Intermittency Analysis Project

The IAP Transmission Story

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IAP Transmission Objective

- Evaluate the impact of intermittency on the transmission grid
  - Provide insight into anticipated transmission congestion
  - Evaluate improvements to accommodate 2010 and 2020 resources
  - Provide contiguous dataset for statewide transmission evaluation
  - Develop new analysis tools to provide insight to incorporate renewables based on least-cost-best-fit and transmission reliability benefit
  - Foster collaborative feedback among utility stakeholders

Agenda

- Topics for workshop
  - Introduction
    - Definitions
    - Previous work overview
  - Base case descriptions (2006, 2010 & 2020)
    - Summary of renewable mix
    - Summary of transmission expansion
    - Description of cases

Agenda Cont'd

- Development of study cases
  - Voltage stability issues
  - RTBR results
  - 2010 maximum penetration assessment
  - Transmission intermittency analysis
    - AMWhCO trends

Definitions

- Available Transmission Capability (ATC)
  - Evaluation of the thermal capacity of the transmission network to deliver new renewable generation
  - Useful for determining possible renewable penetration levels without major additional transmission upgrades
- Power Voltage/VAR Voltage (PV/QV)
  - Evaluation of the capacity of the transmission network to support system voltage while delivering new renewable generation
  - Helps identify steady state voltage instability problems and possible solutions as generation and load increase
- Aggregate MW Contingency Overload (AMWCO)
  - Measure of system security for a single snapshot
  - Higher AMWCO indicates greater propensity for contingent overloads

Definitions Cont'd

- Renewable Transmission Benefit Ratio (RTBR)
  - Improvement in AMWCO per MW of new renewable generation
  - Helps in determination of generation injection locations which are beneficial to the transmission system
- Locational Value Analysis (LVA)
  - Evaluation of transmission security benefits of new renewable generation and the relative benefits of each location in the transmission network
  - Encompasses AMWCO and RTBR measures
- Aggregate MWh Contingency Overload (AMWhCO)
  - Measure of system security over a season, with varying availability of intermittent resources

Renewable Transmission Benefit Ratio (RTBR)

- System AMWCO results were computed for:
  - Base case, to establish a reference security level
  - Cases with additional renewable resources
- RTBR is the change in AMWCO for the renewable cases, divided by the total MW of renewables added
- RTBR < 0 indicates that system security is improved by the renewables

$$RTBR = \frac{AMWCO_{renewables} - AMWCO_{base}}{\sum MW_{renewables}}$$

Transmission Evaluation Techniques

- Site specific transmission benefit ratio tests
  - Impact of proposed generation locations on system security (how it changes the AMWCO)
- System wide benefit tests
  - Aggregate AMWCO assessment for all proposed renewable locations

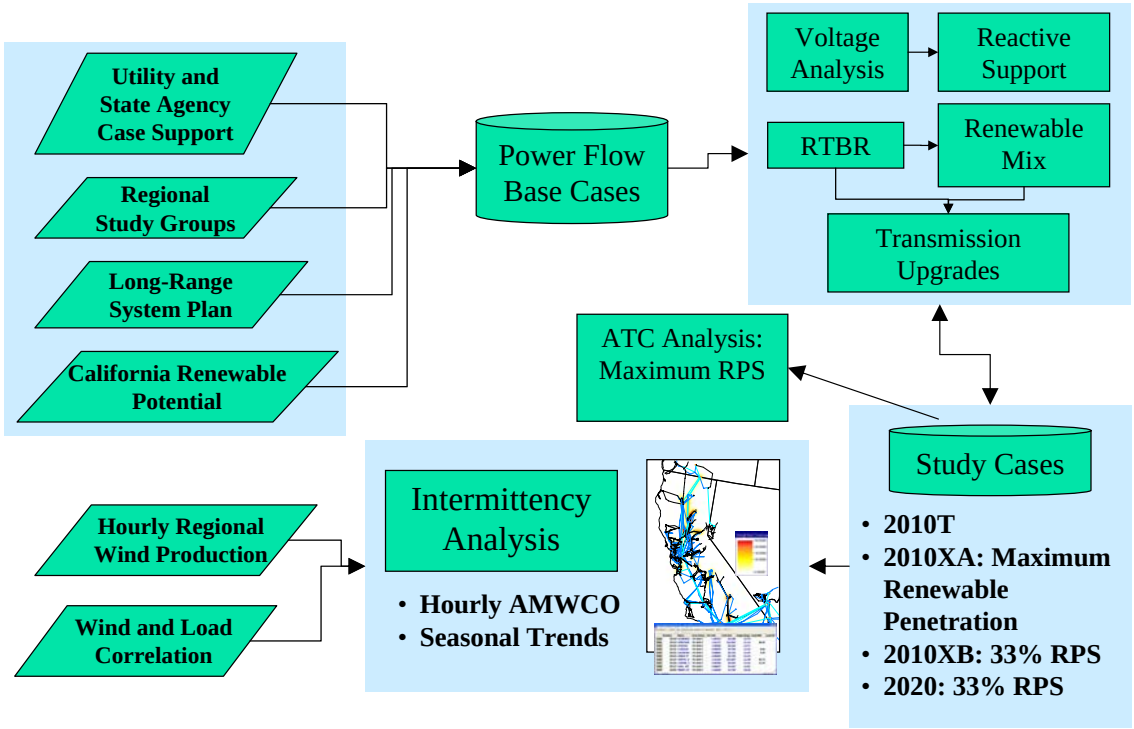
Transmission Evaluation Techniques

- Hourly time step intermittency analysis
  - N-1 analysis
  - Instead of looking at one hour, look at wind generation over a time period based on historical or forecasted patterns
  - Find most probable elements that overload
  - Determine priority list

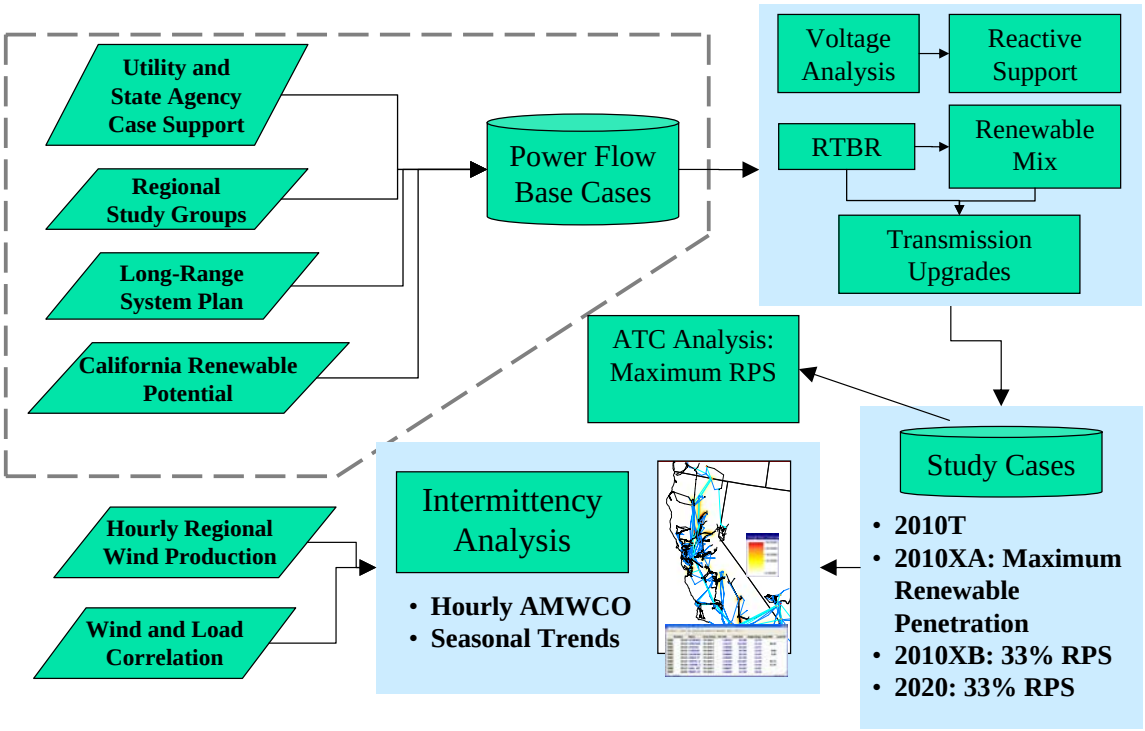
Previous Renewable Integration Project (Background data)

- Provided starting point for the IAP transmission cases using renewable portfolio mix (2010 and 2017) developed for 2005 IEPR
- Previous renewable mix based on a 20% penetration target
- Used a "least cost-best fit" analysis, projected resource availability and timing of renewables and LVA transmission analysis

