

**POWER SECTOR  
&  
COLORADO CLIMATE ACTION PLAN  
SCENARIO ANALYSIS**

**FOR**

**THE STRATEGIC TRANSMISSION & RENEWABLES  
("STAR") REPORT**

**UNDER A CONTRACT  
FROM  
COLORADO GOVERNOR'S ENERGY OFFICE**

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## **INTRODUCTION**

This study provides the results of a scenario analysis of the electric power system in Colorado to meet the greenhouse gas emissions reduction goals of the Colorado Climate Action Plan for the Strategic Transmission and Renewable (“STAR”) Report. For this study, we model the statewide electric power sector while balancing economic costs and environmental benefits. We developed a Reference Scenario for the Colorado power sector incorporating a statewide existing electric power generation fleet, future generation expansion, Renewable Energy Standards (RES) requirements and mandated Demand Side Management (DSM) measures to meet the forecasted energy demand. This study examines the cost and benefits of increasing the level of clean energy technology integration while examining the potential retirement of the existing fleet of aged coal-fired power plants in Colorado. The study also examines the sensitivity in change of resource portfolio due to higher natural gas prices and higher load growth in Colorado.

## **MODELING METHODOLOGY**

We use the MARKAL modeling framework to investigate certain scenarios of future electric power generation technologies in Colorado and their impact on the environment.<sup>1</sup> MARKAL is a model that represents an energy system from the extraction fuels through their conversion to useful forms of energy to meet end-users demands. It determines the least-cost pattern of technology investment while meeting the required energy demands and model constraints, and then calculates the resulting environmental impact, such as greenhouse gas emissions as well as criteria pollutants. The objective function of the model is to minimize the discounted total system cost of a region (or set of regions if multiple regions are modeled) obtained by adding the discounted periods’ total annual cost.

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<sup>1</sup> MARKAL model is a linear programming model focused strictly on the integrated assessment of energy systems.

## MODEL DEVELOPMENT

In order to investigate scenarios of future electric generation technologies and their impact on the state's future carbon and air emissions, the following scenarios were developed and evaluated:

- Reference Case – establishes the baseline for scenario analysis
  - Includes base energy forecast of 1.7% per year with PUC mandated DSM measures and recent legislation of increased RES requirements of 30% by 2020 for Investor Owned Utilities (IOUs) and previously established RES requirements of 10% by 2020 for non-IOUs.
- Carbon Policy Scenario – constrains the amount of CO<sub>2</sub> emissions from the Colorado power sector to the levels prescribed in the Colorado Climate Action Plan “CAP”. The constrained limits of CO<sub>2</sub> emissions in the model are as follows:
  - 20% CO<sub>2</sub> reduction by 2020 from 2005 level
  - 40% CO<sub>2</sub> reduction by 2030 from 2005 level<sup>2</sup>
  - 80% CO<sub>2</sub> reduction by 2050 from 2005 level
- Coal-Fired Power Plants Retirement Scenario – evaluates the impact of the retirement of aging coal-fired power plants on the CO<sub>2</sub> emissions profile, as well as criteria pollutants such as SO<sub>x</sub> and NO<sub>x</sub> emissions with the change in resource portfolio.
  - All coal-fired plants vintage 45 years and older are modeled retired beginning in 2017 unless otherwise scheduled to retire prior to 2017. (e.g., Cameo, Arapahoe, and Zuni plants).
- Sensitivity Scenarios – evaluates the change in resource portfolio due to:
  - High Energy Demand Forecast (3.0% per year)
  - High Natural Gas costs (+20% of Base Case costs)

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<sup>2</sup> A 40% CO<sub>2</sub> reduction by 2030 is the result of direct interpolation of CO<sub>2</sub> reduction between 2020 and 2050 by 20% and 80%, respectively.

We first developed the Base Case which represents an expansion plan for Colorado incorporating the existing generation fleet while optimizing new capacity additions to meet the forecasted energy demand. The Base Case has a planning horizon of 45 years (2005-2050). We then introduced the DSM and RES requirements to the Base Case to develop the Reference Case. Reference Case serves as the basis for the subsequent analysis of alternate technology and policy scenarios.

Table 1 depicts the scenarios we analyzed for this study.

**Table 1: Scenarios Analyzed**

<b>Name</b>	<b>Scenario Descriptions</b>
<b>Base</b>	Base Case
<b>BD</b>	Base Case + DSM Goals (PUC mandated DSM for IOUs)
<b>BDR = R</b>	Reference Case (Base Case + DSM + Renewable Energy Standards Requirements)
<b>RC</b>	Reference Case + Climate Action Plan Goals (CAP)
<b>Retirement Scenarios</b>	
<b>R_RT</b>	Reference Case with Coal-Fired Plant Retired 2017 with Vintage >= 45 years
<b>RC_RT</b>	Reference Case with Coal-Fired Plant Retired 2017 with Vintage >= 45 years + CAP
<b>Sensitivity Scenarios</b>	
<b>R_HL</b>	Reference Case with High Load
<b>R_HG</b>	Reference Case with High Gas
<b>R_HL_HG</b>	Reference Case with High Load and High Gas
<b>Sensitivity Scenarios with CAP</b>	
<b>RC_HG</b>	Reference Case with High Gas Cost + CAP
<b>RC_HL</b>	Reference Case with High Load + CAP
<b>RC_HL_HG</b>	Reference Case with High Load & High Gas + CAP
<b>RC_RHLH</b>	Reference Case with Retirements, High Load, & High Gas + CAP
<b>G</b>	

## **DEMAND SIDE MANAGEMENT**

There are two Investor-Owned Utilities (IOUs) in Colorado subject to rate regulation under the Colorado Public Utilities Commission (PUC). Both IOUs serve approximately 60% of the state's customers and electricity sales.

We modeled the cumulative annual energy savings as part of the Reference Case. For example, by 2020, cumulative energy savings due to DSM measures will reach 3,360 GWh per year, or 8.1% of the IOUs energy forecast. The incremental annual investment

in DSM measures and the associated energy saving is modeled as DSM contribution to energy conservation at the penetration rate of 30% Residential, 55% Commercial, and 15% Industrial.

In this study, DSM is modeled as a conservation resource contributing to the reduction of total energy requirements, and the system's need for fuel and new capacity over the life of the DSM resources. DSM is modeled with 10 years of life. We allowed the model to reinvest in DSM measures at the same 2020 level once the implemented measures reached 10 years life expectancy. We have utilized Xcel Energy's DSM costs reported in the 2009-2010 DSM biennial filing. We used Xcel Energy's Program cost at Generator of \$856/kW for 2009 and \$895/kW for 2010 with an escalation rate of 4.6% throughout the study period as the cost of implementation of DSM measures. We adopted Xcel's DSM costs, as the utility avoided costs, for the cost of DSM programs since Xcel represents the largest electric utility actively pursuing DSM measures in Colorado.

## **RENEWABLE ENERGY STANDARDS (RES) SCENARIO**

In 2007, HB07-1281 increased the amount of electricity a utility must generate, or cause to be generated, from renewable energy resources. The previous RES established by the voter-approved in 2004 Ballot Amendment 37, required utilities to meet a 10% RES by 2015 and required 4% of that standard to be obtained from solar energy sources. HB07-1281 doubled these requirements by mandating that qualifying regulated retail utilities (IOUs) meet a 20% RES, and non-IOUs meet a 10% RES, by 2020.

In 2010, HB10-1001 increased the amount of RES requirement to 30% by 2020 for the IOUs. The same legislation enacted a Distribution Generation requirement at 3% of retail sales by 2020 for the IOUs. We incorporated and modeled the newly enacted RES requirements as part of the Reference Case.

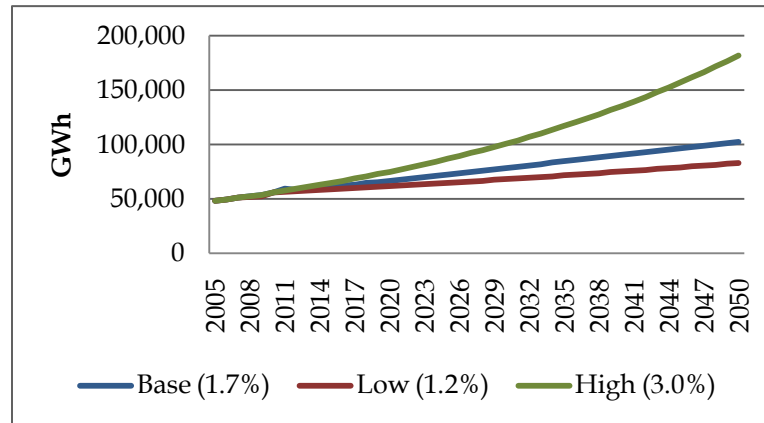
## **MODEL DATABASE DEVELOPMENT**

This study concentrates on the electric power system of Colorado and presents the development of a supply-side energy system incorporating Renewable Energy Standards

(RES), and Demand Side Management (DSM) measures. The focus of the work is to demonstrate the current status of the power sector in Colorado and to quantify the pathways for a sustainable future energy system.

## ENERGY DEMAND FORECAST

We have developed Colorado’s energy forecast with recent data available from large utilities in the state.<sup>3</sup> The energy forecast used for this study’s Reference Case is at 1.7% of the average energy load growth between the years 2005-2050. A high energy load forecast of 3.0% between the years 2010-2050 was also developed. Energy load data for 2005 and 2008 are based on actual reported load for Colorado. Figure 1 depicts a newly developed energy demand forecast for Colorado with the Base, High and Low Forecast.



**Figure 1: Colorado Energy Demand Forecast (2005-2050)**

Table 2 depicts the Base (1.7%) and High (3.0%) energy forecast used in this study. We chose not to model the low energy demand forecast since some of the low energy demand, due to recent economic downturns, is inherent in the Base energy demand forecast.

<sup>3</sup> A load forecast was developed from major utilities’ load forecast in Colorado that own and operate generation and transmission facilities. We used the utilities’ load forecasts that were provided to Conceptual Working Group of Colorado Coordinated Planning Group.

**Table 2: Colorado Energy Forecast (Base and Low)**

Colorado Energy Forecast (GWh)					
Year	Base (1.7%)	High (3.0%)	Year	Base (1.7%)	High (3.0%)
2005	48,353	48,353	2029	77,370	97,925
2008	52,571	52,571	2032	80,947	107,006
2011	59,223	57,521	2035	84,524	116,928
2014	59,986	62,855	2038	88,101	127,770
2017	63,226	68,683	2041	91,678	139,618
2020	66,661	75,052	2044	95,256	152,565
2023	70,215	82,011	2047	98,833	166,711
2026	73,792	89,616	2050	102,410	182,170

We have used the Base energy demand forecast, as represented in Table 2, to model the statewide Reference Case. We have also run a sensitivity scenario with the High energy demand forecast to assess the impacts if, in case, the statewide energy needs grew at a higher pace as a result of a surge in economics activities which were held back in recent economic downturns.

The End-Users in Colorado are represented by three sectors; Residential, Commercial, and Industrial sectors. The relationship of each sector to total energy requirements were developed from the available historical data from EIA for 2000-2005. Table 3 shows the distribution of total energy requirements among three sectors.

