Combined Cycle Combustion Turbines

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CCCT Today's Discussion

1. Quick review from previous GRAC
2. CCCT Capacity Factors in the NW
3. Cost Review & Economies of Scale
4. Wet vs. Dry Cooling
5. Normalizations & Results
6. Reference Plant Proposals

CCCT Review – Last Meeting

CCCT Strengths & Trends	Projects in the region
• Highly efficient power source – dispatchable and baseload	• 20 existing projects in region - Ave capacity 345 MW
• Can provide support for renewable power and serve as coal replacement	• Port Westward in OR (PGE 2007) - 400 MW
• Becoming more flexible with rapid start times and better efficiency at part and min loads	• Langley Gulch in ID (ID Power 2012) - 330 MW
• Plenty of low priced gas	• Carty Generating Station in OR (PGE 2016) - 440 MW

CCCT Review – Last Meeting

- Pricing of 4 advanced units using information from Gas Turbine World
- Other cost estimates from E3, EIA, Power Council 6th Plan
- Normalization of capital costs
- O&M costs
- Emissions

CCCT Last Meeting Follow Up

Discussion from previous GRAC

1. How capacity factors for CCCT units in the NW compare to other regions
2. Address dry-cooling costs in the reference plant
3. Units may be smaller in size in the NW
4. Propose reference plant(s)

CCCT Capacity Factors

Using information from SNL, I did a quick study on CCCT production data from the Northwest - defined as the entire states of Idaho, Montana, Oregon and Washington – along with a few selected NERC regions:

- NPCC – the Northeastern US and Canada
- WECC - the West (the Northwest is included)
- TRE - most of Texas
- MRO – the upper Midwest US and Canada

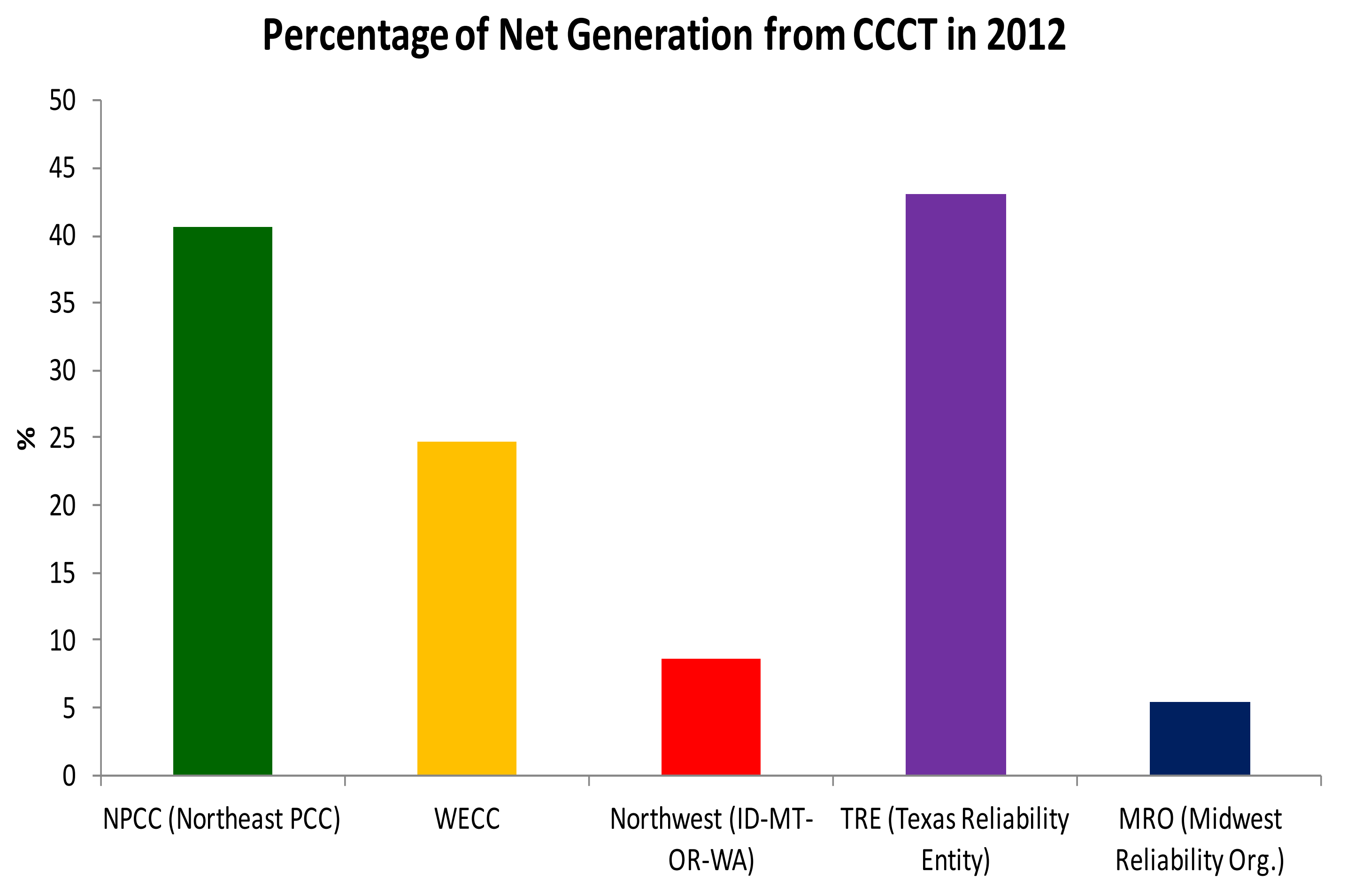
In addition – looked at capacity factor variability from a few selected CCCT units in relation to a hydro unit and a wind unit - all in the Columbia Gorge area.

