



PACIFICORP

Capacity Expansion Model Technical Workshop

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Agenda

- » Overview
- » Model Scope
- » Model Objective and Constraints
- » Model Variables

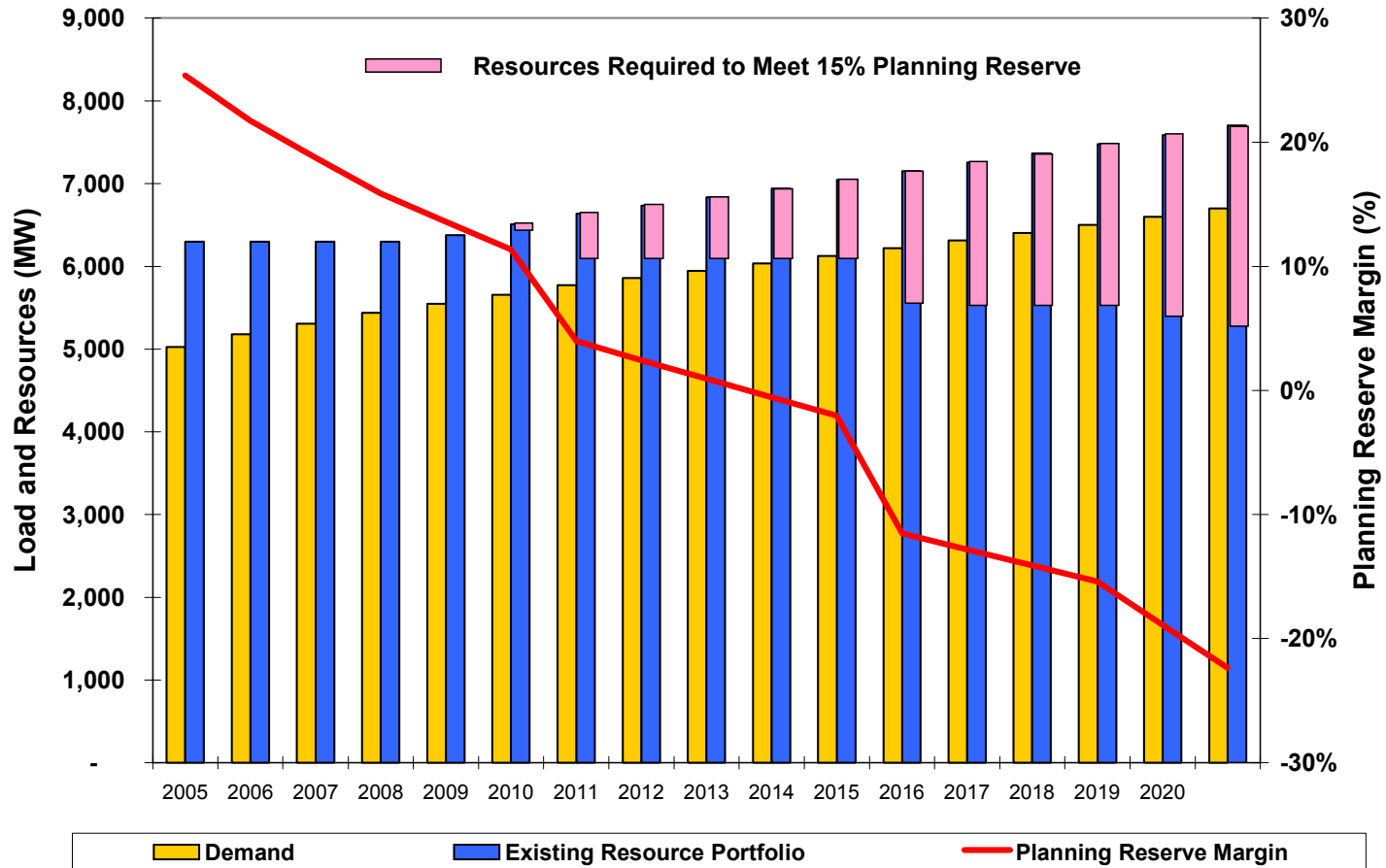
Overview

- » Henwood developed a capacity expansion model (CEM) for automated screening and evaluation of generation capacity expansion and retirement options
- » This economic optimization model to be used as part of the larger IRP effort
- » The CEM answers the key investment decisions of (1) what to build, (2) where to build, (3) how much to build, and (4) when to build