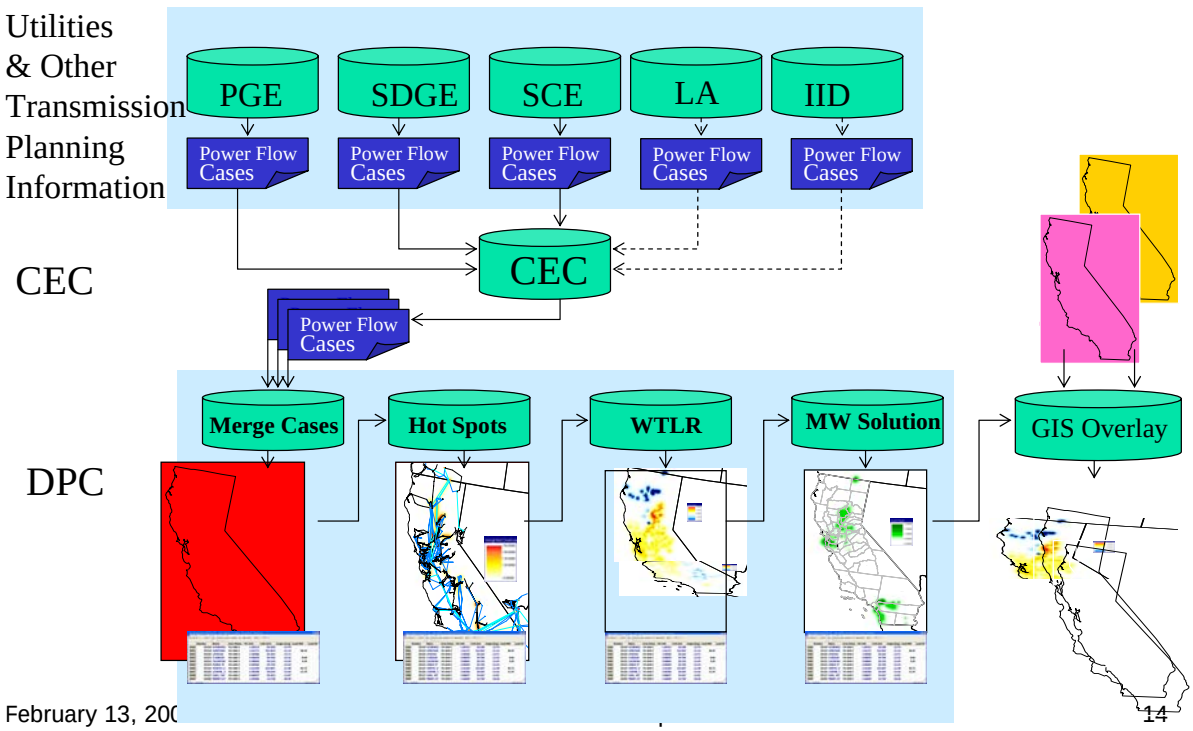
IAP Transmission Evaluation Process



Transmission Base Cases



Transmission Data



Development of Base Cases

- Obtained seasonal WECC approved power flow cases from IOUs
- Load Scaling
  - Applied CEC specified loads by season and control area
  - Scaled load from 2017 to 2020 based on 1.8% projected annual growth rate

Development of Base Cases

- Aggregated individual utility datasets
- Captured existing renewable baseline
- Incorporated plant retirements and approved new power plants
- Added conventional generation resources to meet resource adequacy (CEC EAO)
  - New resources added to meet reserve margins for 2010 and 2015 (last date for production cost runs)
  - Reserve margin at 15% maintaining to current levels

2006 Existing Wind Sites

Location	MW
Solano	220
Altamont Pass	662
Pacheco Pass	13
Tehachapi	760
San Gorgonio	462
San Diego	12
Other	24
Total	**2,153 MW**

Development of Renewable Mix

- Incorporated the technical and economic renewable potential presented in 2005 IEPR
- Incorporated the Locational Value Analysis (LVA) to find renewable locations with transmission benefit (RTBR)
- Power flow cases developed with the following renewable mixes:
  - 2006 – Existing mix
  - 2010T – 20% renewable mix
  - 2010XA – interim case for estimating maximum renewable penetration for planned 2010T transmission (2010T mix)
  - 2010XB – interim case with 33% renewable mix
  - 2020 – 33% renewable mix

New Wind Sites

- 2010 Sites
  - Tehachapi
  - San Gorgonio
  - San Diego County
  - San Bernardino county
  - LADWP wind site
  - Solano county
  - Altamont Pass
- 2020 Wind Sites
  - Medicine Lake/Telephone Flat
  - Imperial county
  - Pacheco Pass
  - Lassen County
  - Low Wind
    - Inyo County
    - Contra Costa County
    - Ventura County
    - Yolo County

Description of Study Cases

- 2006 – Existing Renewables
  - Based on 2005 IEPR in state renewable resource potential
  - Tests the impacts that existing intermittent resources have on system (2,153 MW of wind)
- 2010T – 20% renewables mix
  - Included 3,000 MW at Tehachapi resource area per utilities and working groups
  - Adjusted other resources to meet the 20% energy penetration

Study Cases Cont'd

- 2010 XA – Maximum penetration of renewables
  - Utilized the 2010 Tehachapi case & transmission options to quantify maximum penetration of renewables
  - Develop methodology to determine maximum penetration for a given power flow
- 2010 XB – power flow at 33% renewables
  - Test case to provide insight on transmission build-out needs between 2010 and 2020
  - Expanded 2010T from 20% to 33% renewable penetration
  - End state used 2020 renewable mix and transmission expansion options

Study Cases Cont'd

- 2020 33% Mix
  - Added renewables to meet 33% energy supply target
  - Based on LVA and state resource potential identified in 2005 IEPR
  - Maximized intermittent resources (wind and solar) given purpose of study

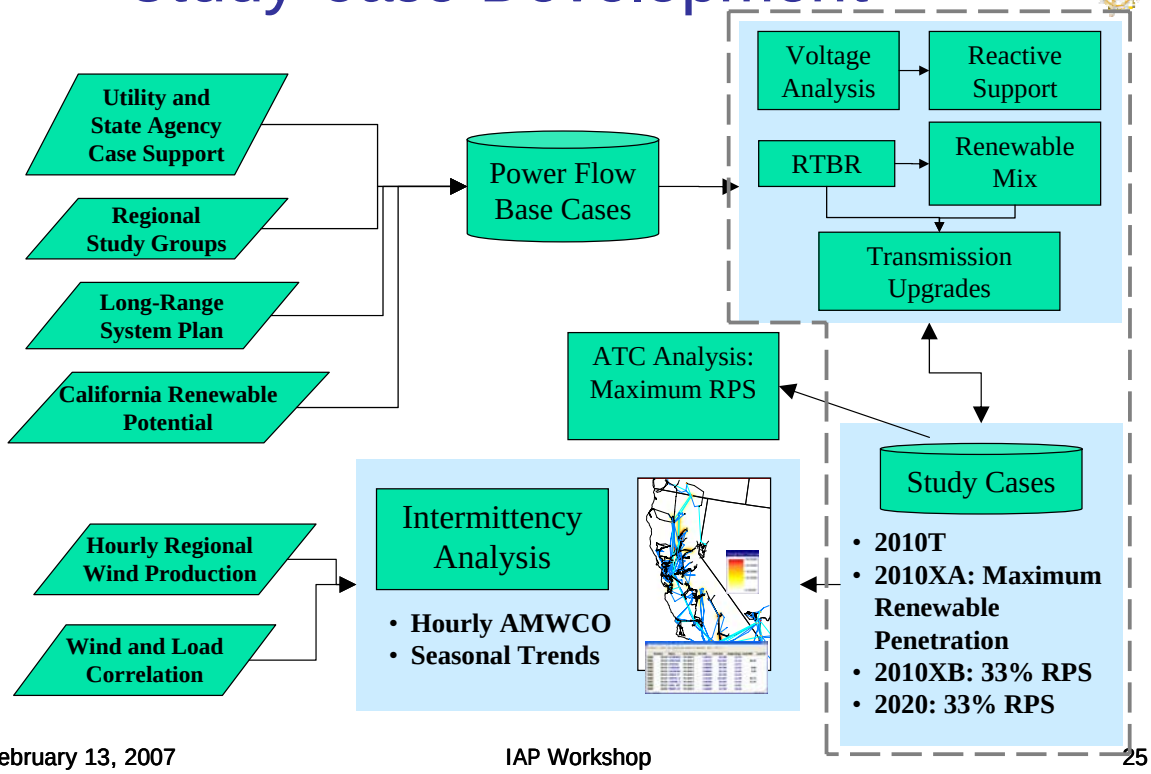
Renewable Targets

- The following tables show connected renewable capacity in MW.
- *Renewable energy targets* are 20% and 33% of the total energy consumption (MWh) of the California utilities
- The capacities reflect the corresponding MW needed to meet the *renewable energy targets* based on capacity factors

Summary of Renewable Additions by Renewable Type: 2010 to 2020

	2010 Tehachapi Additions (MW)	2020 33% Additions (MW)
Geothermal	1,064	2,415
Biomass	221	990
Wind	5,035	10,138
CSP	1,479	5,560
Incremental Total	**7,799**	**19,103**

Study Case Development



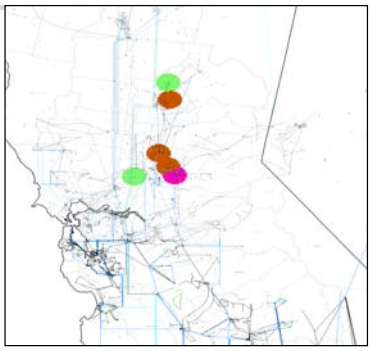
Voltage Stability Issues

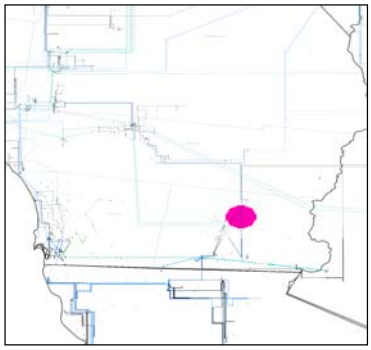
Voltage Stability Analysis

- As renewables were added, voltage stability problems occurred
- Incorporated PV/QV analysis within power flow to determine locations of VAR compensation
- Added compensation in 2020 to get to 33% renewable penetration
- Results in more stable power flow

