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An Analysis of the Effects of Drought Conditions on Electric Power Generation in the Western United States

by

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Study Background

- Work funded by National Energy Technology Laboratory (NETL)
  - Existing Plants Research Program – research component focuses on water use at power plants
  - Study evaluated availability of water at power plants under drought conditions and how that effects the electric power system in the drought region
- Drought is very pervasive in the U.S.
  - Many regions experience frequent droughts; some say western states have been in drought since 1999
  - Serious drought affected southeastern states in summer/fall 2007
- Drop in water levels due to drought can be double-edged sword for power sector
  - Water-cooled plants shutdown or curtail power output if water level drops below water intake structures
  - Low river flows and reservoir levels can reduce power from hydroelectric plants

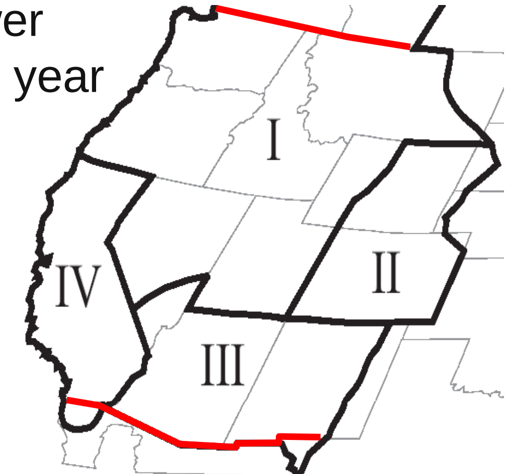
Overall Study Methodology

- Simulate operation of a regional power system under non-drought conditions (base case)
- Simulate operation of a regional power system under drought conditions
- Compare results of both simulations from an operational, cost, and environmental perspective
- Draw conclusions that may be applicable to all U.S. electric power systems

Scope of Power System Simulation Analysis

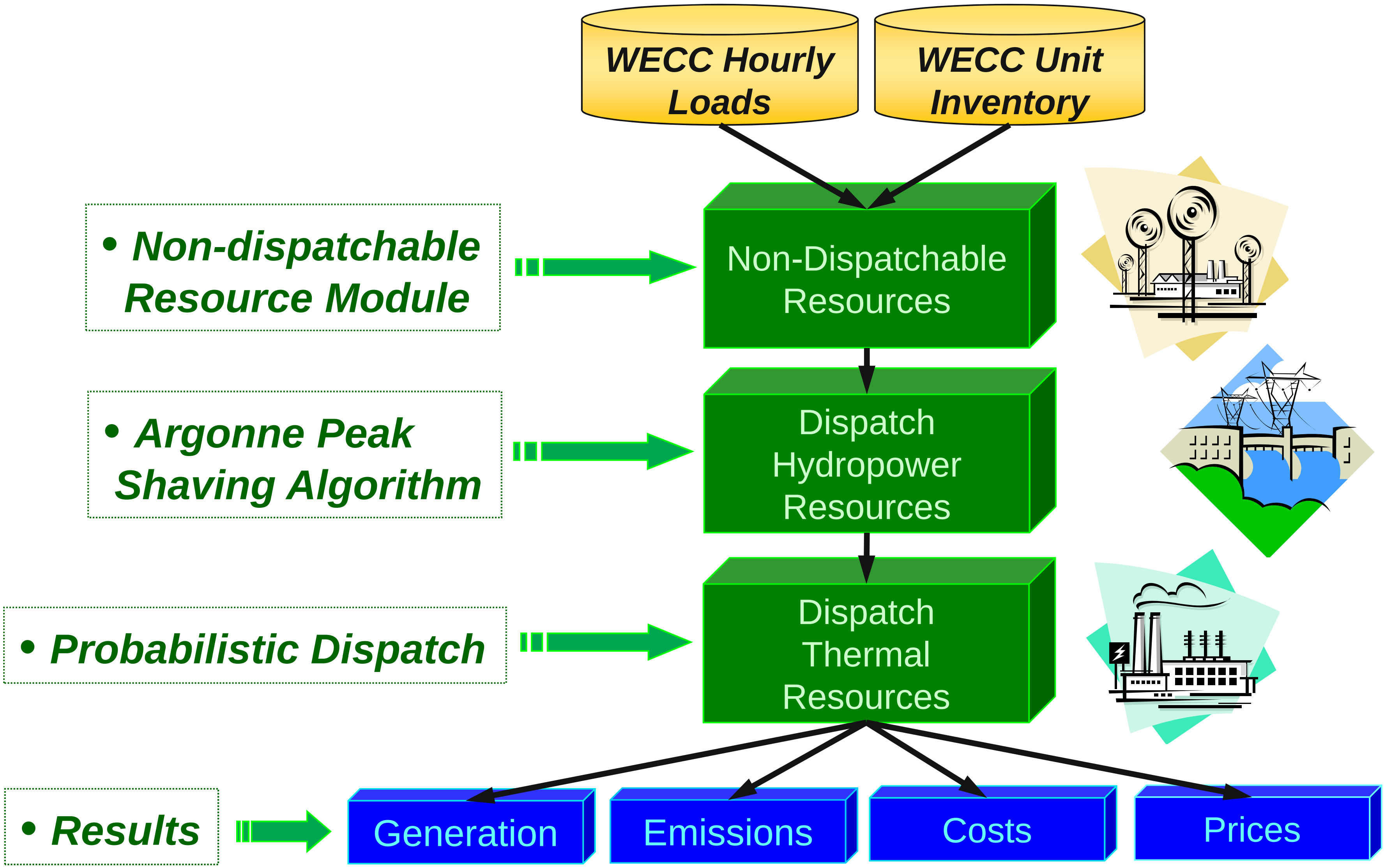
- Western U.S. – Western Electricity Coordinating Council (WECC)
  - Argonne developed verified unit inventory in previous studies
  - Experiences frequent droughts
  - Region has substantial hydropower resources (28% of capacity in average year; up to 40% in wet year)
- Data obtained from public sources – unit characteristics & system loads from DOE/EIA, Federal Energy Regulatory Commission, and WECC publications
- Simulate operation of wind and hydropower plants; thermal plants served remaining loads; simulate their operation with a unit level hourly probabilistic dispatch model developed by Argonne
- Verified methodology and model operation against actual 2006 WECC data
- Simulated operation in 2010, 2015, and 2020; model results included:
  - Monthly unit generation (in Megawatt hours [MWh])
  - Monthly unit production costs ($)
  - Distribution of monthly and hourly system-wide electricity prices
  - CO_2 emissions (million tons) – CO_2 from biomass was neglected; accounts for only 1% of generation in West. Emission factors obtained from Energy Information Agency by fuel type