- Port Westward Generating Project in Oregon
- Goldendale Generating Station in Washington
- Dalles Hydro
- Klondike II wind project

CCCT Capacity Factors

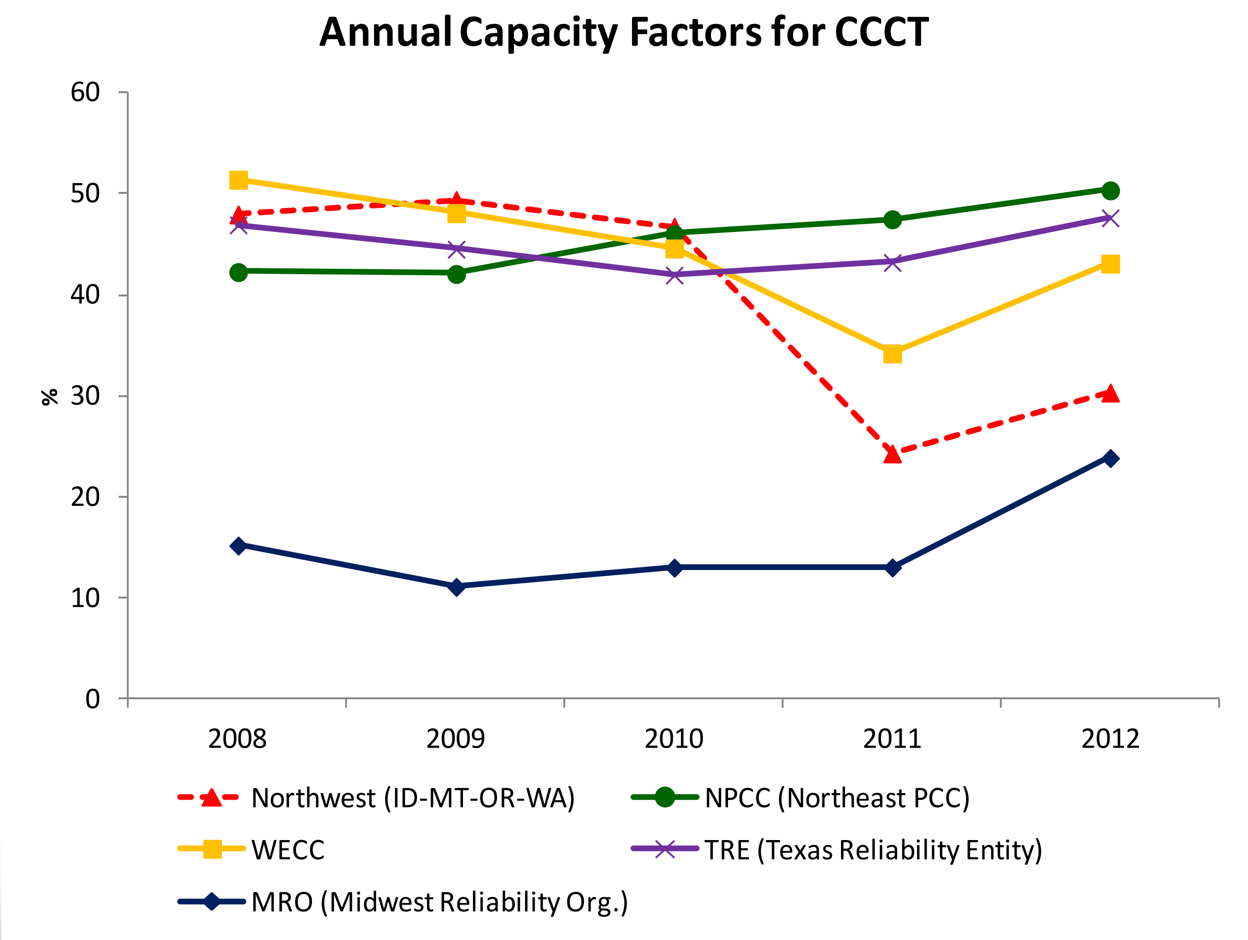
1. The Northwest ranks relatively low in terms of CCCT generation percentage – due to hydro production
2. Northwest CCCT Capacity Factors are similar to other regions during years with average hydro, but lower during strong hydro years – more variation year to year
3. Strong negative correlation between CCCT and hydro capacity factors – annually and monthly