2020 Issues and Constraints

- VAR and Low Voltage problems created problems in obtaining solutions
- Added
  - 80 MVAR each at:
    - Big Bend 115kV (PG&E)
    - Davis 60kV (PG&E)
  - 300 MVAR each at:
    - Poe 230kV (PG&E)
    - Rio Oso 230kV (PG&E)
    - Atlantic 230kV (PG&E)
  - 400 MVAR each at:
    - Gold Hill 230kV (PG&E)
    - Midway X 230kV (Imperial)



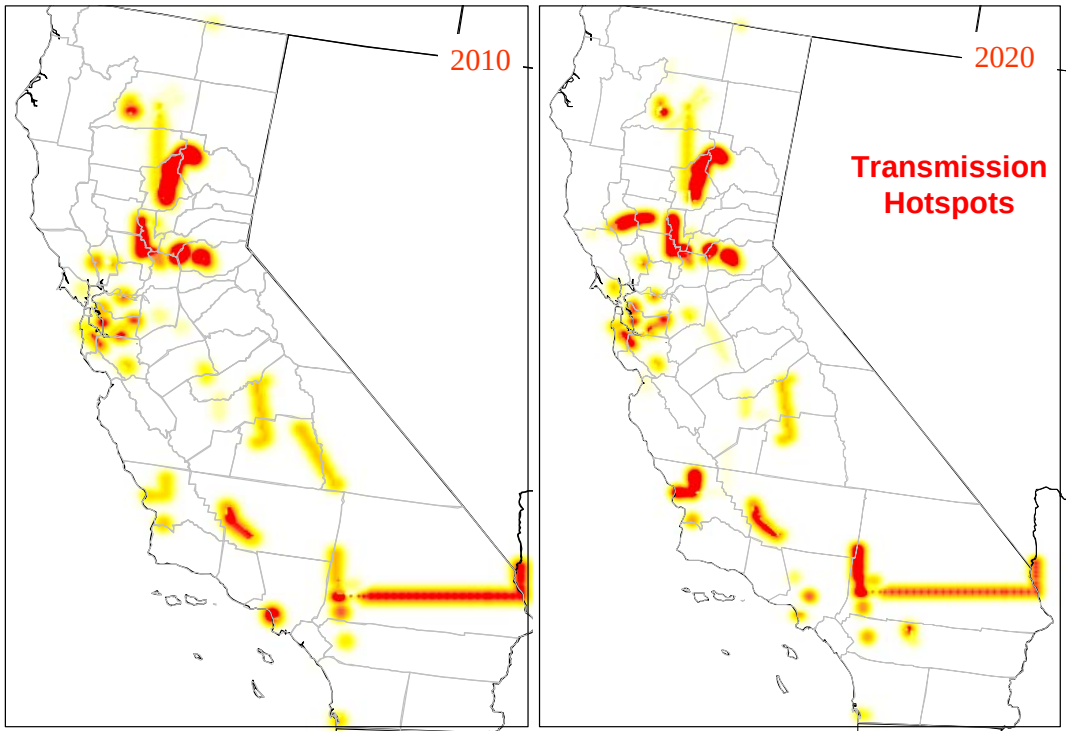


Renewable Transmission Benefit Ratio Results

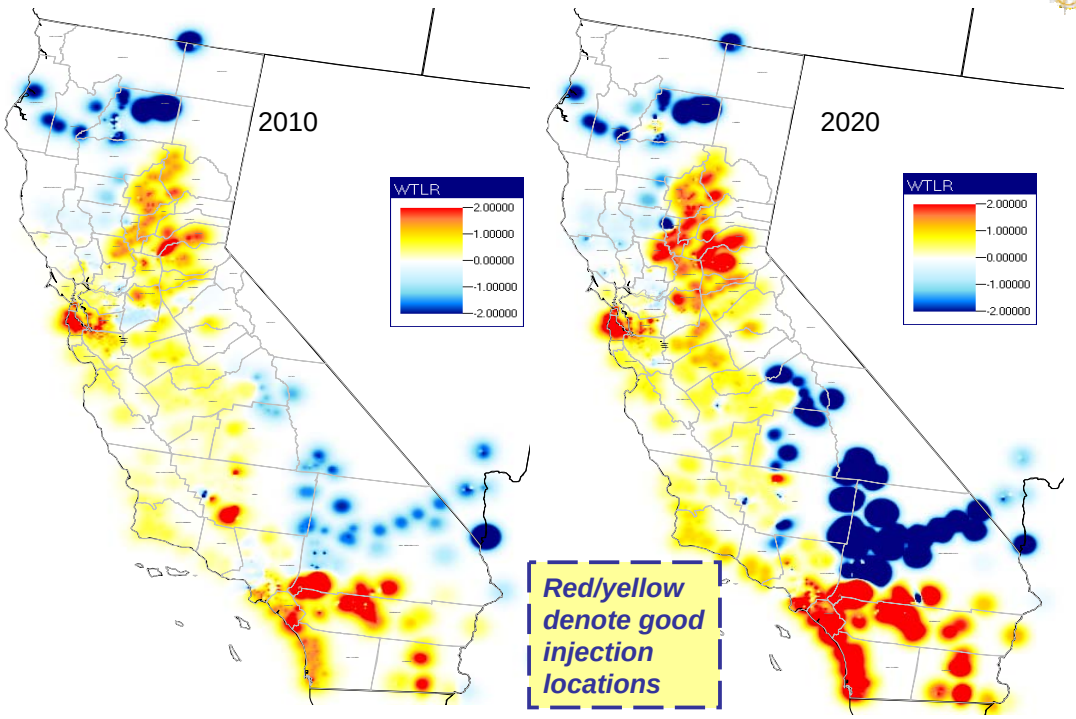
RTBR and Transmission Expansion

- RTBR tests were completed to determine the approximate benefit the new renewable sites had on the transmission system in each base case
- Results of RTBR helped determine the renewable mix and transmission expansion

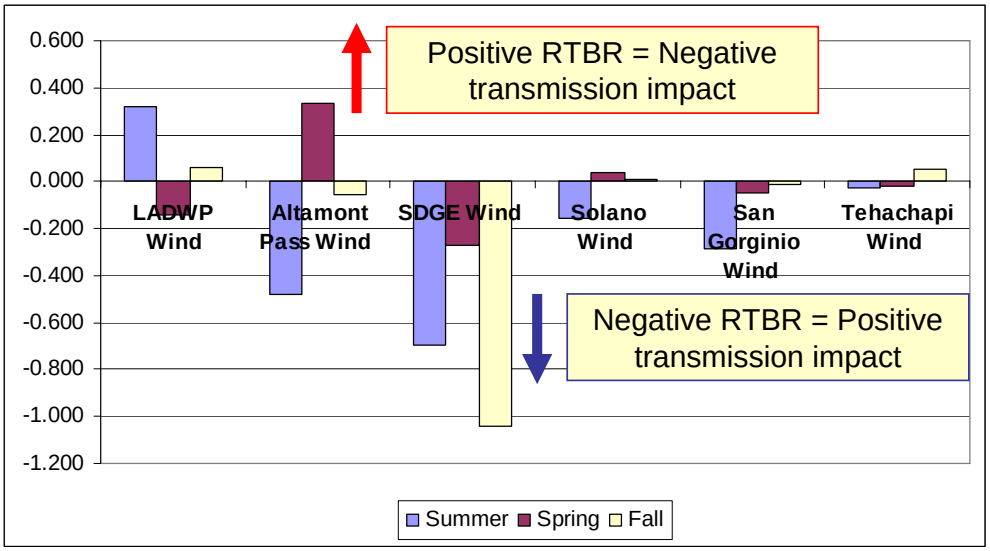
Weak Element Visualization



Locational Value Visualization



2010 Tehachapi Case Wind Site RTBRs



***Negative RTBR shows beneficial improvements to transmission system**

Summary of 2010 RTBR

Region	Resource	Summer RTBR	Spring RTBR	Fall RTBR
Residential	Residential PV	Negative	Negative	
Urban	Biomass	Negative	Negative	Positive
SCE	Solar	Negative		
SDG&E	Solar			
Sulfur Bank	Geothermal	Negative	Negative	Negative
Medicine Lake	Geothermal		Positive	Positive
Salton Sea, Mount Signal, Heber, Brawley North	Geothermal		Positive	Negative
LADWP	Wind	Positive	Negative	Positive
Altamont	Wind	Negative	Positive	Negative
SDG&E	Wind	Negative	Negative	Negative
Solano	Wind	Negative	Positive	
Riverside	Wind	Negative		
Tehachapi	Wind			Positive

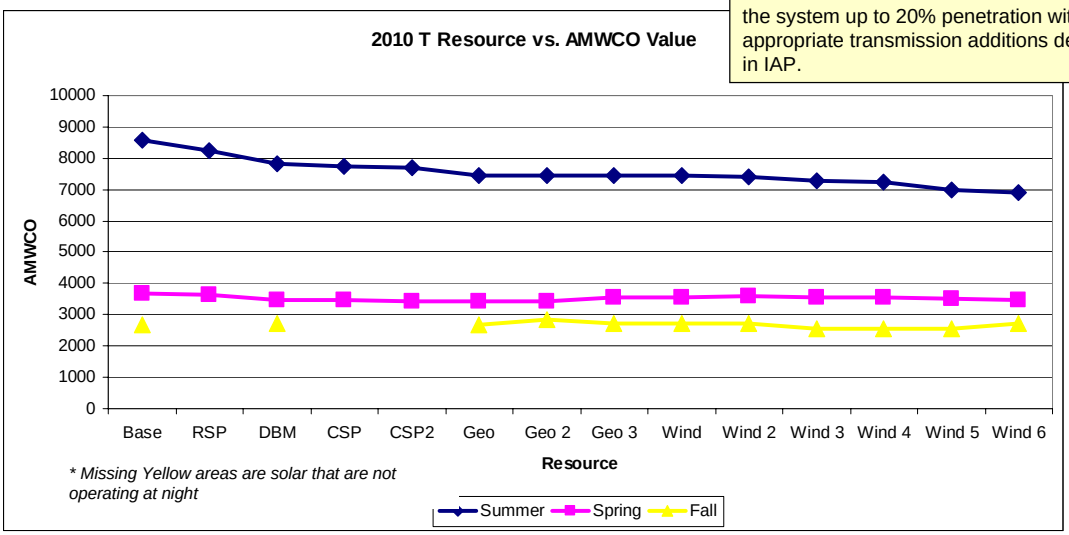
NOTE: Transmission impact changes seasonally.