Simulation Modeling Assumptions



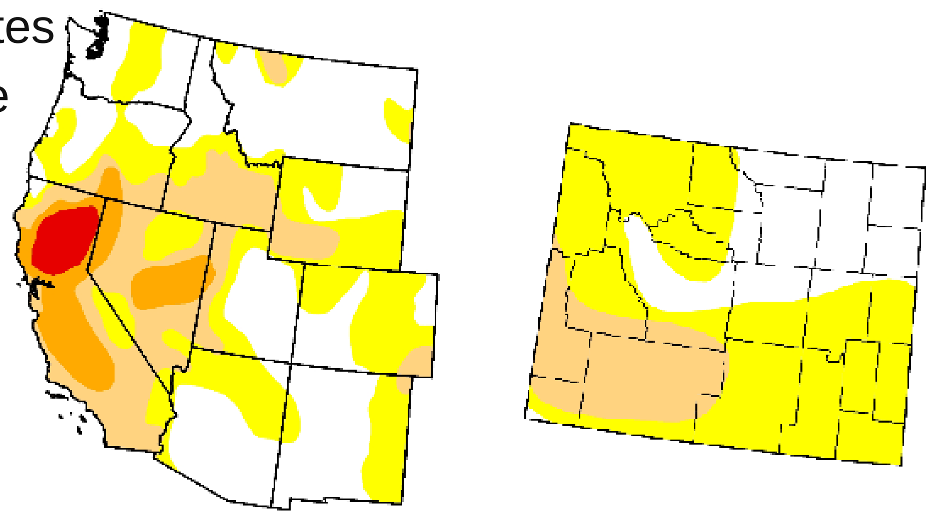
- Normal and drought hydropower scenarios – lowest hydropower generation between 1980 – 2005 chosen to represent drought year
- Future system additions followed current WECC plan & EIA Annual Energy Outlook (AEO) 2008 – units added to maintain 15% reserve margin in each WECC region
- Expansion candidates included
  - 600 MW coal unit – advanced cooling system; little to no surface water use
  - 400 MW combined cycle unit – advanced cooling system on steam turbine portion
  - 230 MW gas turbine unit
  - 50 MW geothermal unit
  - 30 MW municipal solid waste unit
  - 80 MW biomass unit
  - No new nuclear units
- Accounted for existing & new wind generation – matched AEO regional totals
- Chose drought scenario based on U.S. Drought Monitor, operated by University of Nebraska Lincoln
- Units affected by drought were obtained from water intake database

