The National Energy Technology Laboratory Water Energy Modelling

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Water – Energy Interdependency

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Energy

- Power Generation (primarily for cooling)
- Extraction, Transport, and Processing of Fuels
- Irrigation of biofuels feedstock crops

- Power required to transport, distribute, and collect water
- Water treatment
- Local point-of-end use for water heating etc..,

Water Resources

Power Generation*

- Thermoelectric power generation accounts for a majority of water usage for power generation
  - Nearly 52% of surface fresh water withdrawals
  - A total of 43% of total water withdrawals
- Vulnerable to physical constraints of water availability and regulations limiting access to it
  - Power plants in the US forced to modulate/shutdown power generation during a recent drought in 2012
  - Can constrain the type and location of power plants that can be built

Water Resources

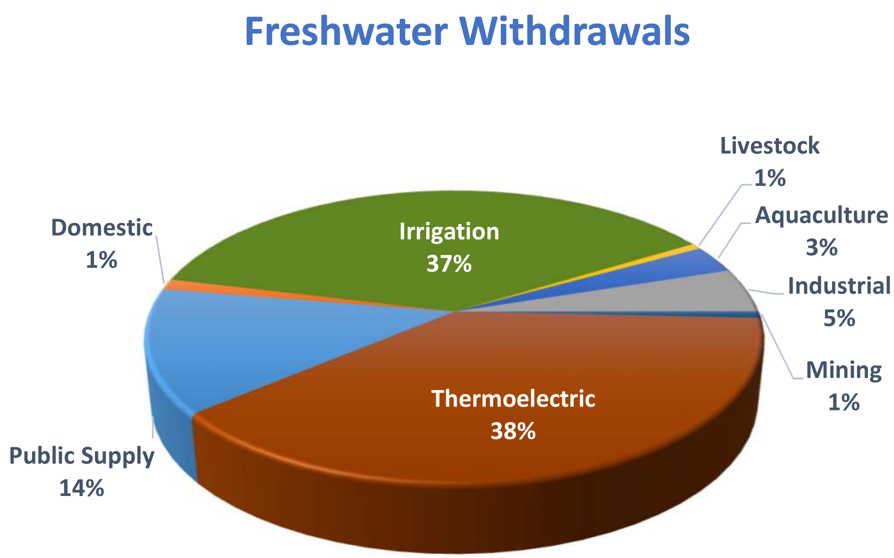
- Water scarcity, variability, and uncertainty are becoming more prominent in the US
  - Population growth
  - Climate change
  - Precipitation profile redistributions
- Environmental impacts and regulations alter water availability profile
- Strong temporal dependence
- Highly localized due to water rights and other region-specific issues

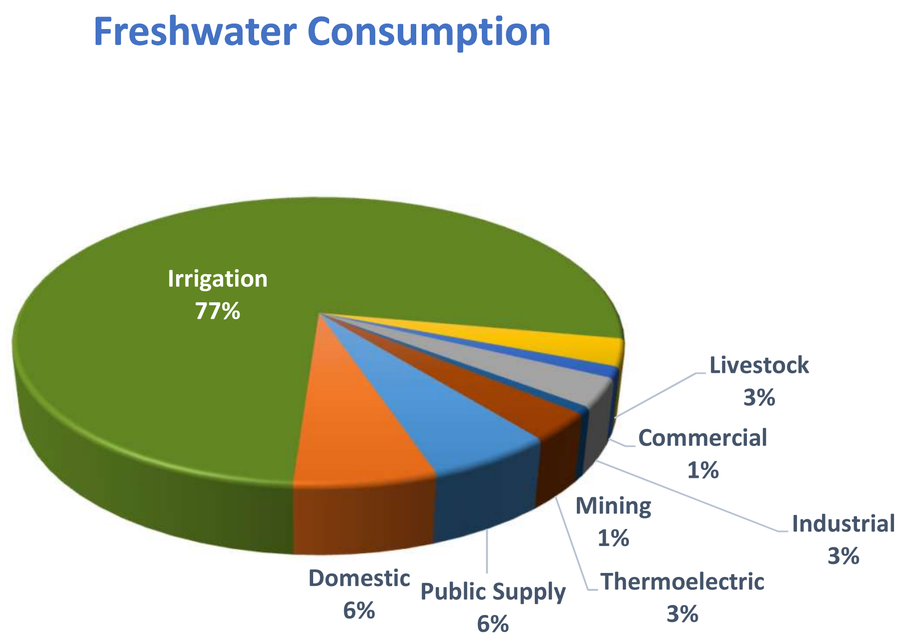
Water – Energy Dependency is one dimension of the larger Water – Energy - Food Nexus

**Sources: 1. US DOE, "The Water – Energy Nexus: Challenges and Opportunities – Overview and Summary," 2014;*
2. IEA, "Water for Energy Resource: Is Energy Becoming a Thirstier Resource," Excerpt from the World Energy Outlook 2012.
3. NREL, "Water Constraints in an Electric Sector Capacity Expansion Model," NREL/TP-6A20-64270 , 2015.
4. "The Energy-Water-Food Nexus", D. L. Keairns, R. C. Darton, and A. Irabien, Annu. Rev. Chem. Biomol. Eng. 2016.7:9.1-9.24

U.S. Water Use

Withdrawal = Consumption + Discharge





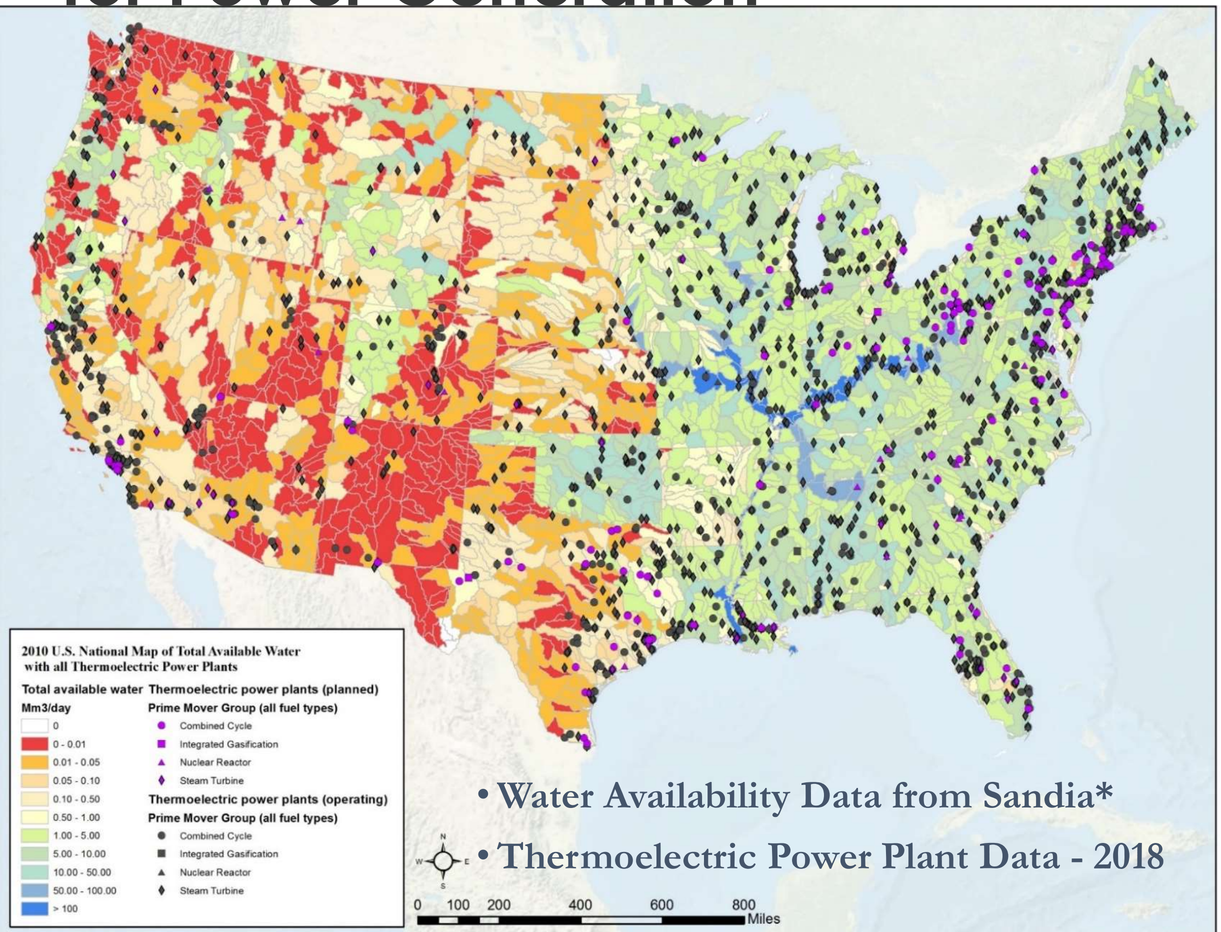
Dominated by Agricultural and Thermoelectric Demand