Overview

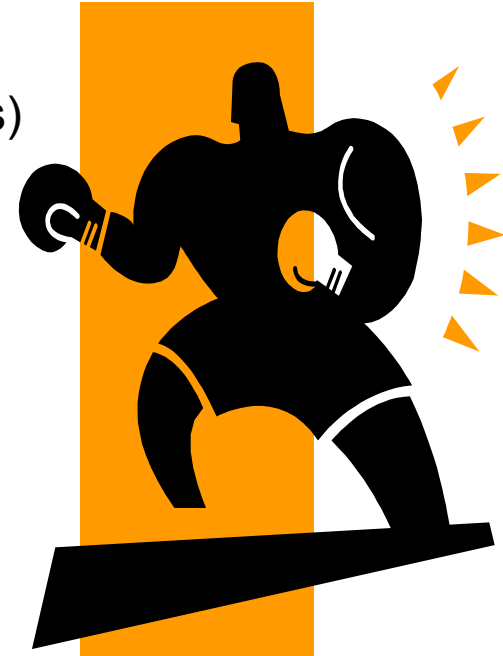
Planning Margin "Gap" Analysis (Sample Utility)



Overview – Feature Set

The features of the CEM (soon to be called CapX™)

- » State-of-the-art MIP algorithm
- » Multi-regional hourly interchange (up to X? regions)
- » Expansion alternatives (up to 30 simultaneous options)
- » Up to 100 existing resources
- » Variable time granularity for hourly dispatch
- » Fast execution
- » Flexible constraint set: energy balance, planning margin, generation, must-run, limited energy, site build, emission limits, group mix, group capacity, aggregate capacity, capital budget
- » Significant production detail: fuel, VOM, MOR, emissions, FOR
- » Calculates inter-regional and external market energy transfers

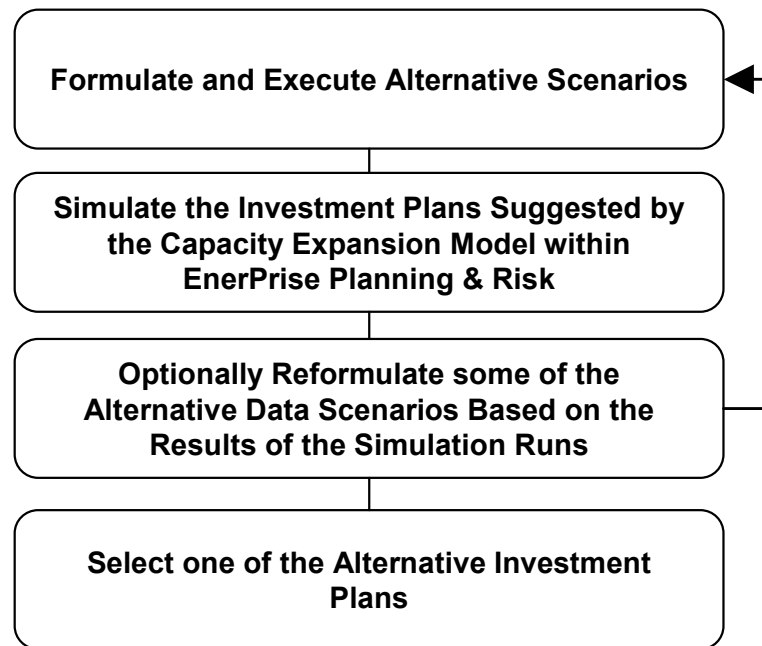


Overview – Objective Function

- » **The goal is to minimize the present value cost of generation, construction, and expansion subject to load balance equations, reliability constraints, and capacity constraints**
- » Thus, the criteria for evaluation is minimization of the expected present value of revenue requirements (PVRR)
- » Mixed integer program for which the objective minimizes the sum of the discounted expansion and generation costs of supplying regions with power. Creates a least cost dispatch of existing resources and installed proposed resources considering heat rates, fuel costs, location, capacities, emissions costs, and variable O&M
 - Includes all existing and proposed plants
 - All expansion choices are represented by build/not build binary variables to characterize the large fixed capital costs involved

Overview – The Only Tool Needed??

