The Energy-Water Nexus (EWN): a New York City Pilot Study

2009 Advanced Energy Center Conference

Vatsal Bhatt, Kenya Crosson, **William Horak**, Ann Reisman*

Brookhaven National Laboratory

**University of Dayton*

BROOKHAVEN NATIONAL LABORATORY

a passion for discovery

Office of Science U.S. DEPARTMENT OF ENERGY

Energy and Water are … Interdependent

<u>*Water for Energy*</u> and <u>*Energy for Water*</u>

Energy and power production require water:

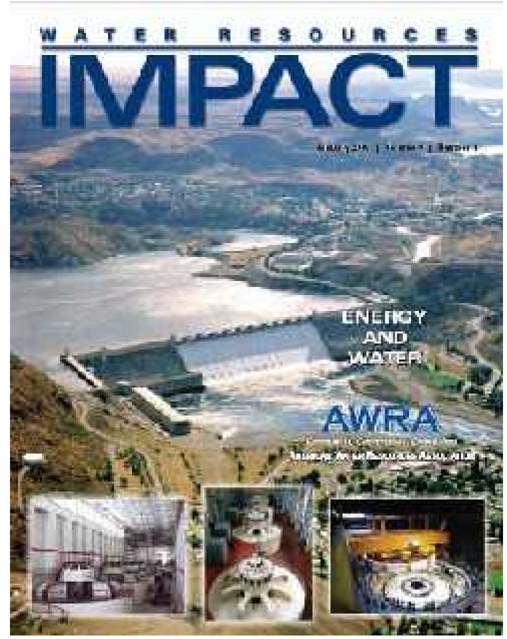
- Thermoelectric cooling
- Hydropower
- Energy minerals extraction/mining
- Fuel Production (fossil fuels, H_2, biofuels)
- Emission control

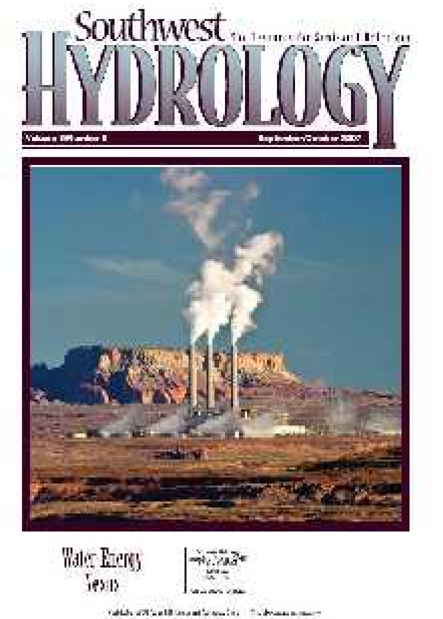
Water production, processing, distribution, and end-use require energy:

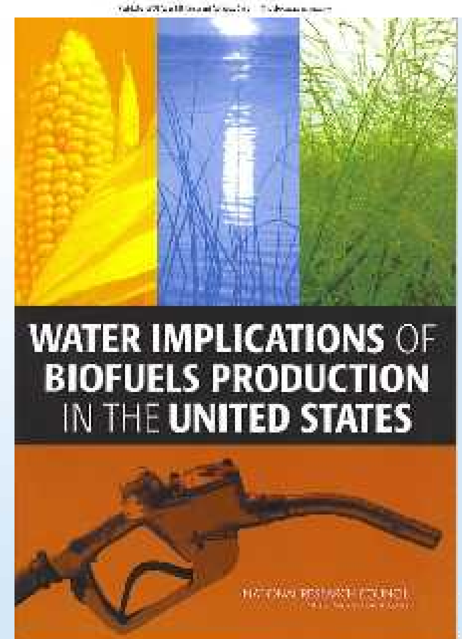
- Pumping
- Conveyance and Transport
- Treatment
- Use conditioning
- Surface and Ground water

Emerging Interest in Energy and Water Issues and Challenges

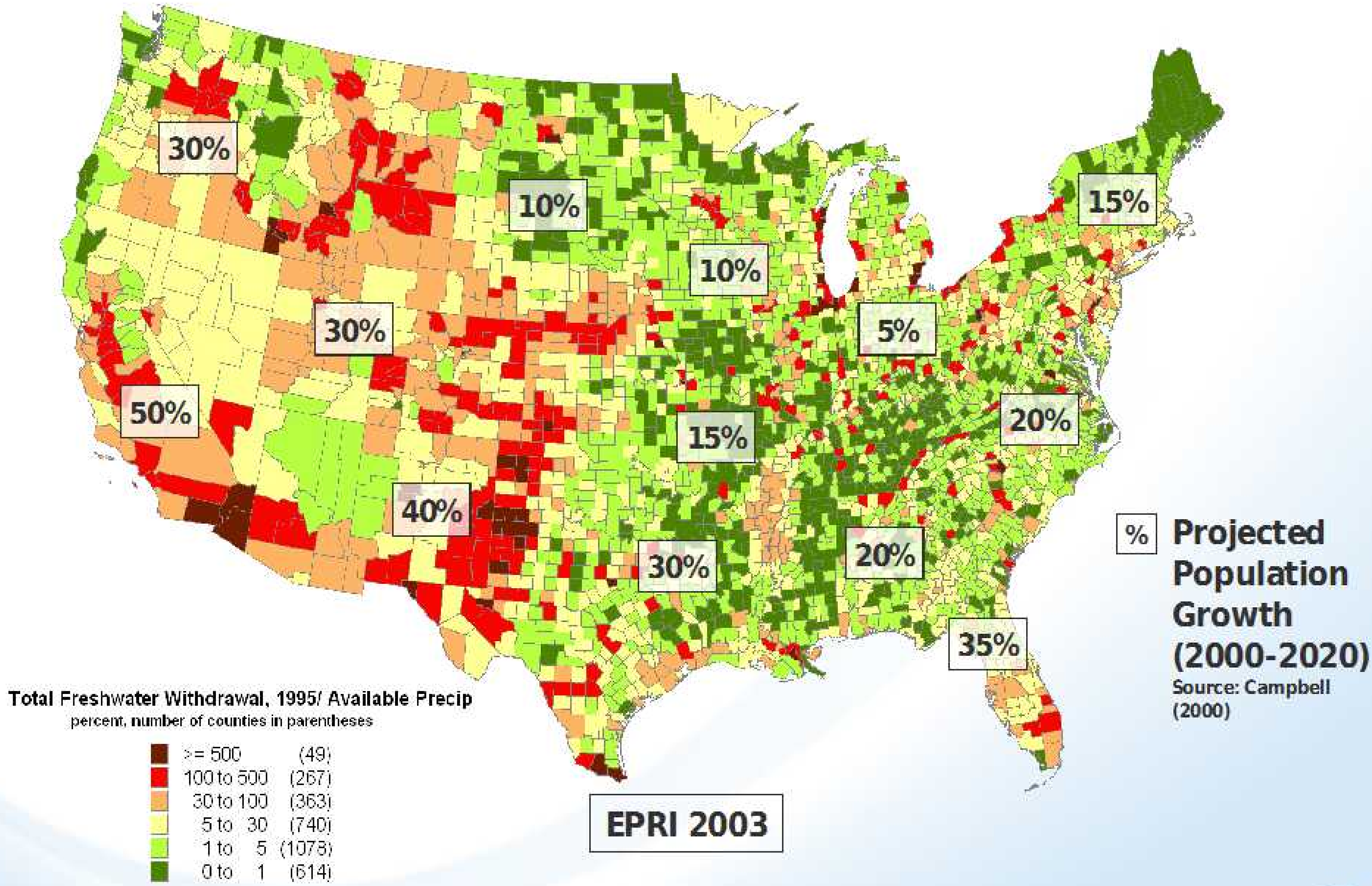
- State and national water and energy groups
  - 24 invited presentations in FY07 and 08 on energy and water challenges
  - Research and regulatory groups considering future energy and water needs
- Increased media interest
  - NATURE, ECONOMIST
  - Technical magazines
- NSF/NRC interest in energy debate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