**Table 3: Colorado End-Use Sectors Share of Total Energy Requirements**

End-Use Percent Share of Total Energy Requirements		
Residential	Commercial	Industrial
34	41	25

## **FUEL SUPPLY PRICE FORECAST**

Before adopting any particular fuel price for this study, we first compared fuel price forecasts between Xcel and EIA. We found that Xcel’s average coal price forecast is slightly lower than EIA’s average power plant delivered coal price forecast in near term, and that the Xcel coal price forecast is in line with the EIA’s forecast in out years. The natural gas price forecast developed by Xcel Energy is lower than EIA’s forecast in

the very near term and then escalates and surpasses EIA’s average price forecast both at Henry Hub and at 48 Wellhead. Table 4 depicts the coal and natural gas price forecast comparison.<sup>4</sup>

**Table 4: Fuel Prices Forecast Comparison (2010\$/mmBTU)**

Year	Xcel Forecast		EIA Forecast		
	Coal	Gas	Delivered Coal	Henry Hub Gas	Avg. Lower 48 Wellhead Gas
2011	1.84	4.89	2.00	5.74	5.07
2014	1.89	5.88	2.01	6.15	5.43
2017	2.02	6.90	2.02	6.45	5.70
2020	2.07	7.81	2.00	6.71	5.93
2023	2.16	8.93	2.01	7.03	6.21
2026	2.17	9.61	2.02	7.22	6.38
2029	2.07	10.50	2.04	7.85	6.94
2032	2.20	11.58	2.07	8.58	7.58
2035	2.29	12.71	2.11	8.97	7.92
2038	2.41	13.96	-	-	-
2041	2.74	15.32	-	-	-
2044	2.90	16.82	-	-	-
2047	-	-	-	-	-
2050	-	-	-	-	-

The fuel supply prices input in the model are those developed by Xcel Energy for the recent proceedings before the Colorado Public Utilities Commission (PUC). Xcel Energy used various sources of data to compile and develop its fuel prices. For example, for gas prices, it used a blend of New York Mercantile Exchange future prices, and other sources. We assumed that Xcel’s fuel price forecast is more representative of the fuel market in the region, and therefore was adopted and utilized as input to the model. We also used sensitivity runs to represent price volatility of natural gas by increasing the baseline natural gas prices by 20 percent. Table 4 depicts fuel price forecasts, including high natural gas prices, used in the model.

<sup>4</sup> For comparison purposes, only available data were compiled. Price forecast were not available for out years.

**Table 5: Modeled Fuel Prices (2005\$/mmBTU)**

Year	Fuel Prices		High Gas (+20%)
	Coal	Gas	Gas
2005	\$1.18	\$8.90	\$8.90
2008	\$1.24	\$8.86	\$8.86
2011	\$1.64	\$4.35	\$5.22
2014	\$1.68	\$5.23	\$6.28
2017	\$1.80	\$6.14	\$7.37
2020	\$1.84	\$6.95	\$8.34
2023	\$1.92	\$7.95	\$9.54
2026	\$1.93	\$8.55	\$10.26
2029	\$1.84	\$9.35	\$11.21
2032	\$1.96	\$10.31	\$12.37
2035	\$2.04	\$11.31	\$13.57
2038	\$2.14	\$12.42	\$14.91
2041	\$2.44	\$13.63	\$16.36
2044	\$2.58	\$14.97	\$17.96
2047	\$2.73	\$15.84	\$19.01
2050	\$2.89	\$16.76	\$20.11

## **RENEWABLE TECHNOLOGIES**

This study encompasses a collection of renewable energy technologies including:

- Biomass-fired generators
- Solar generators;
  - Photovoltaic (PV) technology
  - Concentrated Solar Power (CSP)
- Geothermal power
- Wind power

A Rule-Based constraint is designed to capture the RES requirements in Colorado within the model. The percent requirement is modeled as a floor (i.e., a required bound since it is mandated) for the renewable generation in Colorado. The Rule Based constraint also recognizes the fact that the RES requirements for distributed generation and distributed solar-PV systems (i.e., on-site solar).

## **SOLAR**

We have modeled the Colorado Distributed Generation requirement as 3% of IOUs retail sales by 2020, and 4% of RES requirements for non-IOUs as solar-PV systems located at customers' facilities. We have constrained and modeled the potential installed capacity of CSP in Colorado by 2050 to be at 6 GW. The reason behind this assumption is mostly due to transmission constraints in San Luis Valley where CSP technology is most likely to be developed.

## **WIND**

In 2001, the Colorado PUC ordered Xcel Energy to include a 162 MW wind plant as part of its integrated resource plan. Since the last large wind farm, Xcel has added more than 1000 MW of wind resources to its resource portfolio to meet the minimal non-solar levels of the RES requirements through 2020, and displace fossil-fired generation which reduces both gas and coal burns for electric power production and the associated CO2 emissions. We have modeled Xcel Energy wind capacity for 2005 and 2008 as existing and planned wind capacity, respectively.

We have made a distinction in the model between the availability and capacity factor of wind generation in the Generation Development Area (GDA). Table 6 shows three types of wind power generation modeled with potential MW availability and expected Capacity Factors.

**Table 6: Modeled Wind Power MW Availability and Capacity Factor**

<b>GDA</b> s	<b>MW</b>	<b>Wt. Average Capacity Factor</b>
Wind GDA 1 & 8	2,000	42%
Wind GDA 2	1,283	36.6%
All other GDAs	18,000	34%

These numbers were calculated from the wind GDA data used in the SB 91 report. The best 25% of wind resources in the GDAs were taken, and a weighted average capacity factor was calculated based on the remaining potential in each wind class. Our study showed that by disaggregating the wind into three types, the discounted total system cost is reduced mainly due to a higher capacity factor of Wind in GDAs 1, 2, and

8 than just utilizing one type of wind in the model with an average 35% capacity factor. It should be noted that the wind GDA data used in the SB91 report was based on 50 meter hub heights.

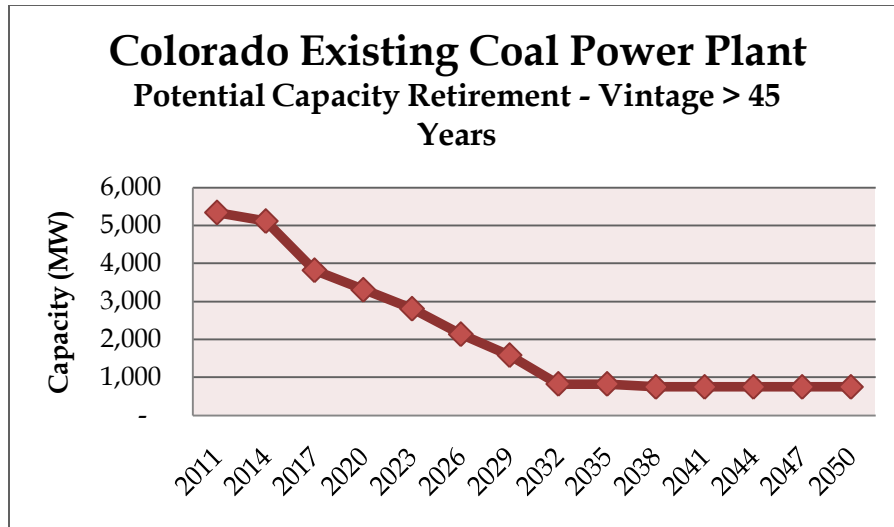
Recent studies show the potential for larger turbines rated at 2-5 MW of energy generation with rotor diameters near 100 meters and hub heights 80-120 meters. These high rated turbines will take advantage of the higher wind speeds aloft to generate more wind energy at higher capacity factors.

For this study, we have constrained the wind integration in the model to reach to about 10 GW by 2035 and to about 16 GW by 2050. The modeled capacity constraint of wind generation would translate into wind integration of about 33% by 2035 and 45% by 2050 under the base load forecast. The percent integration of wind generation would be less if it was compared to the high load forecast.

## **COAL-FIRED POWER PLANTS RETIREMENT SCENARIO**

As part of this study, we have compiled Colorado's entire fleet of coal-fired generating units with their commercial in-service date and nameplate capacity. We have identified any units that have reached, as of 2017, the age of 45 or higher as a candidate for retirement. We chose 2017 as the starting point for retirement in order to be consistent with the recently enacted legislation (HB-1365) for coal-fired power plant retirement in the Denver metro area.

When we apply the age limit to all coal-fired units, we find that all coal-fired units retire by 2038, and the only coal-fired unit remaining is the newly constructed 750 MW Comanche 3 coal-fired unit jointly owned by Xcel and Cooperatives.



**Figure 2: Colorado Potential Coal-Fired Capacity subject to Retirement**

We should note that we have separately modeled Xcel Energy’s 2007 Resource Plan for proposed retirement and repowering of six existing generation units with natural gas generating technologies. In the Reference Case, a total of 353 MW of capacity (i.e., Arapahoe 3 & 4, Cameo 1 & 2, and Zuni units) is retired by 2014 from the Base Year 2005 total installed capacity.

Table 7 depicts the list of all coal-fired power plants in Colorado subject to retirement after reaching age 45 or higher beginning in 2017.

**Table 7: Colorado Coal-Fired Power Plants Potential Retirement Dates**

Colorado Coal-Fired Power Plants Subject to Retirement - Vintage 45 yrs. or higher (2017 and Beyond)#																
Plant	Unit	Commercial Operation	2011	2014	2017	2020	2023	2026	2029	2032	2035	2038	2041	2044	2047	2050
Cameo*	1	1957	-	22	-	-	-	-	-	-	-	-	-	-	-	-
Cameo*	2	1960	-	44	-	-	-	-	-	-	-	-	-	-	-	-
Cherokee	1	1957	-	-	125	-	-	-	-	-	-	-	-	-	-	-
Cherokee	2	1959	-	-	125	-	-	-	-	-	-	-	-	-	-	-
Cherokee	3	1962	-	-	170	-	-	-	-	-	-	-	-	-	-	-
Cherokee	4	1968	-	-	381	-	-	-	-	-	-	-	-	-	-	-
Hayden	1	1965	-	-	143	-	-	-	-	-	-	-	-	-	-	-
Hayden	2	1976	-	-	-	-	103	-	-	-	-	-	-	-	-	-
Martin Drake	5	1962	-	-	50	-	-	-	-	-	-	-	-	-	-	-
Martin Drake	6	1968	-	-	75	-	-	-	-	-	-	-	-	-	-	-
Martin Drake	7	1974	-	-	-	132	-	-	-	-	-	-	-	-	-	-
Nucla	1	1959	-	-	-	-	-	-	-	-	-	12	-	-	-	-
Nucla	2	1959	-	-	-	-	-	-	-	-	-	12	-	-	-	-
Nucla	3	1959	-	-	-	-	-	-	-	-	-	12	-	-	-	-
Nucla	ST4	1991	-	-	-	-	-	-	-	-	-	79	-	-	-	-
Valmont	5	1964	-	-	192	-	-	-	-	-	-	-	-	-	-	-
Arapahoe*	3	1951	-	48	-	-	-	-	-	-	-	-	-	-	-	-
Arapahoe*	4	1955	-	112	-	-	-	-	-	-	-	-	-	-	-	-
Comanche	1	1973	-	-	-	383	-	-	-	-	-	-	-	-	-	-
Comanche	2	1975	-	-	-	-	396	-	-	-	-	-	-	-	-	-
Comanche	3	2010	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Comanche	3	2010	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Craig	1	1980	-	-	-	-	-	80	-	-	-	-	-	-	-	-
Craig	1	1980	-	-	-	-	-	45	-	-	-	-	-	-	-	-
Craig	1	1980	-	-	-	-	-	107	-	-	-	-	-	-	-	-
Craig	2	1979	-	-	-	-	-	80	-	-	-	-	-	-	-	-
Craig	2	1979	-	-	-	-	-	45	-	-	-	-	-	-	-	-
Craig	2	1979	-	-	-	-	-	107	-	-	-	-	-	-	-	-
Craig	3	1984	-	-	-	-	-	-	-	463	-	-	-	-	-	-
Pawnee	1	1981	-	-	-	-	-	-	552	-	-	-	-	-	-	-
Rawhide	ST1	1984	-	-	-	-	-	-	-	294	-	-	-	-	-	-
Ray D Nixon	ST1	1980	-	-	-	-	-	207	-	-	-	-	-	-	-	-
Modeled Potential Retirement (MW)			-	226	1,261	515	499	671	552	757	-	114	-	-	-	-

Notes:

\* Scheduled by Xcel to retire prior to 2017.