Water Withdrawals: USGS Estimated Use of Water in the United States in 2010, Circular 1405, 2014
Water Consumption: USGS Estimated Use of Water in the United States in 1995, Circular 1200, 1998

Drought Events have Resulted in Energy Water Shortages in the Past

- Energy-water collisions have occurred on several occasions
- Collisions will become more frequent with
  - Higher temperatures
  - More frequent drought

Current State of Water Availability for Power Generation



- Water Availability Data from Sandia*
- Thermoelectric Power Plant Data - 2018

Mitigation of Energy- Water Collisions

- In some cases water shortages can be met with technological solutions
- Water shortages may also be met with re-allocation from one use to another

*http://energy.sandia.gov/climate-earth-systems/energy-water-nexus/data-modeling-analysis/#water-availability

U.S. Power Plant Cooling Systems

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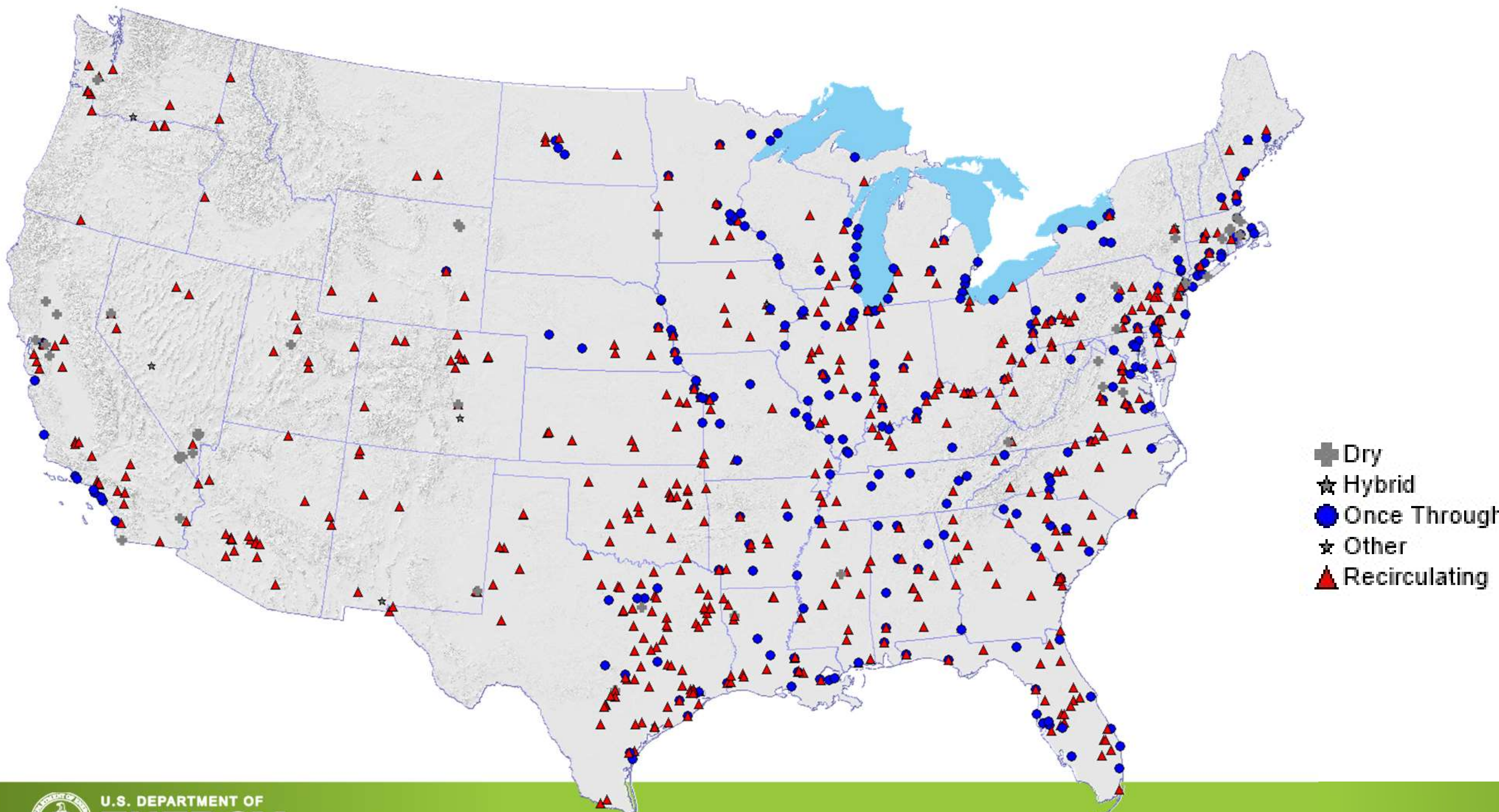

3.6% Dry cooling and Hybrid

43% Once Through

53% Recirculation

Objectives

- **Develop tools and metrics that inform electric power generation design choices related to water availability and the cost of power plant water utilization**
- **Explore electric power technology options and use results to**
  - Mitigate and study the impact of adverse water availability conditions on current and projected future thermoelectric electric power generation capacity
  - Inform R&D
  - Test proposed solutions

NETL Water/Energy Modelling

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Larger Systems Models

Short Term Planning Energy/Water Models
- Regional
- National

Long Term Planning Energy/Water Models
- Regional
- National

Submodels

Techno-Economic Analyses & Models

Model technologies both existing and advanced

Standalone models or Integrated models

Water Related Conditions/Stresses

- **Environmental Stresses**
  - Droughts
  - Hurricanes
- **Regulation Stresses**
  - ELGs, FGD
  - 316b
  - Water limits (dry / hybrid cooling mandates)
- **Sector Stress**
  - Water competition with AG, Municipal and Industrial Sectors