Water challenges are nationwide



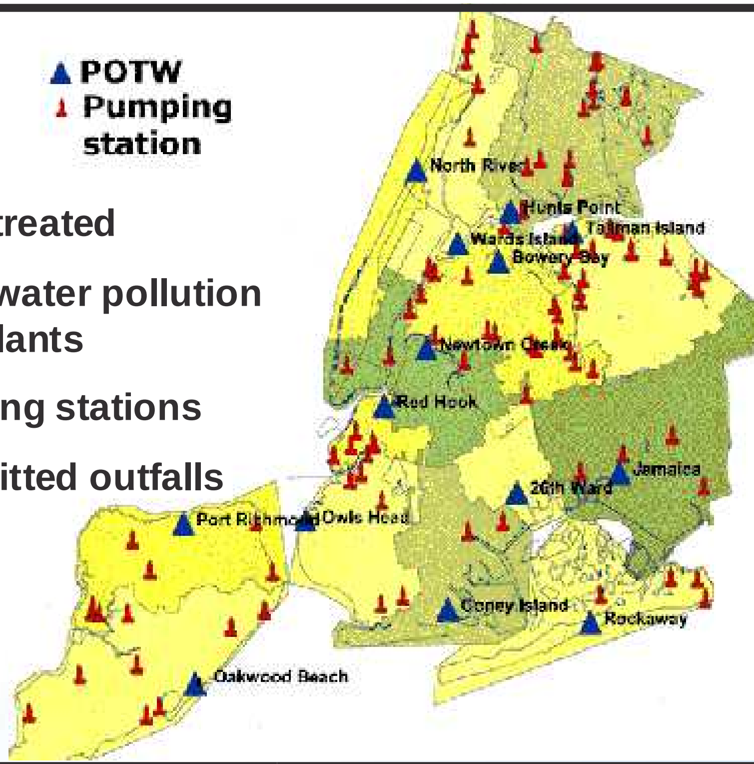
New York City Pilot Study

Goals:

- Determine the key energy-water planning issues for an urban area - New York City
- Develop and apply an integrated energy-water decision-support tool to facilitate urban energy-water planning
- Identify the activities and framework needed to achieve successful integrated energy-water planning
  - Challenges (regulatory/policy issues, data, necessary tools, programmatic issues, etc.)
  - Suggestions for steering committee establishment and the interactions and activities of the steering committee
  - Development and application of tools and methods

New York City Study Area

- 1.3 BGD supplied
- 19 reservoirs, 3 controlled lakes
- 3 aqueducts
- 2 distribution reservoirs
- 3 rock tunnels in the city (1, 2, 3)
- Network of risers and 6000 miles of distribution mains



- **1.4 BGD treated**
- **14 wastewater pollution control plants**
- **93 pumping stations**
- **494 permitted outfalls**