CCCT Generation



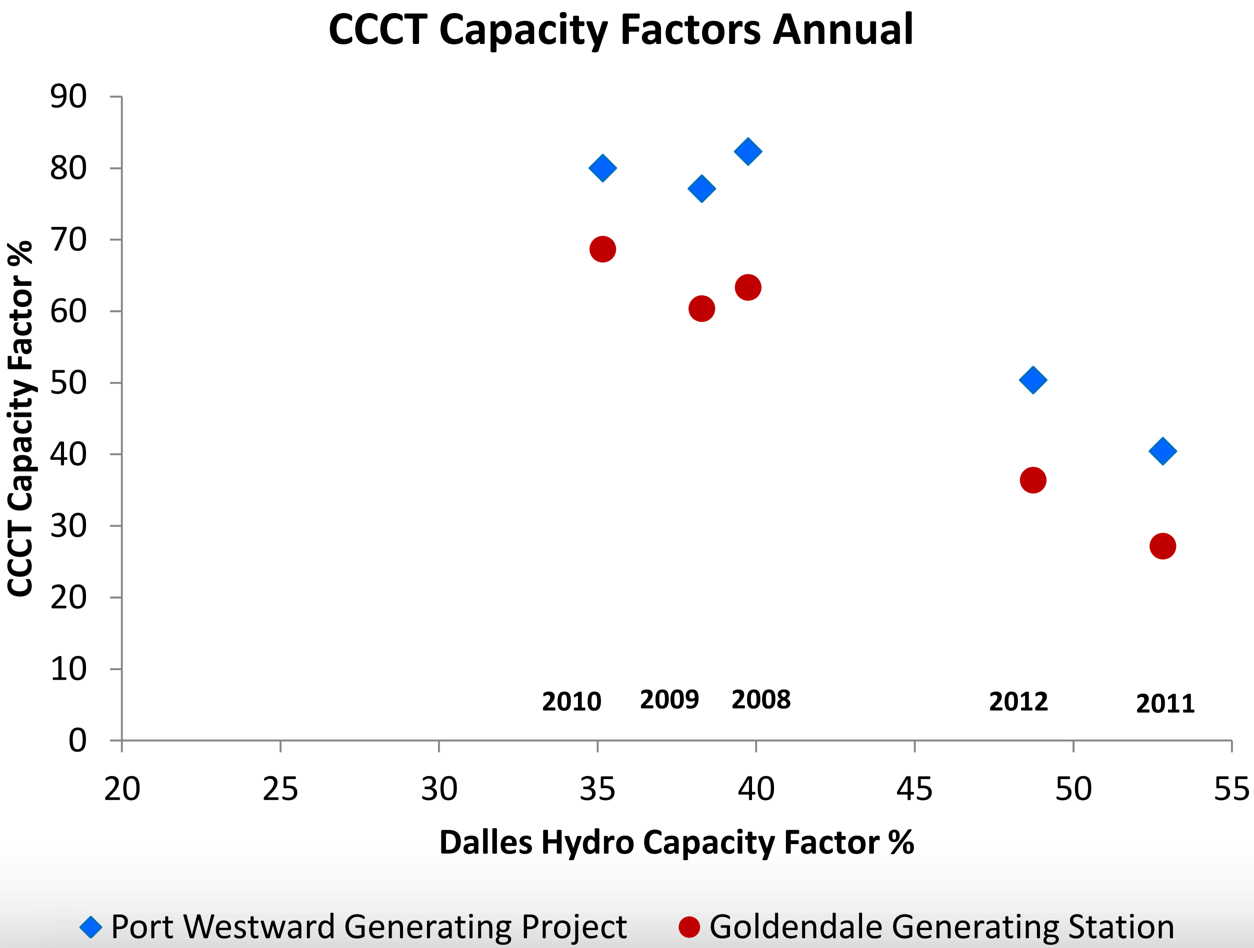
1 - Northwest is relatively low in terms of CCCT generation percentage – due to hydro production

CCCT Capacity Factors



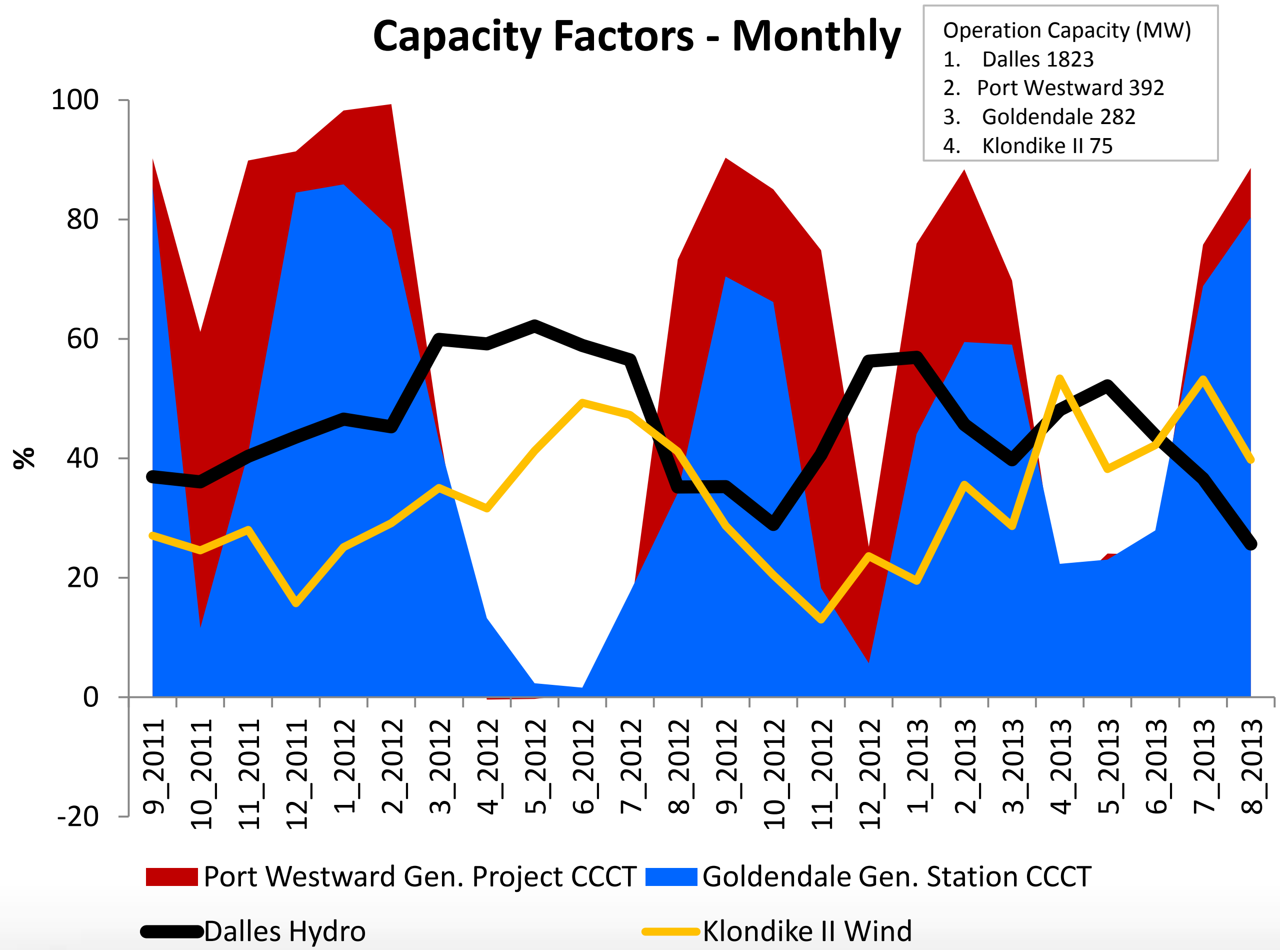
2 -
Northwest CCCT Capacity Factors – similar to other regions during years with average hydro, but lower during strong hydro years

