Outline

1. Introduction
2. Statistical Analysis
3. Production Simulation Analysis
   - Economic Impacts of Renewables
   - Impact of Wind and Solar Forecasting Accuracy
   - Impact on Generation Operation by Type
   - Emissions
   - Impacts on operation of Hydro
   - Impacts on Ramp Rate capability
     - (rate in MW/min, available range in MW)
   - Transmission Loading
   - Observations
4. Quasi-Steady-State Analysis, QSS
5. Operational Implications and Mitigation Methods
6. Conclusions and Recommendations

MAPS Penetration Scenarios

- 2010T system - No new Renewables
  - Geothermal, Biomass, Wind and Solar generation held at 2006 levels
- 2010T system - No new Intermittents
  - Geothermal and Biomass increased to 2010 projections but Wind and Solar held to 2006 levels
- 2010T system – All Renewables
  - Geothermal, Biomass, Wind and Solar generation increased to “2010T” projections
- 2010X system
  - 33% Renewables
- 2020 system
  - High level of Renewables with loads increased to 2020 values

2010T System - "Tehachapi" expansion

- Assumed Cost Based Bids
  - Natural Gas ~ $5.70/MBTU
  - Distillate Oil ~ $6.50/MBTU
  - Coal ~ $1.5/MBTU
- Multiple Renewable Penetrations
  - No New Renewables after 2006
  - New Biomass and Geothermal after 2006
  - New Biomass, Geothermal, Wind and Solar after 2006
- Value of Wind and Solar Forecasts
  - No Forecast
  - Estimated Forecast (using state-of-the-art methodology)
  - Perfect Forecast

2010X System – Accelerated Intermittents

- Wind increased to 12,500 MW
- Solar increased to 2,300 MW
- Designed to simulate 33% Renewable penetration in a system that is comparable to "2010T" scenario
- Value of Wind and Solar Forecasts
  - No Forecast
  - Estimated Forecast (using state-of-the-art methodology)
  - Perfect Forecast

2020 System

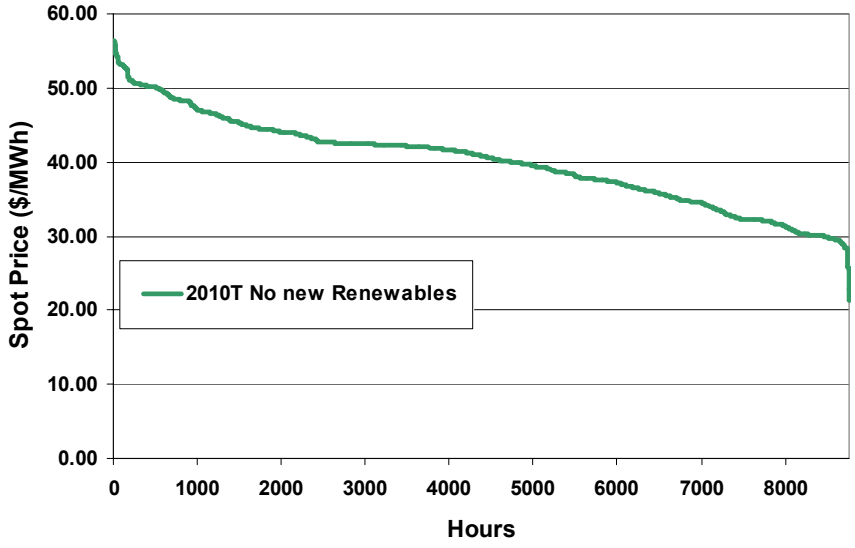
- Similar to 2010X expansion but California loads increased by 25% to simulate 2020 projected levels
- System outside California held constant at 2010 levels
- Prices held at 2010 levels to make results comparable to 2010T and 2010X scenarios
- Determine impact of projected load growth on high penetration of intermittent generation

MAPS Modeling Description

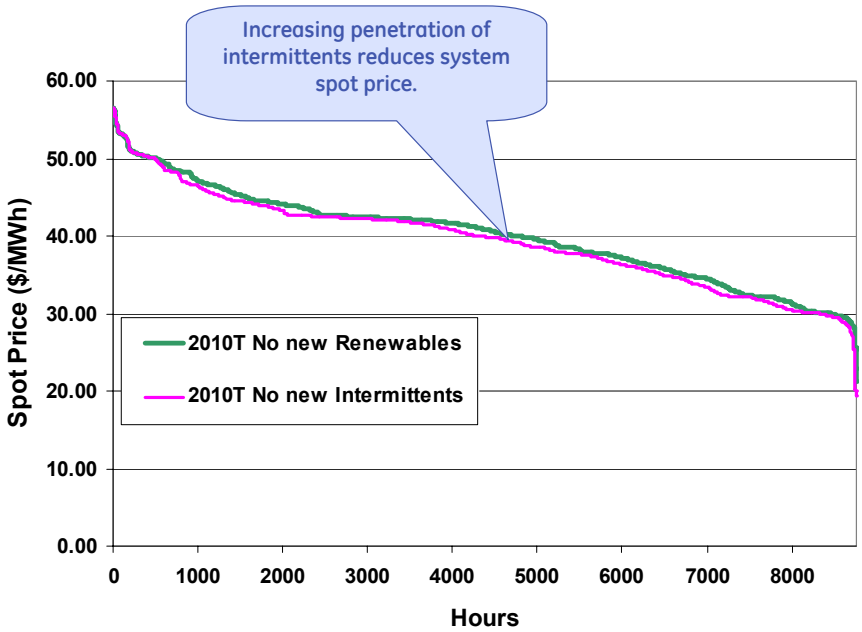
- All of WECC modeled
  - 73 load forecast areas (14 in California)
  - 692 hydro-electric plants
  - 498 hourly shapes for wind and solar
  - 1749 thermal units
  - 15 pumped storage hydro
  - Intermountain and Pacific Intertie HVDC projects
  - 17 phase angle regulating transformers
  - 99 constraints from WECC Path Rating Catalogue
- Generating units assigned to specific busses
- Incremental heat rates, cycling characteristics, emissions
- Multiple years of “historical shapes” for load and intermittent resources: 2002, 2003 and 2004. (also referred to as A, B and C shapes)

Economic Impact

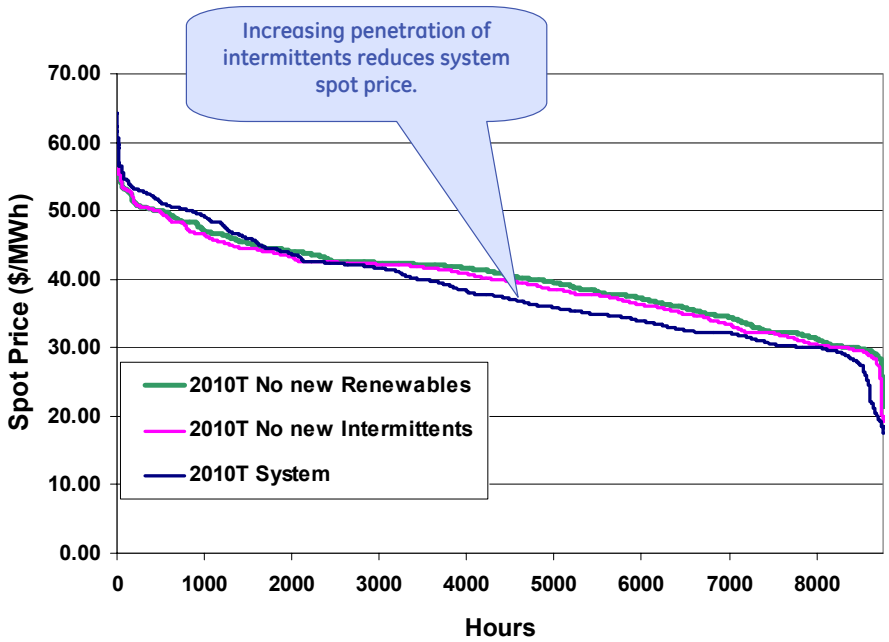
Spot Price Duration Curves – 2002 shapes (1)



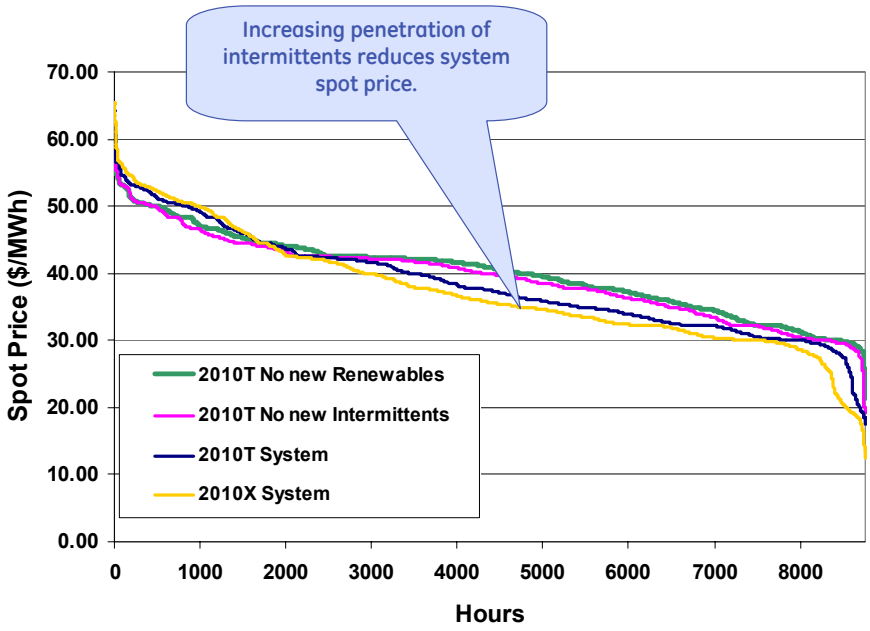
Spot Price Duration Curves – 2002 shapes(2)



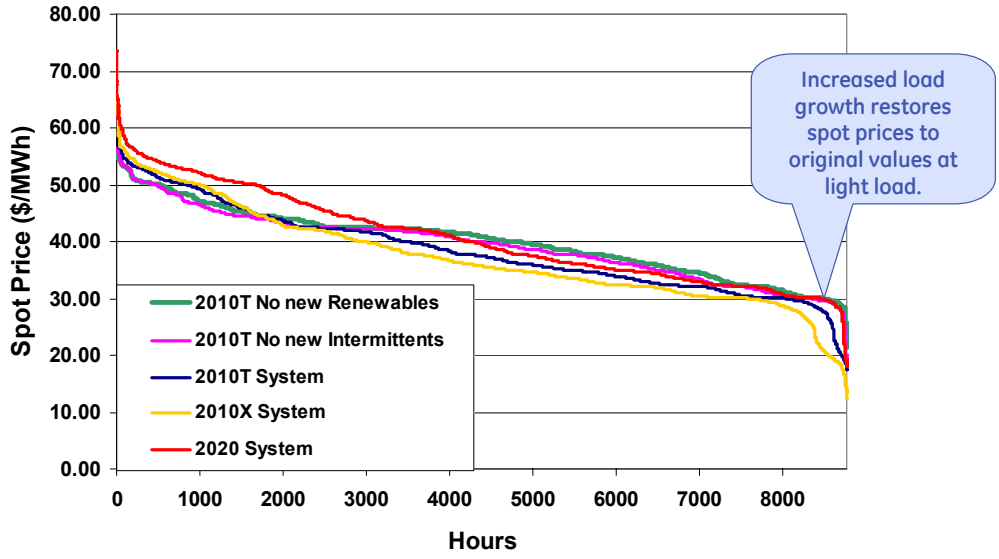
Spot Price Duration Curves – 2002 shapes(3)



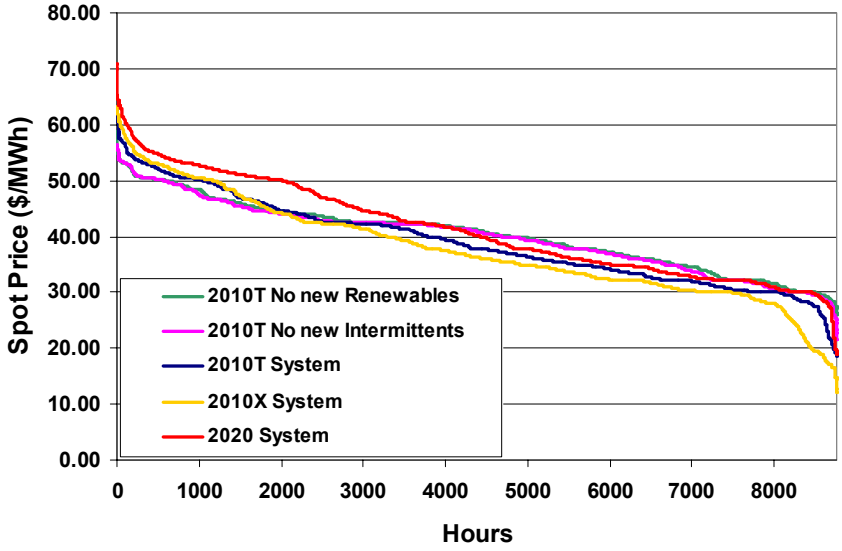
Spot Price Duration Curves – 2002 shapes(4)