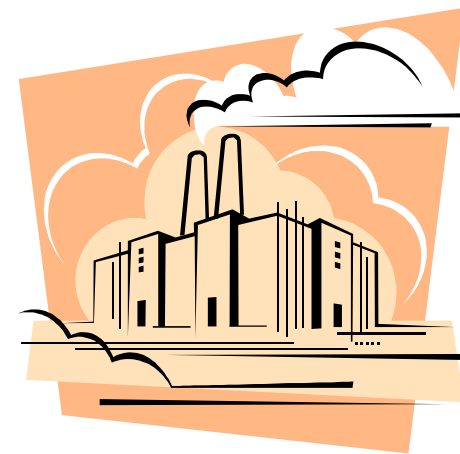
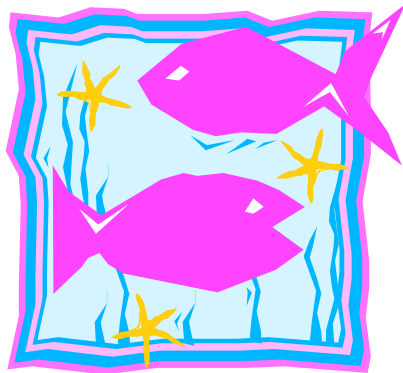
- » Despite the considerable advantages of the CEM (or any automated expansion tool), it is still best used as a preliminary screening tool for narrowing the choice set from tens or hundreds of possible resource plans down to a few “good” alternatives



Why? Does not include all the operational detail needed for use as the sole investment decision tool. Less granularity of dispatch and commitment, **no stochastics**

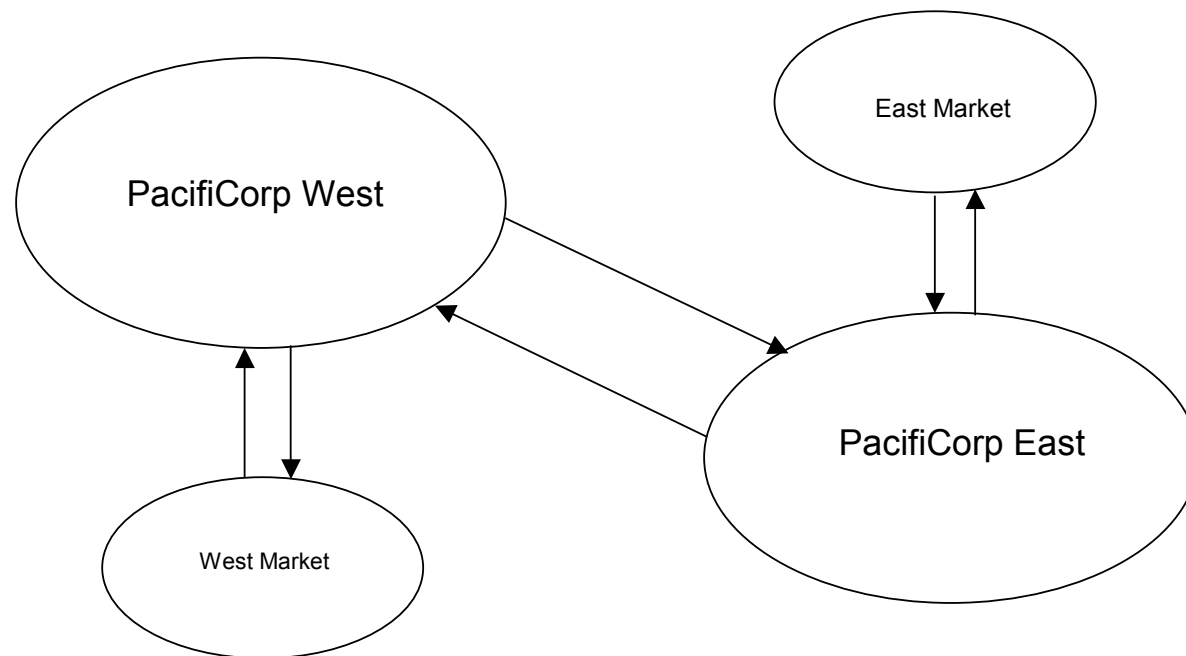
Model Scope - General

- » Study period is 20 years
- » Currently set up for allows portfolio positions (generators, loads, DSM activities, and contracts) in two distinct geographical areas
- » The model accommodates approximately 100 existing resources and 30 potential new resources. Valid resource options include the following types of investments:
 - Supply resource additions, including renewables
 - Supply resource retirements (PacifiCorp will not use this)
 - Demand side options
 - Additional inter-node transmission