System Dispatch Methodology

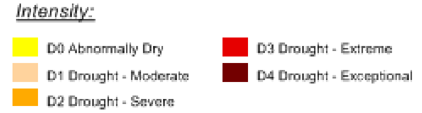


Choosing a Drought Scenario

- Drought conditions chosen from U.S. Drought Monitor (1/27/09)
- Only powerplants using fresh water for cooling and located within areas with a drought intensity of moderate or worse were shutdown
- Plants within drought area were found in database developed by a companion Argonne study (Kimmell and Veil, 2009)
- Drought affected 5 plant sites in 4 states
- If affected plant was a combined cycle plant, steam turbine was shutdown; gas turbine portion could continue to operate
- Year with lowest hydro generation between 1980 and 2005 was chosen



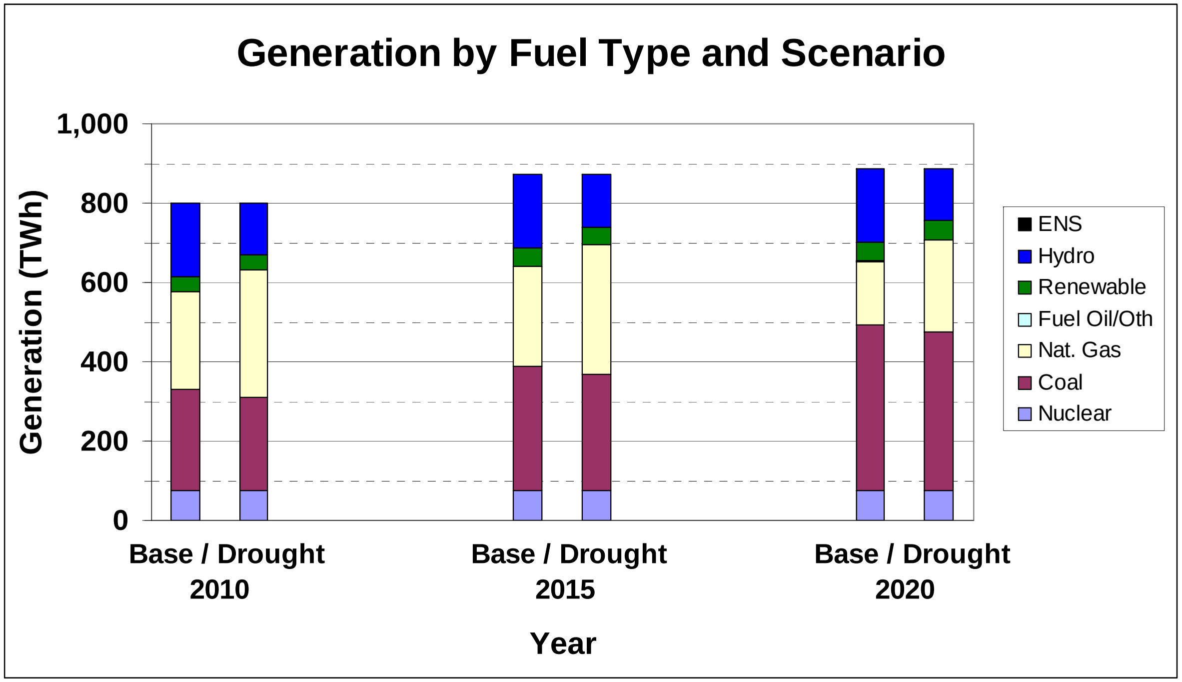
Drought Conditions on January 27, 2009



Source: http://drought.unl.edu/dm

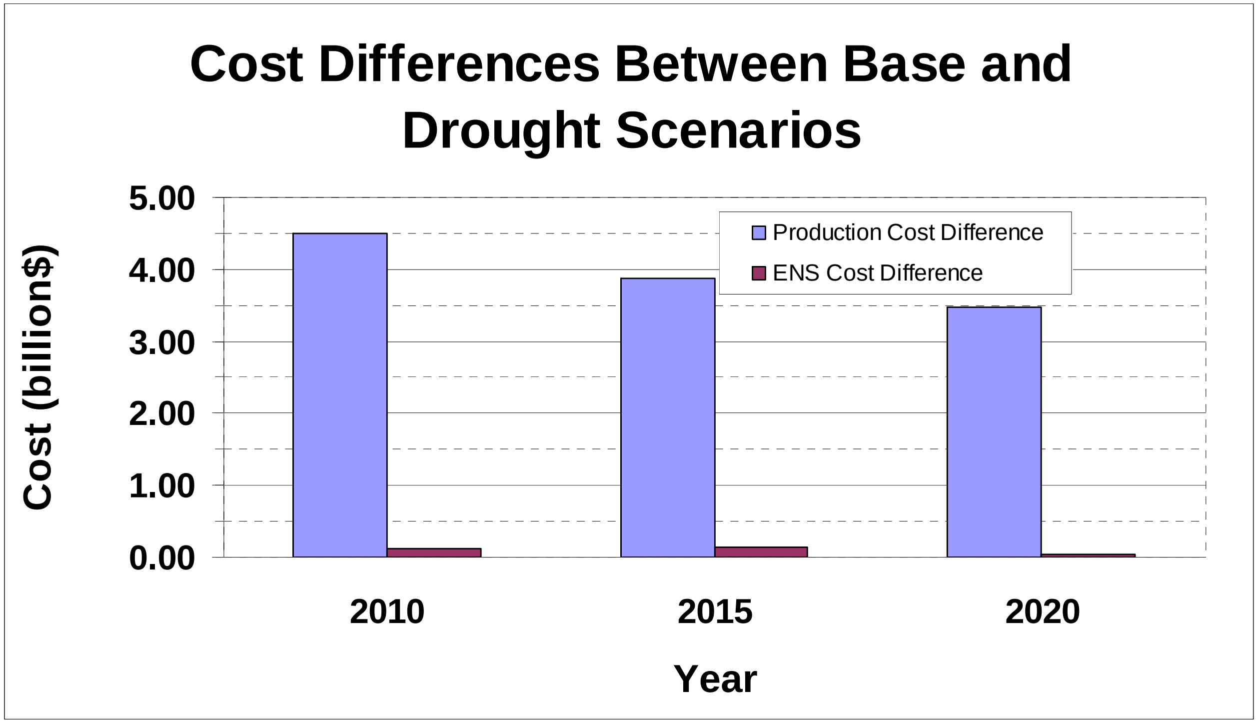
Impact of Drought on Generation Mix

- Hydropower dropped by 54 TWh or about 30%
- Coal generation dropped by 20.6 TWh in 2010 & 2015; by 15.6 TWh in 2020
- Fuel oil and renewables rose only slightly
- No increase in nuclear – capacity factor already at max in base scenario. In WECC, these plants do not rely on fresh surface water for cooling