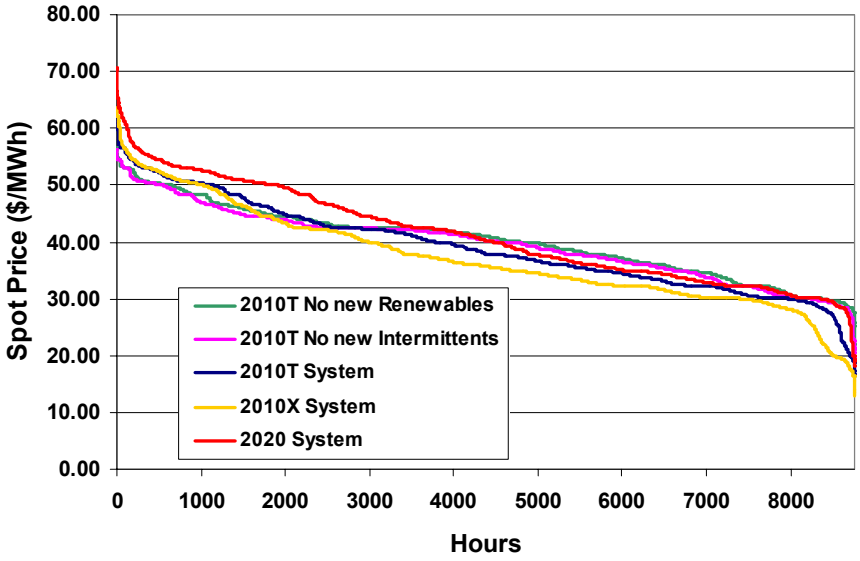
Spot Price Duration Curves – 2002 shapes(5)



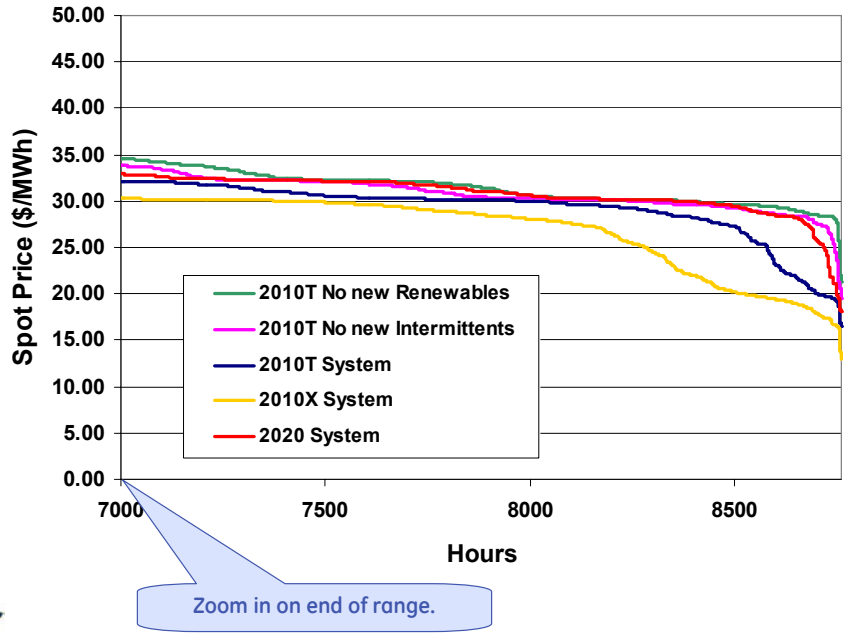
Spot Price Duration Curves – 2003 Shapes



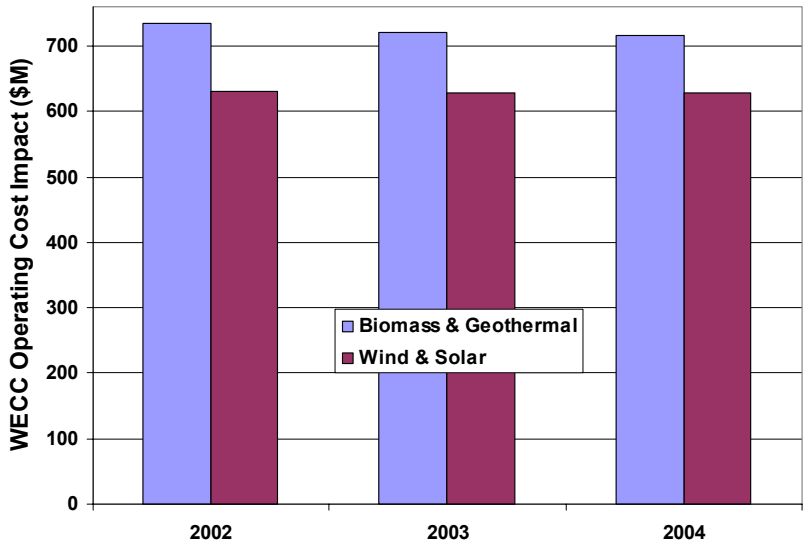
Spot Price Duration Curves – 2004 Shapes



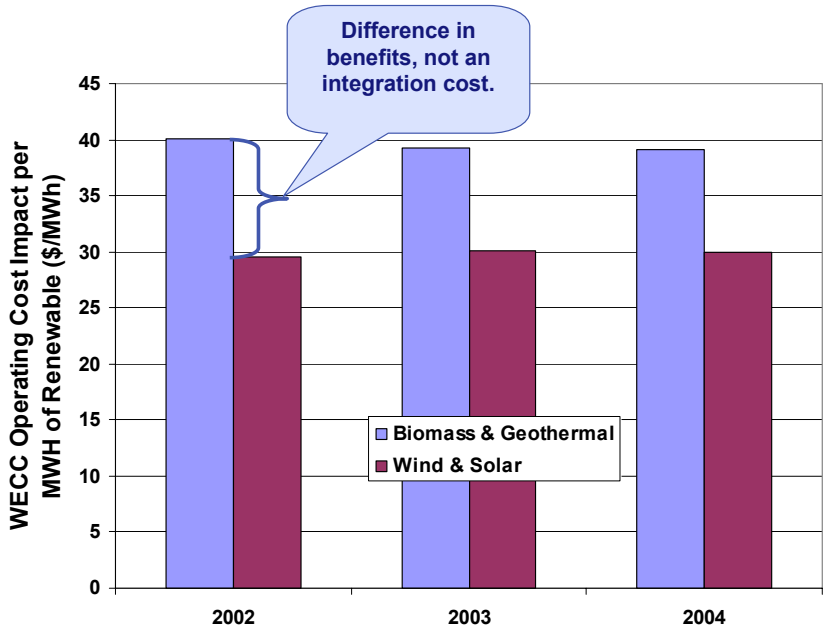
Spot Price Duration Curves – 2004 Shapes



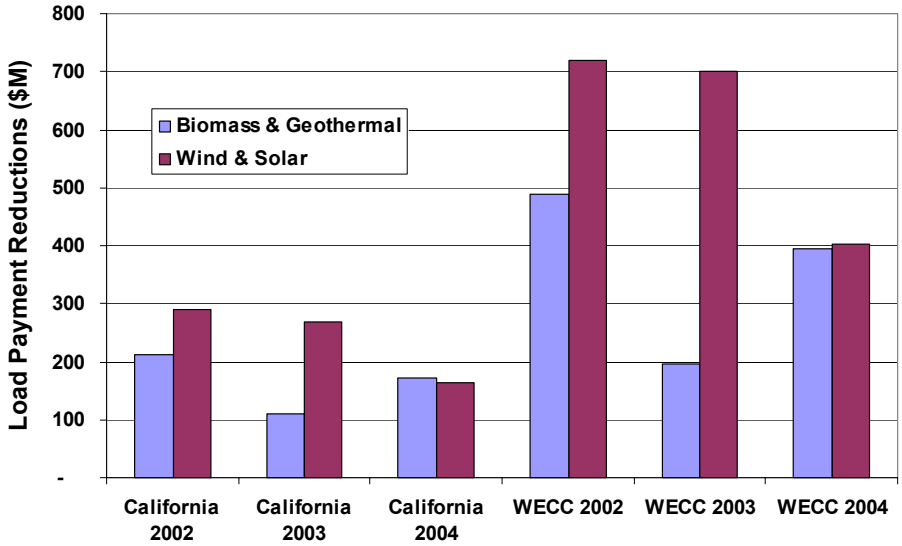
WECC Operating Cost Reductions due to additions of Renewables



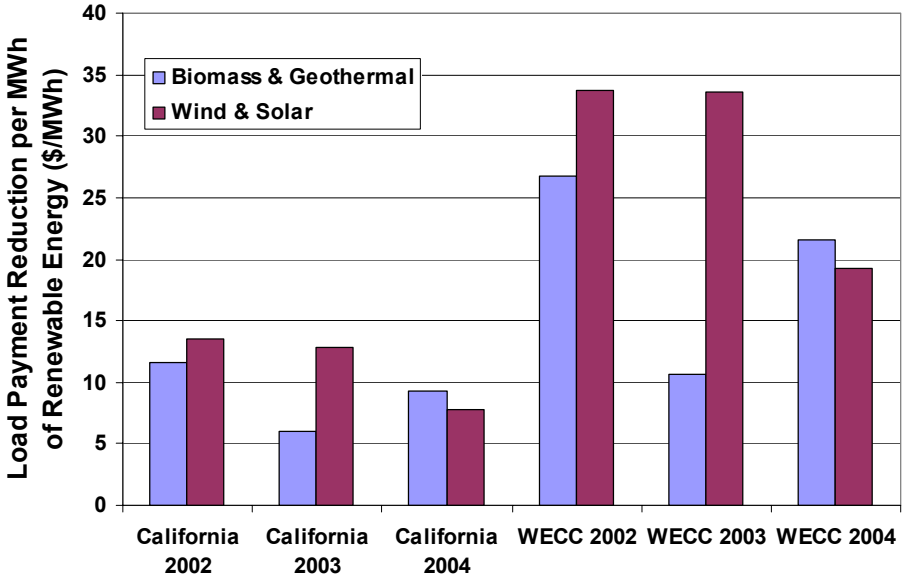
WECC Operating Cost Reductions due to additions of Renewables



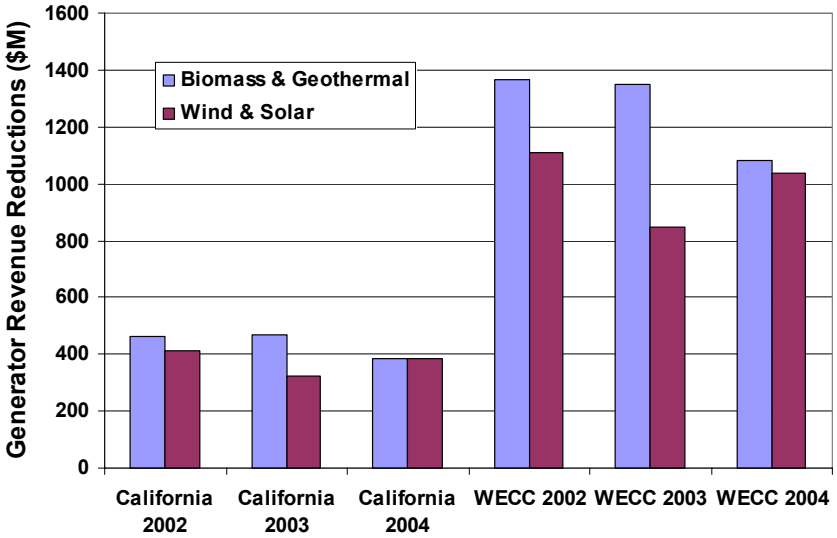
Load Payment Reductions due to Renewables



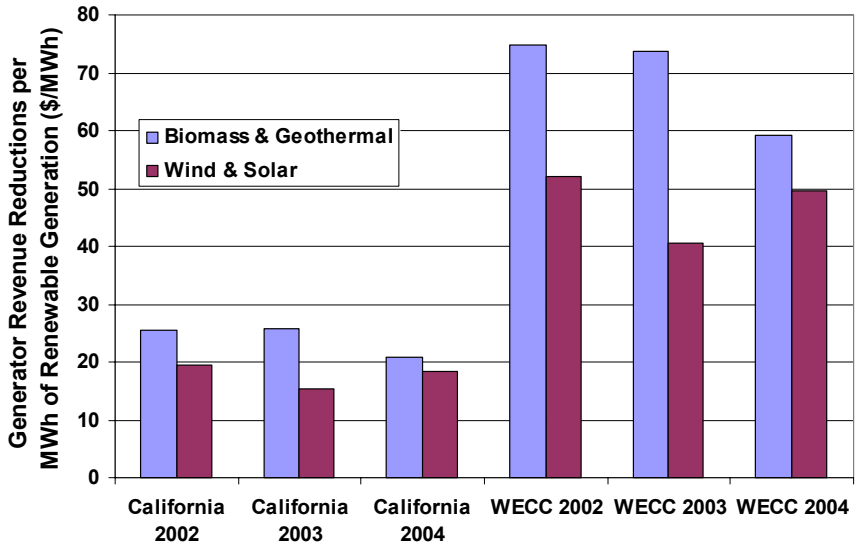
Load Payment Reductions due to Renewables



