transportation Fuel Alternatives

Fuel Type and Process	Relationship to Water Quantity	Relationship to Water Quality	Water Consumption	
			Water consumed per-unit-energy [gal / MMBTU] †	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 ‡§ (ethanol) 14 – 90 ‡§ (diesel)	~ 2 - 6 ‡§ ~ 2 - 6 ‡§
Oil Shale	Water needed to Extract / Refine	Wastewater generated; In-situ impact uncertain; Surface leachate runoff		
- In situ retort			1 – 9 ‡	~ 2 ‡
- Ex situ retort			15 - 40 ‡	~ 3 ‡
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)			
- Coal to Liquid (CTL)		Wastewater generated from coal mining and CTL processing	35 - 70	~ 4.5- 9.0
- Hydrogen RE Electrolysis			20 – 24 ‡	~ 3 ‡
- Hydrogen (NG Reforming)			40 – 50 ‡	~ 7 ‡

† 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
‡ Estimates based on unvalidated projections for commercial processing; § Assuming rain-fed biomass feedstock production

Energy Return on Investment and Water Return on Investment Considerations

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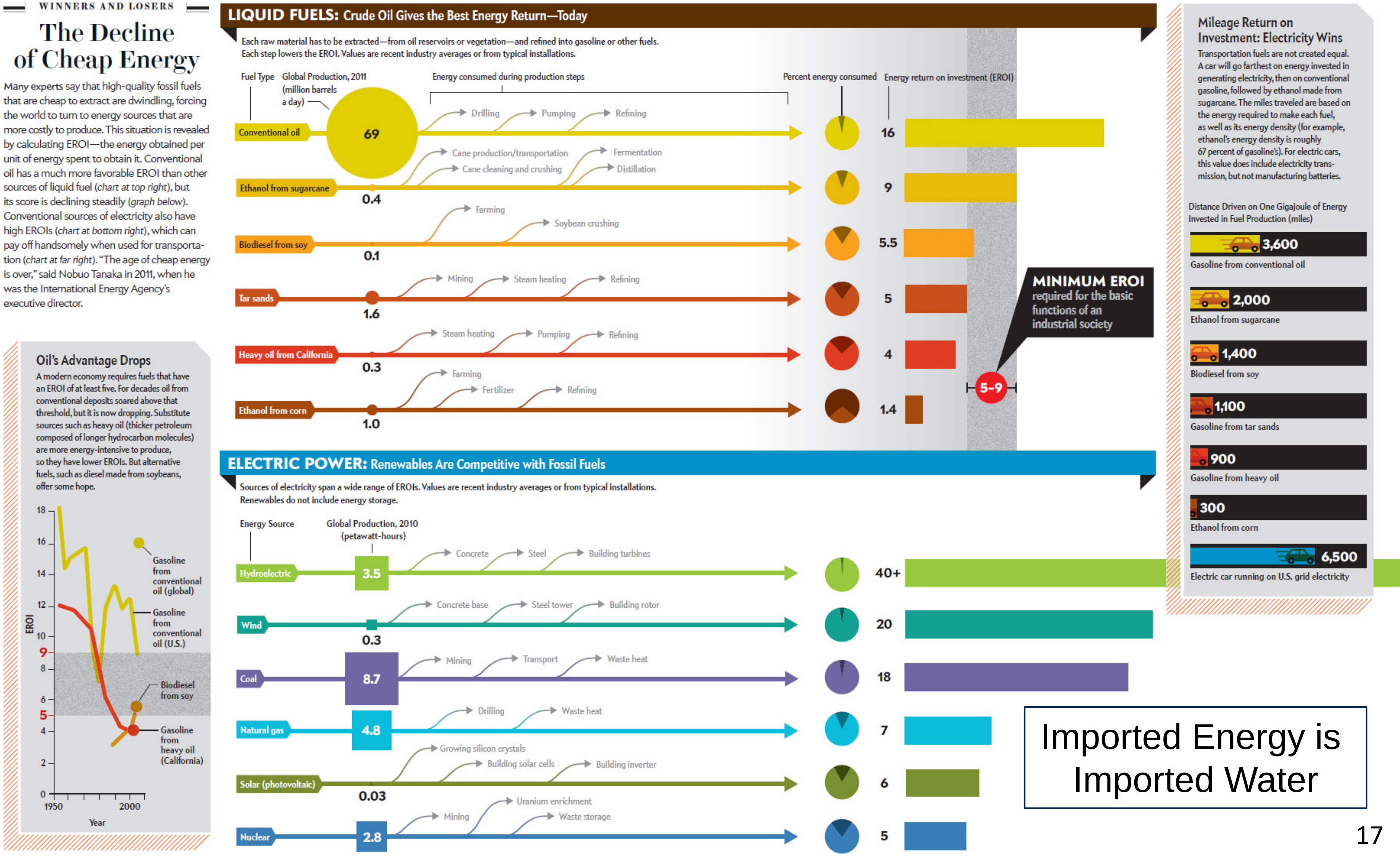

Imported Energy is Imported Water