- Natural gas rose by over 70 TWh in all 3 years – made up almost entire amount not generated by coal/hydro. Not fully utilized in base scenario – have lower capacity factor than coal



Impact of Drought on Generation Cost

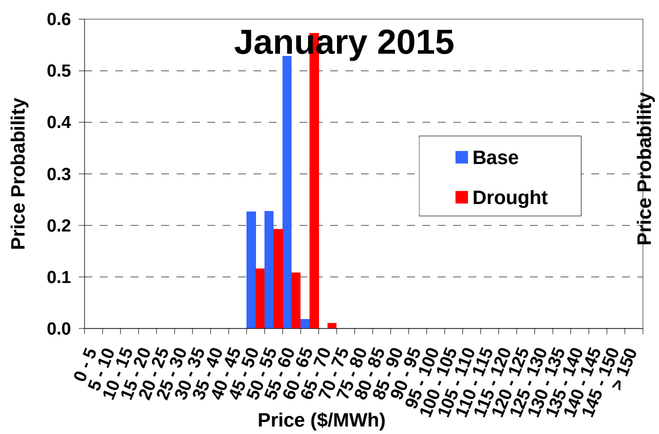
- Production costs rose 25%, 22%, & 23% in 2010, 2015, and 2020
- Energy Not Served (ENS) rose by 3.5 times in 2010 & more than double in 2015 & 2020; Virtually all occurred in July & August, WECC's peak load months
- Production costs and ENS decrease over time because new coal plants with cooling systems less vulnerable to drought displace natural gas plants

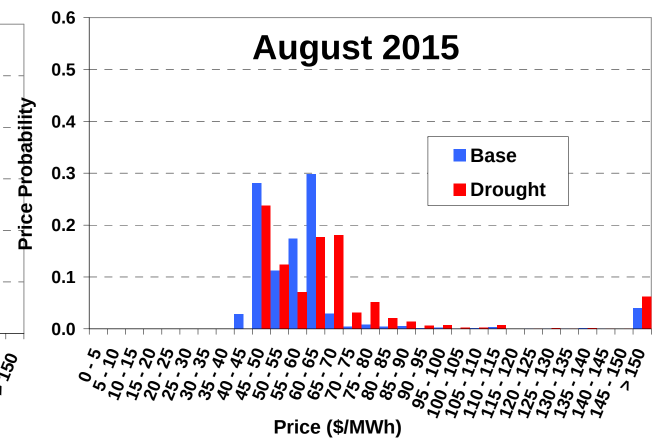


Impact of Drought on Electricity Price

- Average monthly system-wide prices shown in table
- Highest difference in summer – July & August – 25 to 35% in 2010 & 2015, drops to 15 to 25% by 2020
- Price distribution between months varies greatly; much wider in August (summer peak) than January
- 5 to 10% of time prices in August 2010 & 2015 will exceed $150/MWh; drops to 2% by 2020