Area: 321 mi^2 (~ 830 km^2); Population: 8,213,839

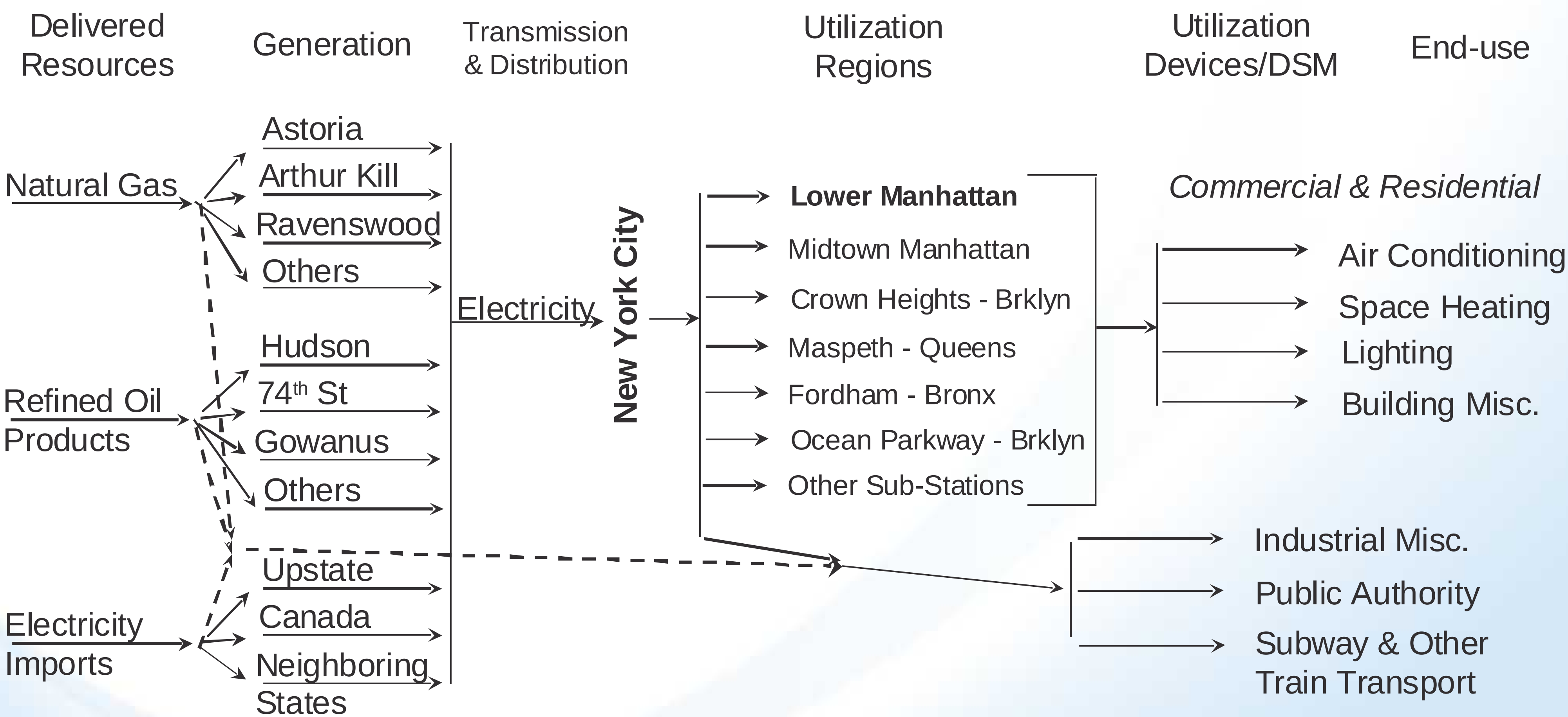
Energy Supply: Keyspan, Reliant Resources, NRG Energy, and NYPA

Distribution: Consolidated-Edison

Forecasted peak electricity demand 11,020 MW (80% in-City generation) 2003

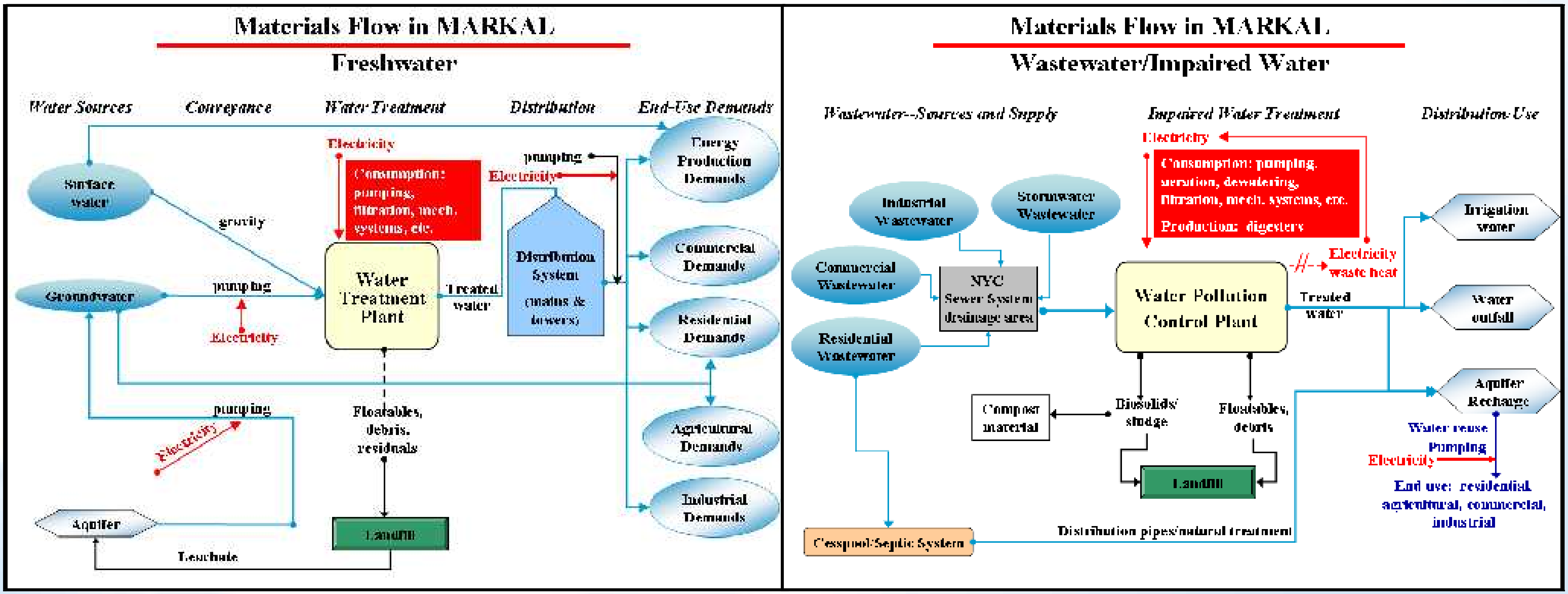
By *2008*, *3,780 MW of new electricity resources needed*