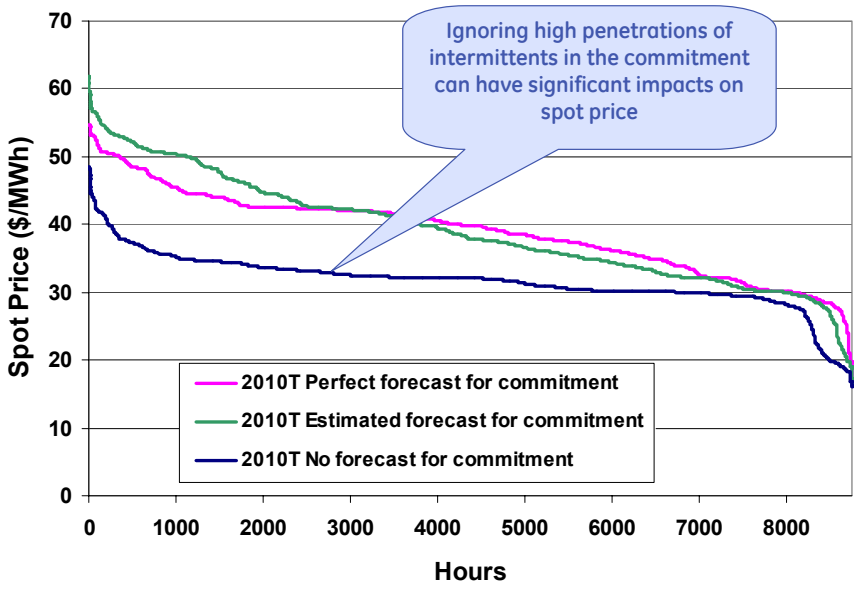
Non Renewable Generator Revenue Reduction due to Renewables



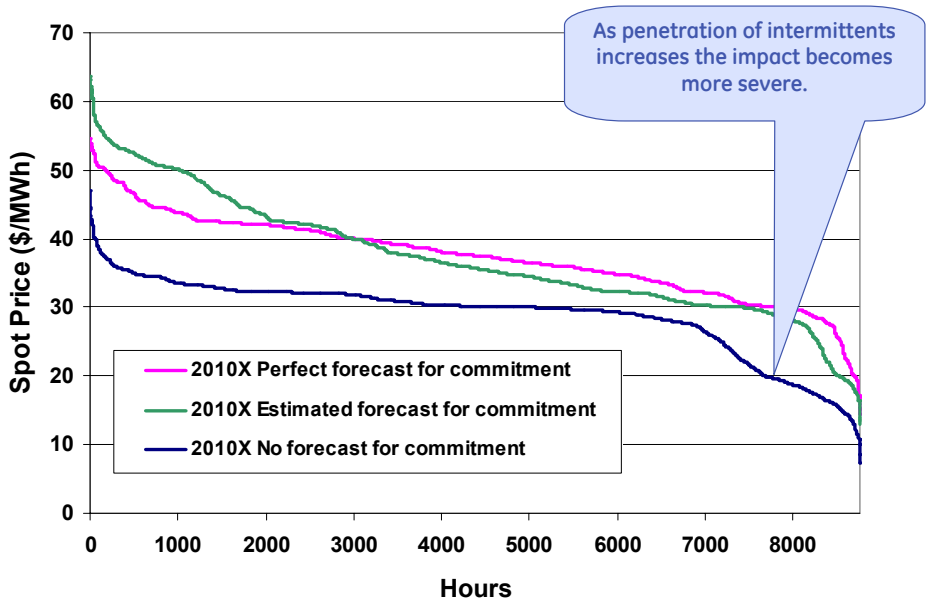
Generator Revenue Reduction due to Renewables



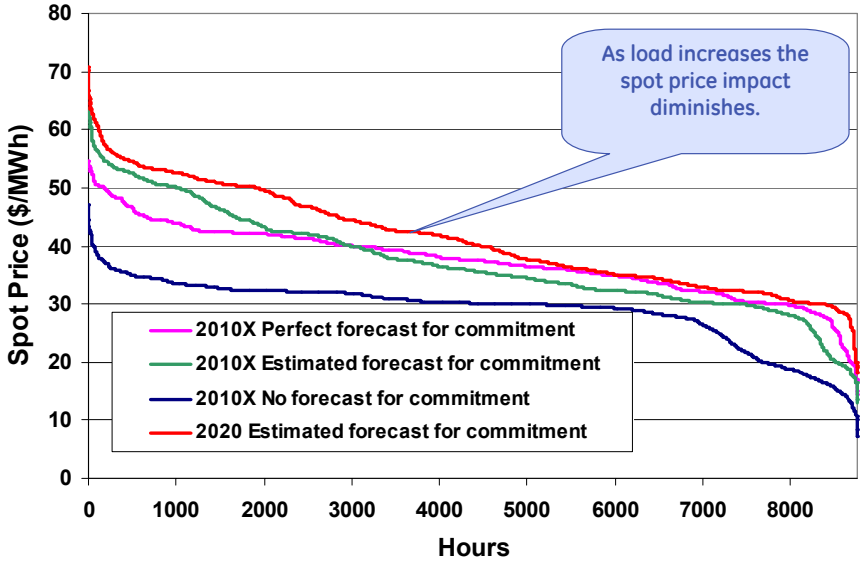
Impact of Forecast on Spot Price – 2004 Shapes



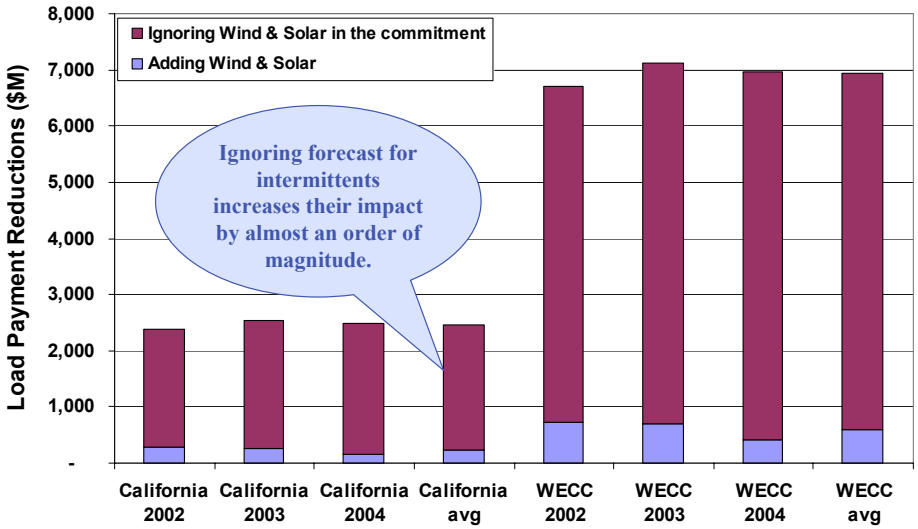
Impact of Forecast on Spot Price – 2004 Shapes



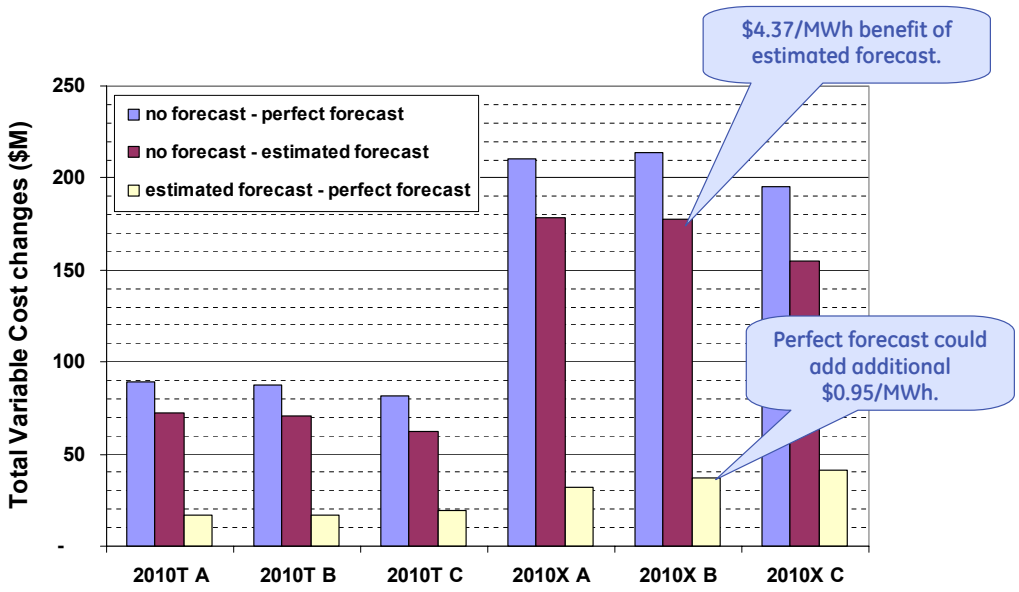
Impact of Forecast on Spot Price – 2004 Shapes



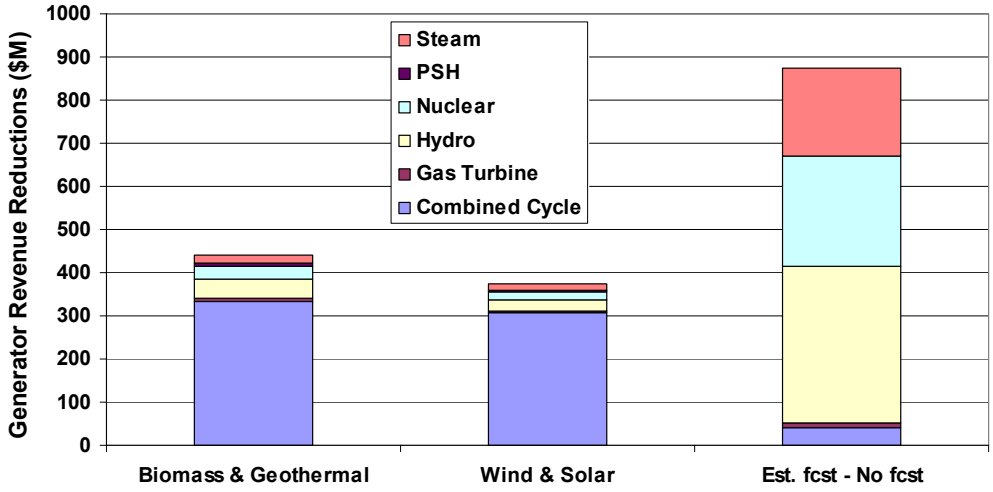
Load Payment Reductions due to Estimated Forecast vs No Forecast



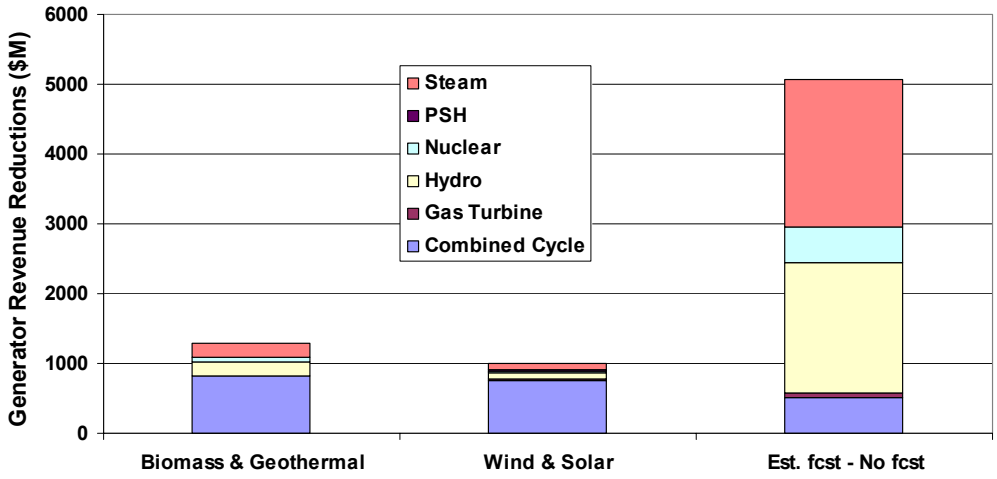
Total Operating Cost Impact of Intermittent Forecasting



California Generator Revenue Reduction (2010T)

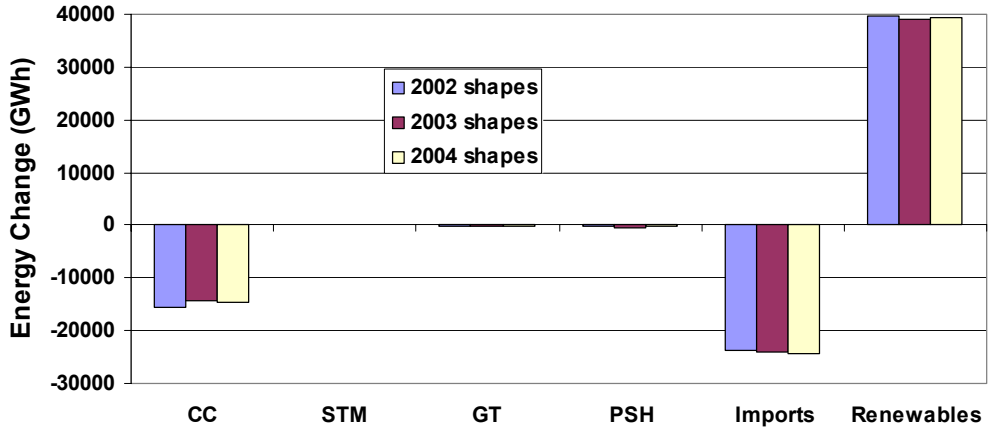


WECC Generator Revenue Reductions (2010T)