Month	Average Price of Electricity ($/MWh)						Price Difference (%)		
	Base Scenario			Drought Scenario					
	2010	2015	2020	2010	2015	2020	2010	2015	2020
Jan	61.01	54.04	51.76	65.97	58.32	56.79	8.1%	7.9%	9.7%
Feb	60.21	53.30	50.67	67.21	59.40	54.29	11.6%	11.5%	7.2%
Mar	55.58	49.14	46.02	60.84	53.38	50.69	9.5%	8.6%	10.1%
Apr	54.95	48.47	43.61	61.08	53.45	50.27	11.1%	10.3%	15.3%
May	54.69	46.88	40.57	62.23	53.06	48.29	13.8%	13.2%	19.0%
Jun	55.35	48.71	40.04	61.80	54.96	47.48	11.7%	12.8%	18.6%
Jul	**69.14**	**68.07**	**54.17**	**91.67**	**89.16**	**67.24**	**32.6%**	**31.0%**	**24.1%**
Aug	**78.48**	**87.87**	**61.75**	**105.70**	**109.75**	**71.27**	**34.7%**	**24.9%**	**15.4%**
Sep	59.97	52.85	44.95	64.05	56.73	50.17	6.8%	7.3%	11.6%
Oct	63.20	55.75	43.04	65.47	57.86	47.24	3.6%	3.8%	9.8%
Nov	62.97	55.36	52.13	65.89	58.18	56.36	4.6%	5.1%	8.1%
Dec	59.44	52.70	50.89	66.72	58.71	55.30	12.2%	11.4%	8.7%





Impact of Drought on CO_2 Emissions

- CO_2 emissions from drought scenario higher by 20 million tons each year
- Overall, increase is small; 5.4% in 2010, 4.3% in 2015, and 3.8% in 2020
- Natural gas plants replaced virtually all generation lost due to drought
- CO_2 emissions are less than what might be expected because natural gas:
  - Produces less CO_2 per BTU than coal; emission factor is 44% less than coal
  - Units are generally more efficient; use less fuel for each unit of electricity produced

Year	Base Scenario (10^6 tons of CO_2)	Drought Scenario (10^6 tons of CO_2)	Difference (10^6 tons of CO_2)
2010	408.4	430.5	22.1
2015	480.5	501.3	20.8
2020	548.1	569.1	21.0

Conclusions from Simulation - Generation Mix

- Natural gas plants heavily utilized during drought; are in best position because they are operated at lower capacity factors than coal plants
- Electric systems without sufficient natural gas capacity may have difficulty generating needed energy in the short term during a drought. Would need to purchase power on the open market at prices driven higher due to drought
- Electric systems relying heavily on coal would benefit in long term by constructing new coal plants with advanced cooling technologies. Coal started coming back by 2020 in WECC example.
- Nuclear may be a wild card in drought scenario
  - Those with cooling systems that don't use fresh surface water would be unaffected – as in WECC example
  - Those with fresh water cooling systems would be subject to shutdown/curtailment – their loss could severely strain electric system
  - Nuclear plants in other U.S. power systems rely more on fresh surface water cooling than in WECC

Conclusions (cont'd) – Electricity Prices, Water Supplies, CO_2

- Increased generation by natural gas plants during drought would likely raise natural gas prices; consumers may be hit twice – high electricity prices and high domestic gas prices. Quantification beyond scope of this study.
- Generators have been trying to diversify coolant water supplies
  - Installing groundwater wells to supplement lake water
  - Piping groundwater from a distance
  - Using wastewater from nearby facilities, such as produced water from a coal bed natural gas project (proposed for 2 Wyoming power stations)
- Groundwater may not be an option in some areas because of competing water needs, such as drinking water
- CO_2 emissions may increase only slightly due to drought

Areas for Future Study

- Transmission constraints
  - Droughts can affect specific areas without affecting others
  - Under normal conditions, transmission lines may be at limit; heavy use and high ambient air temperature (which often accompanies drought) can further reduce operating limit
- Drought effects power plant operation other than low water intake levels
  - Often accompanied by very hot conditions
  - Power plant limits on water temperature discharge – power output reductions even though water intake levels may be sufficient
  - Effect of excessive heat on air intakes; especially gas turbines