Model Scope - Topology

- » Each geographic area has access to an external market to buy and sell power
- » CEM models the hourly transmission constraints between the East and West



Model Scope – Dispatch Granularity

- » CEM makes use of representative or aggregate hours
- » The user can choose the level of aggregation with the understanding that less aggregation can increase solution time
- » Three levels:
 1. 12 months/year x 1 week/month x 3 days/week x 6 hours/day = 216 hours/year
 2. 12 months/year x 1 week/month x 7 days/week x 6 hours/day = 504 hours/year
 3. 12 months/year x 1 week/month x 7 days/week x 24 hours/day = 2016 hours/year

Model Scope – Plant Level Detail

- » Existing Plant characteristic details include:
 - Maximum Capacity –monthly
 - Minimum Capacity – monthly
 - Energy Limit (hydro, DSM) – monthly
 - Average Heat Rate – monthly
 - Fuel Costs (\$/mmbtu) – monthly
 - Emissions (NO_x, SO₂, CO₂, Hg) \$/MWh - monthly
 - Forced and Planned Outage Rates – monthly
 - Variable O&M / MWh – annual
 - Fixed O&M – monthly
 - Decommission Cost (not used yet)
- » Potential Resources - all of the above, plus:
 - Capital Cost, Service Life, Finance Rate
 - Maximum MW installed per site
 - Size per unit installed

Model Scope cont.

- » Capital recovery factors for candidate resources are calculated given an interest rate and an expected life of the resource.
 - Allows for the impact of the profit or loss and investment recovery in the time period outside the study period. The so-called “end effect.”
- » Expected values (deterministic) for inputs such as load, fuel prices, hydro availability will be used. There are no stochastic inputs



Model Objective and Constraints

- » CEM is formulated and solved as a mixed integer linear programming (MILP) model
 - An off-the-shelf modeling package called GAMS (General Algebraic Modeling System) is employed along CLPEX, which solves large scale optimization problems
- » Objective function is to minimize the NPV of portfolio operating cost (fuel, fixed and variable maintenance, un-served energy, and un-served reserves) plus the cost of generation and transmission capacity expansion over the study period
- » The model has two sub-objectives:
 - Minimize thermal and hydro dispatch costs
 - Determine an optimal system-wide resource build plan

Model Objective and Constraints cont.

» Major constraints:

- **Energy balance constraints.** These perform the hourly dispatch of resources to satisfy demand as well as do market purchases and sales
- **Planning margin constraints.** These build resources to ensure that the target planning margin is met while not going over the upper limit on planning margin
- **Generation constraints.** These enforce lower and upper limits on generation in each time period for each resource
- **Must run constraints.** These ensure that must run resources are always run in the dispatch
- **Limited energy constraints.** These enforce monthly energy limits on hydro and energy limited resources
- **Site build constraints.** These allow a number of units to be build on a given site

Model Objective and Constraints cont.

» Major constraints cont.

- **Duct firing unit constraints.** These ensure that duct firing units are built in the same year as the corresponding CCCT
- **Group capacity mix constraints.** These ensure that resource groups are built according to a desired percentage distribution
- **Group capacity level constraints.** These ensure that resource groups are built according to user defined MW limits
- **Aggregate capacity expansion constraints.** These allow the user to specify minimum and maximum MW capacity to build by year
- **Capital budget constraints.** Allows user to limit capital expenditure in a given year across all investments to a specified amount

Model Variables

- » **Energy dispatch variables.** By time period and resource, these determine optimum dispatch levels
- » **Firm capacity variables.** By month and resource, these add proposed resources to respect the planning margin limits
- » **Firm capacity transfers.** These allow the transfer of firm capacity between the East and West for use in planning margin constraints
- » **Energy transfers.** These allow the transfer of dispatched energy between the East and West
- » **Un-served energy variables.** These indicate un-served when the energy balance constraints cannot meet load
- » **Un-met capacity variables.** These indicate unmet capacity when the planning margin constraints cannot meet peak loads

Model Variables cont.