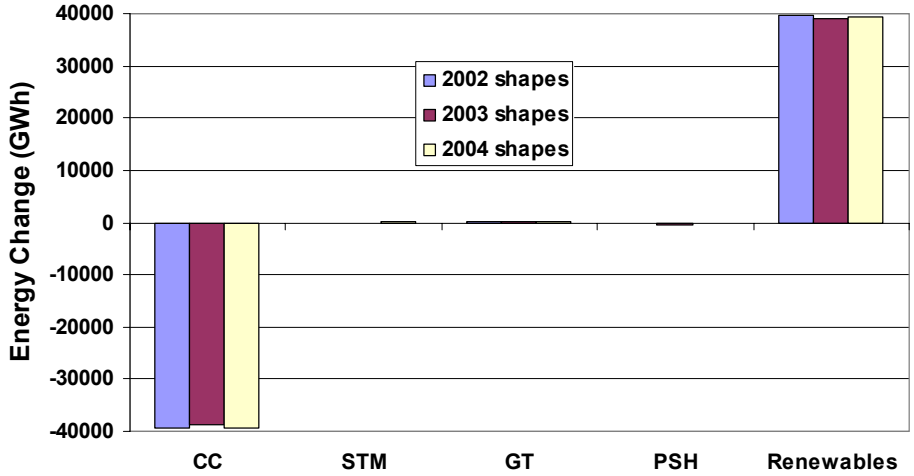


Generation Displacement

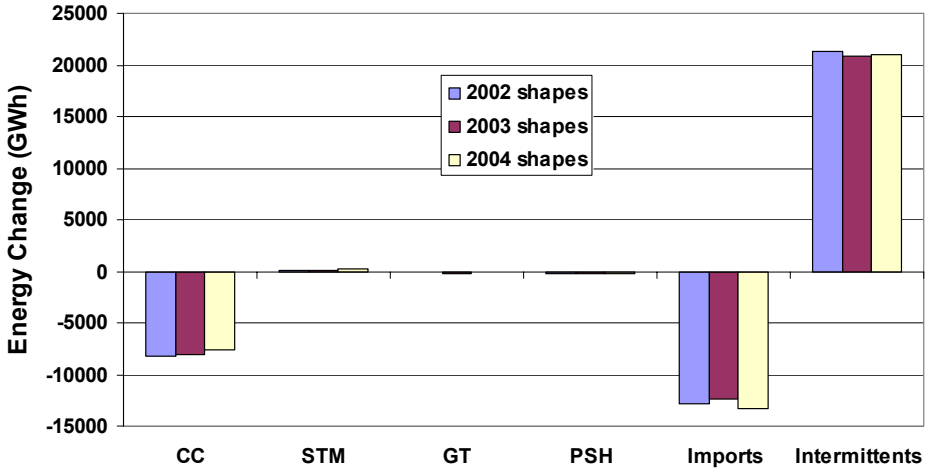
California Energy Change when Renewables are added 2010T



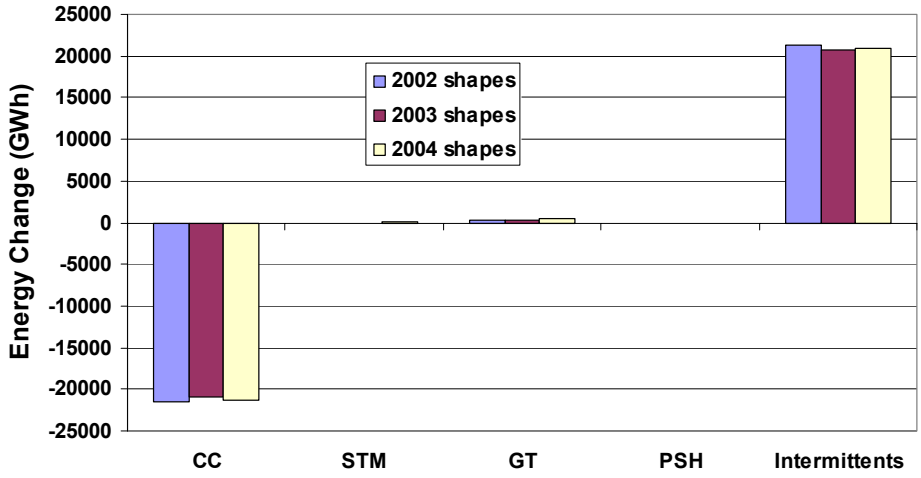
WECC Energy Change when Renewables are added 2010T



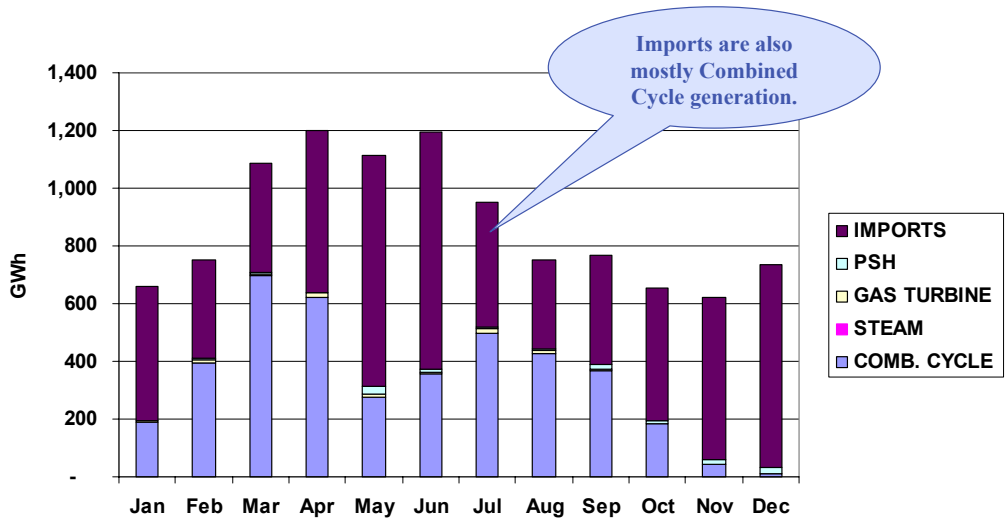
California Energy Change from Intermittents 2010T



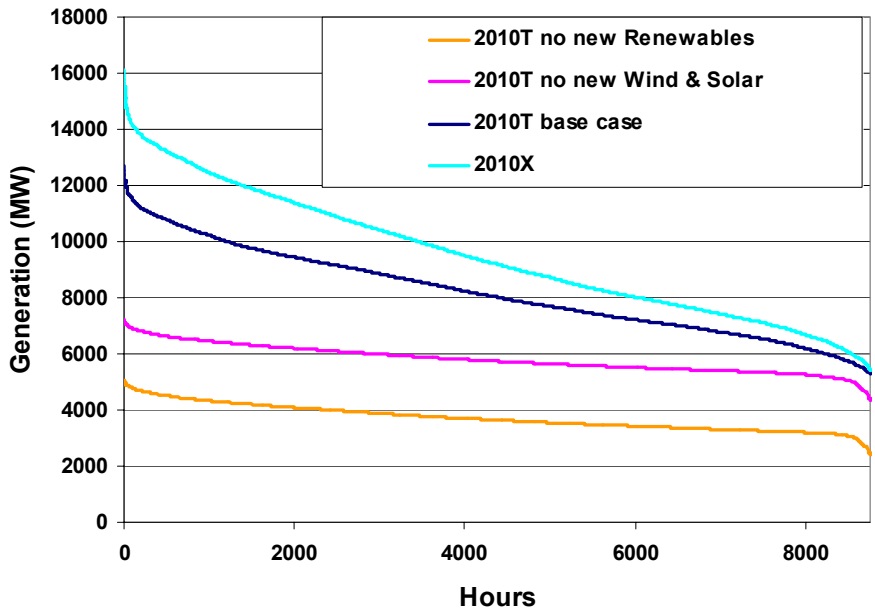
WECC Energy Change from Intermittents
2010T



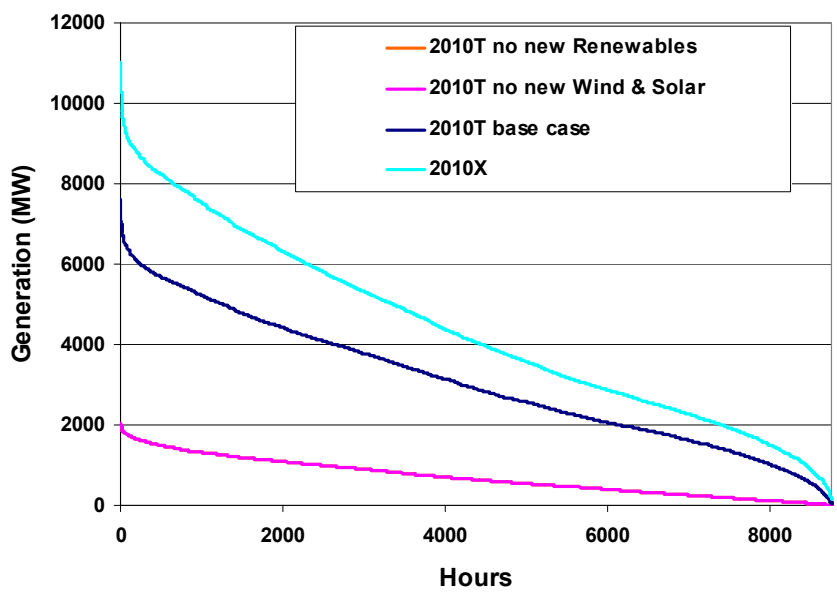
Monthly Generation Displacement:
"With Intermittents" minus "Without Intermittents"