Flexible Cooling Models

Sub modules

Models

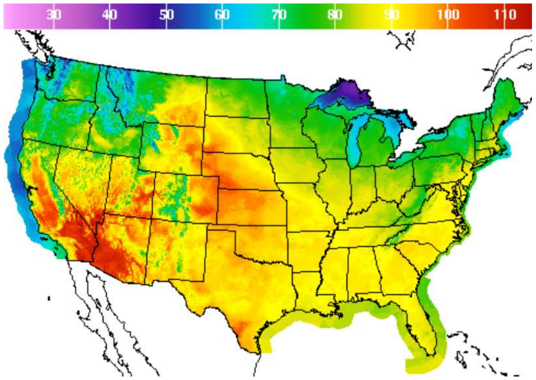
- Develop robust cooling models
  - Once through, Recirculating natural draft, Recirculating mechanical draft, Air Cooled Condenser

Data/Parameters

- Recent historic weather data
  - Wet bulb, Dry bulb, Humidity, …
- Source water temperatures

Modelling

- Apply historic generation and weather parameters
- Forecast out – generation scenarios and weather scenarios



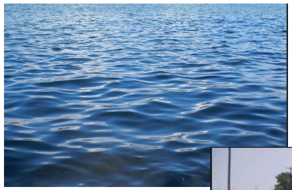
Long Term Planning Energy/Water Models

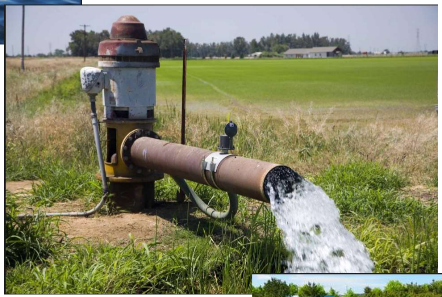
NETL Water-Energy Model (NWEM)

Motivation

- **Water – Energy interdependency is an important factor that has to be taken into consideration in the deployment of power generation technologies**
  - Siting considerations
  - Environmental considerations
  - Technology considerations
  - Municipal, Industrial, and Agriculture considerations
- **Current energy capacity forecasting tools such as NEMS do not adequately take into account potential water constraints in deployment considerations**

Water Availability – Model Data





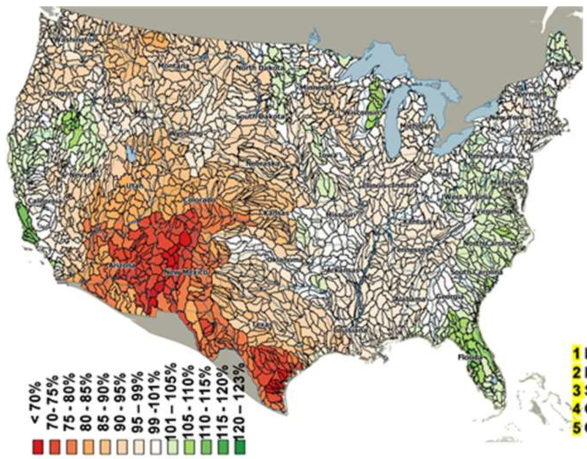
- **Water Sources**
  - Unappropriated surface water
  - Unappropriated ground water
  - Appropriated water (surface & ground)
  - Municipal wastewater
  - Brackish ground water
- **Costs to acquire, convey and treat water sources**
- **20 year water competition for the available water supply**
- **WRI data used to develop water availability scenarios**

Appropriated water - Western water rights, Doctrine of prior appropriation

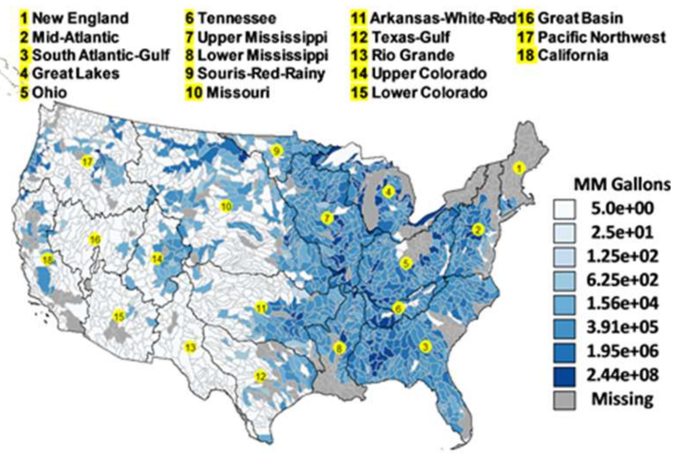
Model Application – Drought Analysis

- Uses WRI Aqueduct Project data
- Aqueduct project "pessimistic scenario" projections were used to define a stressed water availability scenario
- Model exercised against this scenario to analyze implications of water stress on forecast
- Assumed power generation forecast from the Annual Energy Outlook (AEO) 2015 Reference Case