CCCT Capacity Factors



3-
Annual CCCT capacity factors strongly correlated to hydro

CCCT Capacity Factors



3- Monthly Capacity Factors also correlate to hydro

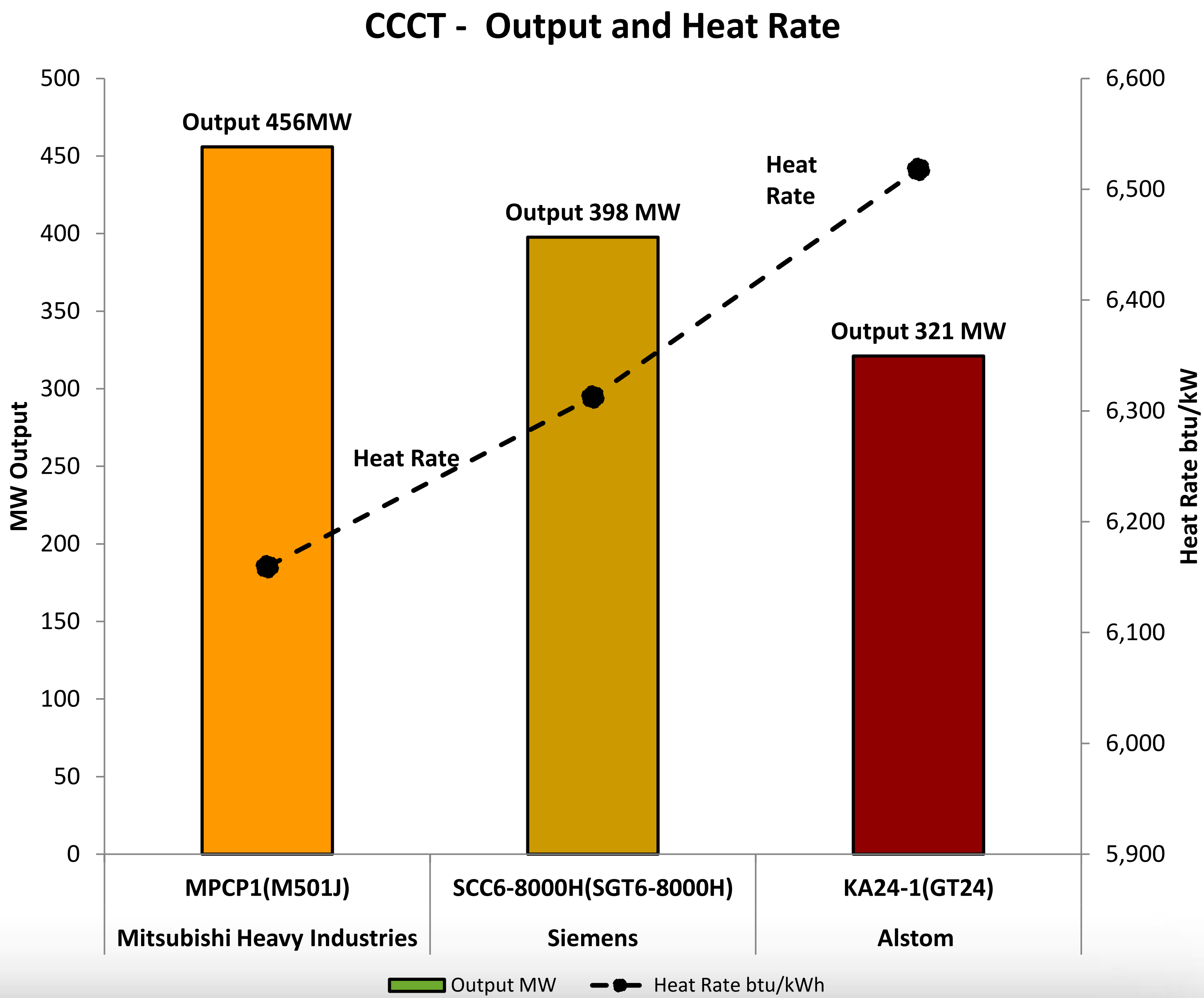
CCCT Costing Sources

	Northwest Power and Conservation Council	E3	EIA	Gas Turbine World	California Energy Commission
Date	2010	Oct 2012, Dec 2013	Apr 2013	2013	Apr 2006
Title	6^{th} Plan	Cost and Performance Review of Generation Technologies Recommendations for WECC 10- and 20- Year Study Process	Updated Capital Cost Estimates for Utility Scale Electricity Generating Plants Prepared by SAIC	2013 GTW Handbook	Cost and Value of Water Use at Combined Cycle Power Plants