Reasons for Positive RTBR

- Did not fully optimize transmission expansion requirements – additional refinements may be needed
- Spring hydro conditions did cause issues associated with northern CA 500 kV power flows
- Fall had minimum load and high SP15 south to north flows

2010 Tehachapi Case
AMWCO for each Renewable Location

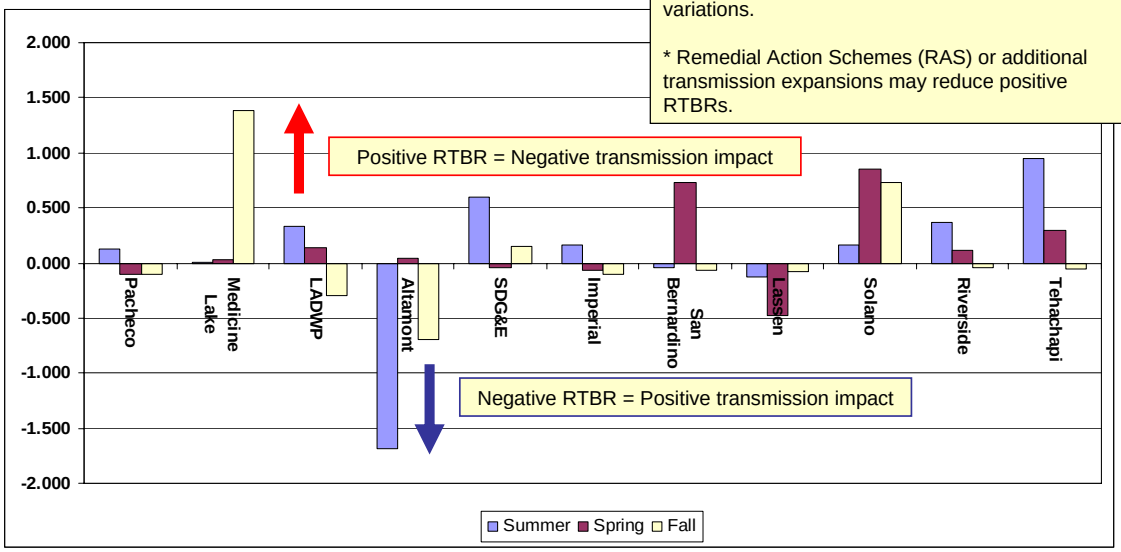
Total system AMWCO generally improved in summer and stayed the same in spring and fall as more renewables were added to the system up to 20% penetration with the appropriate transmission additions defined in IAP.



2020 33% Case Wind Site RTBR

* Note the seasonal variations in the magnitude and number of positive RTBR sites. Optimization of transmission needs to account for seasonal variations.

* Remedial Action Schemes (RAS) or additional transmission expansions may reduce positive RTBRs.



***Negative RTBR shows beneficial improvements to transmission system**

Summary of 2020 RTBR

Region	Resource	Summer	Spring	Fall
Residential	Residential PV	Negative	Negative	
Urban	Biomass	Negative	Negative	Negative
Fire Threat	Biomass	Positive	Positive	Positive
San Diego	Solar	Negative	Negative	
Riverside	Solar	Positive	Negative	
San Bernardino	Solar	Negative		
Lassen	Solar	Positive	Positive	
Imperial	Solar	Negative	Negative	
SDG&E	Solar	Negative	Negative	
SCE	Solar	Negative	Negative	
Yolo	Low Wind	Negative	Negative	Positive
Contra Costa	Low Wind			Negative
Venture	Low Wind	Negative	Negative	Positive
Inyo	Low Wind	Positive	Negative	Positive

Summary of RTBR cont.

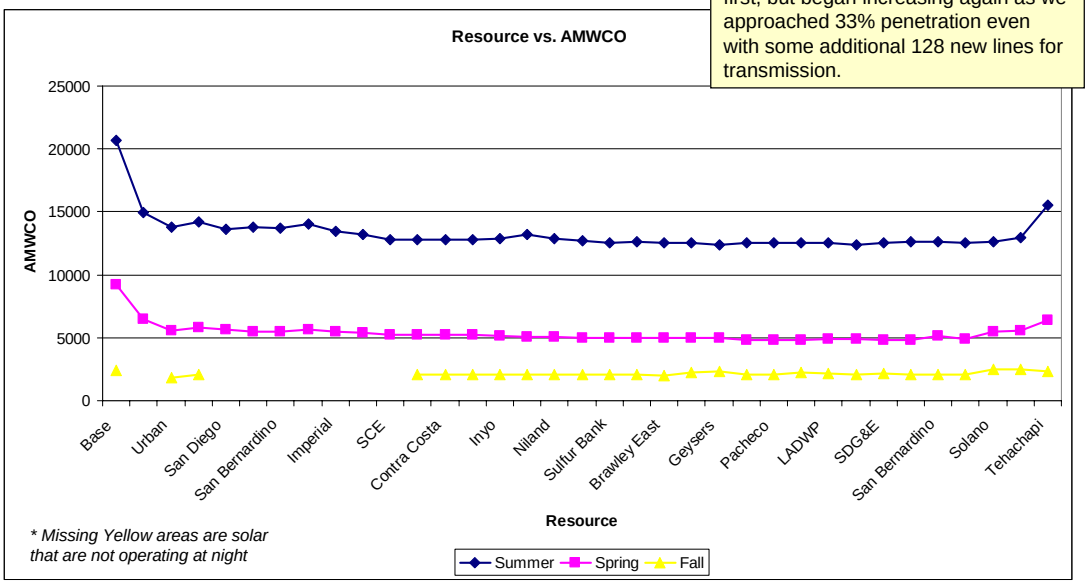
Region	Resource	Summer	Spring	Fall
Mount Signal	Geothermal	Positive	Negative	Negative
Niland	Geothermal	Negative	Negative	Negative
Heber	Geothermal	Negative	Negative	Negative
Sulfur Bank	Geothermal	Negative	Positive	Positive
Brawley North	Geothermal	Positive		Negative
Brawley East	Geothermal	Negative	Positive	Negative
Medicine Lake	Geothermal	Negative	Negative	Positive
Geysers	Geothermal	Negative	Positive	Positive
Salton Sea	Geothermal	Positive	Negative	Negative

Summary of RTBR cont.

Region	Resource	Summer	Spring	Fall
Pacheco	High Wind	Positive	Negative	Negative
Medicine Lake	High Wind			Positive
LADWP	High Wind	Positive	Positive	Negative
Altamont	High Wind	Negative	Positive	Negative
SDG&E	High Wind	Positive		Positive
Imperial	High Wind	Positive	Negative	Negative
San Bernardino	High Wind		Positive	Negative
Lassen	High Wind	Negative	Negative	Negative
Solano	High Wind	Positive	Positive	Positive
Riverside	High Wind	Positive	Positive	
Tehachapi	High Wind	Positive	Positive	Negative

2020 33% AMWCO Trend

As renewables were added for 2020, total system AMWCO decreased at first, but began increasing again as we approached 33% penetration even with some additional 128 new lines for transmission.