# Retirement/Repowering begins at 2017 even if the age of power plants are higher than 45 years prior to 2017.

The amount of capacity shown in each given year is modeled as retired in the Retirement Scenario, and the replacement technology decision is made by the model which, in the Reference Case, would be a replacement of an equal amount of capacity

with conventional or renewable technology based on the cost and performance of each technology. However, in the carbon policy scenario the decision would be based on the economics and carbon policy constraints and the replacement technology would be chosen from less carbon intensive technologies given the cost of performance of each technology.

## **APPROVED POWER PLANTS**

Xcel Energy's Comanche 3 coal-fired power plant with a capacity of 750MW, is modeled with an in-service date of 2011. An overnight construction cost of \$2,020/kW in 2005\$ is modeled.

## **NEW POWER PLANTS**

All new capacity decisions will depend on the costs and operating efficiencies of different technology options, fuel prices, and the carbon policy constraints. Natural gas plants are generally of the least expensive capacity to build with lower CO<sub>2</sub> emissions, but are characterized by comparatively high fuel costs. Advanced clean technologies like IGCC, nuclear, and renewable plants are typically more expensive to build but have relatively low operating costs and meet the low carbon policy objectives.

The database for this study contains 14 generating technology options for future capacity needs considerations. The model covers a 45 years study period from 2005 to 2050 in three year increments. Table 8 depicts the list of all technologies modeled.

**Table 8: Modeled Technologies' Cost, Performance, and Emissions**

Modeled Power Generation Technology##	Capital Cost# (\$/kW)	Life	Heat Rate# (Btu/kWh)	AF (%)	VAROM (\$/MWh)	FXDOM (\$/kW/yr)	Emission Rates#		
							CO2 (lb/MWh) Output	NOx (lb/MWh) Output	SO2 (lb/MWh) Output
Biomass CC***	2,696	30	10,283	80	2.99	45.04	n/a	n/a	n/a
PC with 50% CCS**	3,366	50	11,343	80	10.58	46.21	1,167	0.3730	0.6191
Com3 - Xcel Energy*	2,020	50	8,672	85	3.06	15.64	2,159	0.0000	0.0000
Coal IGCC with 50% CCS*	3,317	50	10,202	80	3.05	17.14	1,048	0.4270	0.7048
Existing Bit Coal Steam	n/a	45	10,618	80	2.78	15.64	2,159	3.8953	2.3873
Existing Sub Bit Coal Steam	n/a	45	10,474	80	2.78	15.64	2,143	3.1810	3.7048
Existing DSF Steam	n/a	45	12,916	85	0.52	0.86	2,000	2.4683	0.1952
Existing Diesel IC	n/a	45	12,916	85	8.89	0.86	2,000	2.4683	0.1952
Geothermal***	3,156	45	10,283	90	22.88	16.71	n/a	n/a	n/a
Existing Hydro	n/a	50	10,283	27	4.48	14.20	n/a	n/a	n/a
Existing Hydro PS	n/a	50	3,754	83	2.65	16.71	n/a	n/a	n/a
Adv CT***	735	30	8,553	94	2.83	8.89	921	0.0873	n/a
Adv CC***	764	30	7,281	92	3.09	9.42	865	0.0714	n/a
Existing CC	n/a	30	7,399	92	0.49	15.75	881	0.1532	n/a
CC**	708	30	7,463	92	2.81	13.19	869	0.3413	n/a
Existing CT	n/a	30	10,525	94	0.10	6.51	1,278	0.5683	n/a
CT***	613	30	10,459	94	7.95	4.31	1,246	0.5175	n/a
Gas_CC with 90% CCS***	1,412	30	7,952	92	2.93	19.95	86	0.0794	n/a
Existing Gas Steam	n/a	45	13,390	85	0.52	0.86	1,587	2.4151	n/a
Adv Nuclear##+	4,245	50	10,512	90	0.60	58.00	n/a	n/a	n/a
PV_Central***	3,830	30	10,283	n/a	n/a	8.96	n/a	n/a	n/a
Solar_CSP** (2014)	3,500	30	10,283	n/a	n/a	43.55	n/a	n/a	n/a
Wind (Include PTC)***	1,690	25	10,283	n/a	n/a	23.24	n/a	n/a	n/a
Coal Based Gen. Imports#	-	-	-	-	-	-	2,159	-	-
Gas Based Gen. Imports#	-	-	-	-	-	-	881	-	-

**Notes:**

CT = Combustion Turbine & CC = Combined Cycle  
 PC = Pulverized Coal  
 IGCC = Integrated Gasification Combined Cycle; CCS = Carbon Capture & Sequestration  
 Com3 = Pulverized coal unit by Xcel Energy with no SO2 and NOx impact (net of other 2 units)  
 PS = Pumped Storage Hydro Facility  
 AF = Availability Factor  
 Heat Rate# = Renewables' heat rates are an equivalent proxy heat rate  
 Capital Cost# = Updated capital costs include transmission interconnection and delivery costs. Costs (2005\$)  
 Emission Rates# = Source of existing power plants emissions is EPA-ETS (Emission Tracking System)  
 Imports# = imports are transmission constrained at 5,100 GWh per year  
 ##Sources data from DOE/EIA or EPA-NM or as noted by \* from other sources  
 ##+ FERC document considering EPRI and other sources.  
 \*Xcel Energy = Operates as Public Service Company of Colorado - 2007 Resource Plan & HB-1365 Case.  
 \*\*EPRI  
 \*\*\*NREL  
 VAROM = Variable O&M, FXDOM = Fixed O&M

**REFERENCE CASE**

The development of energy scenarios allows a way to analyze and examine a range of resource portfolio and policy options for consideration of alternative possibilities. An important step for any energy modelling exercise is to establish a baseline scenario that represents a reasonable progression of the system's advancement into the future years taking into account certain aspects of the current and future

conditions. A Reference Case serves as the basis for the subsequent analysis of alternate technology and policy scenarios. In preparation for this study, a Reference Case has been established and updated with current data.

## **MODEL OUTPUT**

For the Reference Case we first modeled a Base Case and calibrated it to the Base-Year, 2005. We incrementally added the state's requirements of DSM and RES to the Base Case to establish the Reference Case. We assumed DSM and RES, both by IOUs and non-IOUs, as being fully implemented by 2020 at statewide level.

Once the model accounts for energy savings from DSM measures, and builds the required renewable technologies to meet the RES requirements by 2020, the model utilizes coal-fired generation to its full extent to provide the bulk of the electricity generation requirements to meet the load into the future, 2020 and beyond. The increased coal generation in 2011 from the 2005 level is due to the operation of newly constructed Comanche 3 coal-fired power plant with an in-service date modeled as 2011.<sup>5</sup> Gas generation increases over the years mainly due to the fact that the model builds all new capacity additions, after meeting the RES requirements, from gas-fired generation of either combined cycle or combustion turbine technologies. No conventional coal-fired power plant without carbon capture and sequestration technology is available to the model. The hydro generation in the Reference Case includes all small hydro, and generation from pumped-storage facilities, in the peak hours.

The model's output matches the share of generation from renewables that is at about 1.5% in Base-Year. The share of renewables consistently increases over the years, where in 2020; renewables meet the intended requirements of the RES both for IOUs and non-IOUs. It should be noted that as the costs of renewable technologies become more competitive (e.g., solar technology in particular) compared to other conventional technologies, the model utilizes more renewables, more than RES requirements, in the

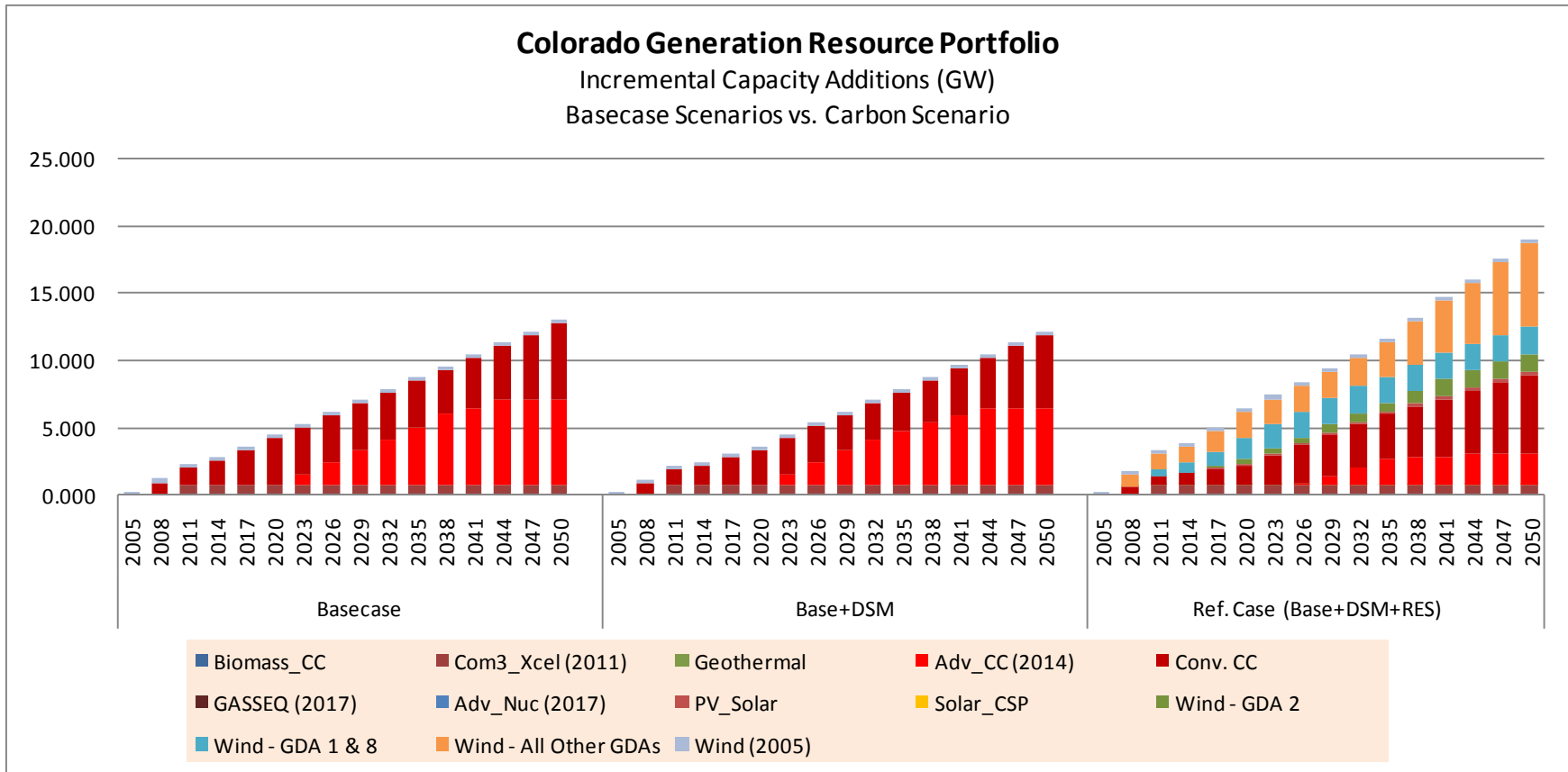
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<sup>5</sup> Xcel Energy's Comanche 3 at 750 MW.

out years. This is due to the fact that RES requirements were set as a floor, not as a ceiling, in the model.