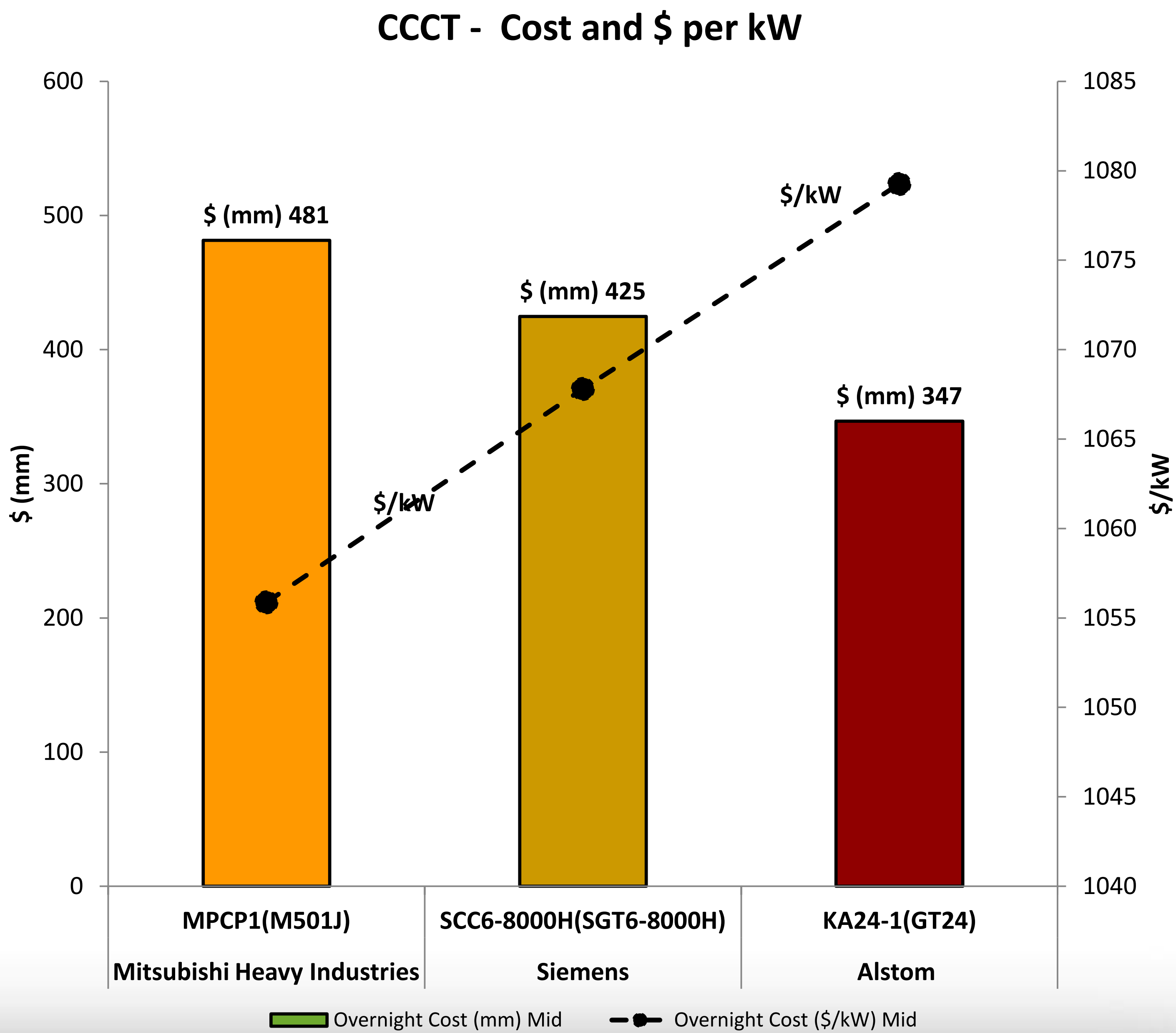
CCCT Costing - GTW

- Used 2013 version of Gas Turbine World (GTW) to price 3 advanced CCCT plants
  1. Mitsubishi Heavy Industry MPCP1 (M501J)
  2. Siemens SCC6 8000H (SGT6-8000H)
  3. Alstom KA24-1 (GT24)
- GTW provides a consensus of what project developers, owners, operators, and OEM suppliers agree on as reasonable for budgeting purposes for a bare bones plant
- Exhibit economies of scale