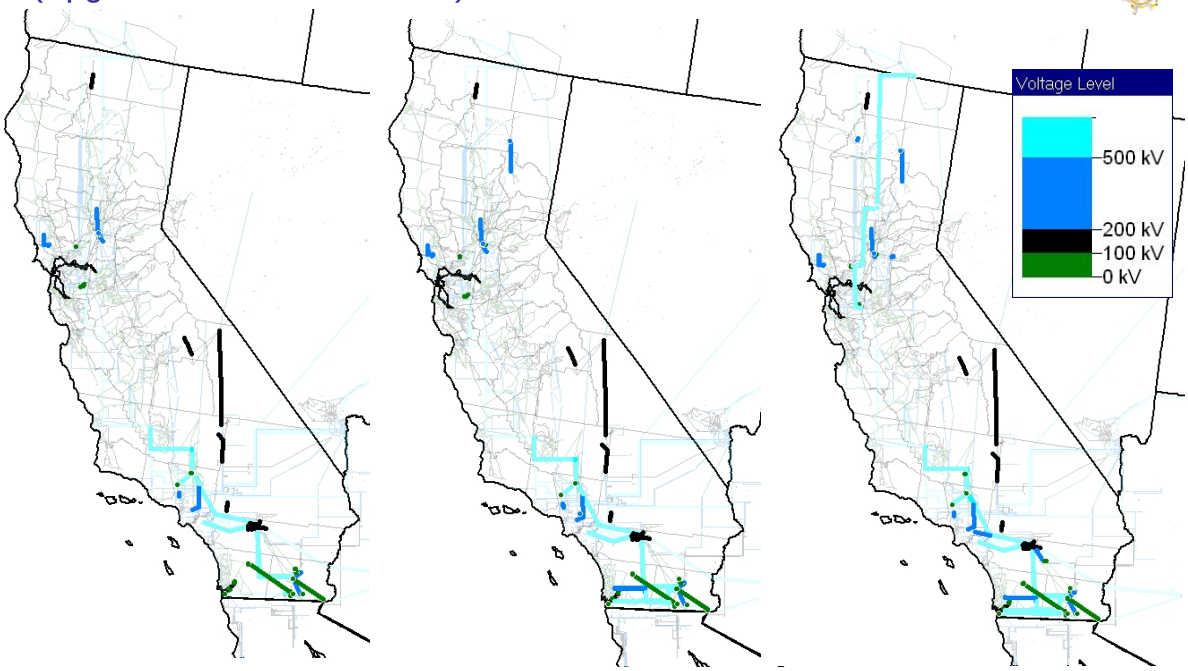
** Missing Yellow areas are solar that are not operating at night*

2010 & 2020 Transmission Expansion Results

Voltage	2010 Line Segments	2020 Line Segments	2010 Transformers	2020 Transformers
500	8	22	2	9
230	8	38	6	18
161/138	0	2	1	0
115	49	49	9	5
Below 110	13	17	14	8
Total	**78**	**128**	**32**	**40**

2010 & 2020 Transmission Expansion

(Upgrades and/or New Lines)



2010 Tehachapi 2010 XB 2020

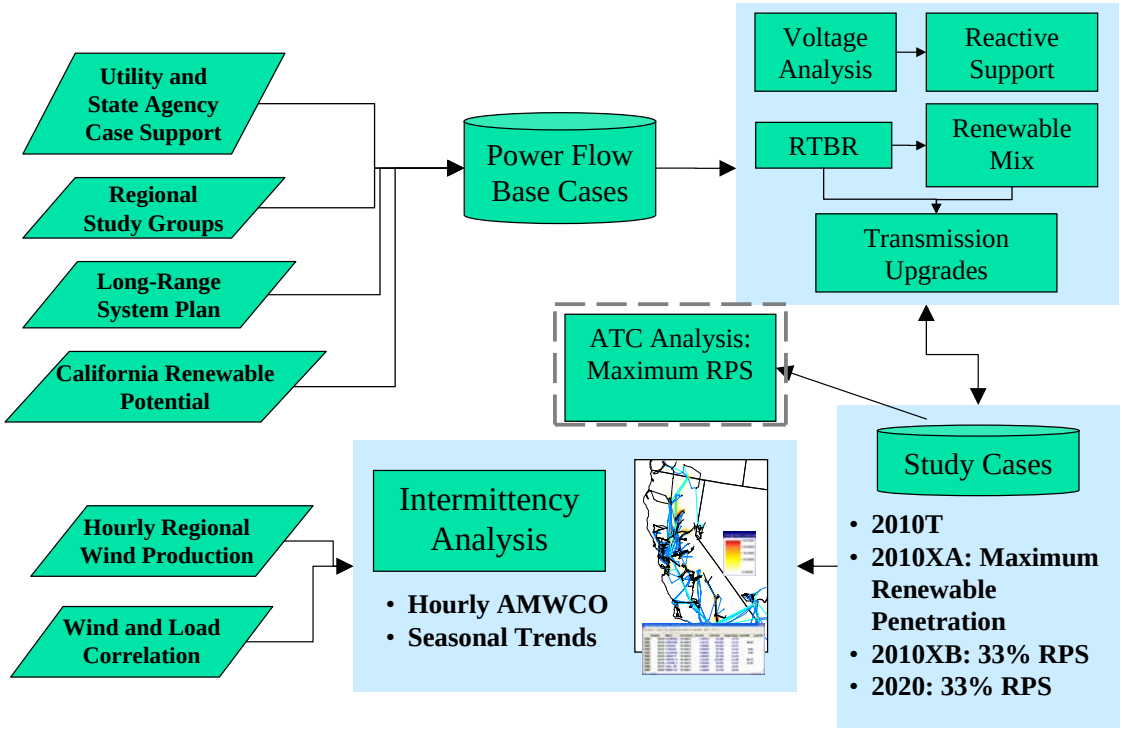
Major Transmission Issues

- A 4th COI 500 kV transmission line needed to off-load line and substation loads at Round Mountain, Table Mountain and Tracy
  - 500 kV line needed between these substations
  - However, if the line was extended to COI or Nevada then out of state renewables could provide additional least cost-best fit renewables to California utilities

Transmission Issues Cont'd

- An Imperial to LADWP or SDG&E transmission line needed to export Imperial Valley renewable generation (geothermal, wind and CSP)
- Tehachapi wind penetrations will increase 500 kV and 230 kV expansion
- High wind penetrations at Solano and Altamont will stress the existing system and will require major upgrades
- Development in the INYO & LASSEN will require major upgrades

2010XA Maximum Penetration



Case 2010XA Maximum Penetration Analysis

Maximum Penetration

- The basis of this exercise was to look at a way to approximate how much renewable penetration we *could* add in a case, without additional expansion
- In 2010 Tehachapi case development, we added transmission upgrades to reduce overloads as more renewables were added
- Developed methodology within model to quickly determine approximate maximum penetration due to transmission limitations (ATC)

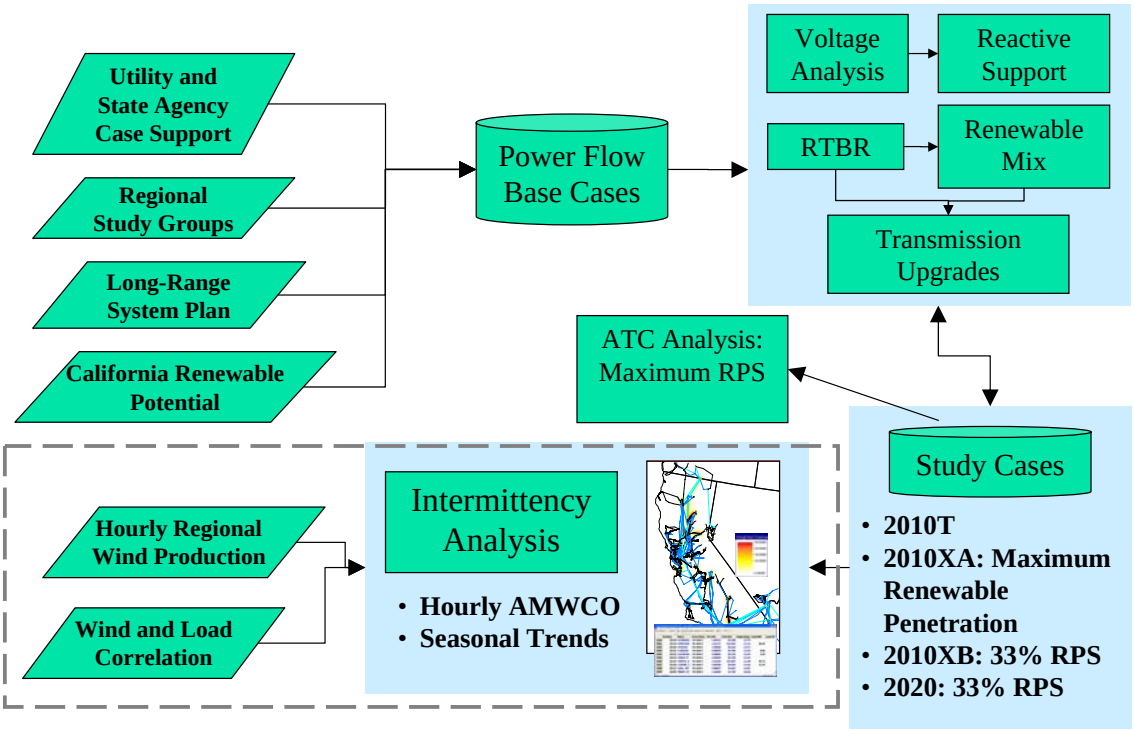
Maximum Penetration

- 2010 Tehachapi study case had 20% penetration
- Maximum penetration analysis determined a range of penetration of 23% to 26%
  - 23% - manual penetration adjustment, sites added sequentially
  - 26% - automatic penetration adjustment using ATC, sites added concurrently

Future Value from Maximum Penetration Analysis

- Methodology could be expanded to better determine transmission limitations
  - Optimize renewable dispatch for maximum penetration while maintaining transmission limits
- This type of exercise could be used in the study case development stage to help screen for transmission bottlenecks that may be eligible for expansion

Intermittency Analysis



Hourly Wind Data Availability

- Only historical CalISO 2004 hourly wind data was available for transmission intermittency analysis
- Assigned each 2010 and 2020 wind site to one of five wind regions
- Applied historic hourly capacity factors by region to projected wind capacity in each future case
- Assumed that the capacity factor would be the same for all wind generation within a region