As more DSM and renewables enter the resource portfolio of Colorado's power sector, the gas consumption decreases due to the fact that DSM and renewable generation both displace gas generation at margin. The Reference Case also accounts for 350 MW of announced old coal-fired generation to be retired between 2011 and 2014, and one new coal-fired power plant with the total capacity of 750 MW to be added in 2011. This is reflected in coal consumptions with an increase in 2011 for a 750 MW coal plant, then a decrease in 2014 for the retirements of the scheduled 350 MW by Xcel Energy.

Figure 3 depicts the generation capacity portfolio of the Base Case incrementally adding the DSM and RES requirements to arrive at the Reference Case. Once the Reference Case is established, we introduce the Carbon Policy Scenario to evaluate the change in the resource portfolio to meet the CAP goals by 2020, 2030, and 2050, which are 20%, 40%, and 80% reductions of CO<sub>2</sub> emissions from the 2005 level, respectively. See Figure 4 for the comparison between the Reference Case and the Reference Case combined with the CAP policy goals.



**Figure 3: Base Case Scenarios and Carbon Policy Scenarios Resource Portfolio<sup>6</sup>**

<sup>6</sup> Read the bar chart from top to bottom. Read the legend from the bottom right to the left, and then move up and read from right to left. For example, for Ref. Case in 2050, the “Wind-2005” is at the top, followed by “Wind-Other GDAs,” followed by “Wind-GDA 1 & 8,” followed by “Wind-GDA 2,” and so on. The last one is “Biomass\_CC.”

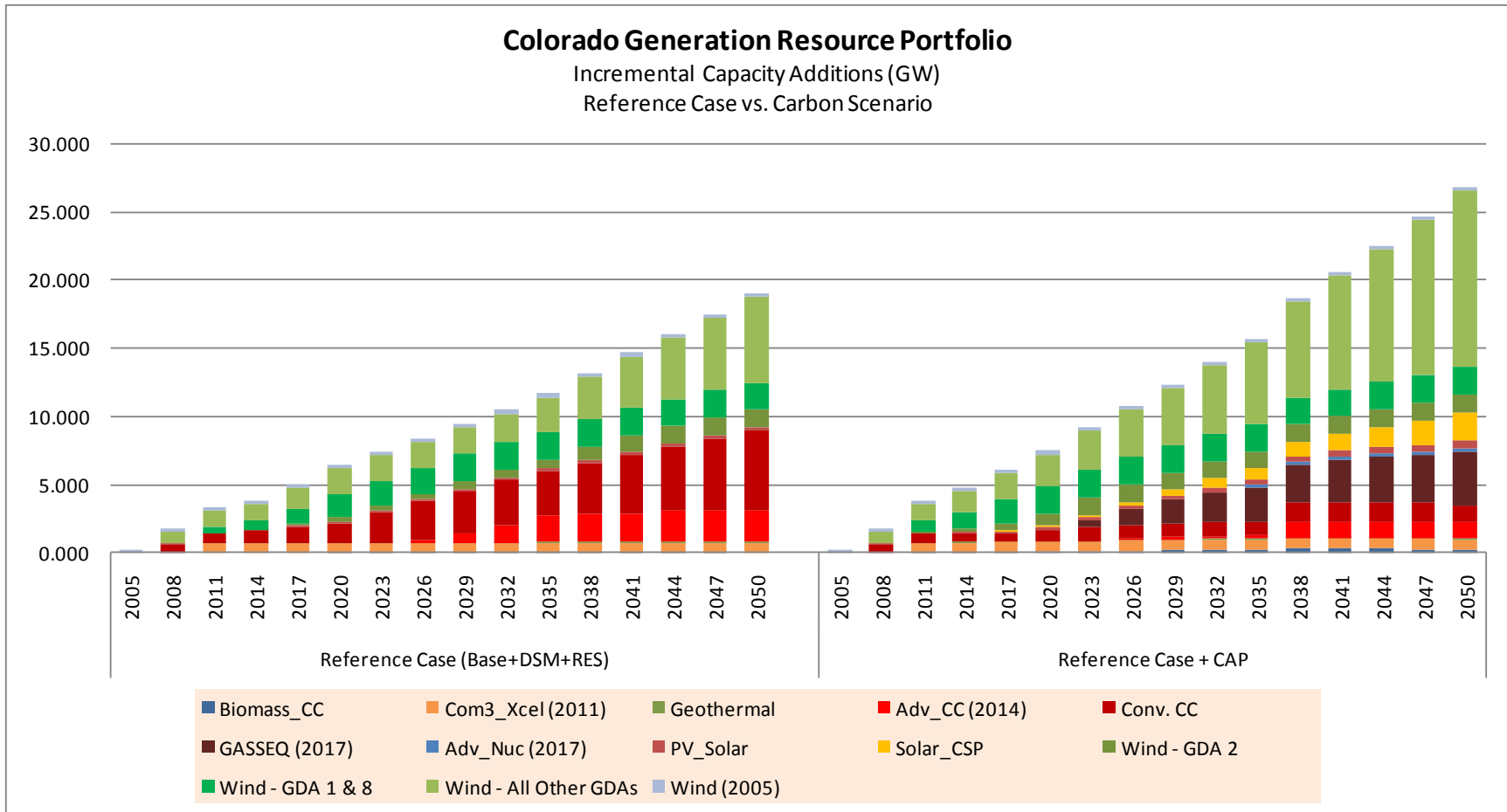
As indicated before, the Reference Case is the progression of Base Case, incrementally adding the requirements of DSM and RES. Table 9 depicts the optimization of the Colorado power sector subject to DSM, RES and CAP requirements in 2020, 2030, and 2050.

**Table 9: Colorado Power Generation Capacity Portfolio**

Technology/Scenario	2020 CAPACITY PORTFOLIO (GW)				2030 CAPACITY PORTFOLIO (GW)				2050 CAPACITY PORTFOLIO (GW)			
	Base	B+DSM	B+D+RES	Ref+CAP	Base	B+DSM	B+D+RES	Ref+CAP	Base	B+DSM	B+D+RES	Ref+CAP
Biomass_CC	0.000	0.000	0.007	0.059	0.000	0.000	0.007	0.240	0.000	0.000	0.000	0.260
Com3_Xcel (2011)	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750
Geothermal	0.000	0.000	0.004	0.013	0.000	0.000	0.009	0.020	0.000	0.000	0.040	0.040
Adv_CC (2014)	0.000	0.000	0.000	0.000	2.556	2.556	0.655	0.151	6.304	5.731	2.284	1.209
Conv. CC	3.496	2.662	1.436	0.867	3.496	2.662	3.128	1.033	5.723	5.463	5.861	1.189
GASSEQ (2017)	0.000	0.000	0.000	0.029	0.000	0.000	0.000	1.710	0.000	0.000	0.000	3.942
Adv_Nuc (2017)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.270
PV_Solar	0.000	0.000	0.126	0.169	0.000	0.000	0.147	0.255	0.000	0.000	0.282	0.550
Solar_CSP	0.000	0.000	0.000	0.117	0.000	0.000	0.000	0.480	0.000	0.000	0.000	2.104
Wind - GDA 2	0.000	0.000	0.350	0.849	0.000	0.000	0.577	1.280	0.000	0.000	1.280	1.280
Wind - GDA 1 & 8	0.000	0.000	1.581	2.000	0.000	0.000	2.000	2.000	0.000	0.000	2.000	2.000
Wind - All Other GDAs	0.000	0.000	1.913	2.365	0.000	0.000	1.913	4.193	0.000	0.000	6.292	13.000
Wind (2005)	0.264	0.264	0.264	0.264	0.264	0.264	0.264	0.264	0.264	0.264	0.264	0.264
<b>Total Inc. Capacity Addition</b>	<b>4.510</b>	<b>3.676</b>	<b>6.431</b>	<b>7.481</b>	<b>7.065</b>	<b>6.232</b>	<b>9.450</b>	<b>12.376</b>	<b>13.041</b>	<b>12.208</b>	<b>19.053</b>	<b>26.857</b>

As we incrementally introduce DSM and RES requirements to the Base Case, the share of fossil fuel generation over the years reduces and is replaced by a higher share of clean energy technologies. When we introduce the CAP requirements, the share of clean energy technologies further increases while fossil fueled generation further drops. By 2030, in order to meet a 40% reduction in CO2 emissions from the 2005 level, the Colorado power generation mix will need to have about 7,750 MW of wind, 480 MW of CSP, and 255 MW of Solar PV. The resource mix will also need to have about 1,700 MW of combined cycle generation equipped with carbon capture and sequestration technology.<sup>7</sup> Figure 4 depicts the resource portfolio comparison between the Reference Case and the Reference Case combined with the Carbon Policy Scenario.

<sup>7</sup> Natural gas-fired Combined Cycle (CC) with Carbon Capture and Sequestration (CCS) technology is made available to the model beginning 2017 with the given cost and performance for 90% CCS.



**Figure 4: Reference Case with Carbon Policy Scenario**

It should be noted, as more clean energy technologies (i.e., renewables and CC with CCS) are added to the resource mix of Colorado, the need for conventional CC technologies reduces. For example, by 2030, the power system will have a need to add about 6,000 MW of conventional CC for the Base Case (i.e., with no DSM or RES) which drops to 5,200 MW when DSM is added, and further drops to 3,800 MW when RES requirements are implemented. When we constrain carbon emission in 2030 to 40% below the 2005 level, the level of conventional generation capacity reduces to 1,200 MW. The replacement capacity is made up by less carbon intensive technologies, such as CC with CCS technology and more wind and solar power.

It should also be noted that by 2050, when carbon emission is constrained further to an 80% reduction from the 2005 level, nuclear technology will become competitive and play a minor role in the mix of generation resources by about 270 MW. Nuclear technology plays a higher role in the high growth load scenario with the high gas cost and coal-fired power retirement scenarios combined. In the following sections we will discuss the retirement scenario and high gas and high load sensitivity runs.