Percentage Change in Total Blue Water 2010-2030, Pessimistic Case



Surface Water Availability in 2030, Pessimistic Case

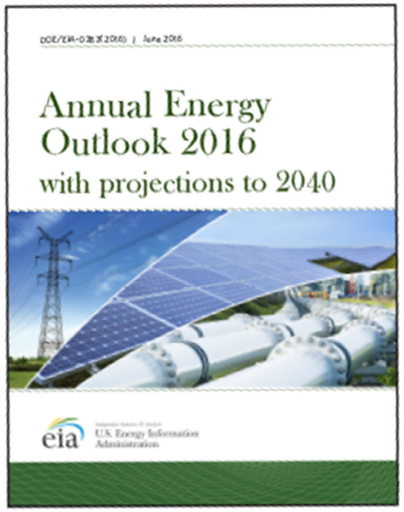


Source: WRI Aqueduct 2015

EIA NEMS – Model Data

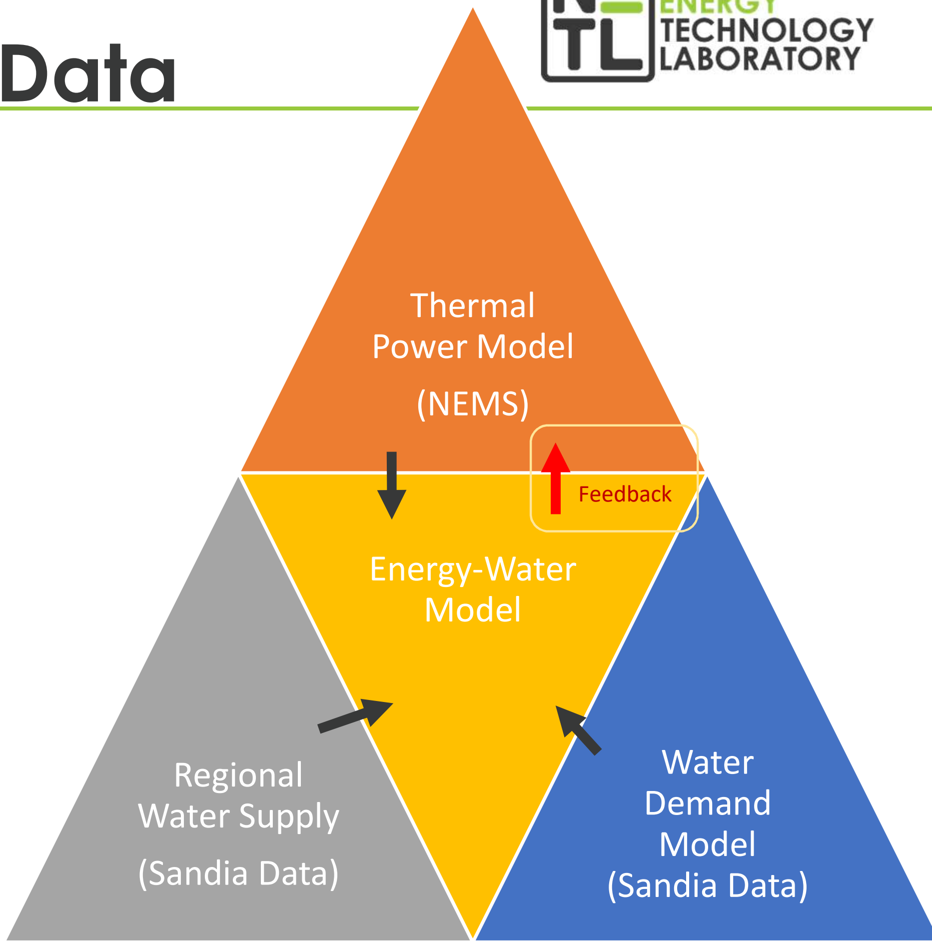
U.S. Energy Information Administration – National Energy Modelling System

- NEMS projects the production, consumption, conversion, import, and pricing of energy
- The primary use for NEMS is to produce the *Annual Energy Outlook*
- NEMS is also used for evaluating the energy generation and landscape under a variety of scenarios including policy and regulatory constraints
- Scenario analysis, primarily from the U.S. Congress



Prototype Model Design and Data

- Time Period: 2012 to 2040
- Regions: HUC 8 – Hydrologic Unit Code (8 digits 2,200 HUs, 700 mi^2)
- Model Objective Function: Minimize the total cost of satisfying water demand in each HUC 8

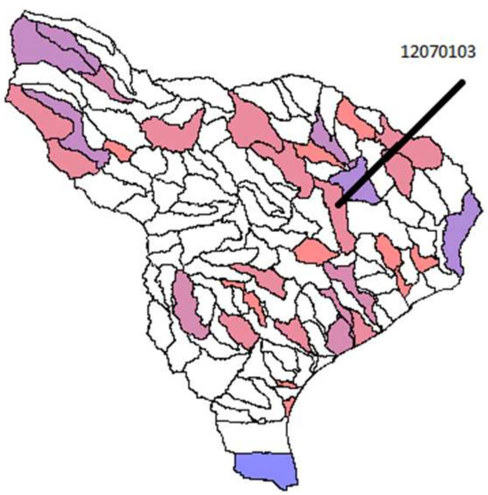


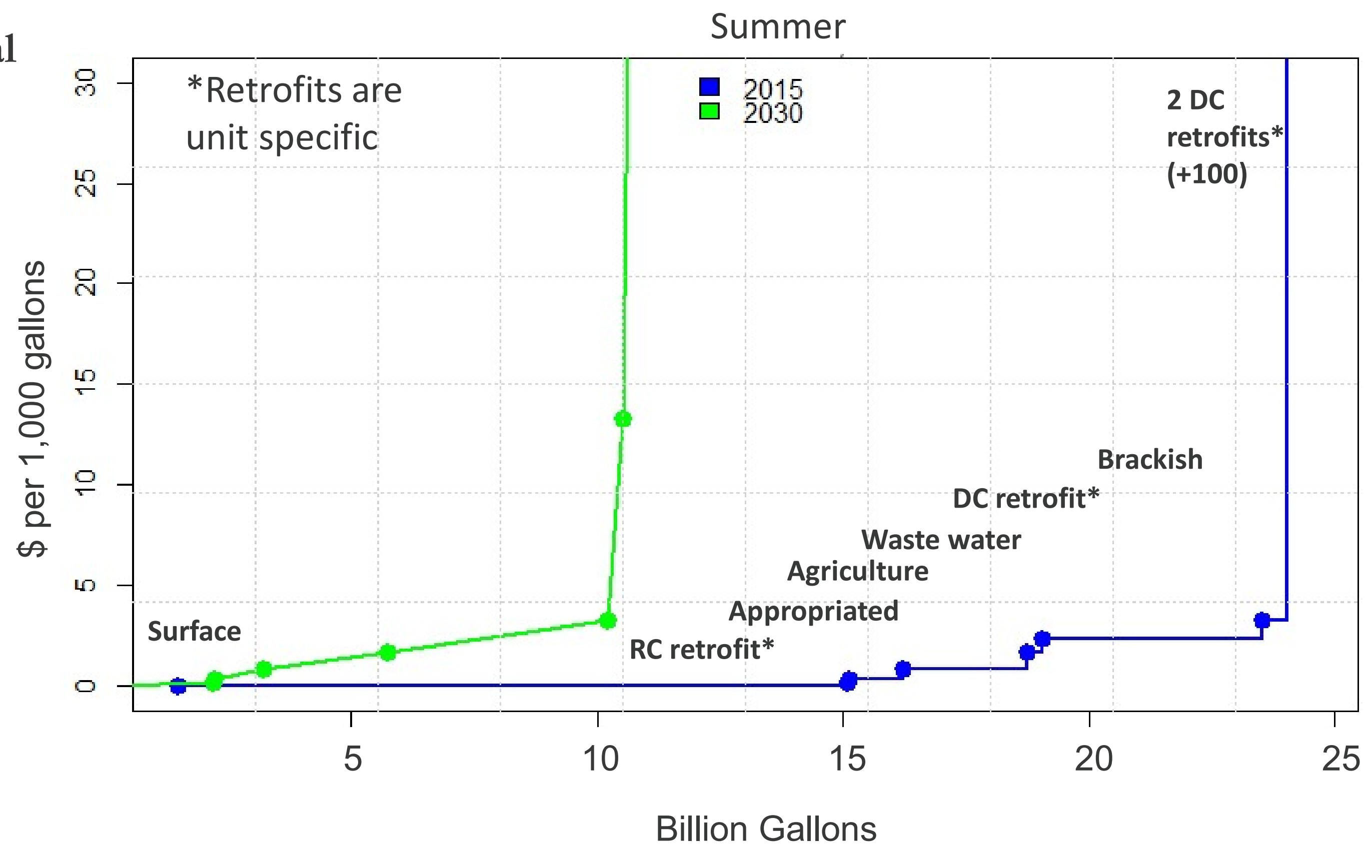
Model Design

- **Multi-period seasonal planning model**
- **Prototype model developed in GAMS**
  - General Algebraic Modeling System – Linear programming model
- **Optimizes to minimize the cost of satisfying the demand for water**
- **LP performs an economic trade-off between purchasing water at various costs from constrained water sources or spend capital to retrofit power plants with less intensive water cooling technologies**
  - Appropriated water
  - Impaired water (waste or bine waters)
  - Purchase from Ag
  - Retrofit cooling system to recirculating or dry cooling