Reference Energy System



Modeling Water Systems

- Detailed fresh and wastewater flows and technologies



Leading NYC Energy and Water Planning Challenges

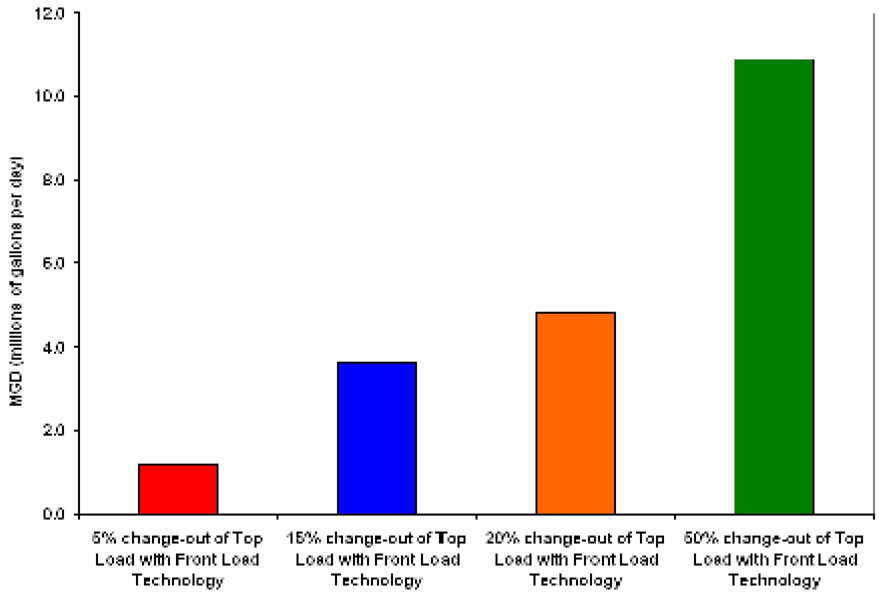
- Identified by the Steering Committee
- Reliable operation of drinking water and wastewater systems increases energy demands (UV treatment and Croton filtration plant)
- Enforcement of water conservation and assessment of the total benefits (e.g., water and energy savings)
- Evaluation of the impacts of climate change on energy and water systems
- Ensuring future energy and water supply security
- Planning for water withdrawals for steam production
- **City-wide integrated planning of energy and water systems**

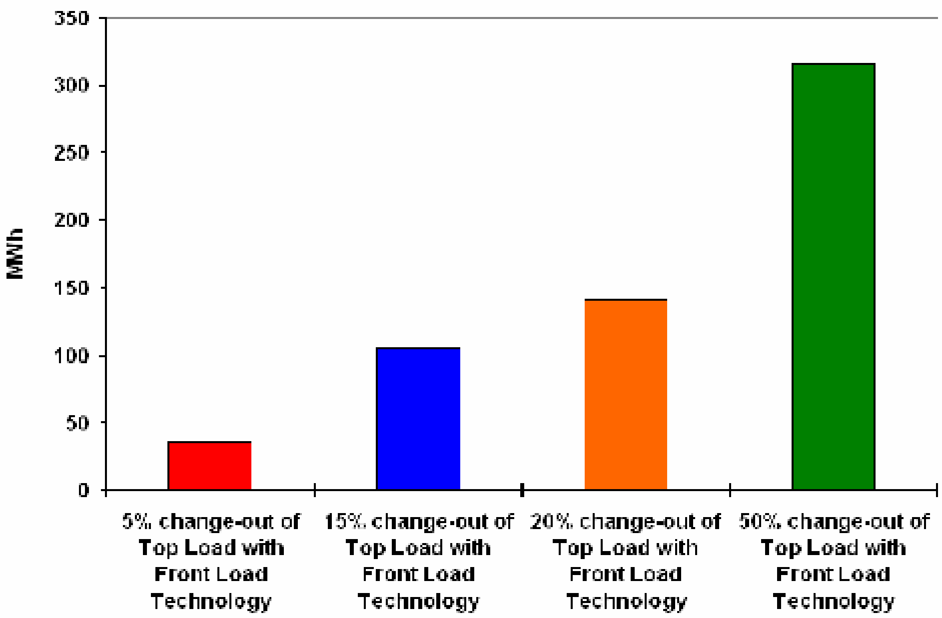
Policy Options Analysis

Several **energy-water integrated planning scenarios** were developed, based on issues identified by the steering committee.