- » **Market purchases.** These allow the model to purchase from market to augment dispatch to meet hourly load
- » **Market sales.** These allow the model to sell to market after hourly load has been met
- » **Site build variables.** These 0/1 integer variables allow the model to build or not build a given resource site in a given year
- » **Unit build variables.** These integer variables allow the model to add units to a site up to the maximum number of units per site



CEM Model Status

Stan Williams

Model Status Agenda

- » Overview
- » Model Validation
- » Resource Options
- » Preliminary portfolio
- » Conclusions
- » Next steps

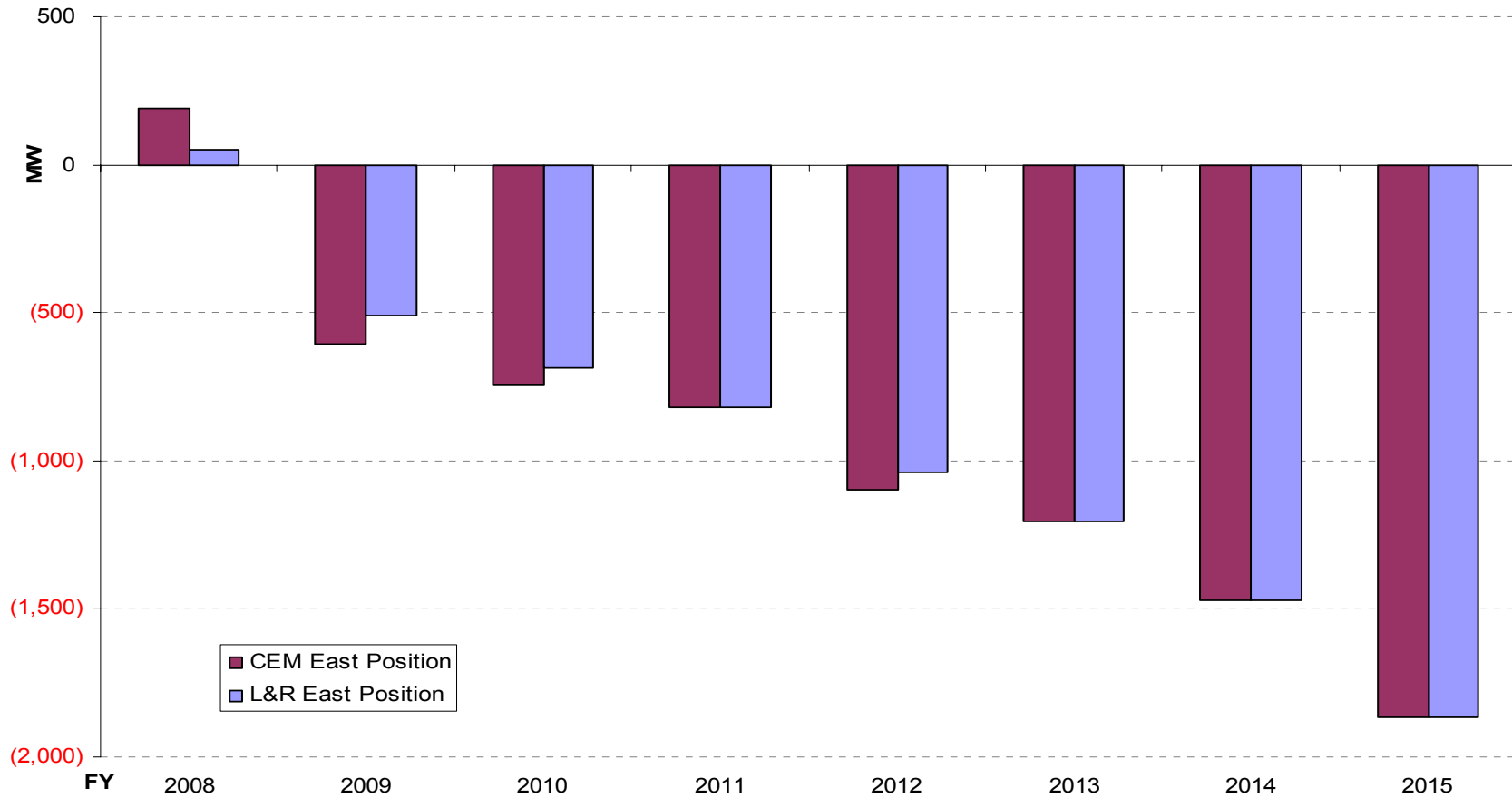
Model Status - Overview

- » Received LP engine of the model
- » Have not received interface
 - Makes full implementation difficult
 - ⇒ Many types of runs can be made
 - ⇒ More complicated runs cannot
 - ⇒ Would be difficult without LP background
 - Should receive it in 2 or 3 months
- » Model validation continues
 - Two of three validations steps are complete
 - Third step will proceed over the next several weeks
- » Preliminary model Implementation begins
 - A resource list has been defined
 - An example preliminary portfolio has been generated