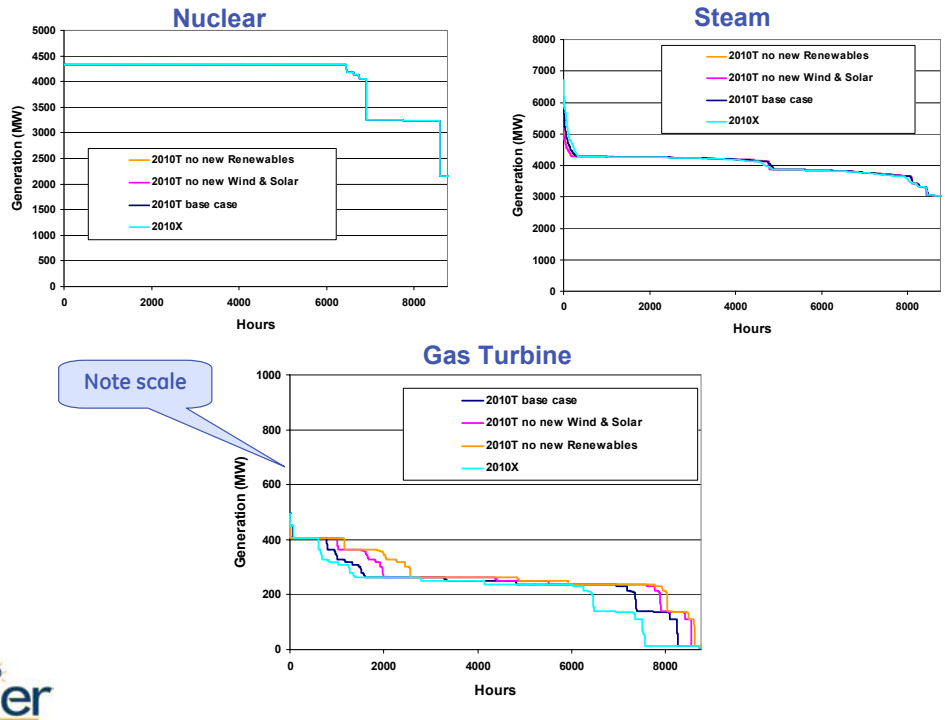
California Renewable Generation



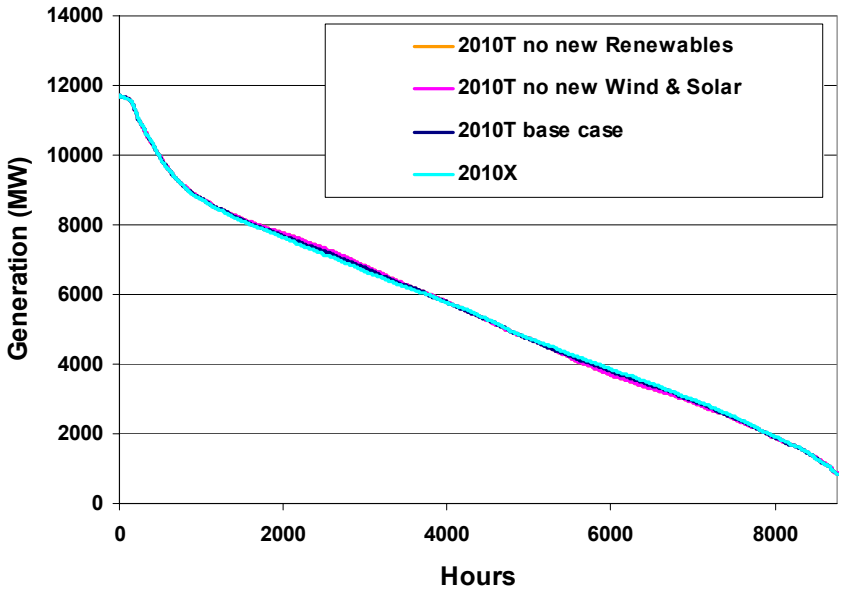
California Wind & Solar Generation



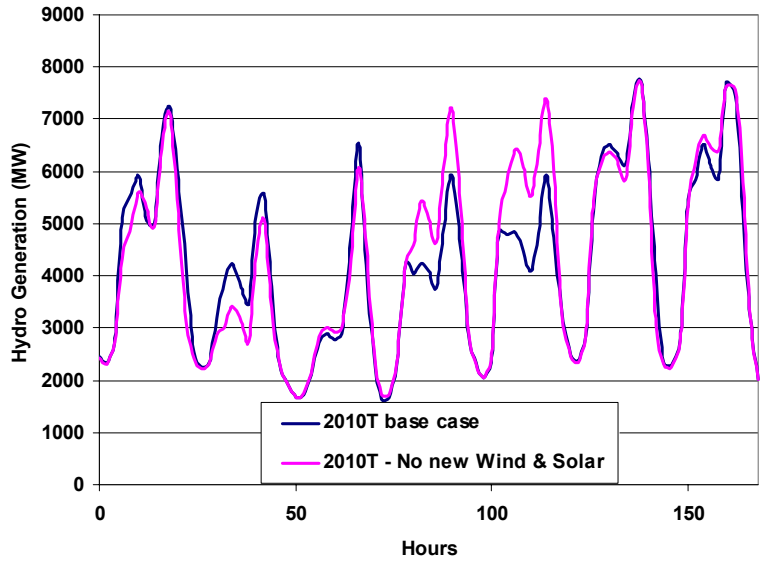
California Nuclear, Steam and Gas Turbine Generation



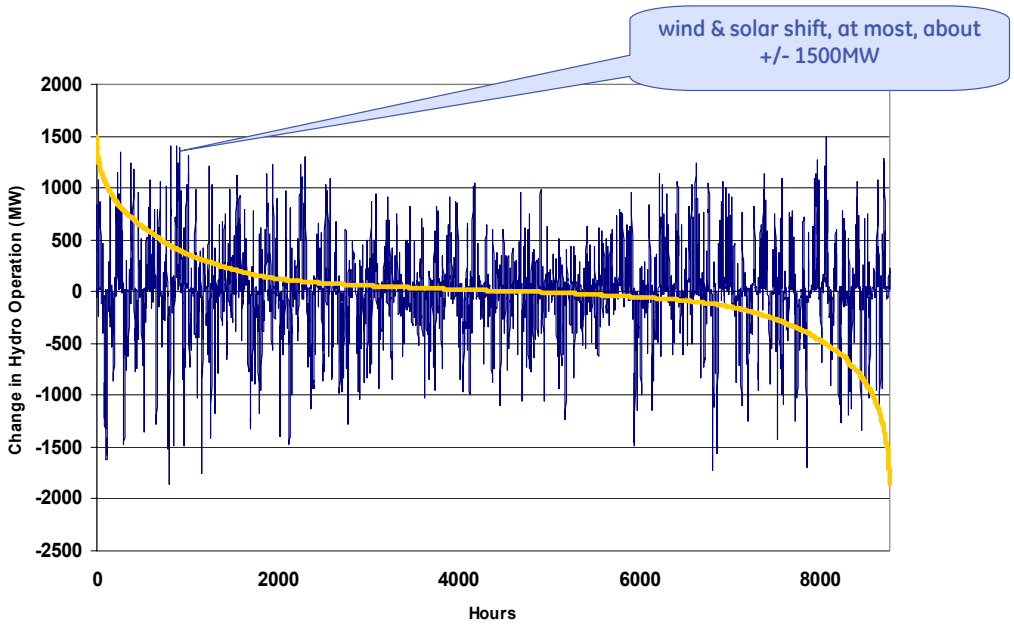
California Hydro Generation



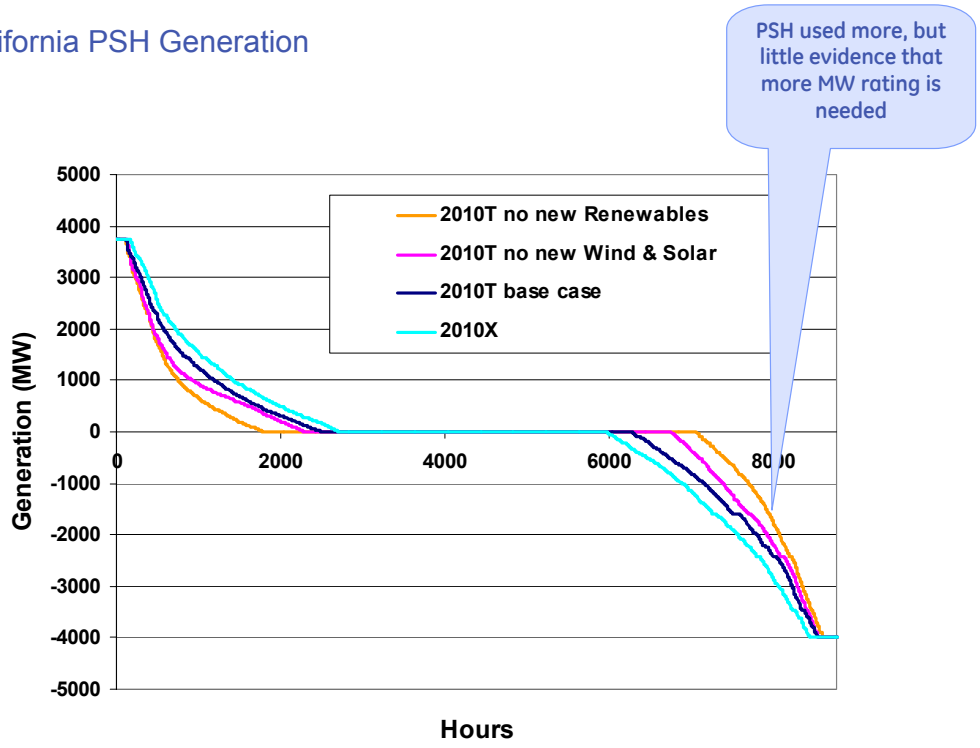
Change in Hydro Operation - 2010T



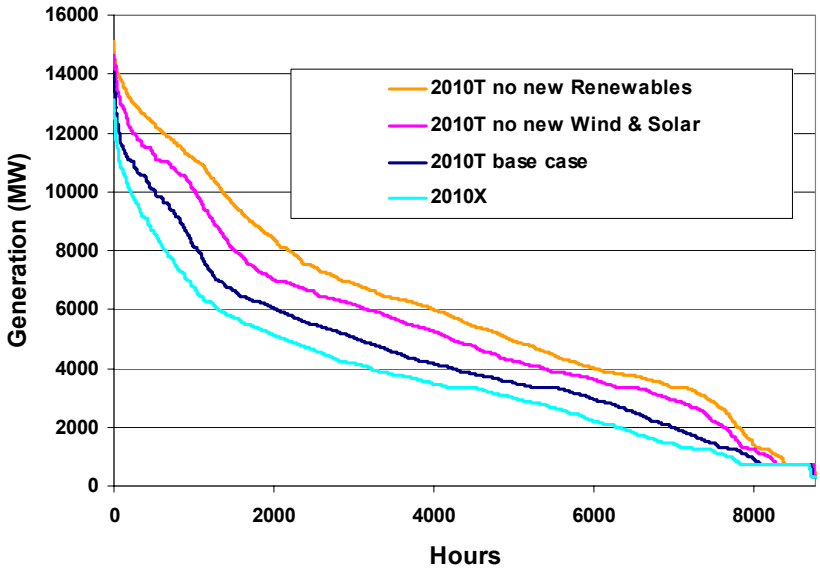
Change in Hydro Operation – 2010T
Delta between "base case" and "without new wind & solar"



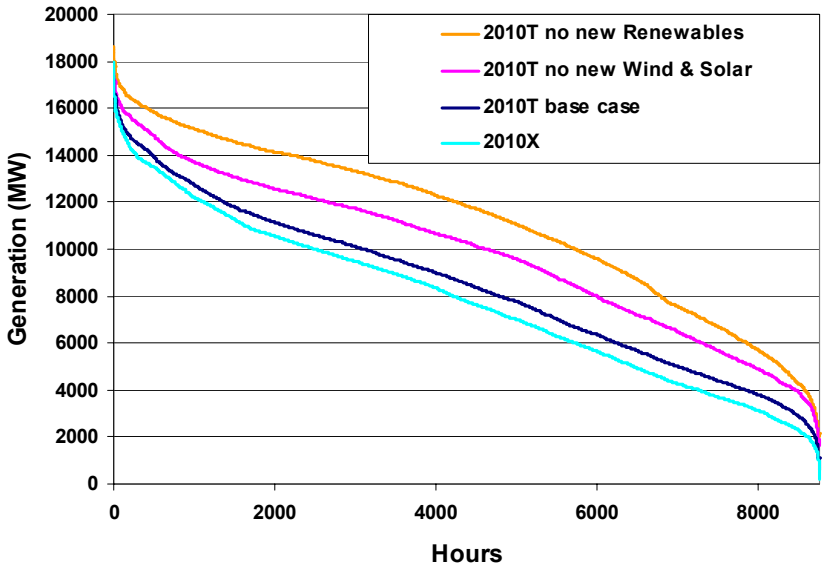
California PSH Generation



California Combined Cycle Generation

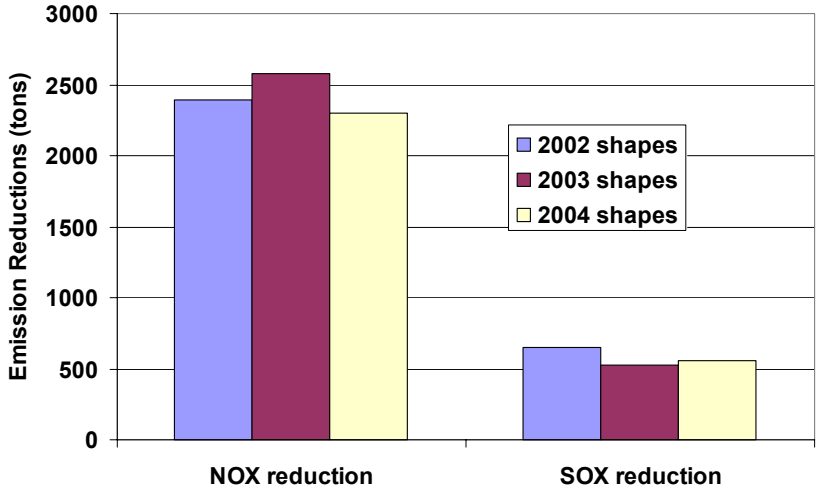


California Imports

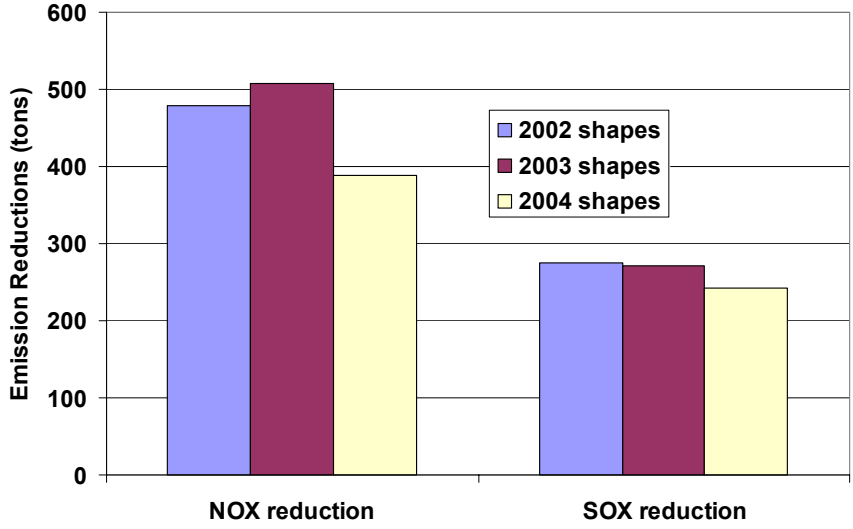


Emission Reductions

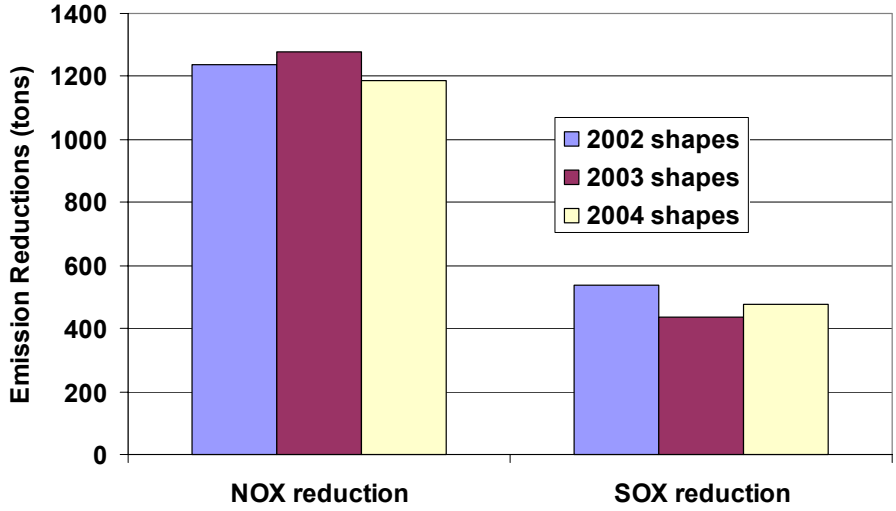
WECC Emission Reductions from Renewables 2010T