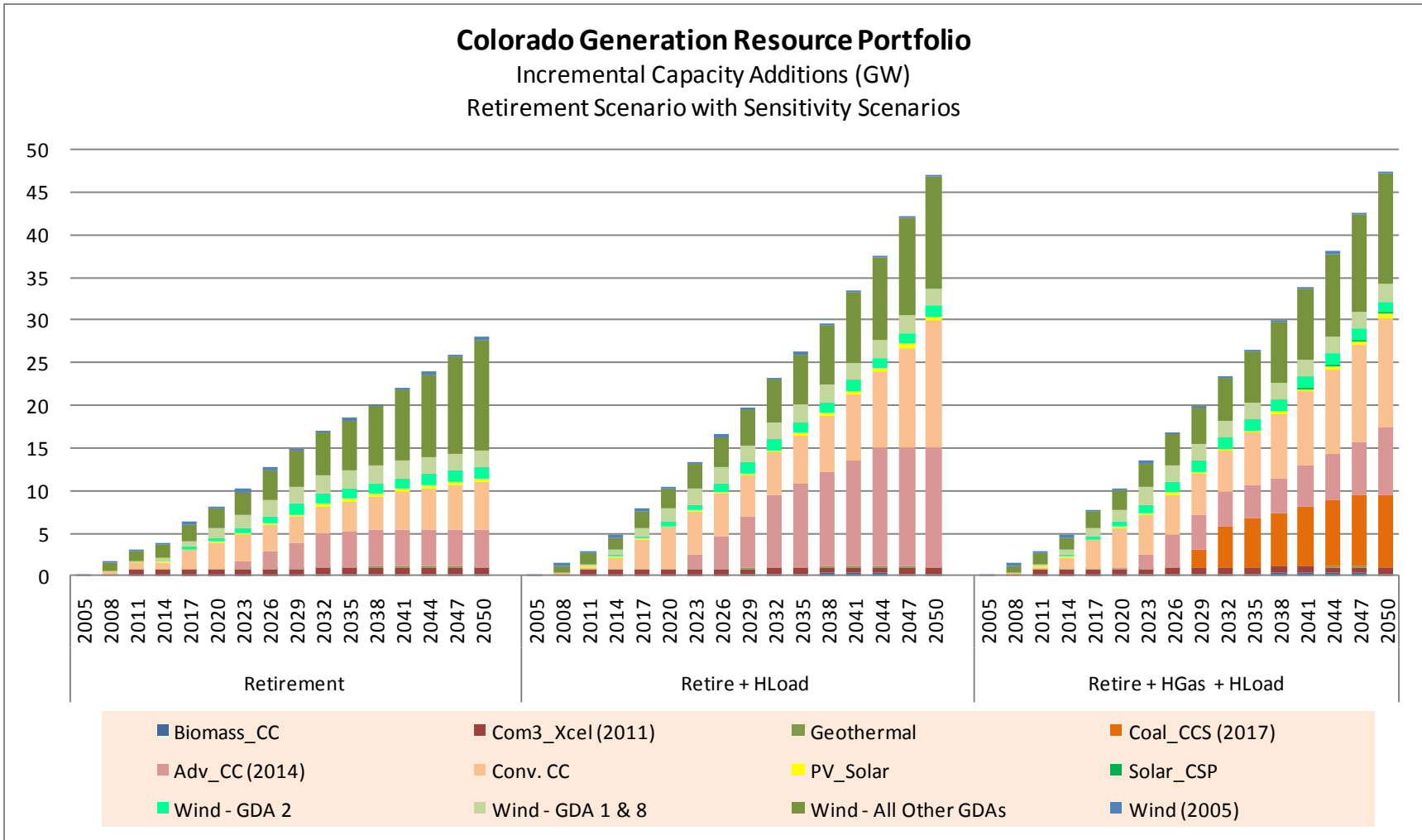
## **COAL-FIRED POWER PLANTS RETIREMENT SCENARIO**

As part of this study, we modeled the retirement of the existing fleet of coal-fired power plants in Colorado vintage 45 years or older as of 2017.

As represented in Table 7, the amount of capacity of power plants subject to retirement in each given year is modeled as retired in the Retirement Scenario, and the replacement technology decision is made by the model. We modeled the Retirement Scenario with and without the carbon policy scenario. When we ran the model without the carbon policy scenario, the model chose the replacement capacity from conventional and or renewable technologies based on the cost and performance of each technology. However, when we introduced the carbon policy scenario, the model made the replacement capacity decision based on the economics and carbon policy constraints and the replacement technology was

chosen from less carbon intensive technologies given the cost of performance of each technology.

Figure 5 depicts the resource portfolio of the Colorado power sector for the Retirement Scenario and the Retirement Scenario combined with High Load sensitivity scenario, and the Retirement Scenario combined with High Load and High Gas sensitivity scenarios.



**Figure 5: Power Plant Retirement Scenarios Resource Portfolio**

Table 10 depicts the resource mix of the Colorado power sector at Climate Action Plan’s major milestones (i.e., 2020 and 2050) including the in between year of 2030.

**Table 10: Power Plant Retirement Resource Mix at CAP milestones**

Technology/Scenario	2020 CAPACITY PORTFOLIO (GW)				2030 CAPACITY PORTFOLIO (GW)				2050 CAPACITY PORTFOLIO (GW)			
	Ref.	Ret.	Rt+HL	Rt+HL+HG	Ref.	Ret.	Rt+HL	Rt+HL+HG	Ref.	Ret.	Rt+HL	Rt+HL+HG
Biomass_CC	0.007	0.018	0.034	0.059	0.007	0.069	0.096	0.240	0.000	0.260	0.260	0.260
Com3_Xcel (2011)	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750
Geothermal	0.004	0.006	0.009	0.009	0.009	0.020	0.020	0.020	0.040	0.040	0.040	0.040
Coal_CCS (2017)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.126	0.000	0.000	0.000	8.342
Adv_CC (2014)	0.000	0.000	0.000	0.076	0.655	3.024	6.066	3.960	2.284	4.339	13.953	7.959
Conv. CC	1.436	3.080	4.919	4.676	3.128	3.080	4.919	4.872	5.861	5.558	14.974	12.845
PV_Solar	0.126	0.126	0.143	0.143	0.147	0.231	0.234	0.240	0.282	0.483	0.492	0.485
Solar_CSP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.253
Wind - GDA 2	0.350	0.525	0.615	0.589	0.577	1.280	1.280	1.280	1.280	1.280	1.280	1.280
Wind - GDA 1 & 8	1.581	1.038	1.410	1.390	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Wind - All Other GDAs	1.913	2.365	2.365	2.365	1.913	4.193	4.193	4.193	6.292	13.000	13.000	13.000
Wind (2005)	0.264	0.264	0.264	0.264	0.264	0.264	0.264	0.264	0.264	0.264	0.264	0.264
<b>Total Inc.Capacity Addition</b>	<b>6.431</b>	<b>8.172</b>	<b>10.507</b>	<b>10.319</b>	<b>9.450</b>	<b>14.911</b>	<b>19.821</b>	<b>19.945</b>	<b>19.053</b>	<b>27.974</b>	<b>47.013</b>	<b>47.477</b>

Under the Retirement Scenario, conventional combined cycle technology plays a major role in fulfilling the replacement capacity when coal-fired power plants begin to retire due to their age reaching 45 years or older in 2017 and beyond. As we introduce high load conditions to the Retirement Scenario, other fossil-fueled technologies with higher efficiencies replace some of the retired capacity. The replacement capacity due to retirement is also furnished from higher shares of renewables like wind and solar particularly in the out years.

We modeled the Retirement Scenario with both higher gas cost and higher load forecast to evaluate the impact of the retirement on the resource portfolio when there are higher gas prices coupled with a higher load forecast. We found that coal-fired technology with carbon capture and sequestration capability begins to compete with other technologies and enters the generation fleet as early as 2030 (2.1 GW) and continues into the out years until 2050 (8.3 GW) to displace higher gas generation due to higher gas costs (i.e., 20% higher than base gas cost) to meet the higher load forecast. It should be noted that under the Retirement Scenario with high load and high gas cost, wind generation reaches its maximum capacity limit of 16 GW by 2050 and solar CSP reaches its maximum capacity

limit of 6 GW by 2050. In the following sections we show the results of the Retirement Scenario when constrained with CAP policy requirements.

## **SENSITIVITY SCENARIOS**

We performed a high energy load forecast and a high gas cost sensitivity analysis in conjunction with other scenarios including the retirement scenario, to gauge the change in resource mix. We modeled natural gas price volatility at a 20% higher price from the baseline, and a higher energy demand forecast at 3.0% growth per year, as opposed to the Base forecast of 1.7% growth in energy demand. See Table 1 for the descriptions of scenarios analyzed.

## **SENSITIVITY SCENARIOS RESOURCE PORTFOLIO**

Figure 6 depicts the resource portfolio stacking of the sensitivity scenarios, including the Retirement Scenario and the Reference Case for comparison. In the following section, we discuss the results of modeling the sensitivity scenarios with the Retirement Scenario and carbon constrained future, or the carbon reduction goals of the Climate Action Plan.

### Colorado Generation Resource Portfolio Incremental Capacity Additions (GW) High Load, High Gas & Retirement Scenarios

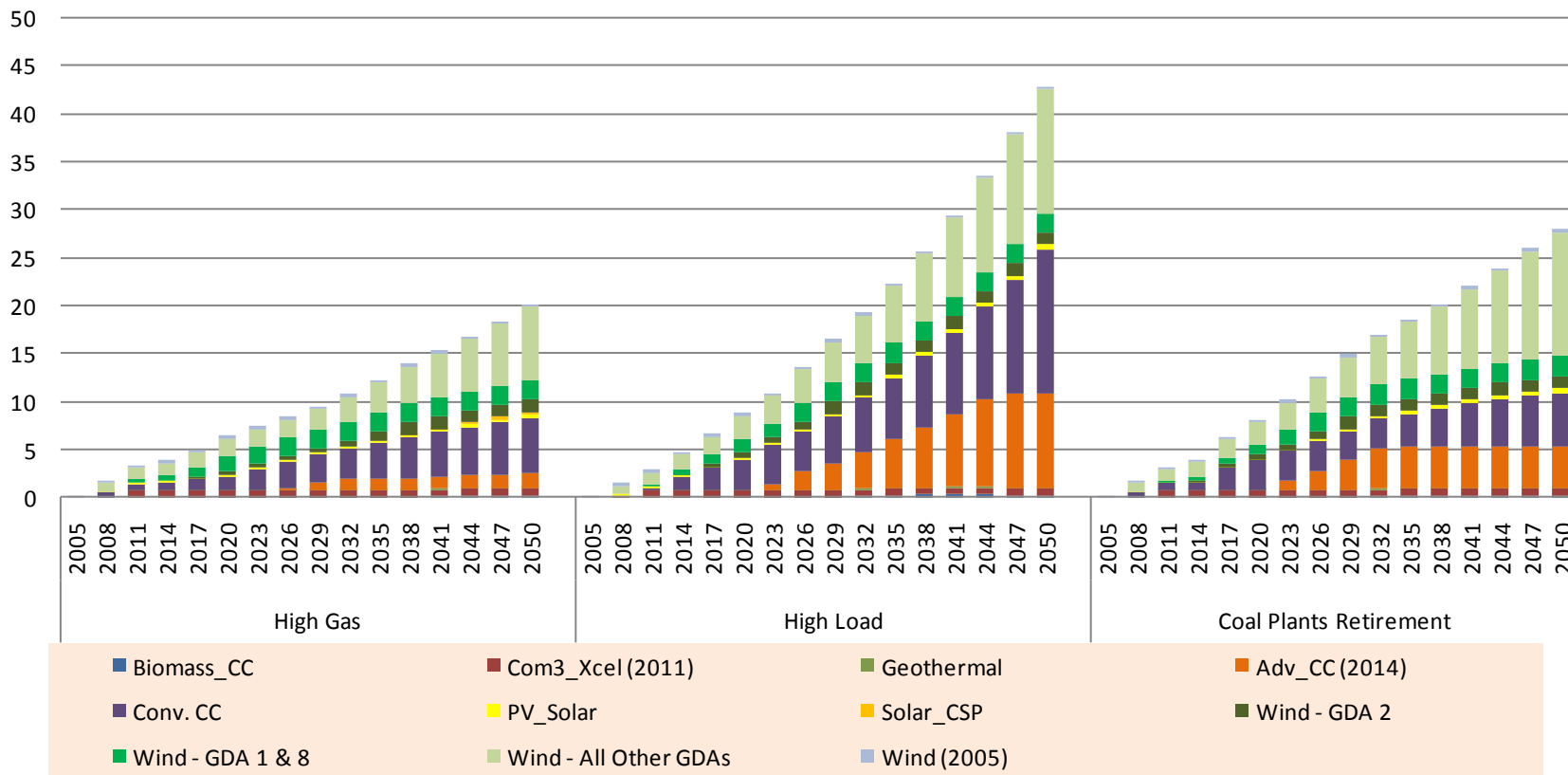


Figure 6: Sensitivity and Retirement Scenarios Resource Portfolio

Table 11 depicts the generation capacity portfolio of both sensitivity scenarios compared with the Reference Case and the Retirement Scenario. As load growth increases, the need for fossil-fuel capacity additions increases as well. Most of the capacity addition due to the higher load growth is from gas-fired generation technologies, like combined cycle technology. Higher load growth also has a direct impact on the renewable technologies, resulting in a higher generation from renewables to meet the share of RES requirements due to a higher load growth.