Availability Data Further Used to Derive Marginal Cost Supply Curves for Water

Illustrative forecast: water marginal supply curve for HUC 12070103 – Navasota TX



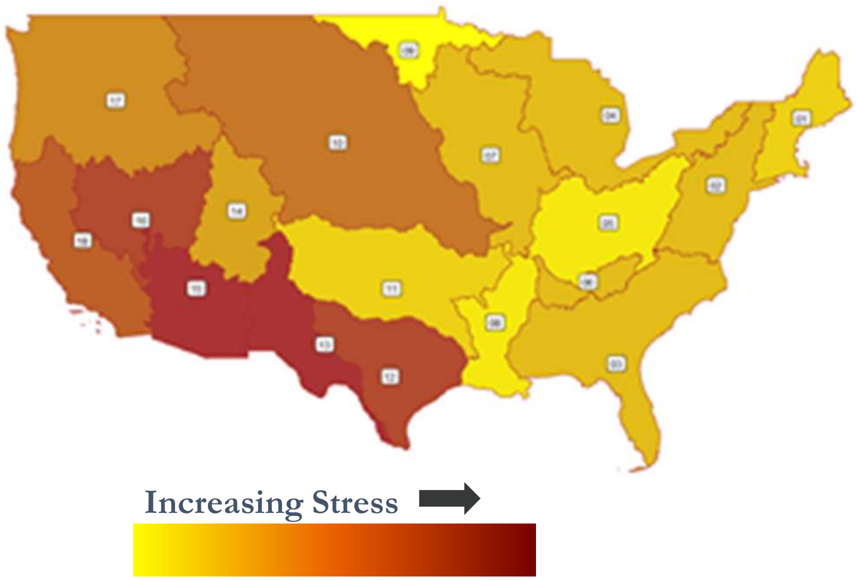


Model Application

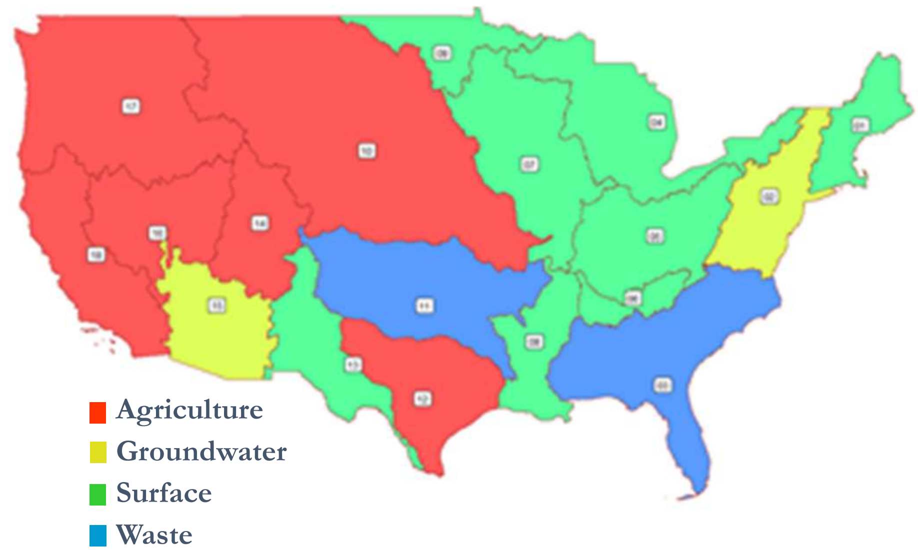
Availability Data Enables Location Specific Estimates for Water Stress and Marginal Water Sources

Water Stress - 2020

Water Used by Power/Water Available



Marginal Water Sources - 2020

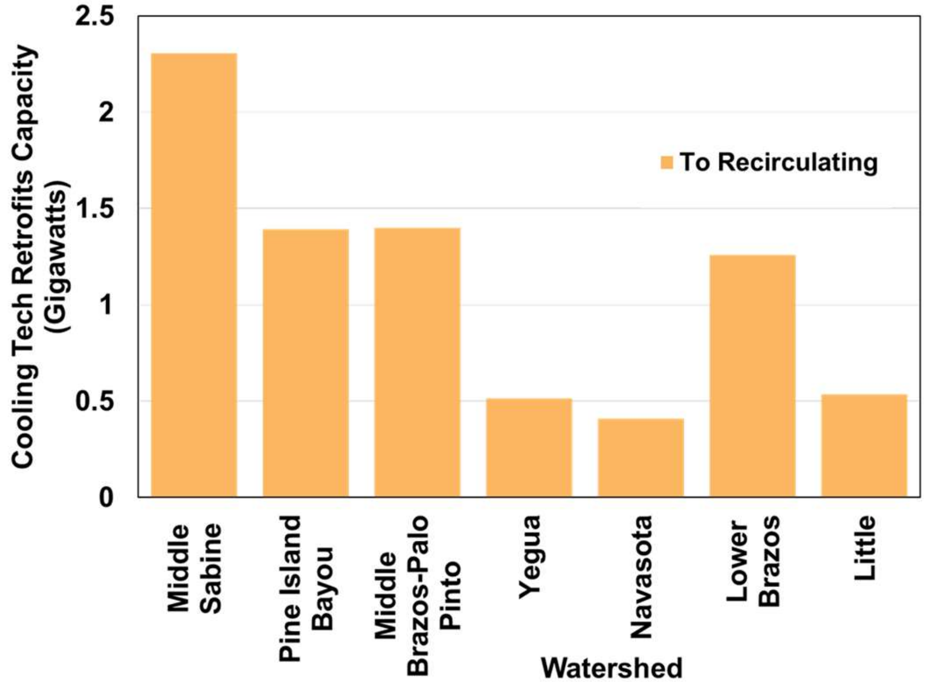


Source: NETL

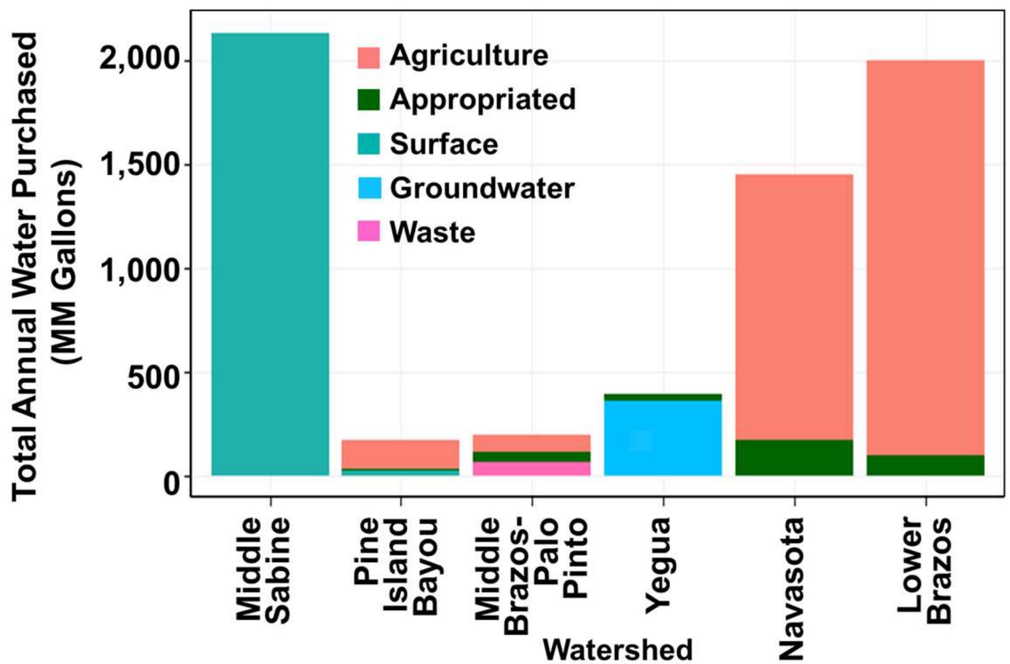
*http://energy.sandia.gov/climate-earth-systems/energy-water-nexus/data-modeling-analysis/#water-availability