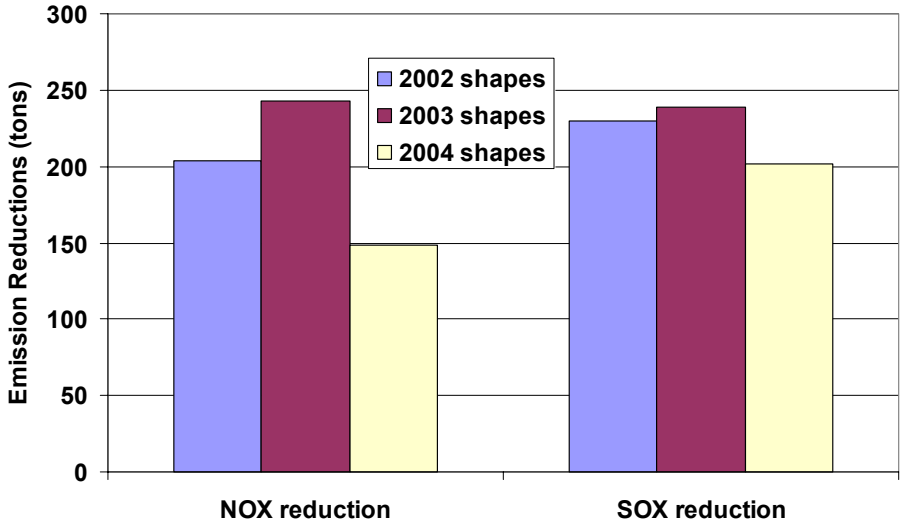
California Emission Reductions from Renewables 2010T