When we modeled the Reference Case with the higher gas cost, we found that concentrated solar power (CSP technology) becomes more competitive in the out years (i.e., 2035-2050) with the overnight construction cost of \$3,500/kW (2005\$) with other conventional gas-fired generation. Solar CSP technology combined with other renewables and clean energy technologies play higher roles when CAP Policy scenarios are modeled. Carbon policy scenarios are discussed in the next section.

**Table 11: Sensitivity Scenarios Capacity Additions Compared to Reference & Retirement Scenarios Capacity Additions**

Technology/Scenario	2020 CAPACITY PORTFOLIO (GW)				2030 CAPACITY PORTFOLIO (GW)				2050 CAPACITY PORTFOLIO (GW)			
	Ref.	HG	HL	Ret.	Ref.	HG	HL	Ret.	Ref.	HG	HL	Ret.
Biomass_CC	0.007	0.018	0.034	0.018	0.007	0.018	0.074	0.069	0.000	0.260	0.260	0.260
Com3_Xcel (2011)	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750
Geothermal	0.004	0.003	0.009	0.006	0.009	0.009	0.020	0.020	0.040	0.040	0.040	0.040
Adv_CC (2014)	0.000	0.000	0.000	0.000	0.655	0.849	2.681	3.024	2.284	1.417	9.772	4.339
Conv. CC	1.436	1.434	3.242	3.080	3.128	2.923	5.002	3.080	5.861	5.856	15.061	5.558
PV_Solar	0.126	0.126	0.143	0.126	0.147	0.147	0.229	0.231	0.282	0.326	0.483	0.483
Solar_CSP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.253	0.000	0.000
Wind - GDA 2	0.350	0.350	0.532	0.525	0.577	0.350	1.280	1.280	1.280	1.280	1.280	1.280
Wind - GDA 1 & 8	1.581	1.577	1.483	1.038	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Wind - All Other GDAs	1.913	1.896	2.365	2.365	1.913	2.145	4.193	4.193	6.292	7.674	13.000	13.000
Wind (2005)	0.264	0.264	0.264	0.264	0.264	0.264	0.264	0.264	0.264	0.264	0.264	0.264
<b>Total Inc. Capacity Addition</b>	<b>6.431</b>	<b>6.417</b>	<b>8.819</b>	<b>8.172</b>	<b>9.450</b>	<b>9.454</b>	<b>16.492</b>	<b>14.911</b>	<b>19.053</b>	<b>20.119</b>	<b>42.911</b>	<b>27.974</b>

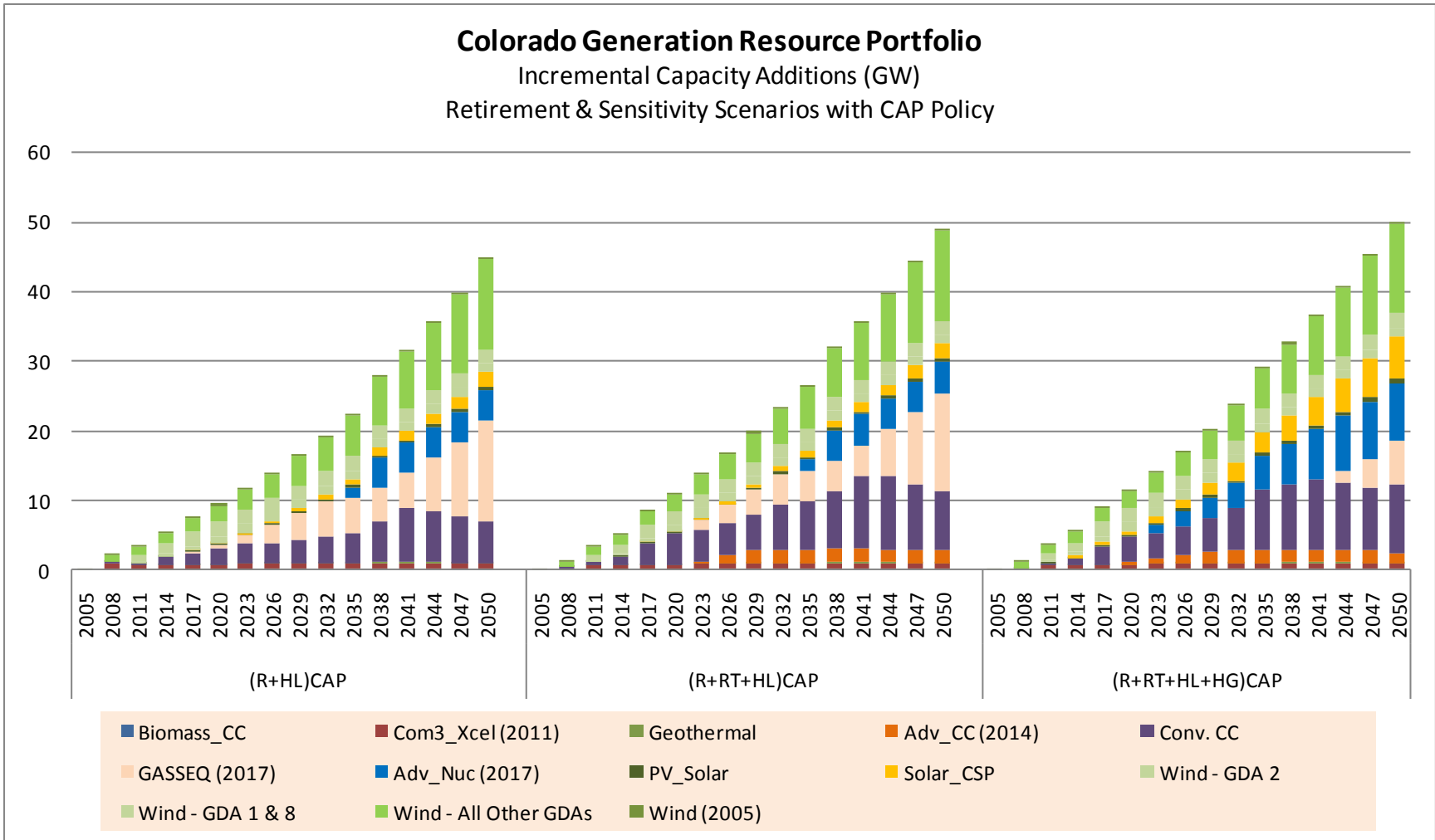
The high load forecast, by 2030, adds an additional amount of gas-fired generation capacity to the resource portfolio (i.e., about 2,000 MW of conventional and 2,000 MW of advanced combined cycle technology) when compared to the Reference case. To meet the increased energy demand forecast, the high load forecast, by 2030, also adds an additional amount of wind generation (about 3,000 MW) and 80 MW of solar PV to the resource portfolio when compared to the Reference Case.

## **CARBON CONSTRAINED RESOURCE PORTFOLIO**

We modeled all scenarios (i.e., Reference Case, Retirement Scenario, and Sensitivity Scenarios) with the Climate Action Plan Policy requirements to identify the mix of generation technologies to meet the state's electric power needs in a carbon constrained future. We found that clean energy technologies and renewables (i.e., wind and solar) play a major role in reducing the state's carbon footprint in the future years.

Figure 7 depicts the resource portfolio of carbon constrained retirement and sensitivity scenarios. When we constrain carbon emission in 2030 to 40% below the 2005 level, the level of conventional generation capacity reduces to 1,200 MW as compared to the Reference Case. Once the scenarios are constrained with the CAP Policy goals, the replacement capacity is made up by less carbon intensive technologies, such as combined cycle (CC) with carbon capture and sequestration (CCS) technology.

Renewables play a major role in meeting the carbon constrained future. For example; when the Reference Case is constrained with the CAP requirements (i.e., 40% in 2030 below the 2005 CO<sub>2</sub> emissions level), the renewables share of the resource portfolio increases by about 480 MW of solar CSP, 100 MW of solar PV, and 3,000 MW of wind generation (see Figure 4 and Table 9 for the Reference Case constrained with the CAP Policy goals).