Model Results – Texas Gulf Basin

Retrofits in the Texas-Gulf Basin 2015-2030



Water Purchases by Watershed in the Texas-Gulf Basin 2015-2030



Source: NETL

Conclusions/Future Research

- Inclusion of water availability projections into energy economy forecasting can have impacts on system cost and ultimate composition of the generation portfolio
- NWEM operates at a watershed level and incorporates a framework to address these issues into the larger NEMS framework
- Improvements are being made to representation of local and regional water markets that enable cross sector/region water transfers
- More thorough development of water availability data, including drought scenarios and water conservation impacts could be useful to inform cost effectiveness assessments and aid decision making

Short Term Planning Energy/Water Models

PROMOD Dispatch Model

Short Term Analysis

Analysis how weather stresses impact dispatch related factors

Stresses

- **Drought Conditions**
  - Limited water availability
  - Warm intake
  - Thermal discharge limitations
  - Increased TDS
- **Flood/Hurricane Conditions**
  - Water Quality
  - Outages

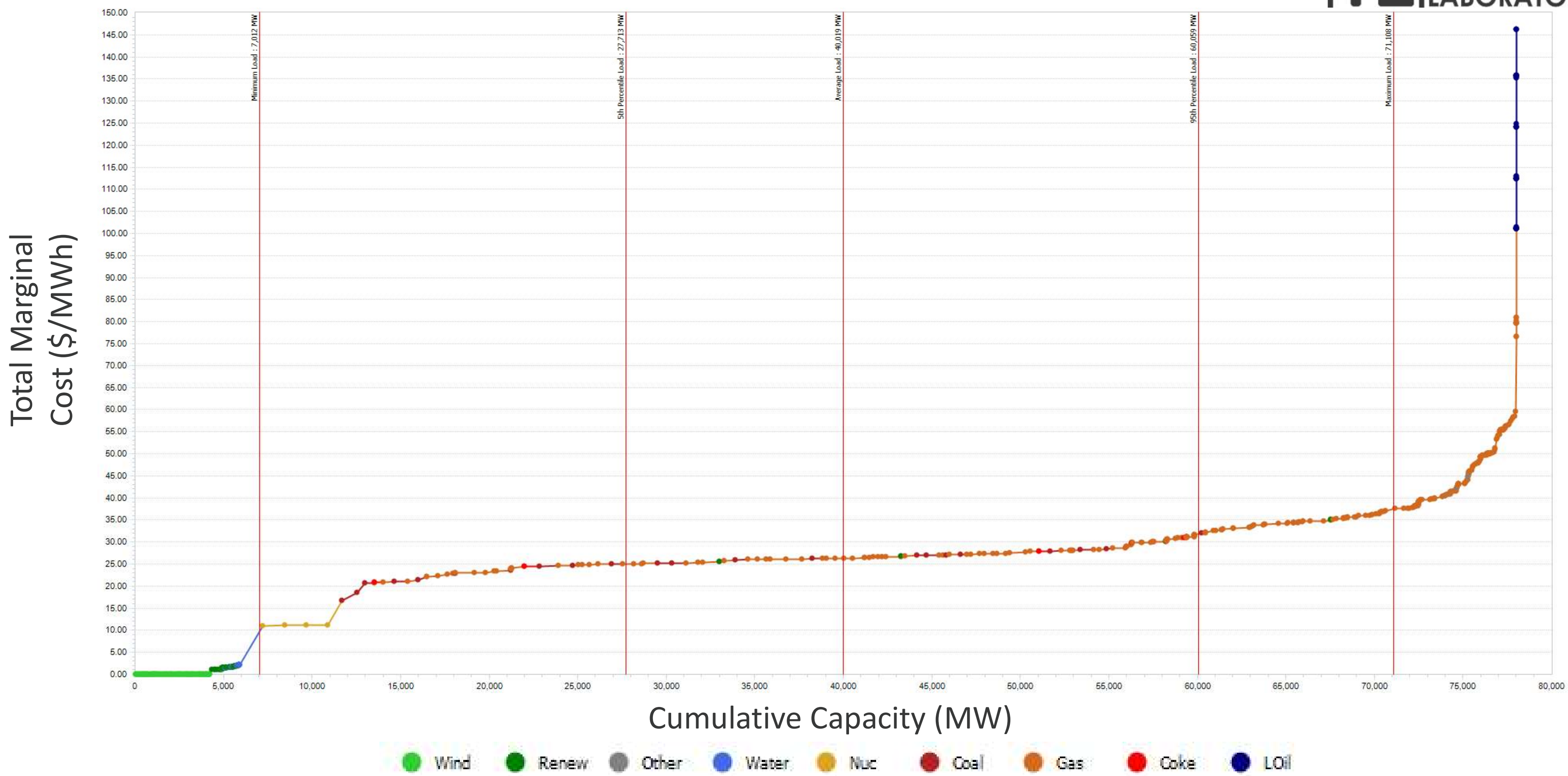
Impacts

- **Reserve Margin**
- **Curtailment**
  - Discharge water temperatures
- **Brown- or Blackouts**
- **Cost of electricity**
- **Change in emissions**
- **Increased Load on intermittent generation**