Unit size and heat rate inversely related



Economy of Scale:
Unit size and capital cost inversely related to cost/kW

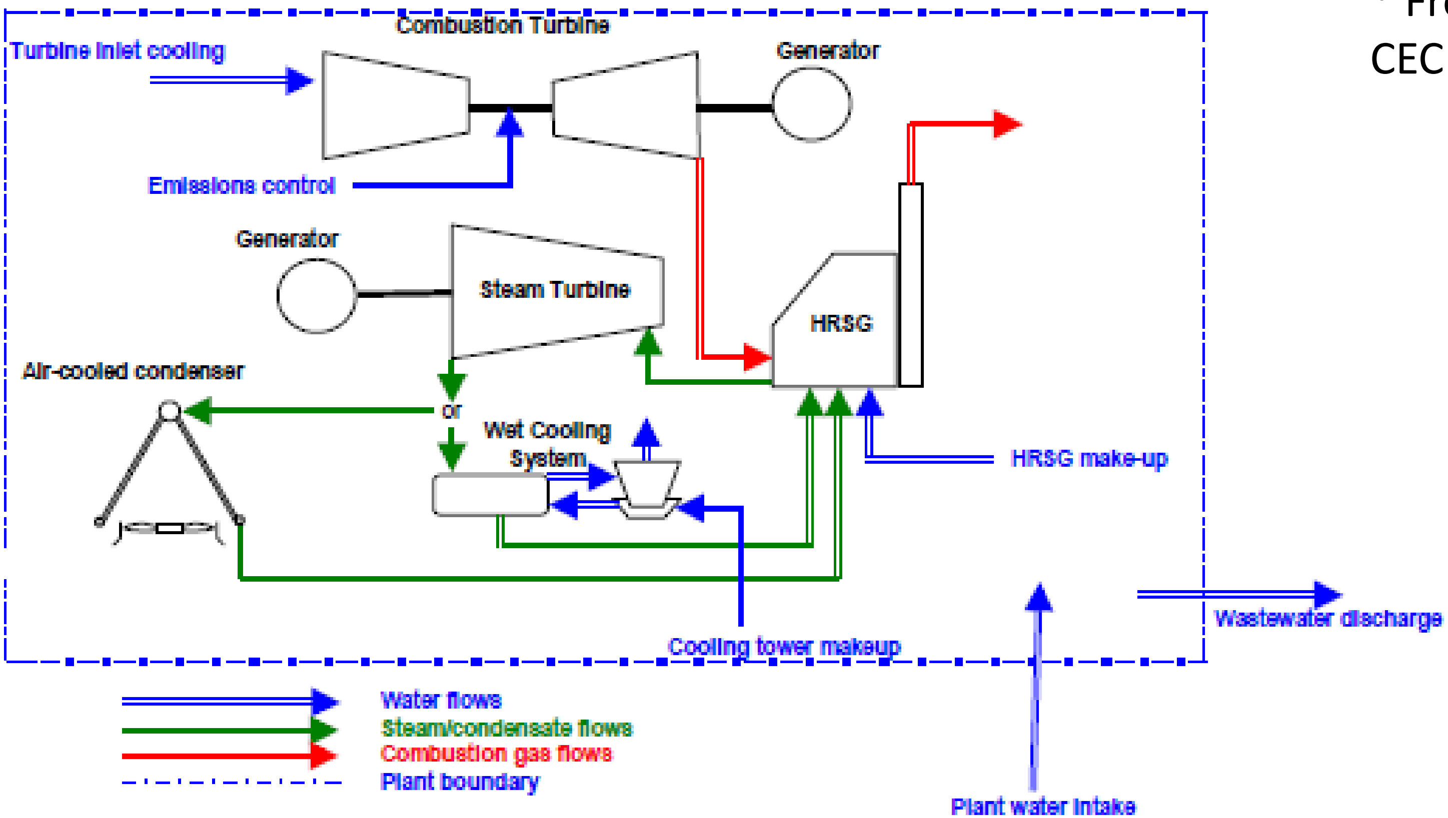


CCCT Water Cooling

<u>3 Types of Cooling</u>

1. Once Through Cooling - no longer used for new plants
2. Wet Cooling - recirculating system with a steam surface condenser and wet cooling tower
3. Dry Cooling - forced draft air-cooled condenser

CCCT Water Cooling



* From CEC

CCCT Water Cooling

Using the Central Valley as an example, going from Wet Cooling to Dry Cooling results in a

- 96% drop in water usage
- 13.5 % increase in capital cost
- 1.5 % increase in heat rate