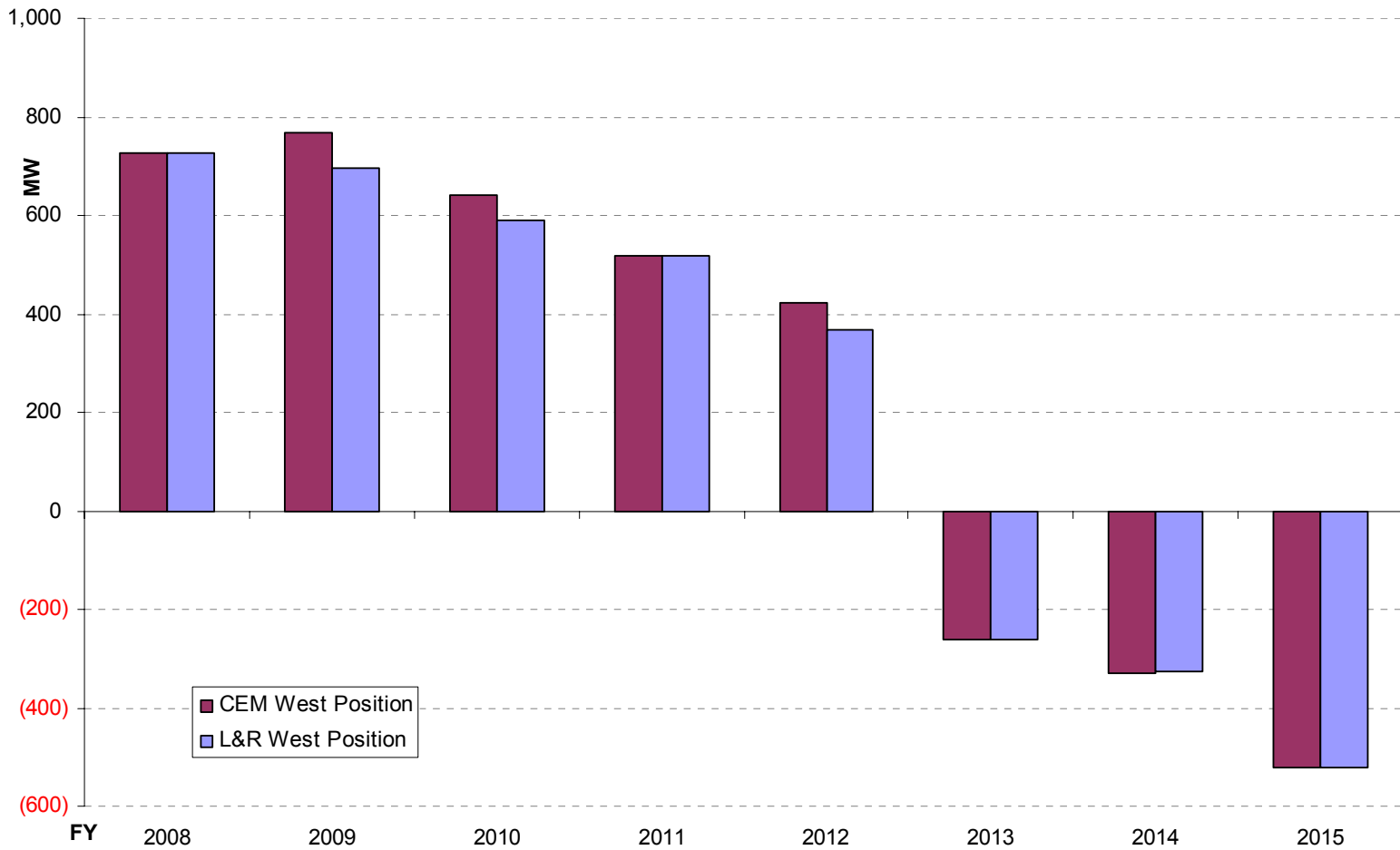
Model Status - Validation

- » Continuing with third step of model validation
 - ✓ Generation and variable costs of existing resources have been validated between the CEM and PROSYM
 - ✓ Completed before last PIM
 - ✓ Validate the short position the CEM computes to L&R balance
 - ✓ Short positions validated by comparing peak load capacity of existing resources of CEM to L&R balance
 - CEM is very close to actual L&R
 - Results are on next two slides
 - Validate CEM portfolio PVRR against PROSYM
 - Most difficult one

Model Status – Validation - East Positions



Model Status – Validation - West Positions



Model Status - Validation – What remains?

- » Third and final step is to validate CEM PVRR against PROSYM
 - Most difficult of the three validation steps
 - Portfolios will be generated with the CEM and then simulated with PROSYM. The PVRR outputs of both models will then be compared
 - ⇒ For each year, the “All in” cost of the CEM will be compared to the consolidated fixed and variable costs generated in PROSYM
 - ⇒ This validation should be complete in about two months
- » Meanwhile, examples of preliminary portfolios can be generated
 - First step is to create the candidate resource list

Model Status - Resource Options

	East	West
<u>Gas</u>		
CCCT 2x1 - Dry Cooling / Duct Firing	X	X
Intercooled Aero SCCT	X	X
<u>Coal</u>		
Brownfield Pulverized Coal (PC)	X	
Greenfield IGCC	X	
Greenfield PC	X	
<u>DSM</u>		
Commercial Cooling Control	X	X
Res./Small Comm'l Air Conditioner Control		X
<i>*Extension of Cool Keeper past FY2014</i>	X	
Electric Space/Water Heat Control		X
Commercial Lighting Control		X
Irrigation Control	X	X
<i>*Extension of Idaho Irrigation Program past FY2014</i>	X	
<u>Distributed Generation</u>		
<i>*Standby Generators</i>	X	X

* - Not currently active in model

Preliminary Portfolio - Example

Area	Resource	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Totals