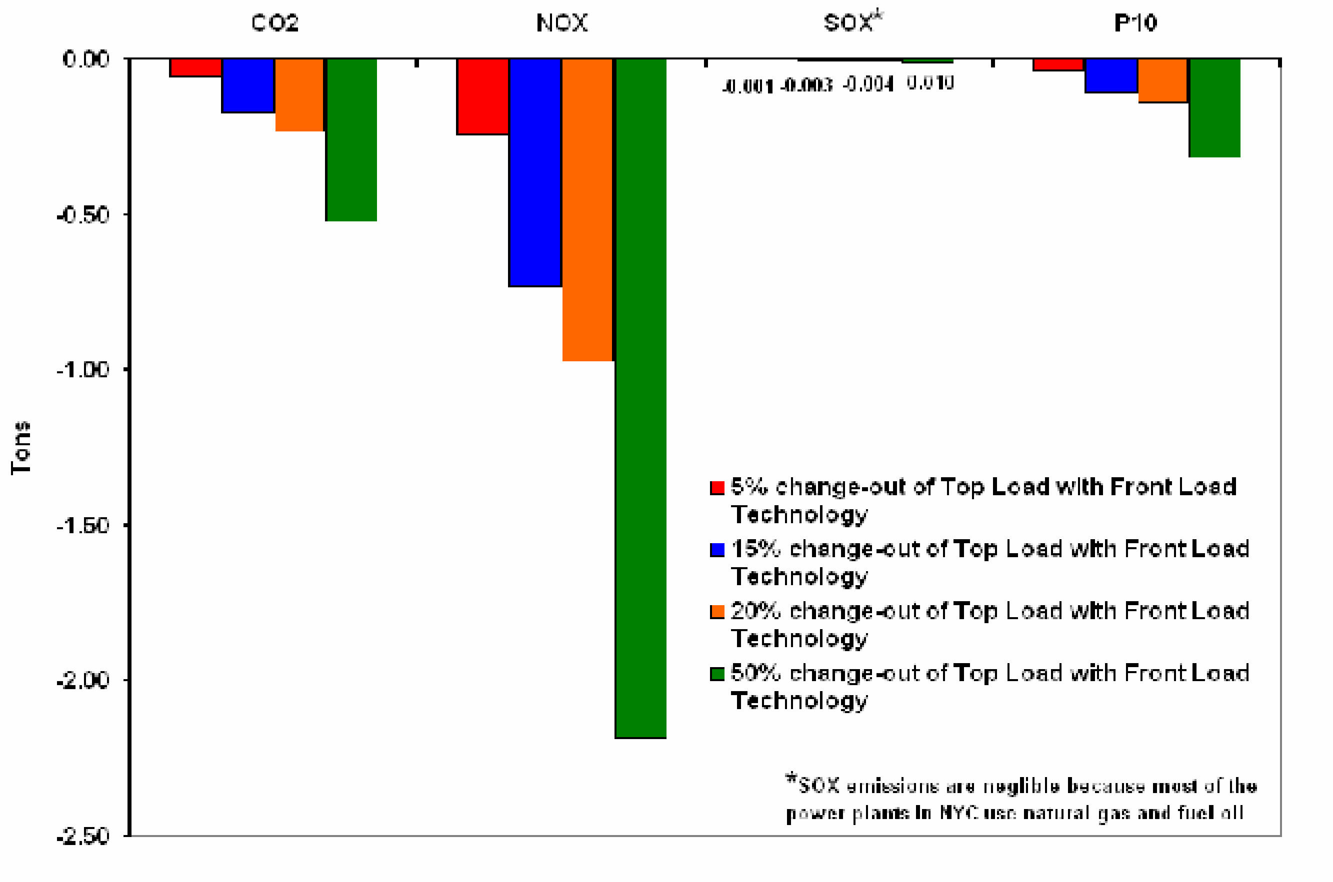
- *Scenario 1:* Water-Efficient Appliances: Energy and Water Use Impacts
- *Scenario 2:* WasteWater Treatment: Deploying More Fuel Cells
- *Scenario 3:* New York City Water Supply: Impacts of Increased Energy Demands for New Treatment
- *Scenario 4:* New York City Steam Generation: Water Supply and Energy Impacts
- *Scenario 5:* Climate Change Models and Research: A Link with Energy and Water