Solutions

- **Technologies**
- **Generation Configurations**
- **Plant Operations**

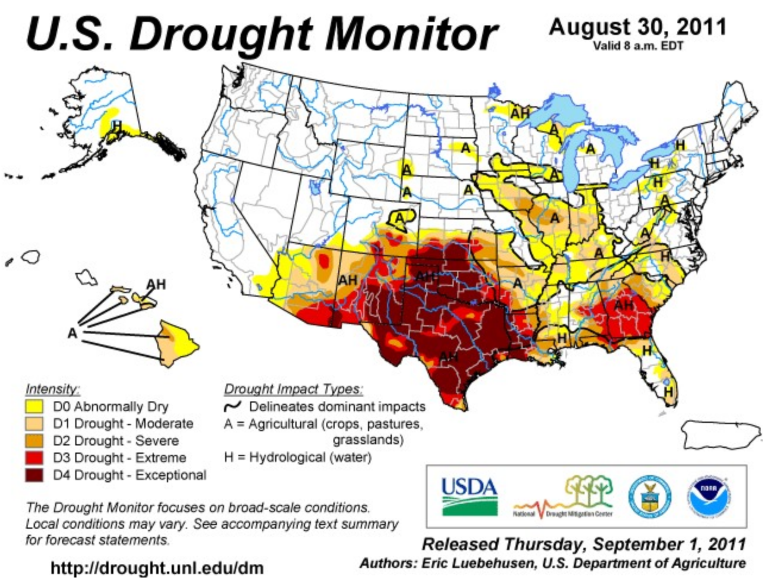
Dispatch Curve

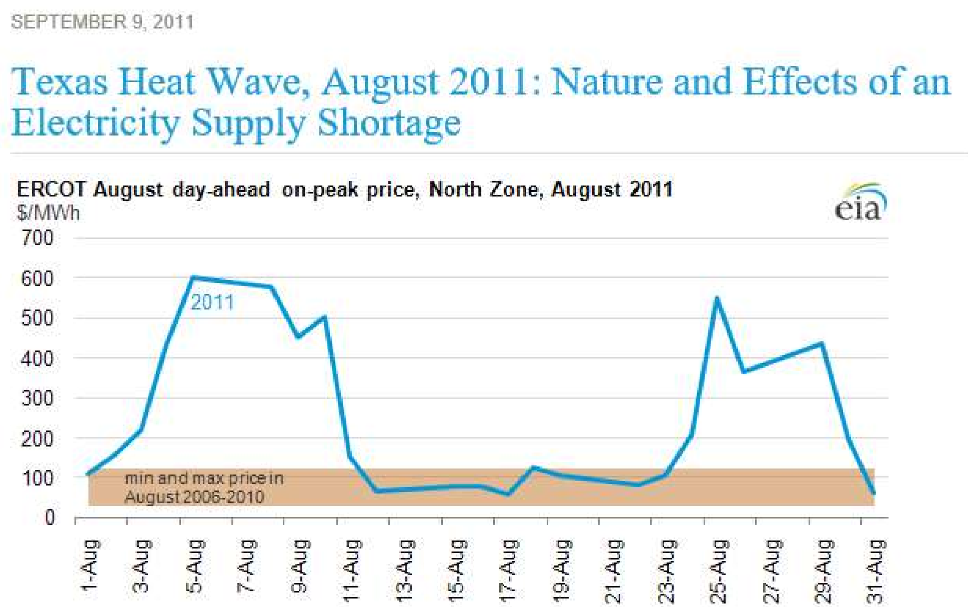


Test Case

ERCOT – 2011 drought

- Need to add info on Texas drought background and Examples
- This emphasis the need for a short-term model





- **Officials from ERCOT, were concerned. High energy usage and scorching temperatures caused ERCOT to close one factory overnight during the height of the summer's heat. Officials worry that another spring and summer with low rainfall could mean the closure of some power plants.**

Thank You

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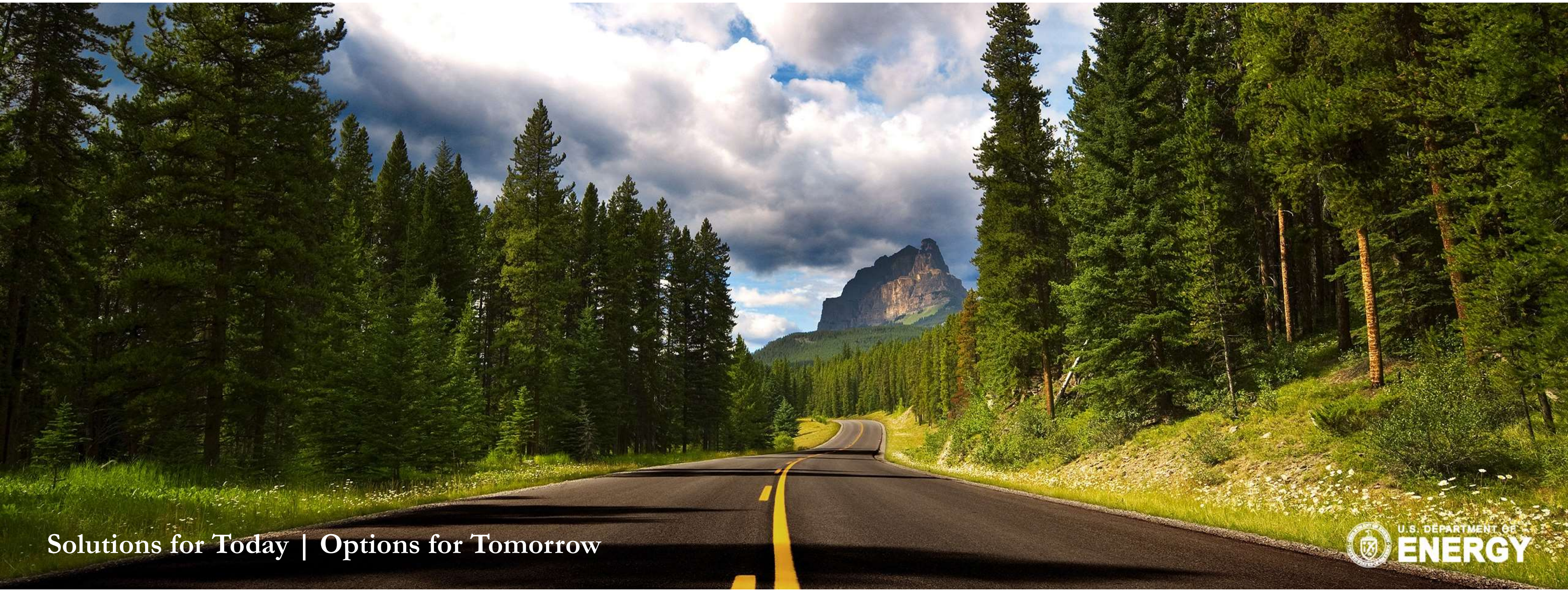
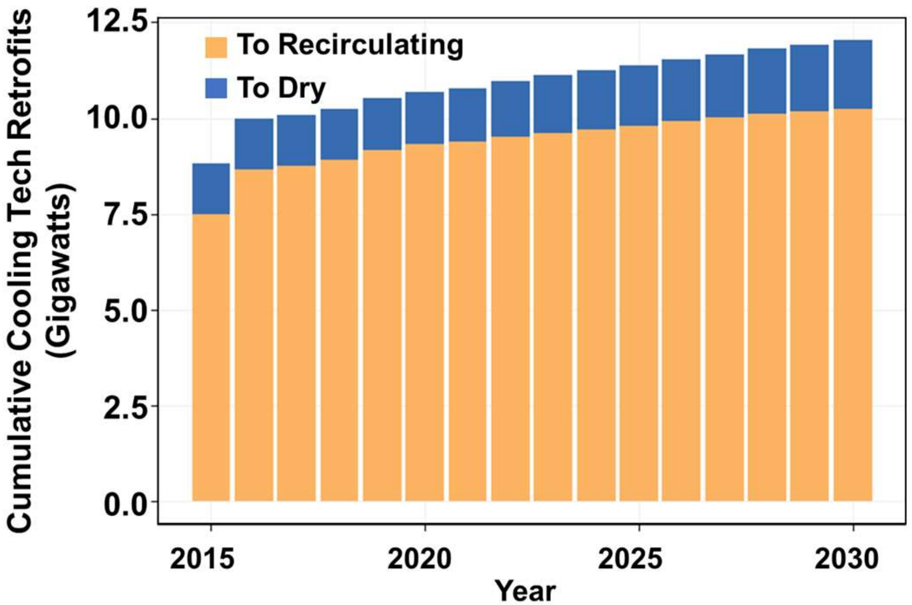
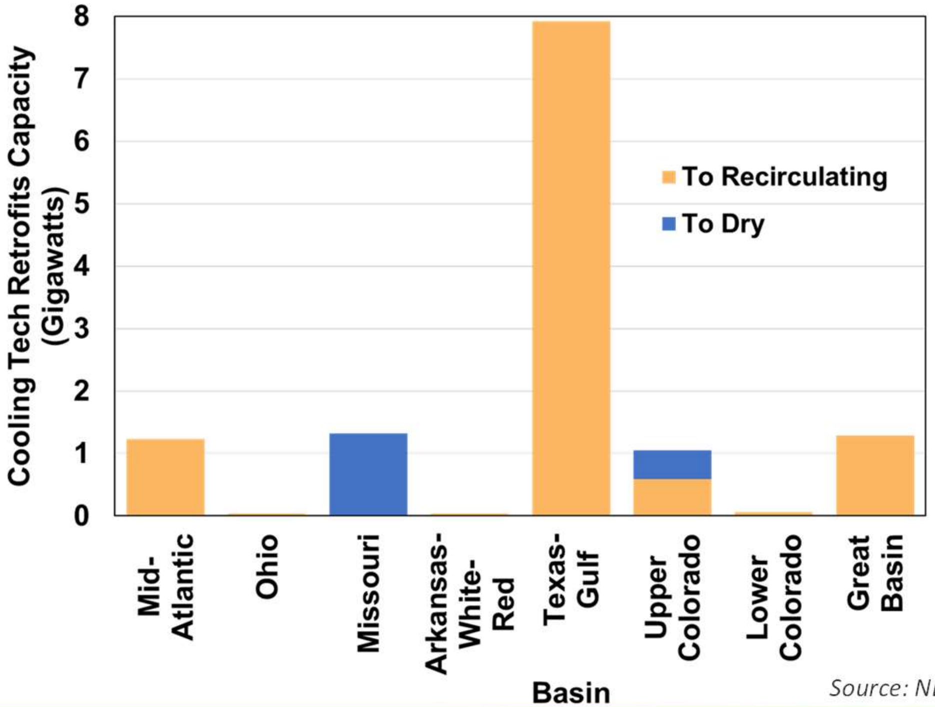