WECC Emission Reductions from Intermittents 2010T

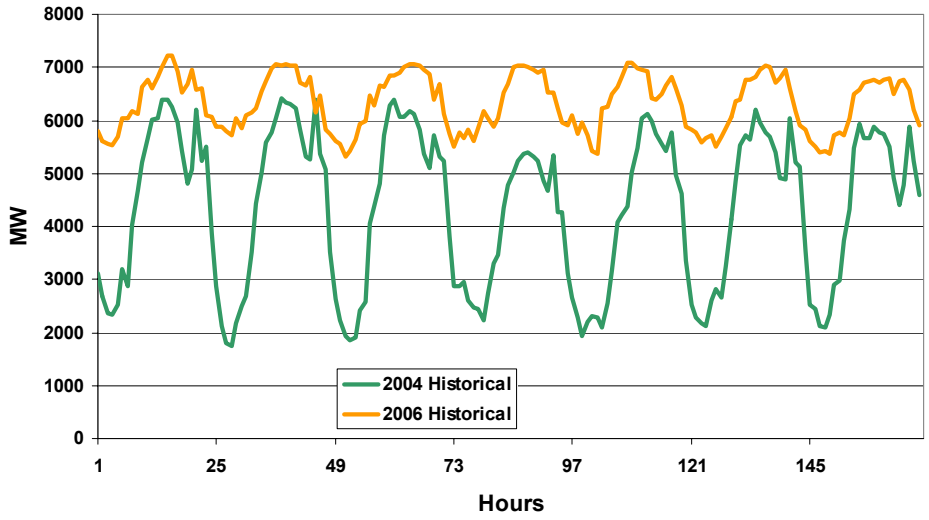


California Emission Reductions From Intermittents 2010T

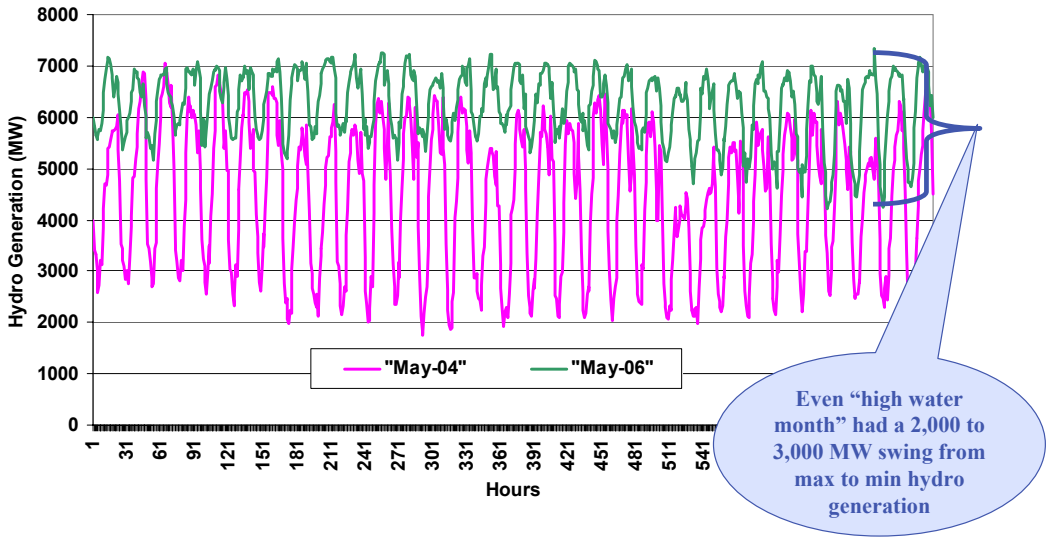


Hydro Operation

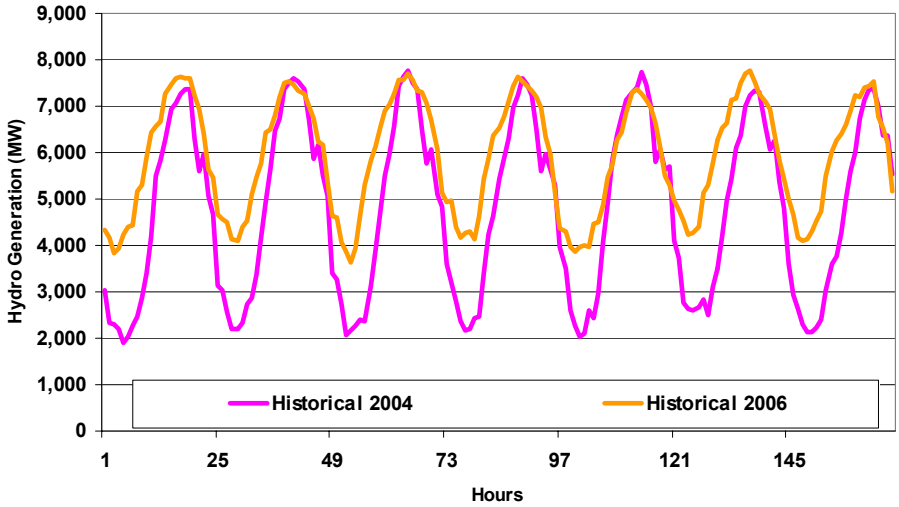
Hydro Operation – Sample May Week



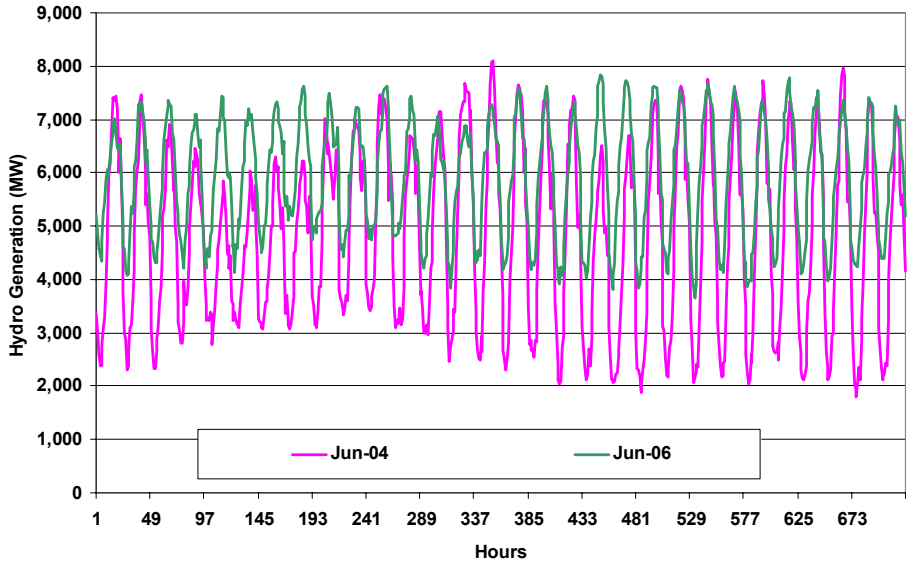
Historical May Hydro Operation



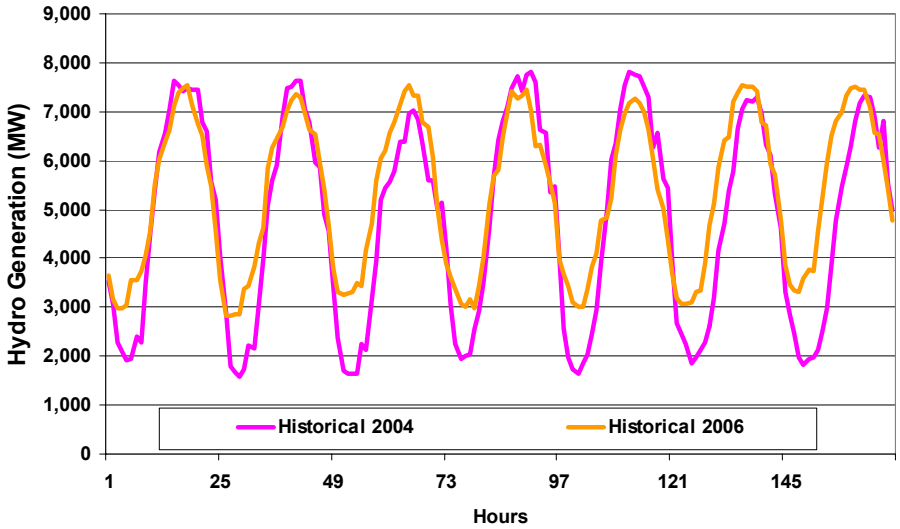
Hydro Operation – Sample June Week



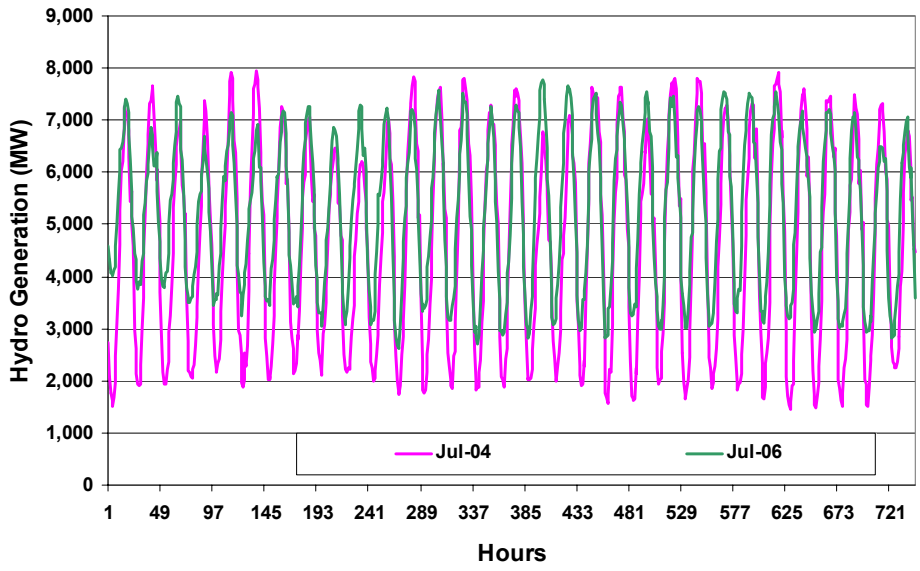
Historical June Hydro Operation



Hydro Operation – Sample July Week

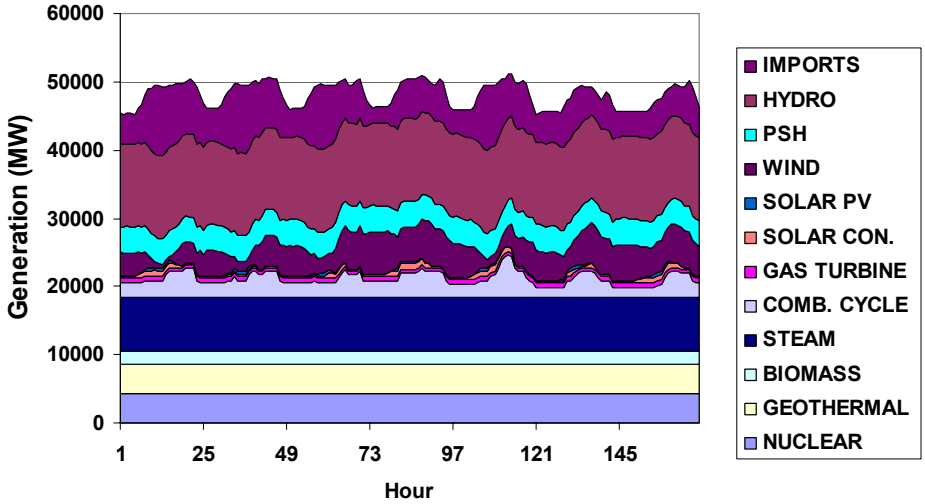


Historical July Hydro Operaion

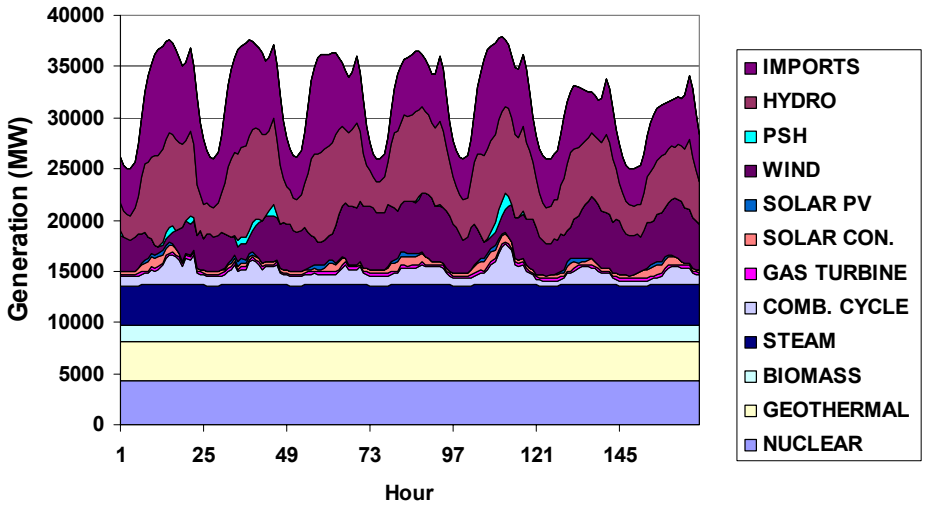


Ramp Rate and Range of Operation

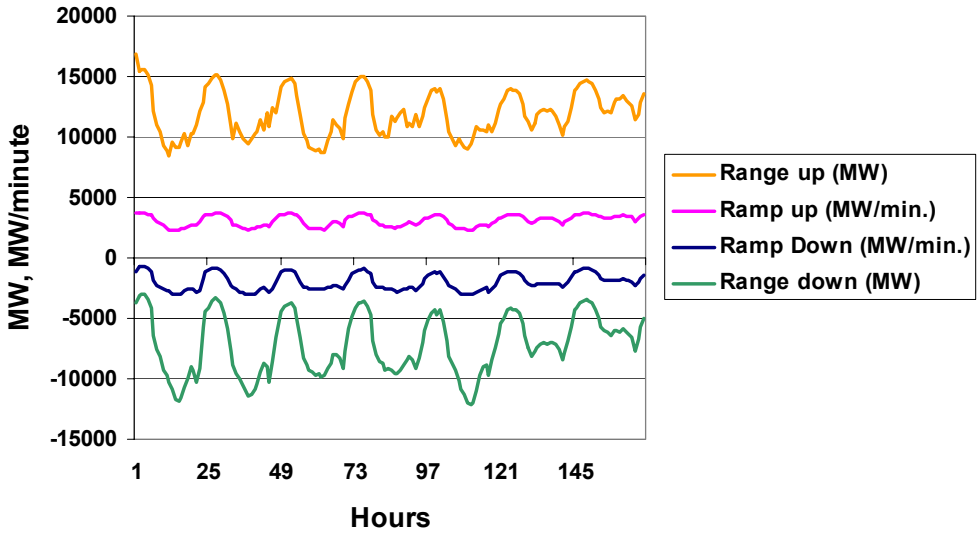
Commitment – Week of May 10th



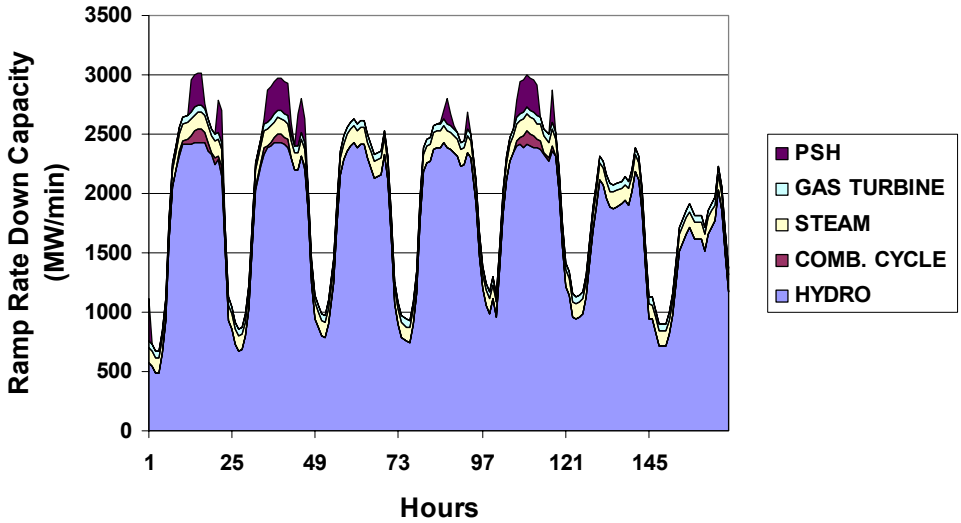
Dispatch – Week of May 10th



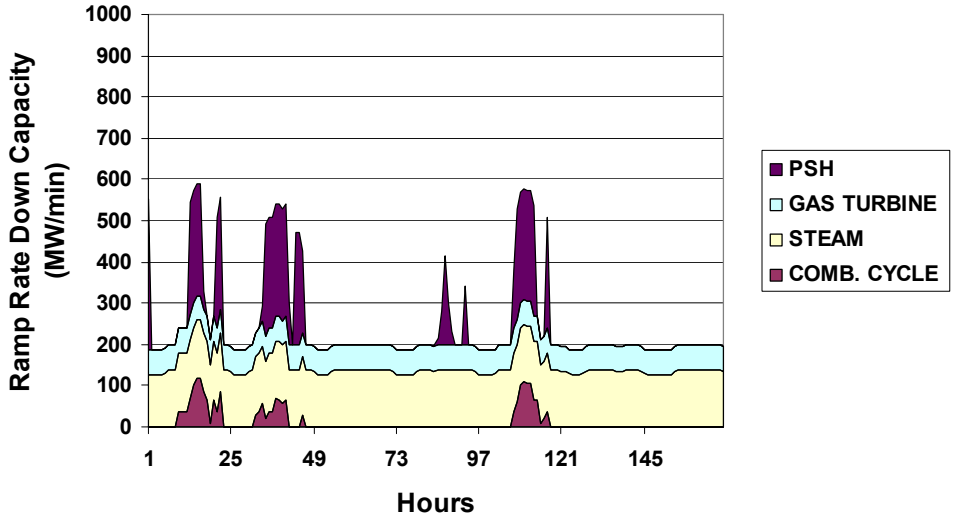
Ramp and Range Capability – Week of May 10th



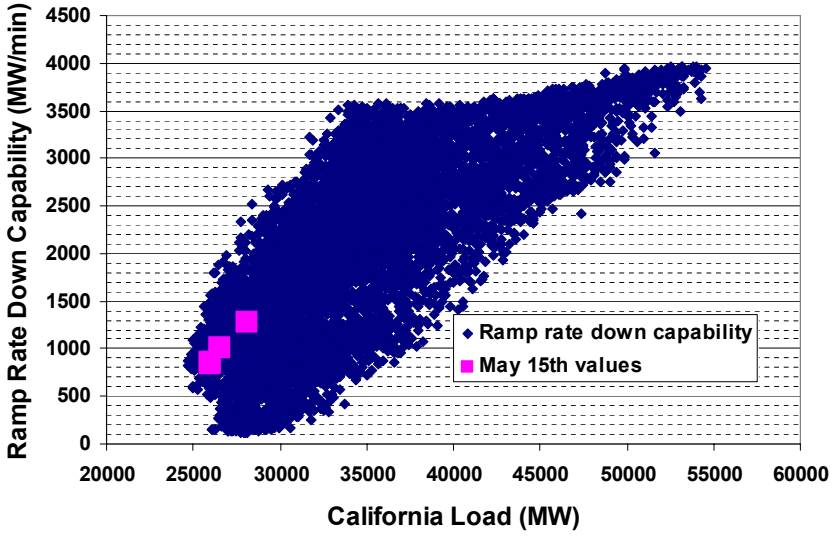
Ramp Rate Down Capacity – Week of May 10th



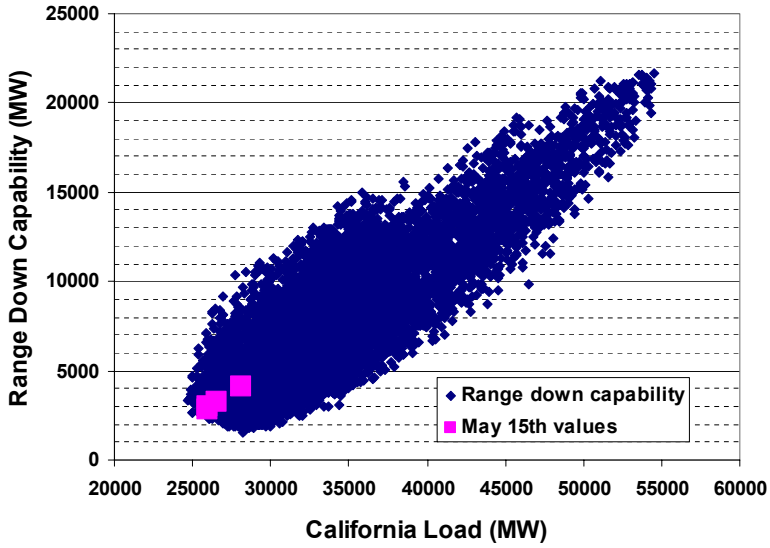
Ramp Rate Down Capacity w/o Conventional Hydro – Week of May 10th