Scenario 1
Water-Efficient Appliances

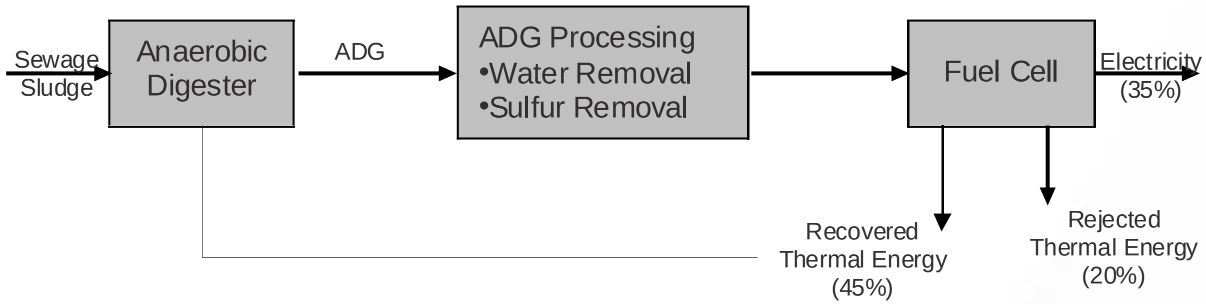


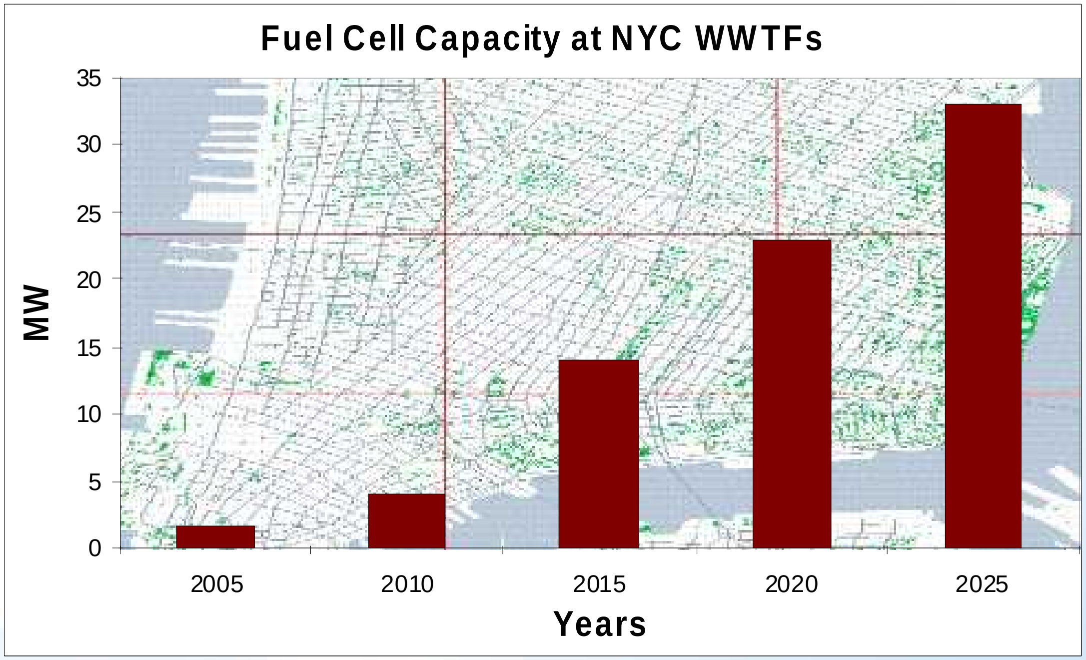


Scenario 1
Water-Efficient Appliances

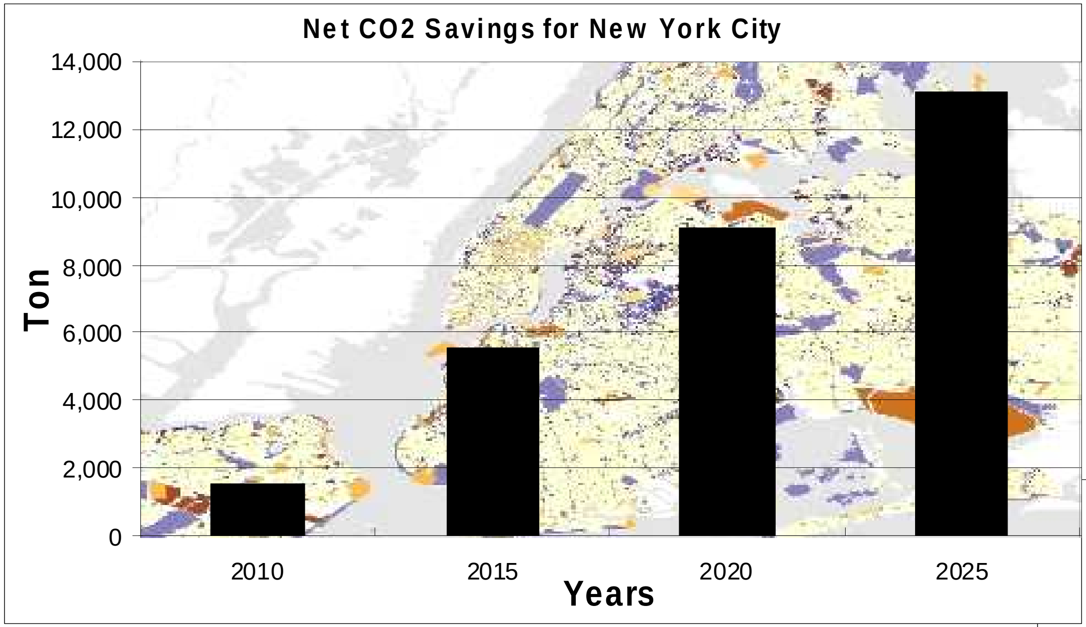


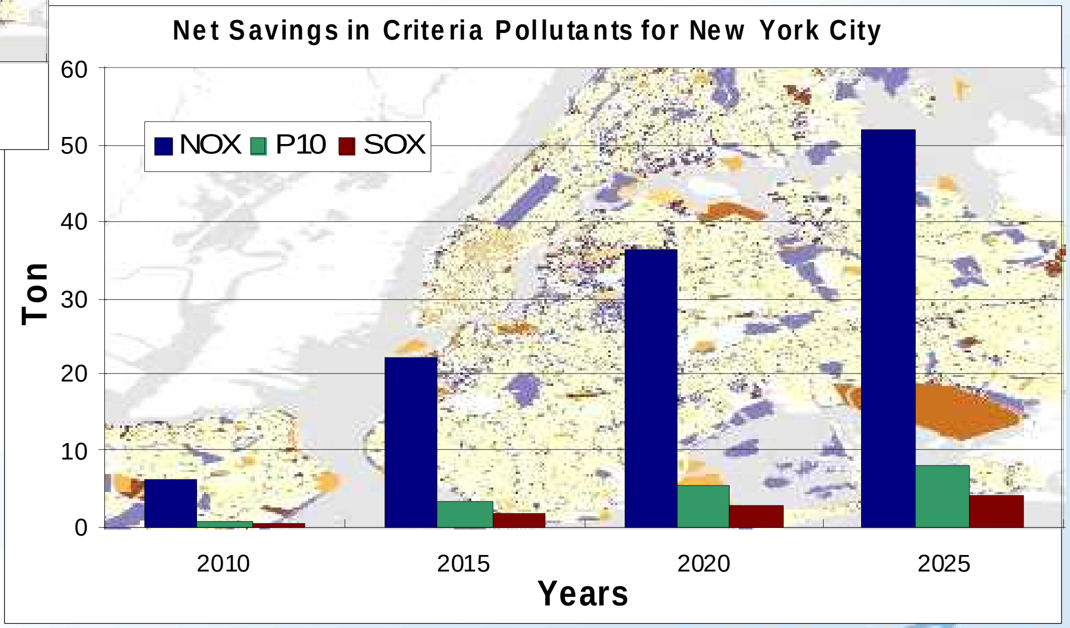
Scenario 2
Wastewater Treatment: Deploying More Fuel Cells