East	Brownfield Pulverized Coal (PC)						575					575
	Intercooled Aero SCCT					87		87		174		348
	CCCT 2x1 - Dry Cooling				420						420	840
	CCCT 2x1 - Dry Cooling / Duct Firing				105						105	210
	Commercial Cooling Control					44						44
	Irrigation Control			44								
West	Intercooled Aero SCCT							194				194
	CCCT 2x1 - Dry Cooling								469			469
	CCCT 2x1 - Dry Cooling / Duct Firing								117			117
	Res./Small Comm'l Air Conditioner Control					45						45
	Irrigation Control							44				44
Totals		0	0	44	525	176	575	325	586	174	525	2,930

Area	Resource	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	Totals
East	Brownfield Pulverized Coal (PC)											575
	Intercooled Aero SCCT			87	87		261	348		261	522	1,914
	CCCT 2x1 - Dry Cooling				420	420	420	840	420	420		3,780
	CCCT 2x1 - Dry Cooling / Duct Firing				105	105	105	210	105	105		945
	Commercial Cooling Control											44
	Irrigation Control											
West	Intercooled Aero SCCT											194
	CCCT 2x1 - Dry Cooling					469		938	469			2,345
	CCCT 2x1 - Dry Cooling / Duct Firing					117		234	117			585
	Res./Small Comm'l Air Conditioner Control											45
	Irrigation Control											
Totals		0	0	87	612	1,111	786	2,570	1,111	786	522	10,515

Model Status - Conclusions

- » CEM is not currently ready for full implementation
 - Third phase of validation must be completed
 - ⇒ Match PVRRs of CEM to PROSYM
 - User-friendly interface and reporting module must be received and understood
 - ⇒ Inputs are difficult to make
 - ⇒ Outputs are difficult to interpret
- » Can generate preliminary portfolios
 - Informs the manual build process

Model Status - Next Steps

- » Continue validation
 - PVRR validation
- » Further develop preliminary portfolios
- » Receive interface to the model
 - Incorporate into MarketSym
- » Receive enhancements to model
 - Reporting capability
- » Goals for next year
 - Have user-friendly interface
 - Fully validated
 - Become primary capacity expansion methodology