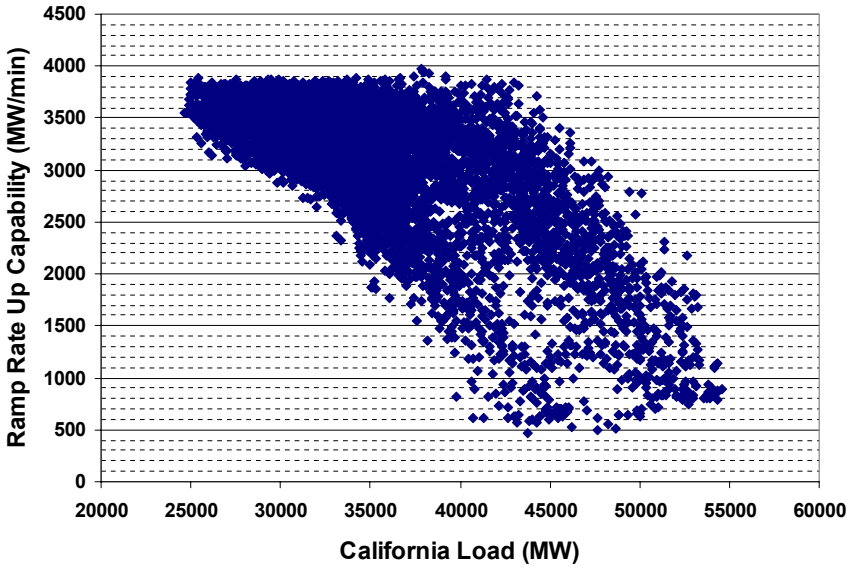
2010X Ramp Rate Down Capability



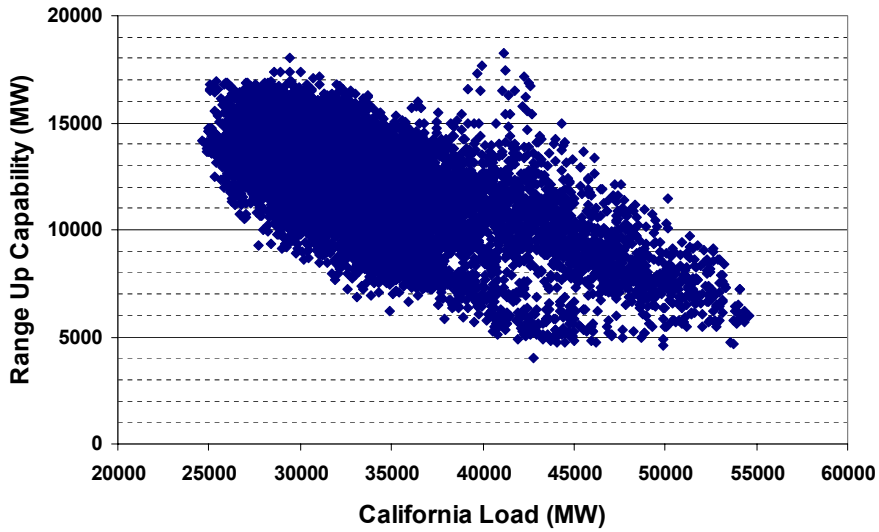
2010X Range Down Capability



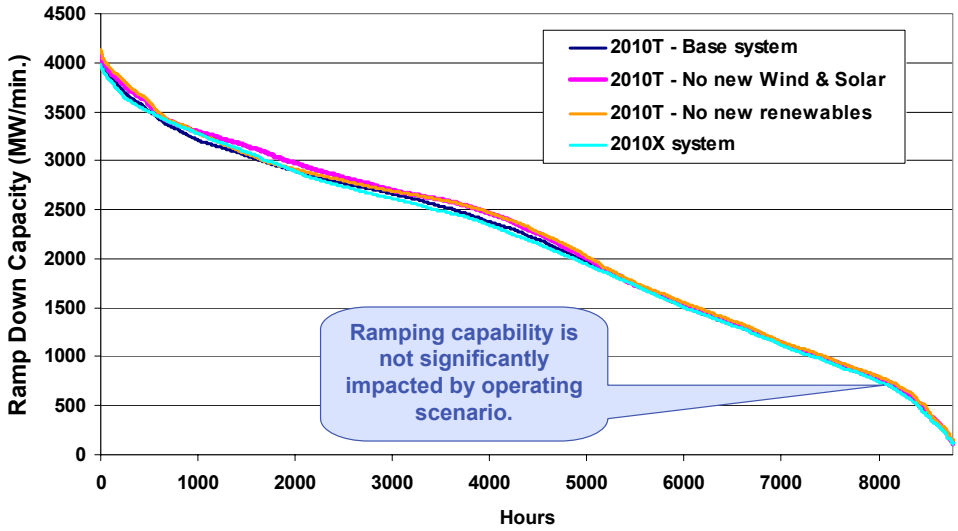
2010X Ramp Rate Up Capability



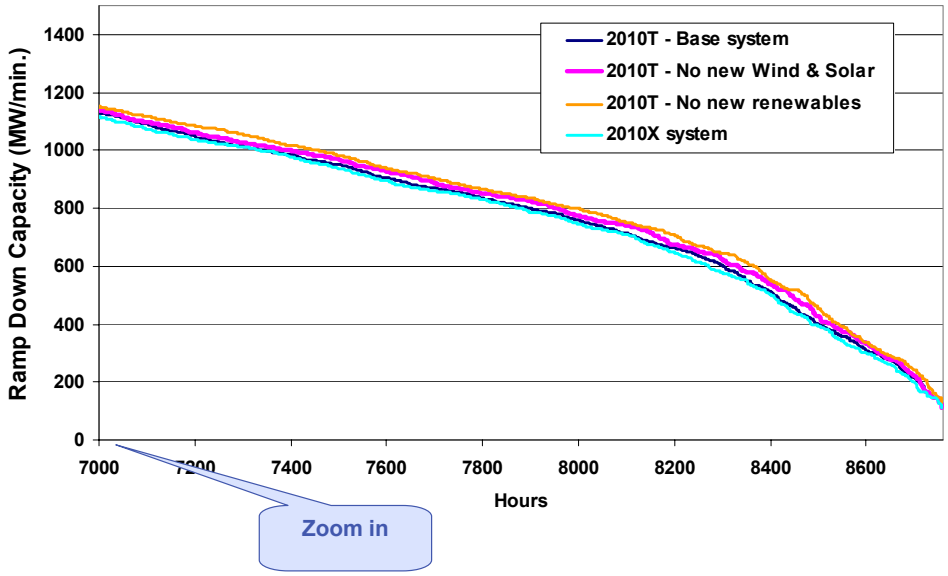
2010X Range Up Capability



Annual Ramp Down Capacity

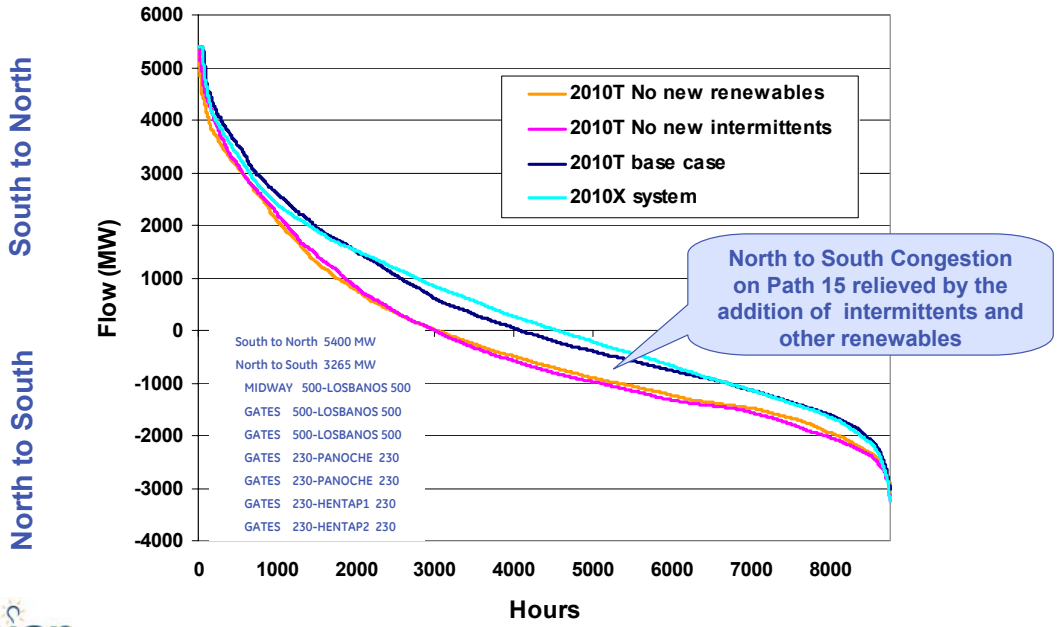


Annual Ramp Down Capacity

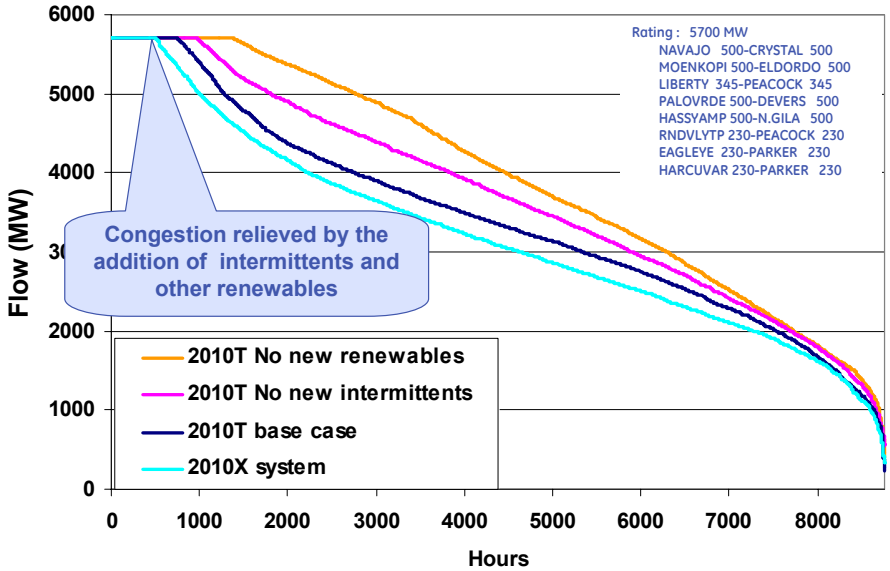


Transmission Loading

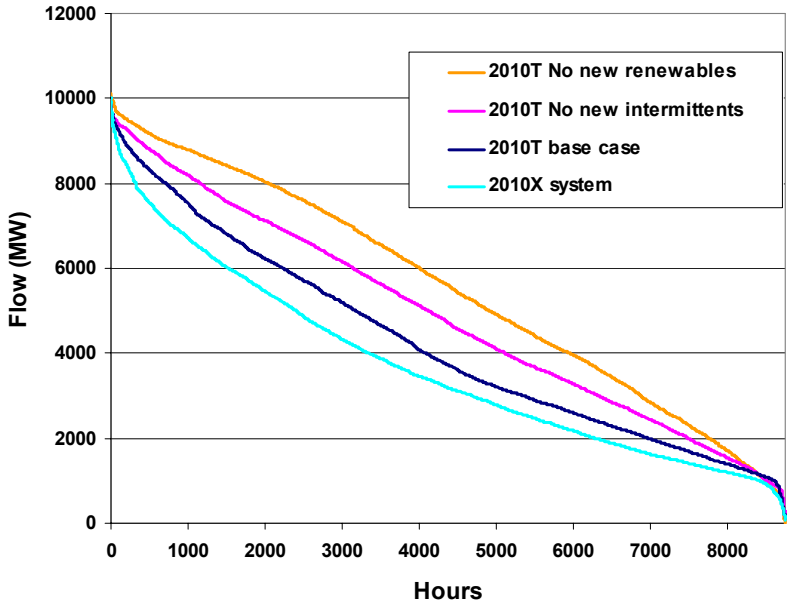
Path 15 : South of Los Banos



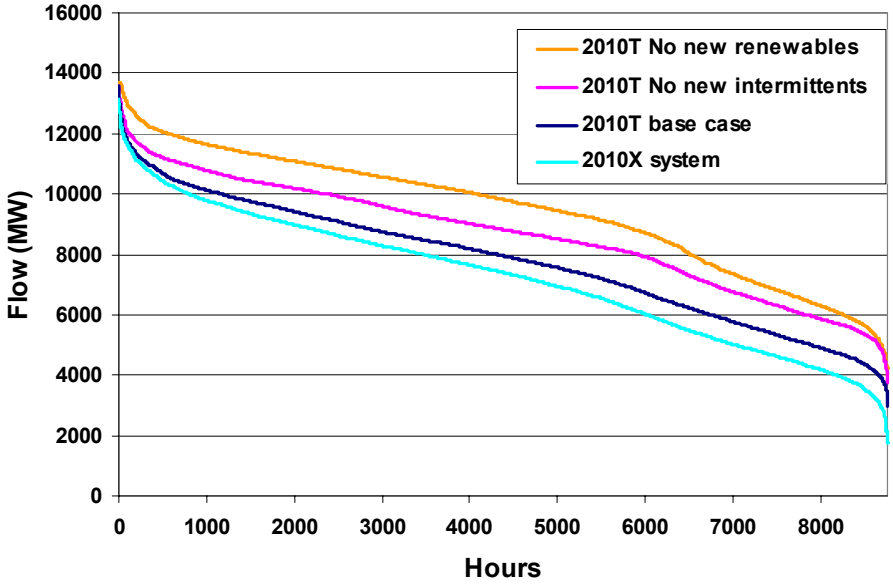
Path 21: Arizona to California



Path 46: West of Colorado River



Total SCIT
(Southern California Import Transmission)



Observations

- Increasing penetrations of renewables will decrease system spot prices.
  - Impacts can be more severe at low load periods.
    - 2010T ~ 250 hours 2010X ~ 500 hours
  - Average Load Payment reductions per MWh of renewable :

($/MWh)	California	WECC
Biomass & Geothermal	8.97	19.66
Wind & Solar	11.41	28.86

  - Average Generator Revenue reductions per MWh of renewable :

($/MWh)	California	WECC
Biomass & Geothermal	23.98	69.17
Wind & Solar	17.78	47.42

Observations

Not a sustainable market.

- Recognition of Intermittents in the commitment is critical.
  - Average Load Payment reductions from renewables :

($M)	California	WECC
adding Wind & Solar	240	607
ignoring W&S in cmt	2231	6330

- Average WECC emission reductions per MWh of renewable :

(lbs/MWh)	NOX	SOX	CO2
Biomass & Geothermal	130	10	830
Wind & Solar	117	46	810

Observations

- Primary energy displaced in WECC is from combined cycle plants.
- Primary energy displaced in California is from combined cycle plants and imports.
  - Hydro schedules within California adjusted but no energy spilled.
  - PSH operation increased but no apparent need for additional capacity.

- **At the hourly level there were no significant operational problems identified with renewable penetrations of 33% (energy).**