Scenario 2
Fuel Cells



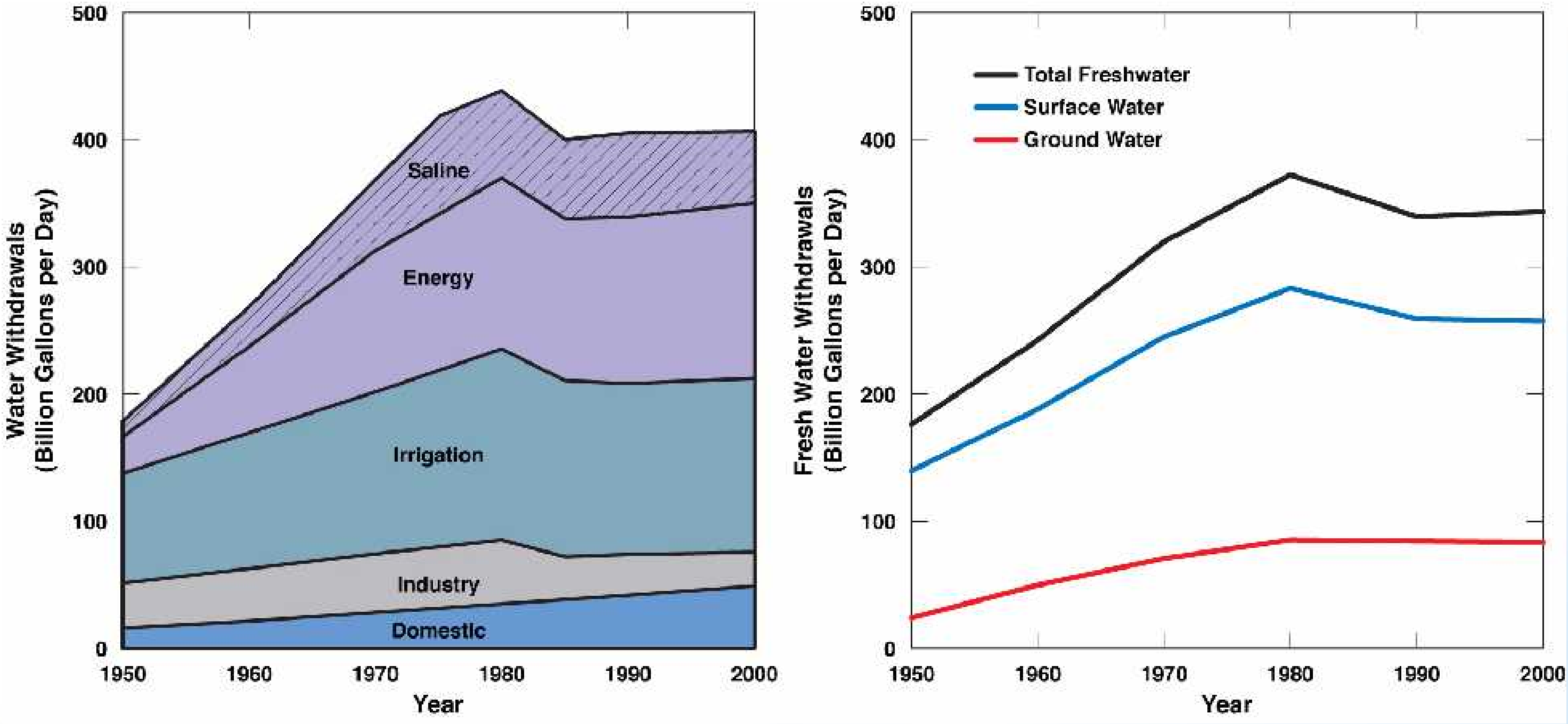


Energy-Water Nexus Summary

- Energy and Water Issues are inter-connected
- Numerous stakeholders
- Data needs are a challenge (GAO, 2009)
- Developing for DOE a 10-region Markal Water Model
- Linkages to Climate Models will be a Challenge

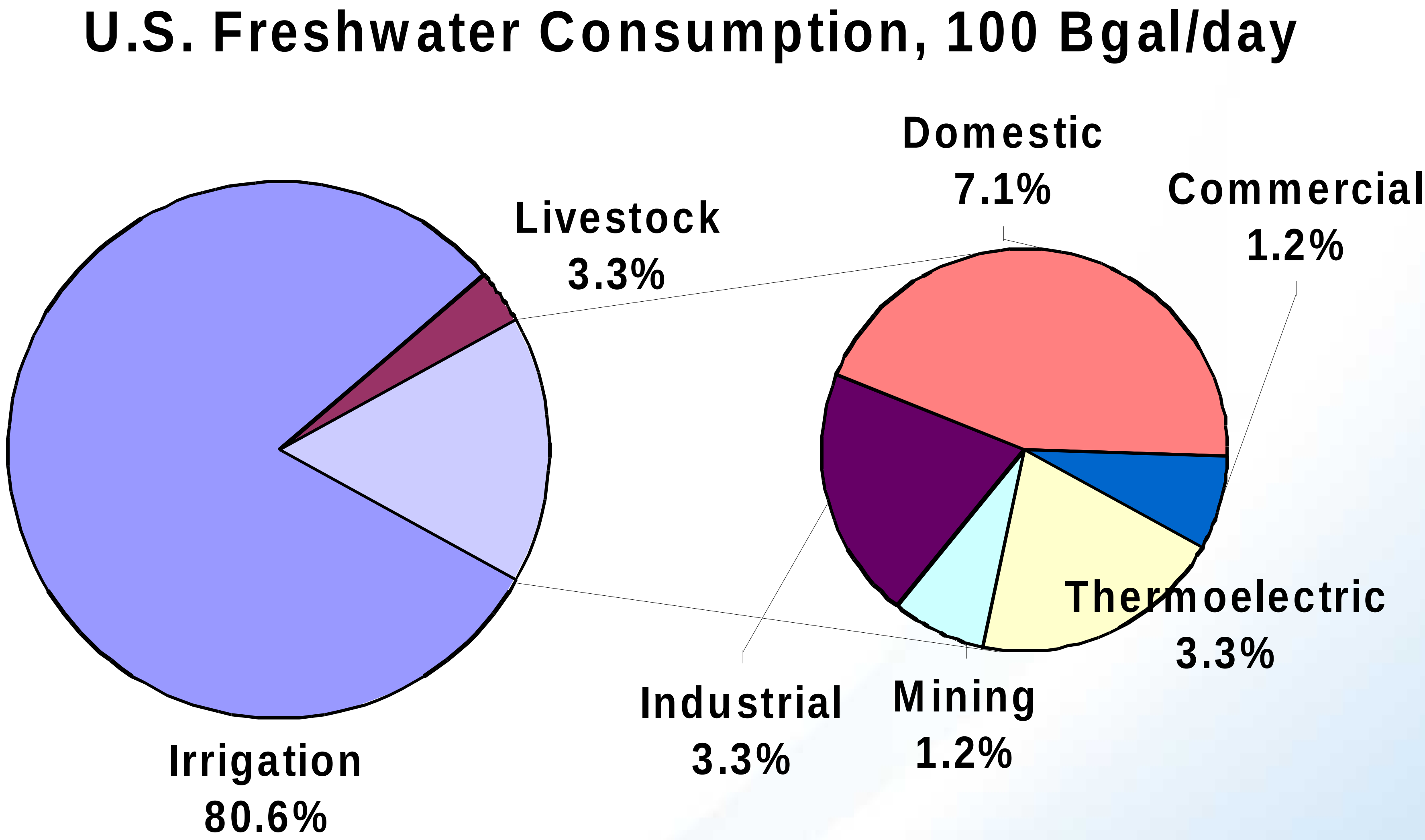
Additional Slides

Water Withdrawal Trends by Sector



[USGS, 2004]