**Figure 7: Resource Portfolio of Carbon Constrained Scenarios**

**Table 12: Resource Mix of Carbon Constrained Scenarios**

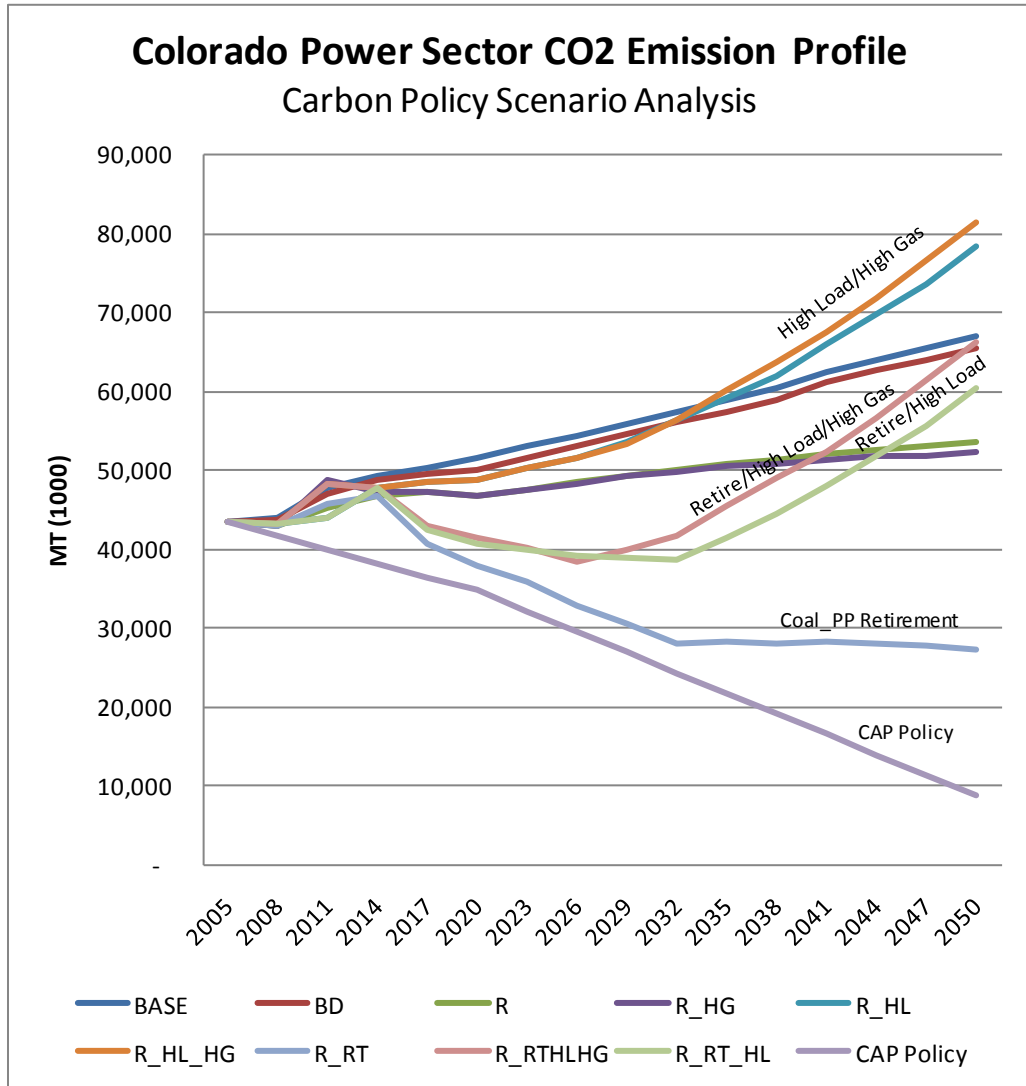
Technology/Scenario	2020 CAPACITY PORTFOLIO (GW)				2030 CAPACITY PORTFOLIO (GW)				2050 CAPACITY PORTFOLIO (GW)			
	R	R+HL	R+RT+HL	R+RT+HL+HG	R	R+HL	R+RT+HL	R+RT+HL+HG	R	R+HL	R+RT+HL	R+RT+HL+HG
Biomass_CC	0.059	0.059	0.059	0.059	0.240	0.240	0.240	0.240	0.260	0.260	0.260	0.260
Com3_Xcel (2011)	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750
Geothermal	0.020	0.020	0.013	0.020	0.020	0.020	0.020	0.020	0.040	0.040	0.040	0.040
Adv_CC (2014)	0.000	0.000	0.000	0.315	0.151	0.000	1.916	1.545	1.209	0.000	1.916	1.436
Conv. CC	2.304	2.304	4.538	3.598	1.033	3.270	5.055	4.871	1.189	6.053	8.277	9.895
GASSEQ (2017)	0.503	0.503	0.000	0.000	1.710	3.865	3.488	0.000	3.942	14.408	14.202	6.192
Adv_Nuc (2017)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.060	0.270	4.283	4.455	8.351
PV_Solar	0.174	0.174	0.171	0.202	0.255	0.259	0.258	0.296	0.550	0.548	0.548	0.659
Solar_CSP	0.117	0.117	0.117	0.709	0.480	0.480	0.480	1.877	2.104	2.104	2.104	6.000
Wind - GDA 2	0.993	0.993	0.849	1.280	1.280	1.280	1.280	1.280	1.280	1.280	1.280	1.280
Wind - GDA 1 & 8	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Wind - All Other GDAs	2.365	2.365	2.365	2.365	4.193	4.193	4.193	4.193	13.000	13.000	13.000	13.000
Wind (2005)	0.264	0.264	0.264	0.264	0.264	0.264	0.264	0.264	0.264	0.264	0.264	0.264
<b>Total Inc. Capacity Addition</b>	<b>9.547</b>	<b>9.547</b>	<b>11.125</b>	<b>11.561</b>	<b>12.376</b>	<b>16.620</b>	<b>19.944</b>	<b>20.395</b>	<b>26.857</b>	<b>44.990</b>	<b>49.096</b>	<b>50.126</b>

Table 12 depicts the resource mix of scenarios analyzed under the carbon constrained condition for the three time periods 2020, 2030, and 2050. When high load forecast is combined with the Reference Case and constrained for the carbon, the need for clean energy technologies and renewables increases accordingly to meet the higher energy demand. For example, by 2050, under the high load forecast, the retirement, and high gas cost conditions combined with carbon constrained at 80% CO2 emissions below the 2005 level, solar PV capacity reaches 660 MW while solar CSP capacity reaches the maximum allowed in the model, 6.0 GW, with wind reaching the maximum integration level of 40%, 16 GW. Other technologies such as CC with CCS technology and advanced nuclear generating technology fulfill the energy demand of the future when renewables reach their maximum allowed levels within the model. It should be noted that this study has not attempted to quantify the implication and costs associated with the nuclear spent fuel storages. As was stated earlier, technologies compete within the model with respect to their cost and performance criteria, including the emissions rates, to meet the energy needs while meeting the CAP policy requirements. In the next section we quantify the emissions profile of the scenario analyzed.

**EMISSIONS PROFILE OF ANALYZED SCENARIOS**

Figure 8 depicts the CO2 emissions profile of the Reference Case compared to all other scenarios including the carbon policy or CAP Scenario. Our study shows that the highest CO2 emission profile throughout the planning horizon (i.e., 2005-2050) is from

the High Load combined with the High Gas scenario. The lowest CO2 emissions profile is from the Retirement Scenario. Other scenarios have varying levels of CO2 emissions as depicted in Figure 8.



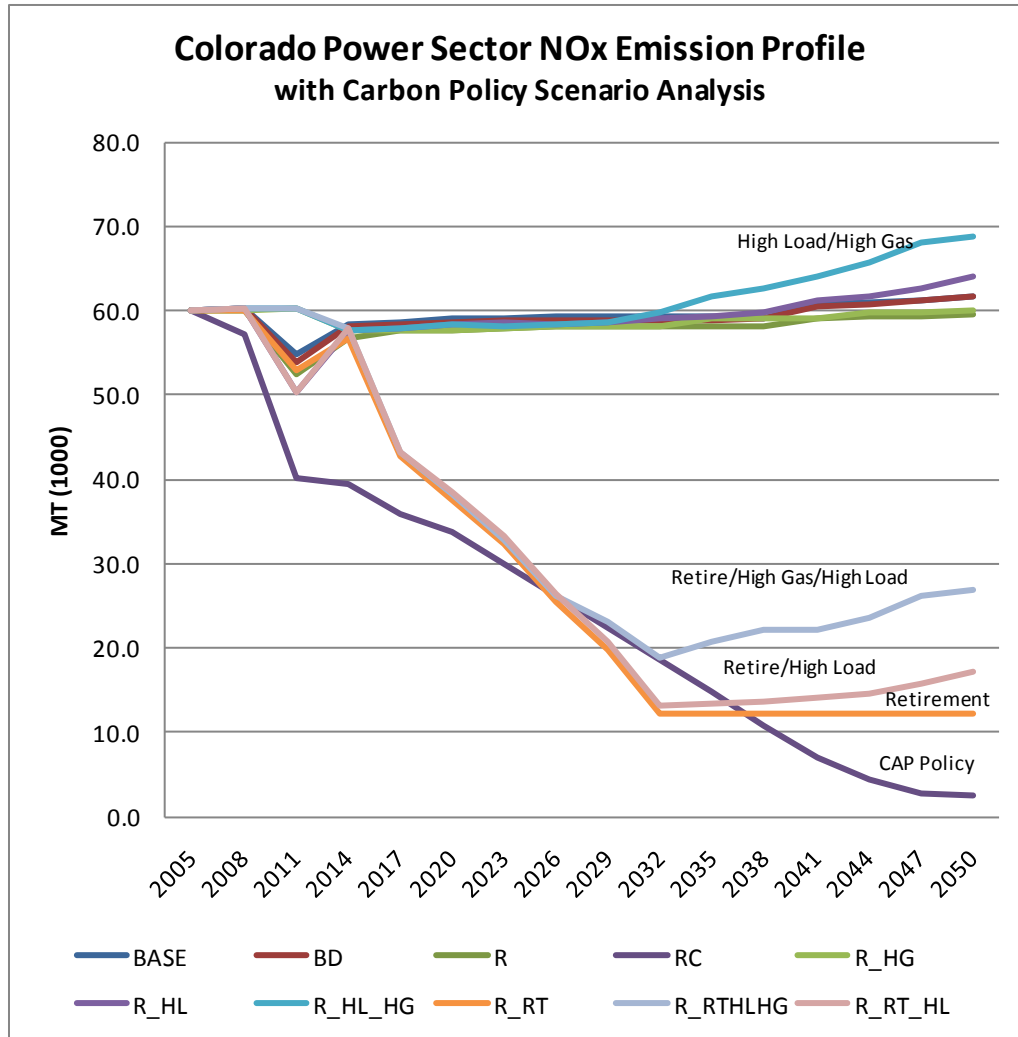
**Figure 8: Scenarios CO2 Emissions Profile vs. CAP Policy**

As we introduce PUC mandated DSM for IOUs, CO2 emissions reduce for the Base case plus DSM (“BD Scenario”). CO2 emissions are further reduced as newly enacted 30% RES for IOUs and 10% for non-IOUs by 2020 are introduced to the Base case plus DSM to arrive at the Reference Case (“BDR => R for Ref. Case”).

When we compare the Reference Case (“R”) to a Carbon policy or CAP Scenario (“RC”), we notice a gap of about 26% to reach the CO<sub>2</sub> reduction goals of CAP by 2020, and about 45% to reach the CAP goals by 2030. This gap increases to 45% by 2030. However, when coal-fired power plant retirement takes place by 2017, the gap reduces to 8% and 12% by 2020 and 2030, respectively. When we combine the Retirement Scenario with the high load demand forecast, the gap increases and backs up to about 17% and 44% by 2020 and 2030, respectively. When we further combine the Retirement Scenario with high load and high gas cost, the gap drops back to 16% and 33% by 2020 and 2030, respectively.