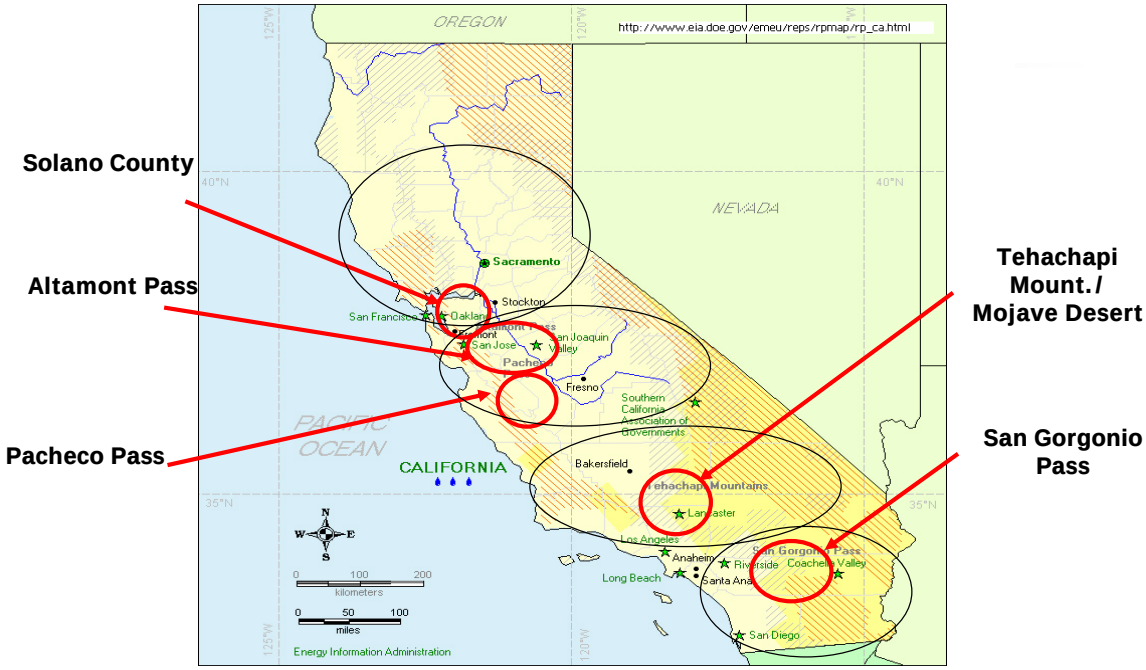
Intermittency Methodology

- Hourly wind capacity factors matched to seasons and time of day conditions represented in power flow cases
- Load held constant within each season and time of day scenario to isolate the impact of wind intermittency
- Natural Gas-fired resources across California followed hourly wind variation

Season and Peak Definitions

	Begin	End
Spring	April 8	June 3
Summer	July 9	September 3
Fall	October 8	December 3
Peak	12:00 pm	6:00 pm
Off-Peak	12:00 am	6:00 am

Wind Generation Regions in CA



Source: California ISO

Wind Region Definition

Wind Region	Included Counties
Altamont	Alameda, Contra Costa, San Joaquin
Pacheco	Merced
San Gorgonio	Imperial, Riverside, San Bernardino, San Diego
Solano	Lassen, Sacramento, Shasta, Solano, Yolo
Tehachapi	Inyo, Kern, Los Angeles, Tulare, Ventura

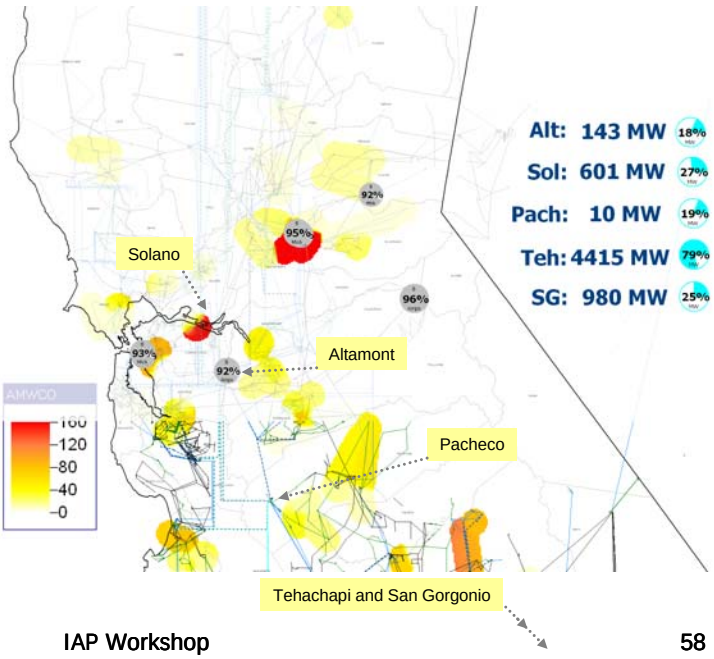
Seasonal Wind Statistics

State-Wide Capacity Factor	Spring Peak	Summer Peak	Fall Off Peak
Average	35.0%	23.3%	17.0%
Median	39.7%	21.6%	11.7%
Standard Deviation	20.4%	14.4%	15.1%
Minimum	0.0%	-1.2%	0.1%
Maximum	73.1%	57.8%	68.8%

There was very little consistent correlation between regions except Altamont and Solano.

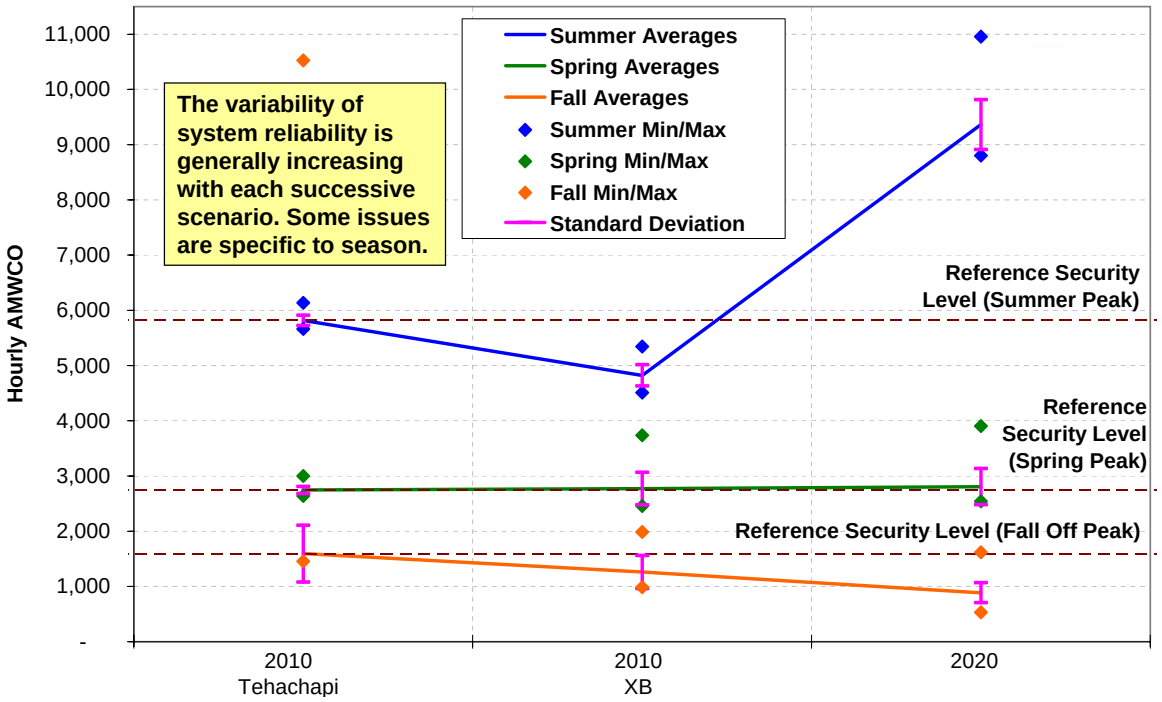
Intermittency Illustration

- Capacity factors from 4-day historical peak sequence, applied 2020 Summer Peak
  - Aug 30 – Sep 2
  - 12pm – 6pm
- Some congestion increases when production is high at Tehachapi and low at Altamont and Solano