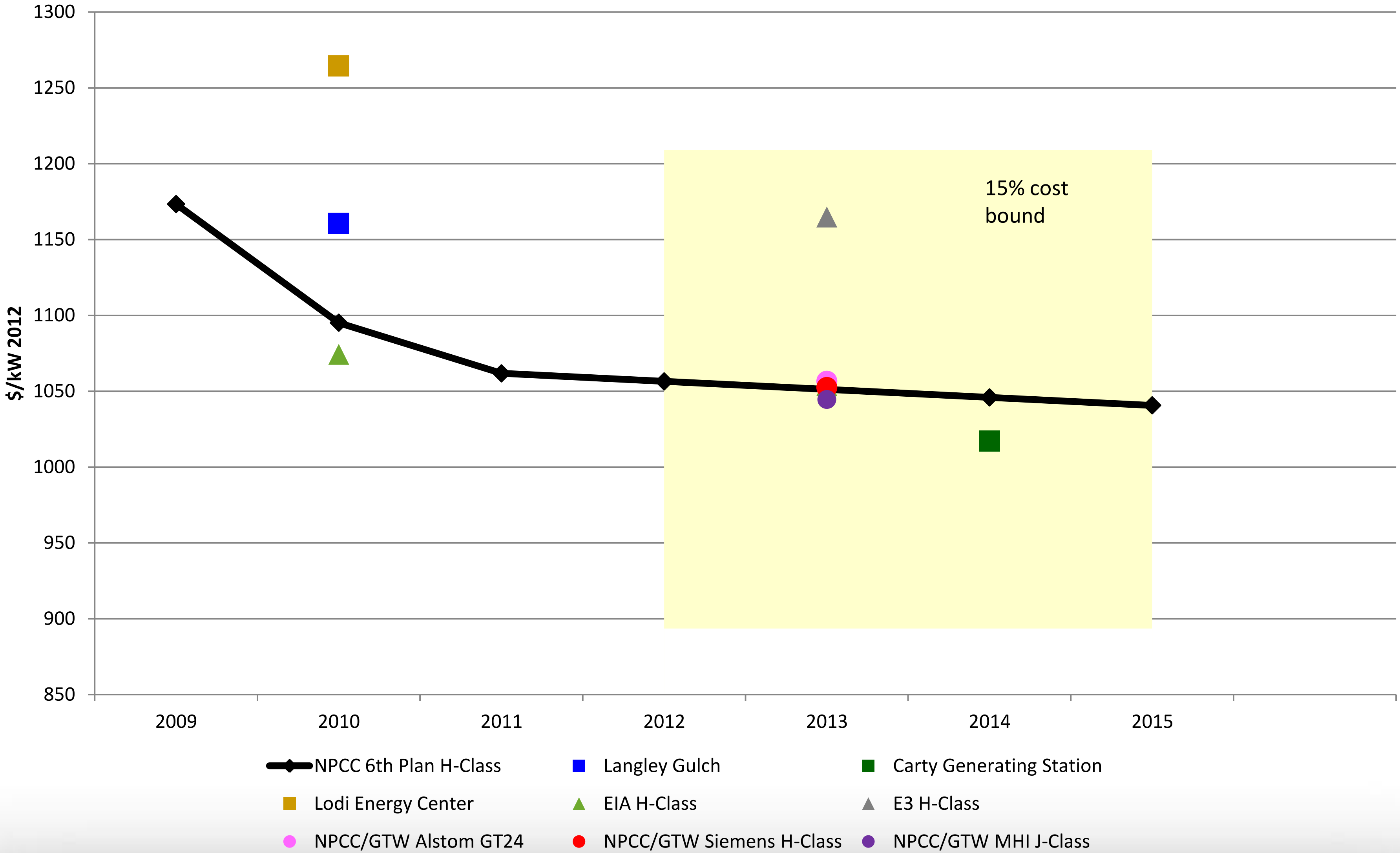
CCCT Projects

	Lodi Energy Center	Langley Gulch	Carty Gen Station
In Service	2012	2012	2016
Location	Lodi, CA	New Plymouth ID	Boardman, OR
Elevation	50	2260	308
Model	1x1 Siemens SCC6-5000F	1x1 Siemens SGT6-5000F	1x1 MHI M501GAC
Capacity MW	296	330	440
Capital $ (mm)	388	389.4	447.5
$/kW	1,311	1,180	1,017
Note	Wet cooling - uses treated wastewater from a nearby municipal wastewater treatment plant	Wet Cooling	Wet Cooling