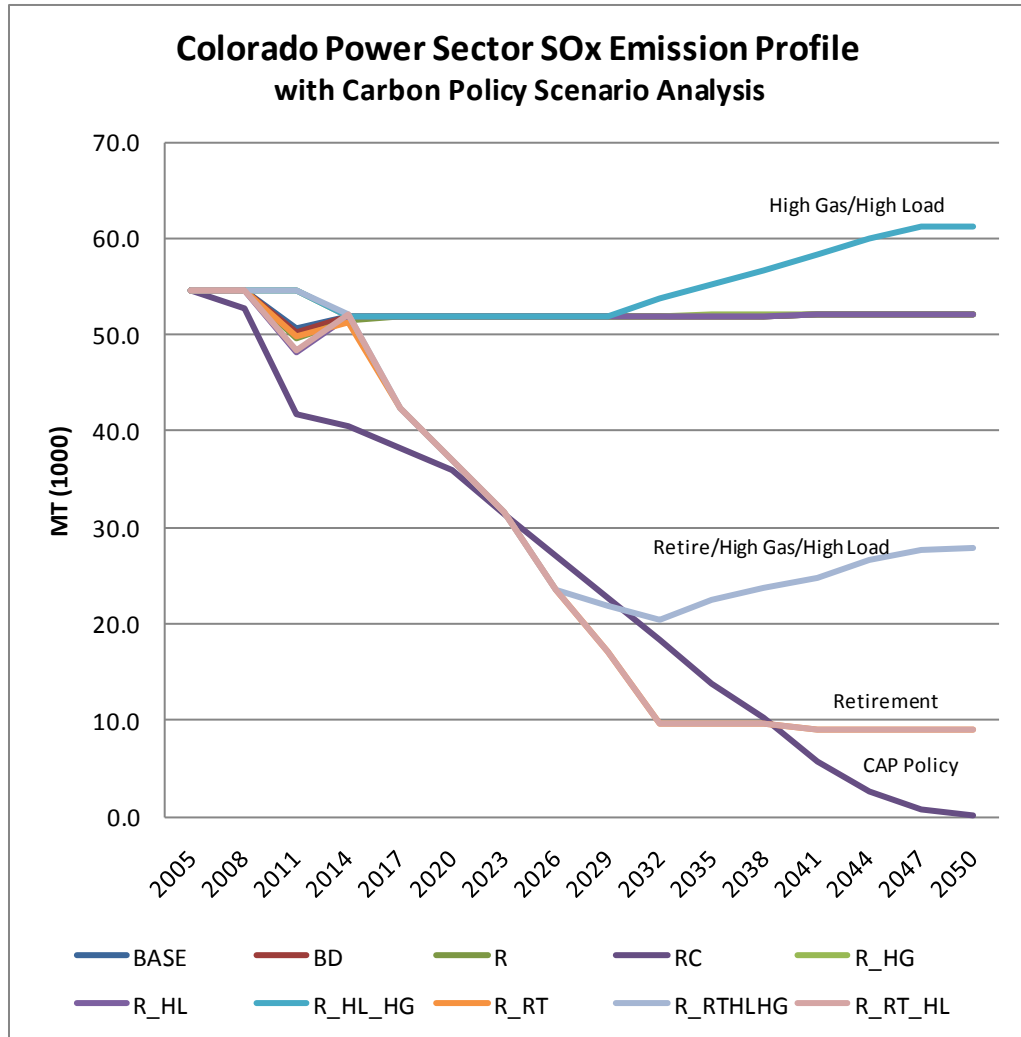
The gaps stated above are resolved by the model by allowing various less intensive carbon technologies to compete within the model to build the required capacity to meet the load by adding more renewables and clean energy technologies to the resource mix to displace carbon intensive technologies.

Figure 9 depicts the NO<sub>x</sub> emissions profile of the Reference Case compared to all other scenarios including the CAP Scenario. The study shows that the highest NO<sub>x</sub> emissions profile throughout the planning horizon (i.e., 2005-2050) is from the High Load scenario combined with the High Gas scenario. The lowest NO<sub>x</sub> emissions profile, as was the case for the CO<sub>2</sub> emissions, is from the Retirement Scenario. Other scenarios have varying levels of NO<sub>x</sub> emissions as depicted in Figure 9.



**Figure 9: Scenarios NOx Emissions Profile vs. CAP Policy**

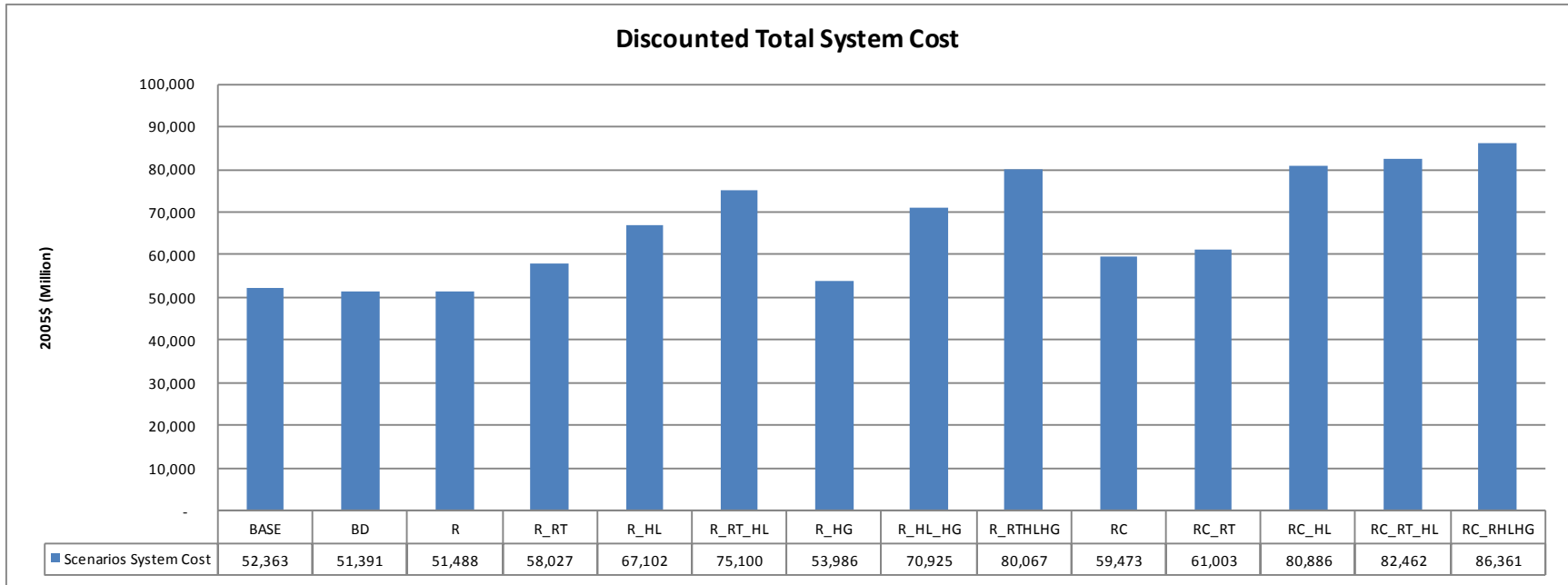
Figure 10 depicts the SOx emissions profile of the Reference Case compared to all other scenarios including the CAP Scenario. The study shows that the highest SOx emissions profile throughout the planning horizon (i.e., 2005-2050) is also from the High Load combined with the High Gas scenario. The lowest SOx emissions profile, as was the case for the NOx and CO2 emissions, is from the Retirement Scenario as well. The reason for the CO2, NOx, and SOx emissions, at almost constant level beyond the 2032, is due to the only coal-fired plant remaining to operate in the state, Comanche 3 (750 MW), and to all gas-fired generations that are replacing the retired coal-fired generation.



**Figure 10: Scenarios SOx Emissions Profile vs. CAP Policy**

**DISCOUNTED TOTAL SYSTEM COST OF SCENARIOS**

Figure 11 depicts the total discounted system cost of all the scenarios for the 45 year planning horizon (2005-2050) in 2005 dollar.



Scenario Descriptions	
Base	Business as Unusual under 1.7% Load Growth (No DSM or RES)
BD	Base with DSM
R	Reference case [Base + DSM + RES (30% IOUs and 10% non-IOUs by 2020)]
RC	Reference Case with Colorado Climate Action Plan Goals (CAP at 20%, 40%, and 80% below 2005 CO2 level by 2020, 2030, and 2050)
RC_HL	Reference Case with CAP, and High Load Growth (3%)
RC_RHLHG	Reference Case with CAP, Retirement, High Load Growth, and High Gas Cost
RC_RT	Reference Case with CAP, and Retirement
RC_RT_HL	Reference Case with CAP, Retirement, and High Load Growth
R_HG	Reference Case with High Gas Cost (+20%)
R_HL	Reference Case with High Load Growth (3%)
R_HL_HG	Reference Case with High Gas Cost and High Load Growth
R_RT	Reference Case with Coal-Fired Power Plants Vintage 45 yrs. or Higher Retire Beginning 2017
R_RTHLHG	Reference Case with Retirement and High Load Growth and High Gas Cost
R_RT_HL	Reference Case with Retirement and High Load Growth

**Figure 11: Scenarios Discounted Total System Cost**

The second lowest system cost is for the Reference Case (“R”) when DSM and RES savings due to fuel costs are realized.<sup>8</sup> As stated earlier, the Reference Case is constrained with the CAP requirements (“RC”), the discounted total system costs for the Reference Case for the 45 year planning horizon increases by 15.5% to meet the CAP requirements by reducing the Reference Case’s carbon footprint by 26%, 45%, and 81% by 2020, 2030, and 2050, respectively to 2005 level. The moderate increase in costs is due to building and utilizing more clean energy and renewable technologies.

Other scenarios have varying degree of higher system cost depending on the characteristics of the scenario. For example, the Retirement Scenario has about 12.7% higher system cost than the Reference Case. When the Retirement Scenario is carbon constrained to meet the CAP goals, the cost differential is about 5% higher than the Retirement Scenario. The highest system cost is due to carbon constrained scenario that includes the Retirement Scenario, High Load Forecast, and High Gas cost.

## **CONCLUSION**

For this study, we used the MARKAL modeling platform to optimize the statewide power sector’s generation expansion, while balancing economic costs and environmental benefits. A Reference Case for the Colorado power sector was developed to analyze the impact of Demand Side Management and statewide Renewable Energy Standards to meet the goals of Colorado’s Climate Action Plan (CAP). This study provides results of a statewide energy planning modeling and policy evaluation that not only considers ways to respond to increased energy needs but also ways to decrease the sector’s carbon footprint to meet the CAP’s goals.

The study shows that as DSM and RES requirements are added to the Base Case, the share of fossil fuel generation over the years reduces, and is

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<sup>8</sup> The lowest cost is for the Base Case combined with the DSM measures.

replaced by a higher share of clean energy technologies. When the CAP requirements are introduced, the study shows that the share of clean energy technologies further increases while fossil fueled generation drops further. By 2030, in order to meet the 40% reduction in CO<sub>2</sub> emissions from the 2005 level, the Colorado power generation mix will need to have about 7,750 MW of wind, 480 MW of CSP, and 255 MW of Solar PV. The resource mix will also need to have about 1,700 MW of combined cycle generation equipped with carbon capture and sequestration technology.

For the Retirement Scenario, the study shows that when coal-fired plants begin to retire due to their vintage of 45 years and older beginning in 2017, conventional combined cycle technology plays a major role in fulfilling the replacement capacity. By 2030, about 2,400 MW of advanced combined cycle technology with higher efficiencies replaces the retired capacity when compared to the Reference Case. In addition to combined cycle technology, about 2,000 MW of wind and 100 MW of solar PV will replace the retired capacity by 2030. The high load forecast combined with the Retirement Scenario adds 3,000 MW more of advanced combined cycle, and 1,900 MW of conventional combined cycle to meet the increased load forecast. When higher gas cost is introduced, about 2,100 MW of coal IGCC with carbon capture and sequestration technology replaces gas-fired generation in the Retirement Scenario, combined with higher load forecast and high gas forecast in the year 2030.

For the High Load Forecast sensitivity scenario constrained for the carbon emissions, the study shows that about 4,400 MW of additional combined cycle technology will need to be installed by 2030 to meet the high load growth. About 2,200 MW is from conventional combined cycle (CC), and about 2,100 from combined cycle with carbon capture and sequestration technology. When the High Load scenario is combined with the Retirement Scenario, the system need for CC technology increases by 1,800 MW, with an additional need of 1,900 MW from advanced CC with a higher efficiency. By 2030, the renewable share of the High Load scenario constrained for carbon emissions is about 260 MW of solar

PV, 480 MW of solar CSP, and about 7,500 MW of wind with 1,280 from GDA 2, 2,000 MW from GDA 1 and 8 and about 4,200 MW from all other GDAs.

Other carbon constrained scenarios, as represented in Table 12, have varying degree of clean energy technologies combined with renewables (wind and solar) to meet the CAP goals by 2020, 2030, and 2050.