Thank you for your attention

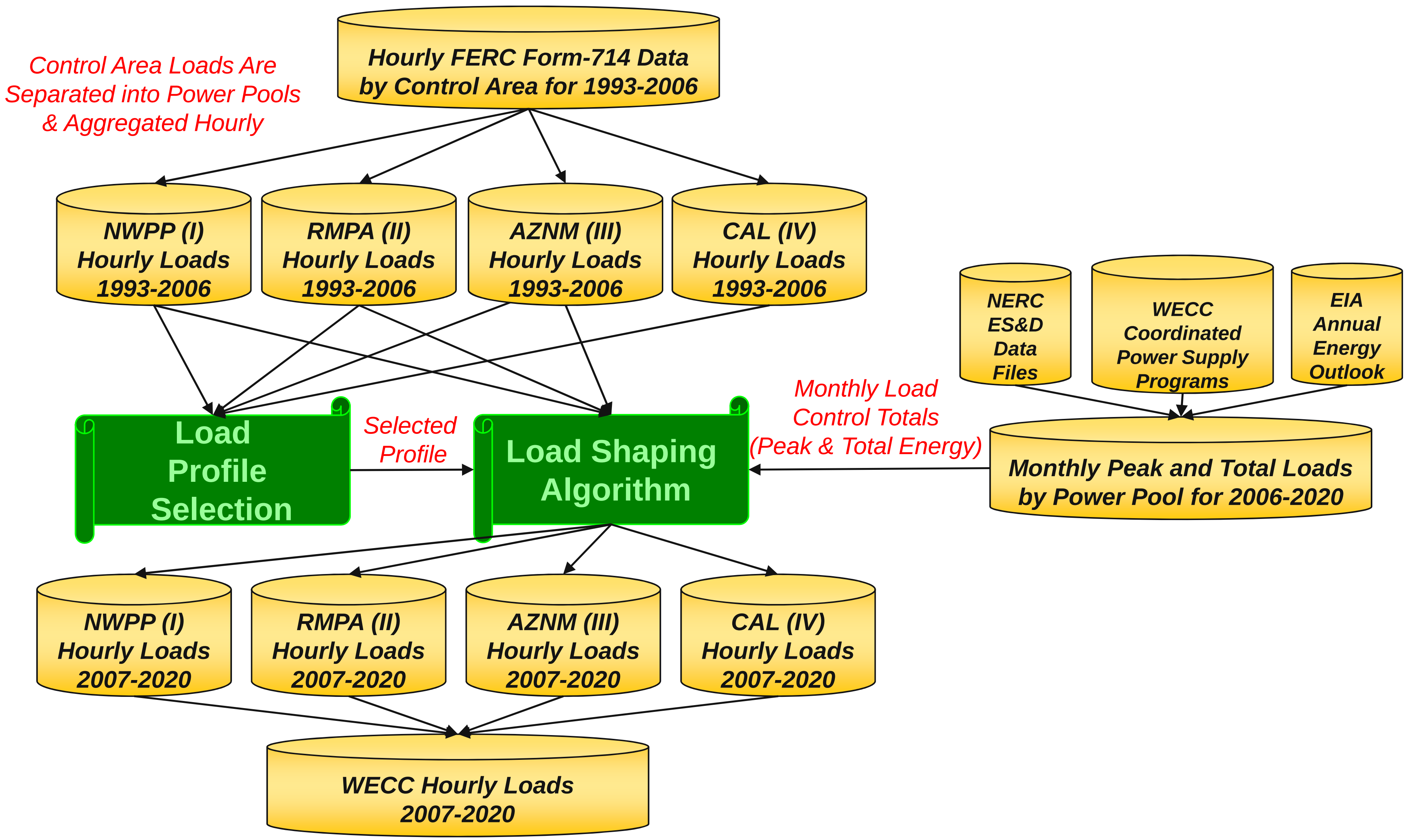
The full report is available at:

- NETL web site
  - ***http://www.netl.doe.gov/technologies/coalpower/ewr/water/***
  - Kimmell and Veil 2009 study also located on this page

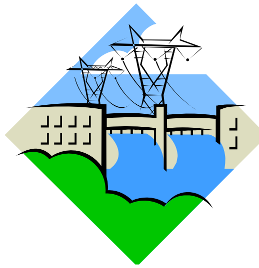
- Argonne National Laboratory web site
  - ***http://www.dis.anl.gov/publications/group_publications.html***
  - ***http://www.dis.anl.gov/pubs/63599.pdf***