Model Results – Cooling Tech Retrofits Nationally

Projected Cooling Technology Retrofits from 2015-2030



Projected Cooling Technology Retrofits Capacity by Basin from 2015-2030



Source: NETL

Model Results – Water Purchased Nationally

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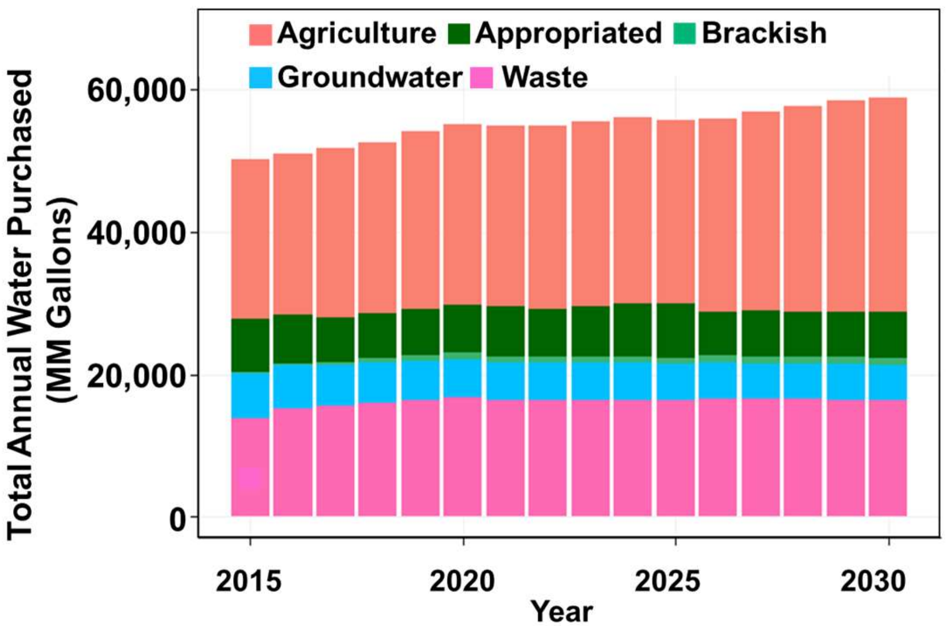
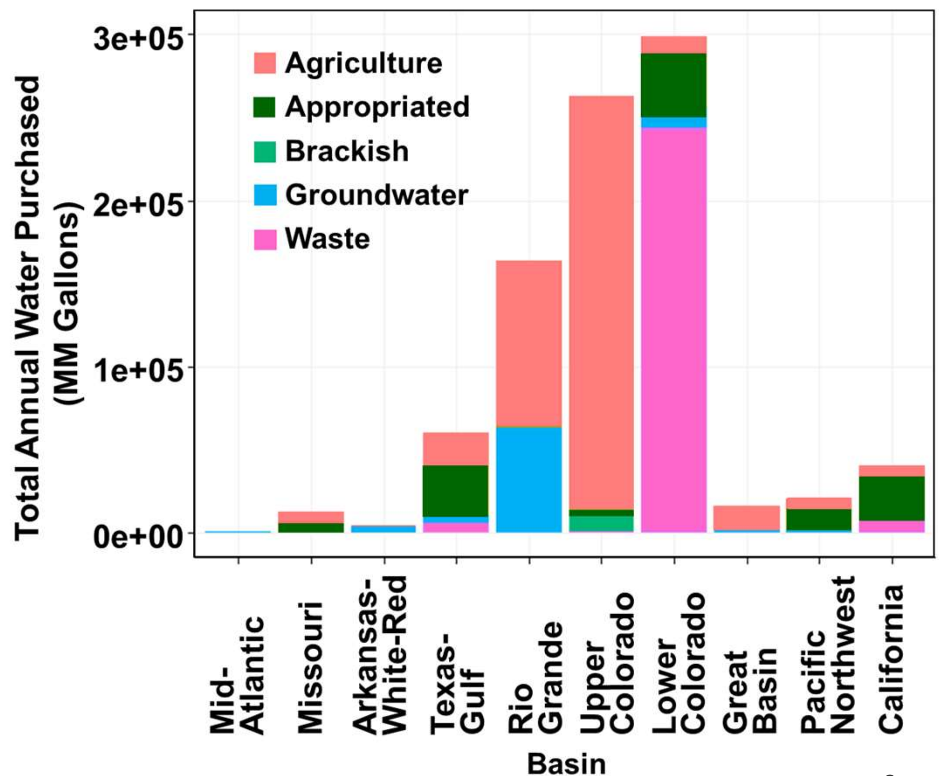
Total Annual Water Purchased from 2015-2030



Total Water Purchased by Basin from 2015-2030



Source: NETL