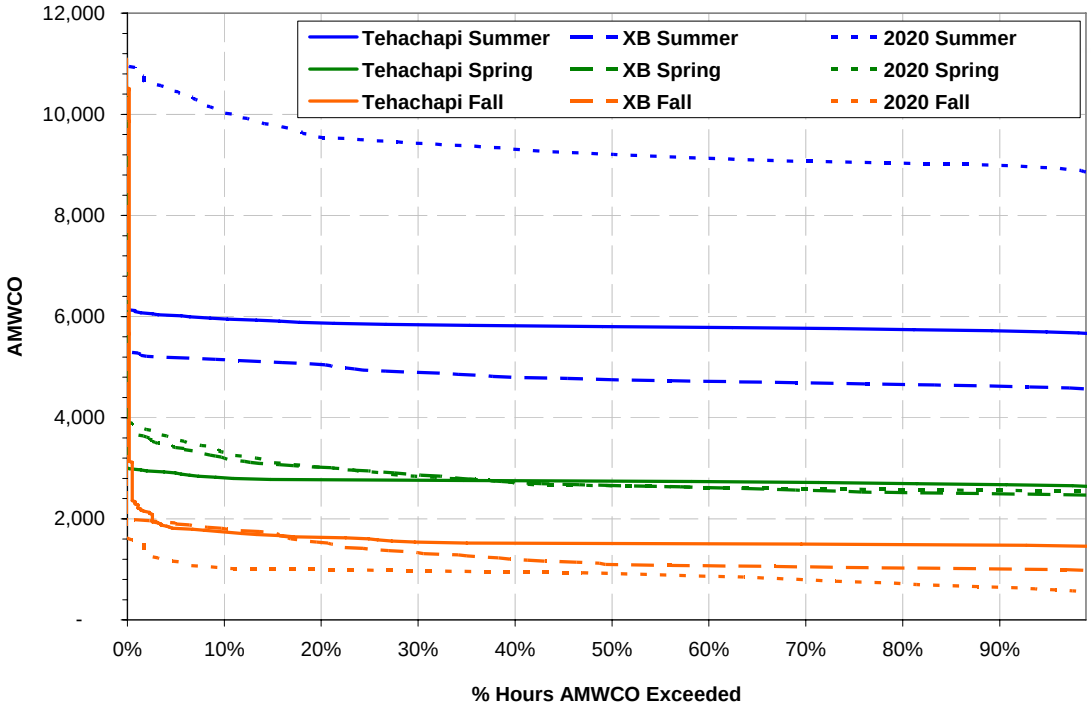


Stop for Movie

System Hourly AMWCO Trend

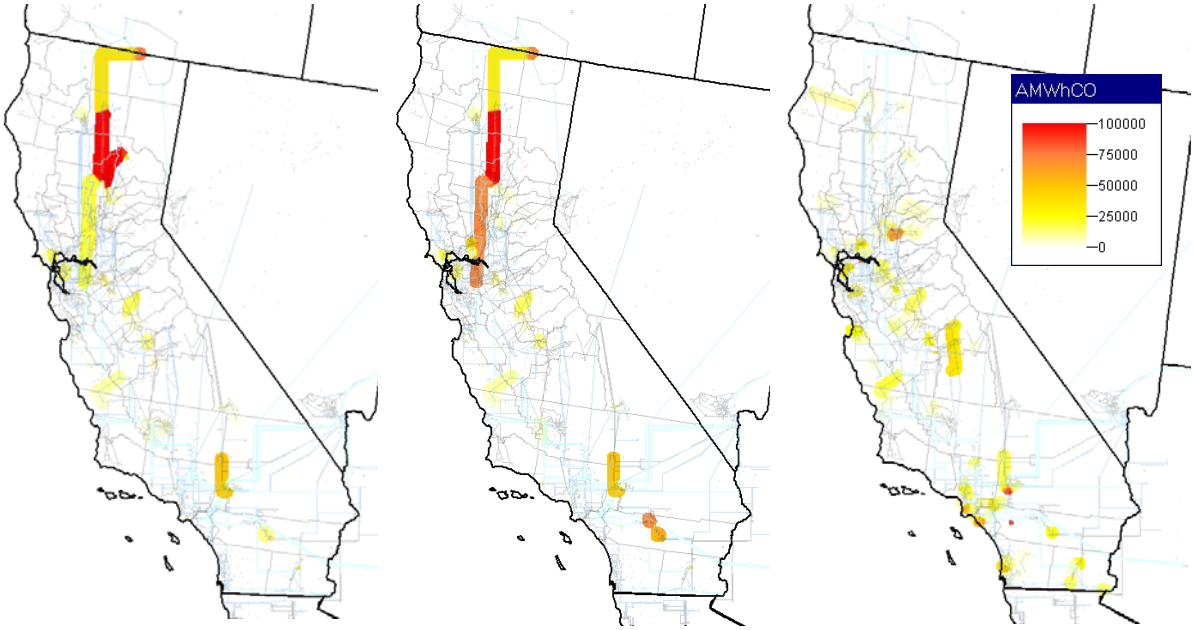


System AMWCO Duration



Summer Peak AMWhCO Trend:

Comparing Three Different Generation Portfolios



2010 Tehachapi 2010 XB 2020

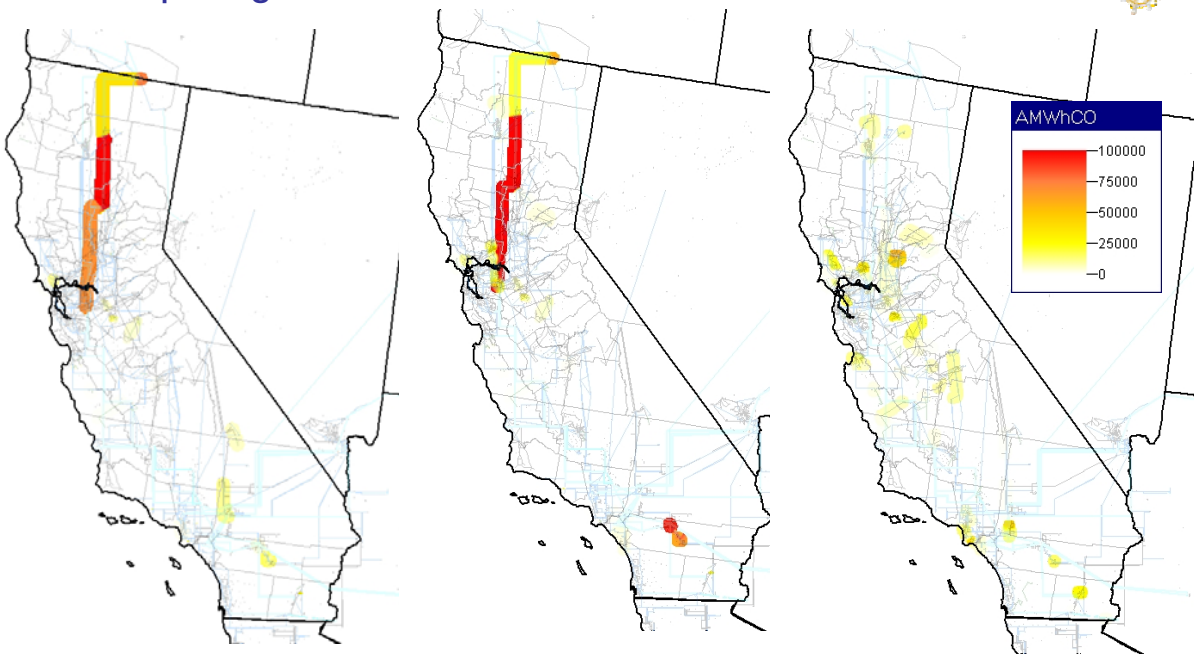
Summer Peak AMWhCO Trend

	2010T	2010XB	2020
No. of CTG Overloaded Elements	131	132	231
Hourly AMWCO Average	5,818	4,822	9,364
AMWCO Std. Dev./Average	1.6%	4.0%	4.8%
AMWCO Std. Dev./Load	0.15%	0.31%	0.61%
AMWCO Std. Dev./Wind Std. Dev.	9%	11%	26%
Wind Production Average/Load	2.8%	5.0%	4.3%
Wind Production Std. Deviation/Load	1.7%	2.8%	2.4%

Summer Peak Trend

- Light wind production relative to load
- Increasing number of overloaded elements and overload variability with each successive scenario
- Highest absolute level of overloading in 2020
  - Increase in number of overloaded elements
  - Increase due to load more than intermittency
  - Intermittency is still an issue as evidenced by high variability of System AMWCO

Spring Peak AMWhCO Trend:
Comparing Three Different Generation Portfolios



2010 Tehachapi 2010 XB 2020

Spring Peak AMWhCO Trend

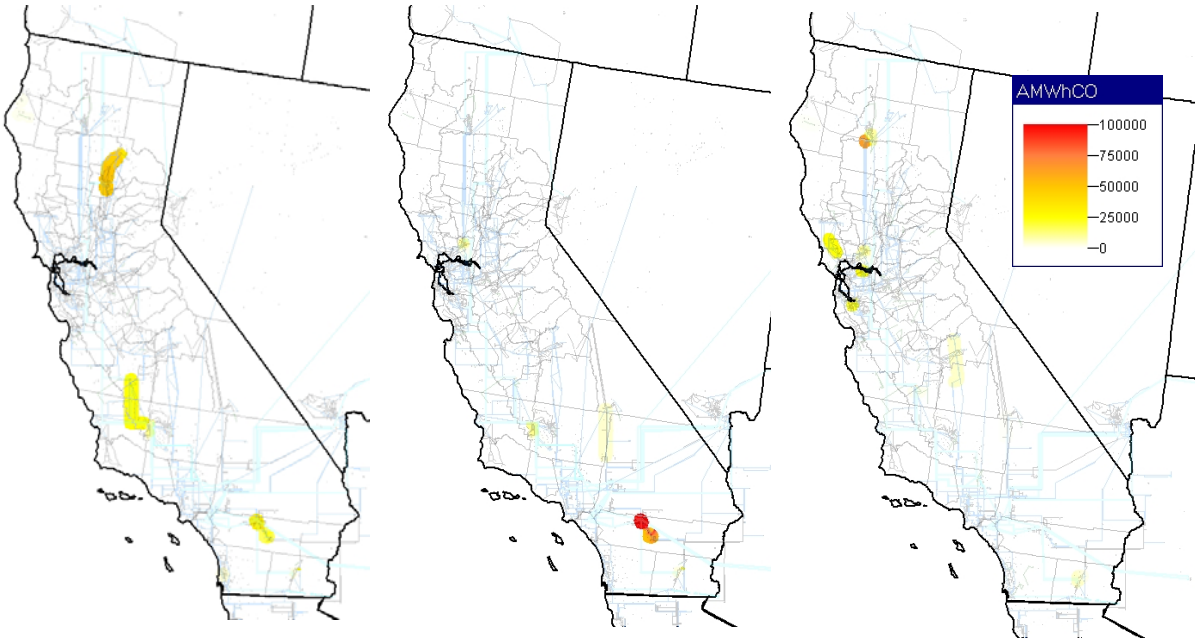
	2010T	2010XB	2020
No. of CTG Overloaded Elements	68	74	133
Hourly AMWCO Average	2,747	2,711	2,808
AMWCO Std. Dev./Average	2.3%	10.7%	11.6%
AMWCO Std. Dev./Load	0.14%	0.63%	0.58%
AMWCO Std. Dev./Wind Std. Dev.	4.2%	12%	13%
Wind Production Average/Load	5.5%	9.0%	7.7%
Wind Production Std. Deviation/Load	3.2%	5.1%	4.4%