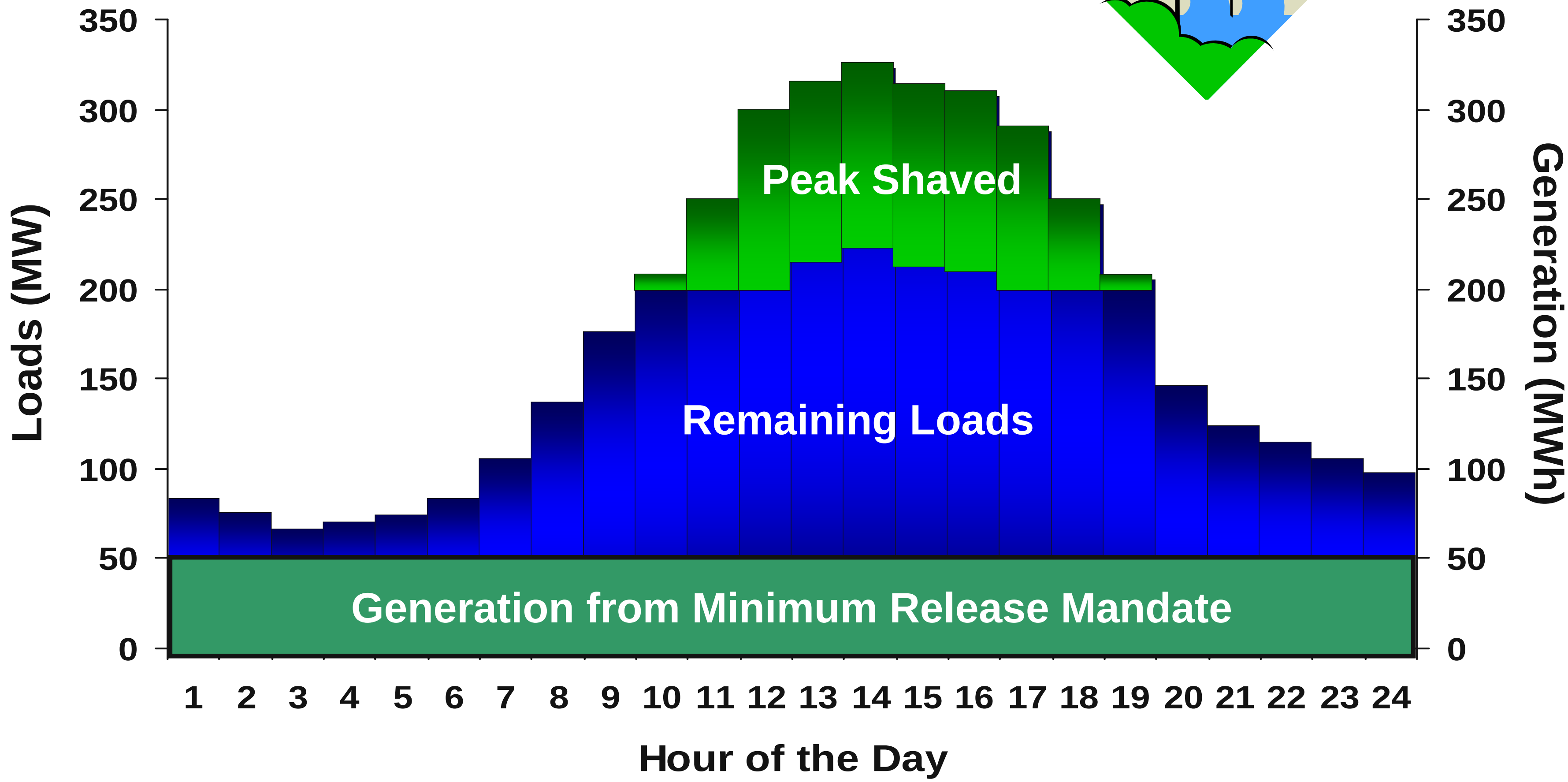
Supplemental Slides Follow

Processing Historic Hourly Loads to Obtain Future Load Profile

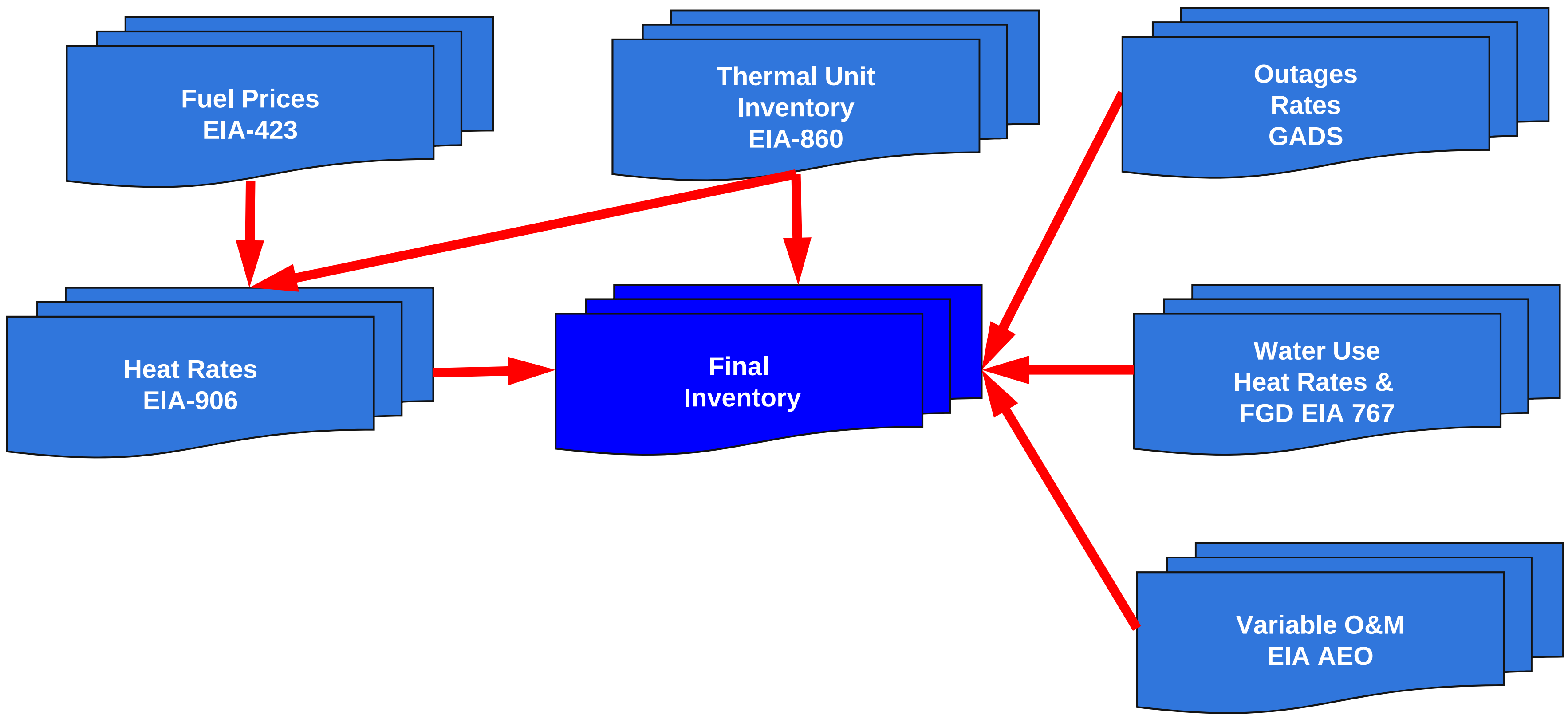


Simulating Hydropower Plant Operations Using the Argonne Peak Shaving Algorithm





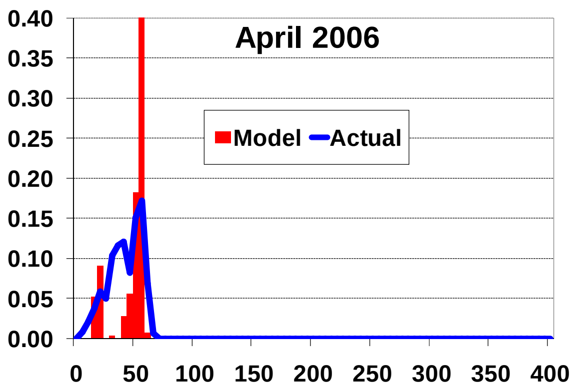
Creating a Thermal Unit Inventory

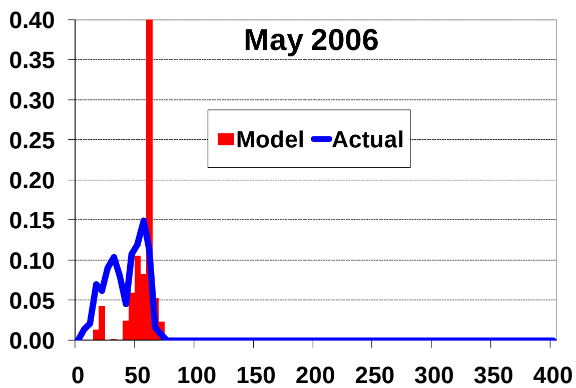


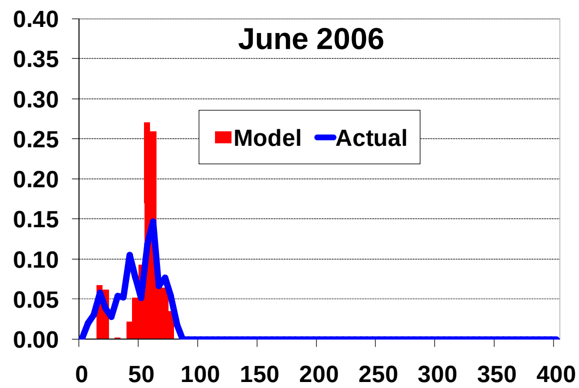
Model was Calibrated to WECC 2006 Data

Technology	Model Generation Mix (%)	Actual Generation Mix (%)
Coal	31.5	31.2
Gas	26.2	25.6
Nuclear	10.4	9.4
Hydro	28.1	28.8
Wind	1.6	1.4
Others	2.2	3.6
Total	100	100
Note: Actual generation mix is calculated based on AEO 2008.		

2006 Model Calibration for Generation Mix







Model Calibration – Price Probability Distributions for April through June 2006