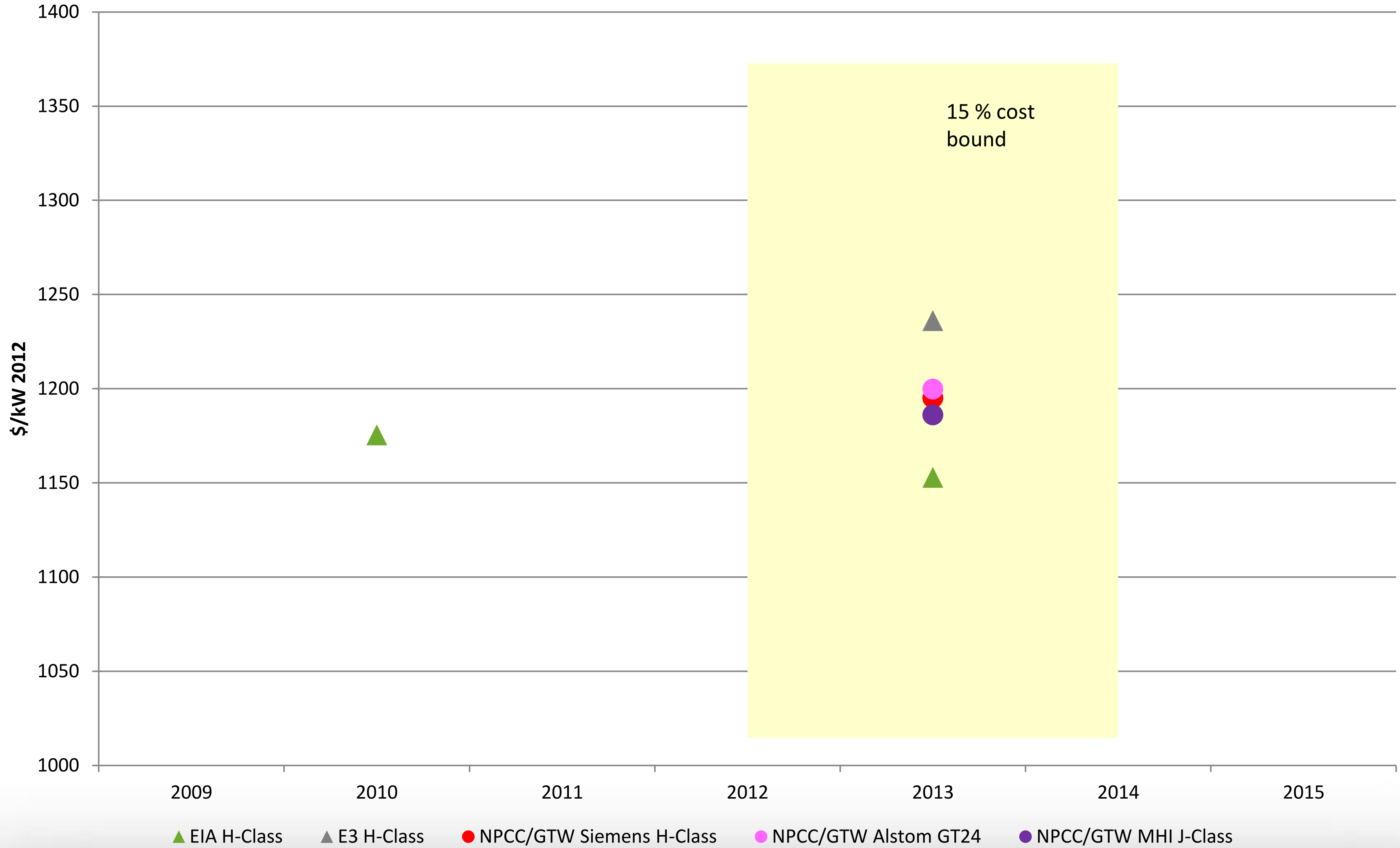
Normalization Adjustments

Output Related – MW	Heat Rate Related (btu/kWh)	Cost Related $
Configuration - 2x1 to 1x1	Configuration - 2x1 to 1x1	Configuration - 2x1 to 1x1
Duct Firing	Duct Firing	Duct Firing
Inlet & Exhaust Losses	Inlet & Exhaust Losses	
Electrical & Mechanical Auxiliaries	Electrical & Mechanical Auxiliaries	
Location Elevation – Boardman OR (308 ft)		Location Labor - OR
	Water Cooling – Wet to Dry	Water Cooling – Wet to Dry
	Fuel Heating Value – LHV to HHV	
		Year Dollar - 2012

Normalized CCCT Overnight Capital Cost $/kW
Wet Cooling



Normalized CCCT Overnight Capital Cost $/kW
Dry Cooling



CCCT data normalized with reference plants highlighted

Manuf/Source	Model (GT)	Vintage	Capital Cost - $/kW	Output - MW	Heat Rate - btu/kW	Cost - $ mm	Configuration	Cooling	Source
Mitsubishi Heavy Industries	MPCP1 (M501J)	2013	1,045	469	6,365	490	1X1	Wet	GTW 2013
Mitsubishi Heavy Industries	MPCP1 (M501J)	2013	1,186	469	6,459	556	1X1	Dry	GTW 2013
Siemens Energy	SCC6-8000H(SGT6-8000H)	2013	1,195	412	6,628	492	1X1	Dry	GTW 2013
Siemens Energy	SCC6-8000H(SGT6-8000H)	2013	1,052	412	6,531	433	1X1	Wet	GTW 2013
Alstrom	KA24-2(GT24)	2013	1,200	336	6,858	404	1X1	Dry	GTW 2013
Alstrom	KA24-2(GT24)	2013	1,057	336	6,758	355	1X1	Wet	GTW 2013
Advanced Reference Plant	H-Class	2013	1,236	N/A	6,900	N/A	1X1	Dry	E3 2013
Advanced Reference Plant	H-Class	2013	1,165	N/A	6,700	N/A	1X1	Wet	E3 2013
Advanced Reference Plant 2013	H-Class	2013	1,153	400	6430	461	1x1	Dry	EIA 2013
Advanced Reference Plant 2013	H-Class	2013	1,054	400	6430	421	1x1	Wet	EIA 2013
Advanced Reference Plant 2010	H-Class	2010	1,175					Dry	EIA 2013
Advanced Reference Plant 2010	H-Class	2010	1,074					Wet	EIA 2013
NPCC 6TH PLAN	H-Class	2013	1,194	390	7,033	466	1x1	Dry	NPCC 6th Plan
NPCC 6TH PLAN	H-Class	2013	1,051	390	6930	410	1x1	Wet	NPCC 6th Plan
Langley Gulch	Siemens SGT6-5000F	2010	1,161	353	n/a	410	1X1	Wet	Tracking Sheet
Carty Generating Station	1x1 Mitsubishi M501GAC	2014	1,017	440	n/a	447.5	1X1	Wet	Tracking Sheet
Lodi Energy Center	1x1 Siemens SCC6-5000F	2010	1,264	293	n/a	371	1x1	Wet	Tracking Sheet

CCCT Reference Plants

Ref Plant	Adv 1		Ref Plant	Adv 2
Model/Tech	Siemens H-Class		Model/Tech	MHI J-Class
Location	Boardman OR		Location	Boardman OR
Earliest In Service	2014		Earliest In Service	2018
Configuration	1X1		Configuration	1X1
Cooling	Wet		Cooling	Dry
Baseload Capacity	392	MW	Baseload Capacity	449
Duct Firing Augmentation	20	MW	Duct Firing Augmentation	20
Net Capacity	412	MW	Net Capacity	469
Heat Rate	6,531	btu/kWh	Heat Rate	6,459
Capital Cost Overnight	433	$ mm	Capital Cost Overnight	556
Capital Cost $/kW	1,052	$/kW	Capital Cost $/kW	1,186
Fixed O&M	15.37	$/kW/yr	Fixed O&M	15.37
Variable O&M	3.27	$/MWh	Variable O&M	3.27
Economic Life	30	years	Economic Life	30
Annual Life Cycle Degradation	0.39 - 0.31	%/year	Annual Life Cycle Degradation	0.39 - 0.31
Ave Life Cycle Net Capacity	389	MW	Ave Life Cycle Net Capacity	443
Ave Life Cycle Heat Rate	6,833	btu/kWh	Ave Life Cycle Heat Rate	6,758
Life Cycle $/kW	1,113	$/kW	Life Cycle $/kW	1,255