Spring Peak Trend

- High wind production relative to load
- Increasing variability of overloading with each scenario
- Absolute level of overloading fairly constant
- High correlation of overloading with regional wind production
- 2010 XB: Sharp increase in AMWCO variability relative to load and wind production
- 2020: Sharp increase in number of overloaded elements

Fall Off-Peak AMWhCO Trend:

Comparing Three Different Generation Portfolios



2010 Tehachapi 2010 XB 2020

Fall Off-Peak AMWhCO Trend

	2010T	2010XB	2020
No. of CTG Overloaded Elements	32	22	30
Hourly AMWCO Average	1,594	1,261	886
AMWCO Std. Dev./Average	32%	24%	20%
AMWCO Std. Dev./Load	1.9%	1.1%	0.57%
AMWCO Std. Dev./Wind Std. Dev.	46%	17%	10%
Wind Production Average/Load	4.8%	7.7%	6.6%
Wind Production Std. Deviation/Load	4.2%	6.5%	5.6%

Fall Off-Peak Trend

- Absolute level of overloading and variability decreasing with each scenario
- 2010T: skewed by Tehachapi series capacitor
- 2010 XB: Reduction in number of overloaded elements

Chronic Transmission Issues

- Tehachapi 500 kV: entire proposed circuit, including series capacitors, must be able to handle projected wind variation
- Vaca Dixon – Peabody 230 kV: extreme variability and vulnerability under contingency across seasons, 2010 XB and 2020
- COI and downstream 500 kV: vulnerable during periods of high Northwest imports
- Altamont low voltage collector network: upgrades may be desirable if remedial action schemes are insufficient to direct power flows away from overloads

Presentation Summary

Findings/Conclusions

- Transmission upgrades added for 2020 were adequate for maintaining overall system security in fall off-peak and spring peak conditions, but not for summer peak
- Wind variability may occasionally contribute to transmission congestion
- Transmission congestion patterns become more difficult to predict as the penetration of intermittent resources increases

Conclusions Cont'd

- Transmission limitations during contingency situations tend to increase with increasing penetration of intermittent resources
- The IAP analysis helps identify the transmission elements that are more susceptible to congestion variability
  - This could help identify:
    - additional transmission expansion requirements
    - modification of system operation requirements, including the possible curtailment of wind resources

Conclusions Cont'd

- There are sufficient in-State renewables to meet the 20% and 33% renewable targets
- Not all of these renewable resources meet the least cost-best fit criteria
- However, transmission system requires extensive upgrades across all voltage ranges
- Intermittency will impact some transmission elements in different seasons, time periods and durations
- Mitigation measures will include new elements, upgrade of elements and RAS procedures

Conclusions Cont'd

- Voltage stability will be a problem as higher penetrations of renewables are developed
- Measures should be taken to ensure that the base cases have stable flows and proper VAR compensation to minimize transmission loading due to VAR flows
- RMR designated units will change by season as more renewables are added

Further Analysis

- Repeat intermittency analysis presented here using:
  - forecasted wind data for all anticipated wind sites
  - more detailed contingency definitions, including special protection scheme definitions
- Apply forecasted wind and load correlation to identify hourly transitions of interest for further detailed analysis

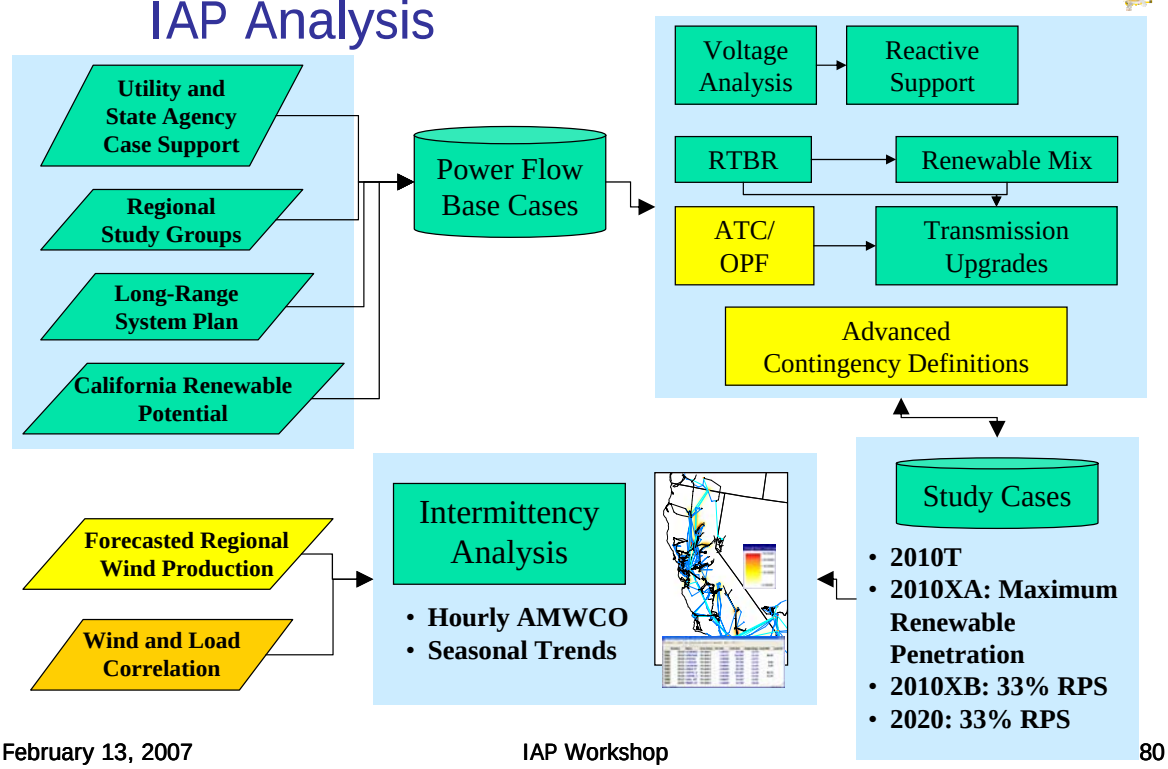
Further Analysis

- Use ATC tool to screen for possible critical transmission constraints
- Use optimal power flow techniques with anticipated wind sites and screened transmission elements to:
  - estimate optimized renewable penetration
  - identify and rank critical binding transmission constraints for upgrade consideration

Summary of Application Potential

- Max penetration analysis may be a good screening analysis tool to determine renewable potential
  - ATC tool can quickly screen for limiting transmission elements
  - OPF tool can optimize penetration while maintaining transmission limits
- Can help identify critical congestion elements that require detailed planning and operations analysis as renewable resources grow
  - rank transmission upgrade alternatives
  - identify renewable generation patterns where contingent special protection schemes may need to be instituted or modified

Possible Flow Chart for Improved IAP Analysis



IAP Contributors

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  - California Energy Commission
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  - Renewable Collaboratives
    - Tehachapi Wind Energy Collaborative & Imperial Valley Geothermal Collaborative

Questions????

Summary of Renewable Additions by Location: 2010 to 2020

Location	Technology	2010 Tehachapi Additions (MW)	2020 33% Additions (MW)
Salton Sea	Geothermal	600	1,400
Mount Signal	Geothermal	19	19
Heber	Geothermal	20	42
Brawley North	Geothermal	135	135
Sulfur Bank	Geothermal	50	
Medicine Lake	Geothermal	175	175
Niland	Geothermal	65	65
Geysers	Geothermal		450
Brawley East	Geothermal		129

Summary of Renewable Additions by Location: 2010 to 2020

Location	Technology	2010 Tehachapi Additions (MW)	2020 33% Additions (MW)
Fire Threat	Biomass		133
Urban, Agr, Veg	Biomass	221	857
Imperial	CSP	146	450
Riverside	CSP		200
San Bernardino	CSP		300
SCE CSP	CSP	300	850
SDG&E CSP	CSP	500	600
Lassen CSP	CSP		300
Statewide PV	Res Solar	533	2,860

Summary of Renewable Additions by Location: 2010 to 2020

Location	Technology	2010 Tehachapi Additions (MW)	2020 33% Additions (MW)
Tehachapi	High Wind	3,000	4,500
Riverside	High Wind	1,412	1,412
San Bernardino	High Wind	168	640
SDG&E	High Wind	90	500
Solano	High Wind	165	1,085
Altamont	High Wind	80	200
Medicine Lake	High Wind		130
Pacheco	High Wind		40

Summary of Renewable Additions by Location: 2010 to 2020

Location	Technology	2010 Tehachapi Additions (MW)	2020 33% Additions (MW)
LADWP Wind	High Wind	120	200
Lassen Wind	High Wind		650
Imperial Wind	High Wind		600
Inyo	Low Wind		28
Contra Costa	Low Wind		100
Ventura	Low Wind		50
Yolo	Low Wind		3
Totals (MW)		**7,799**	**19,103**