Water Consumption by Sector



[USGS, 1998]

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

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] †	Water Consumption: 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

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

Bort-les-Orgues Réservoir

Normal conditions in August

August 27, 2003

Projected New Electric Power Generation Capacity through 2035

- Coal
  - 350, 400 MW steam turbine plants (140,000 MW)
- Natural Gas
  - 150, 100 MW natural gas combined cycle (15,000 MW)
- Renewables
  - 125, 200 MW wind or solar farms (25,000 MW)
- Nuclear
  - 5, 1000 MW nuclear reactors (5,000 MW)
- Hydroelectric
  - None (~40,000-60,000 MW available)

Water Use and Consumption for Electric Power Generation

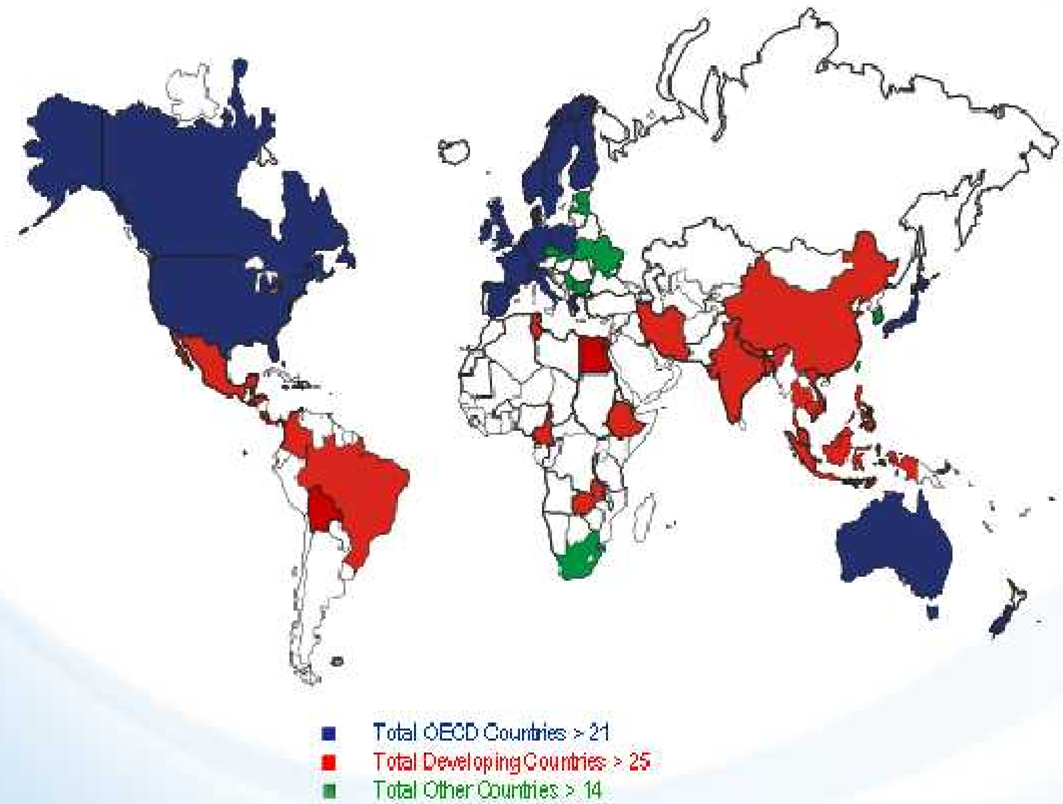
Plant-type	Cooling Process	Water Use Intensity (gal/MWh_e)		
		Steam Condensing		Other Uses
		Withdrawal	Consumption	Consumption
Fossil/ biomass steam turbine	**Open-loop**	**20,000–50,000**	**~200-300**	**~30**
	Closed-loop	**300–600**	**300–480**	
Nuclear steam turbine	**Open-loop**	**25,000–60,000**	**~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**

New York City Pilot Study
Steering Committee Roles

- **Tasks and Activities**
  - Identify the energy-water issues for NYC
  - Guide the development of the integrated energy-water tool
  - *Assist* and guide BNL researchers in obtaining needed energy-water data and information
  - Select key energy-water strategies to be evaluated using the developed decision-support tool
  - Review final report
- **Comprised of a Diverse Group of Stakeholders**
  - Columbia University Professor/NASA GISS Researcher
  - USEPA Region 2 – Senior Energy Policy Advisor
  - Consulting Firm (HDR)
  - Water Environment Research Foundation
  - NYC Department of Environmental Protection
  - Energy Company in NYC (Consolidated Edison)

Decision Support Tool: MARKAL

- *Developed at BNL* in 1970s in collaboration with IEA (International Energy Agency) – continuously updated/validated
- *Flexible* and *transparent* framework with a *well documented* methodology



- *Over 100 institutions* in *55 countries* currently use it for energy systems analysis
- Use of MARKAL at *U.S. DOE R&D policy decisions*
  - Applied R&D Programs (NE, EERE, FE & OE) – GPRA 1993
  - Office of Nuclear Energy – GNEP
  - Office of Policy and International Affairs
  - Hydrogen Economy
  - Energy-Water Nexus

MARKAL Model Basics

- Utilizes a state-of-the-art ***dynamic linear programming*** framework
- Provides a ***technology-rich*** basis for estimating energy dynamics ***over a multi-period horizon*** (2005-2050)
- Models ***environmental, technological*** and ***policy*** restrictions
- Generates ***least-cost*** energy path based on ***perfect foresight*** and ***life-cycle costs*** of technologies and competing alternatives (cradle-to-grave)
- Identifies the ***most cost-effective*** pattern of ***resource use*** and ***technology deployment*** over time