



**Public Service Company of Colorado**

**Final Report**

**Innovative Clean Technology**

**“The Colorado Integrated Solar Project”**

**Docket No. 09A-015E**

**March 2, 2011**



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# Cameo Integrated Solar Project

## Final Report

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### **Section 1 Overview**

There are increased requirements in Colorado for clean energy to be a part of the resource mix of regulated utilities. In response, Public Service Company of Colorado (“Public Service” or “Company”) has established a process to investigate potential new clean technologies. Under its innovative clean technology (“ICT”) program, Public Service is investigating demonstration projects that have the potential for cost-effective modification of existing generation assets for the production of clean energy. The Company believes the end result of implementing its ICT program will be (1) to expedite technology transformation to serve increasing state demand for economical clean energy; (2) to provide a more diverse and robust portfolio of clean energy alternatives in Colorado; (3) greater energy security; and (4) to position the state as a leader in clean energy technology. However, before many of these new technologies can be fully utilized, Public Service believes there is a need to demonstrate they can meet utility, Commission, and customer expectations with respect to reliability, safety, and cost effectiveness. In addition, the Company needs to understand how these technologies integrate with our electric system.

The first innovative technology the Company sought to demonstrate was Concentrating Solar Power (“CSP”) Thermal at a demonstration project at our Cameo Generating Station. The project’s objective was to assess the technical feasibility of integrating concentrated solar thermal technology with conventional coal power generation. The project used solar thermal energy to supplement the steam cycle to reduce the use of fossil fuel in the production of electric power at the plant. This project was the first of to supplement coal-fired electric generation with solar thermal heat input built in the United States.

The System was expected to operate for approximately one year or until the closure of the Cameo Station in December 2010.

## Section 2 Project Description

The Colorado Integrated Solar Project (“CISP”) was a project to design, construct, and install a parabolic-mirror-type concentrating solar thermal facility adjacent to the existing Cameo coal generating plant near Palisade, Colorado. The CISP provided supplemental heat to the Cameo Unit 2 heat exchanger to reduce the fossil fuel required by that generating unit to produce electrical power. The project installed solar thermal loop(s) to assist with heating the feedwater used in the production of steam. The photograph that appears on the top of page 20 of the report provides a visual of the preliminary site plan of the existing generation site with the addition of the solar field. Factors considered in the technical feasibility study of the project included: operational reliability, electric generation, reduction in coal usage, and reduction in emissions. The installation demonstrated that this type of supplemental application to an existing fossil boiler will work and will not interfere with normal generation operations.

A number of environmental and economic benefits were anticipated as a result of this solar technology application. By integrating concentrating solar thermal facilities with an existing fossil steam power plant, there was an expectation that the amount of fossil fuel - in this case coal - that would otherwise be needed to be burned to provide the heat input required to power the plant's steam turbine could be reduced. It was expected that this, in turn, would reduce the plant's fuel cost for the amount of coal displaced and reduce the amount of CO<sub>2</sub> and other air emissions associated with combustion of that amount of coal. Likewise, it was expected that using solar energy to augment the steam produced from coal would also reduce environmental impacts from coal ash disposal, wastewater treatment, and coal delivery. Finally, incorporating this technology at an existing coal fired power plant was anticipated to offer a less expensive alternative to a new stand alone solar thermal facility, by avoiding the additional cost of a turbine-generator and other power block equipment that would otherwise be necessary.

Cameo, Unit 2, was designed to generate 49 MW operating on coal or natural gas as an alternate fuel. The unit consists of a two pressure steam turbine - high-pressure and low-pressure. It has two low pressure feedwater heaters, a dearator, and two high pressure feedwater heaters. The solar powered heat exchanger provided additional feedwater heating in between the two high-pressure feedwater heaters.

Cameo Unit 2 was one of the smaller and older fossil fired unit's on Public Service's system. Its planned retirement date was the end of 2010. Cameo Unit 2 stopped generating electricity on December 29, 2010. The use of this unit for the demonstration project provided the Company with an opportunity to conduct the testing with minimal disruption and risk to the rest of the system in case any problems arose during testing. The Company anticipated that the results of the demonstration would inform the applicability of this technology to the Company's other fossil fired generation units.

## Section 3 Project Details

The purpose of this description is to provide a general understanding of the operation of the Cameo Station Solar Feed Water Heater System and its associated major equipment.

### Components

The major components of the system listed below are described in the following sections.

- The Heat Transfer Fluid Pump and Piping
- The Solar Field
- The Solar Heat Exchanger
- The Expansion Vessel
- The Nitrogen System
- The Weather Station

The system essentially consists of a closed thermal circuit that enables heat exchange between the Heat Transfer Fluid (“HTF”), heated by means of parabolic trough solar collectors, and the Feedwater. The circuit includes an expansion vessel to allow safe expansion of the HTF as it heats to operating temperature, and a recirculation pump that moves the HTF through the closed circuit. The solar heat is collected in a 6.4-acre solar field on Company property located southwest of the power plant and directly south of the coal haul road.

The collectors are parabolic metal structures with specially designed curved, ultra-pure glass mirrors mounted on them. The mirrors concentrate the incoming solar radiation at the focus of the parabola, where a line of receiver tubes, also known as Heat Collecting Elements (“HCE”), collect and transport the radiant heat. As the HTF circulates through the HCE of the solar field, it is heated to approximately 576°F, and returns to the solar heat exchanger where the fluid is used to heat the high-pressure feedwater. The HTF is pumped through the HCE, and absorbs the heat to carry it through the system and to the heat exchanger, where the heat is transferred to the feedwater. The then cooled HTF cycles back through the pump to repeat its circuit through the solar field. Because the HTF expands as it heats to the operating temperature, the system also includes a nitrogen-blanketed expansion vessel to contain this additional HTF volume, without overpressuring the system.

Further details regarding each component are as follows:

- **Heat Transfer Fluid, Pump, and Piping**

*Heat Transfer Fluid.* The HTF used in this system is Xceltherm® 600. The Material Safety Data Sheet (“MSDS”) for Xceltherm® 600 is provided in Exhibit 1. This product is a blend of two highly refined white mineral oils, designed to maintain thermal stability at sustained operating temperatures up to 600°F. It is also pumpable to -4°F. This HTF is non-hazardous, non-toxic, odorless, and food-grade. It has a relatively high flash point

at 380°F. Reprocessing by the manufacturer is the recommended means of disposal. The entire system contains approximately 5,940 gallons of the HTF (at 77°F).

*HTF Pump.* The HTF pump is used to circulate the HTF through a closed circuit that runs through the solar field and back to the solar heat exchanger. The pump operates at one speed and flow through the system is not controlled through the pump. At design temperatures, the HTF circulates at approximately 400 GPM in the header piping, and this flow splits between the four parallel loops to provide approximately 100 GPM per loop.

*HTF Piping Header.* HTF is transported through the solar field using a supply (cold) and return (hot) header system. Piping expansion loops were constructed along the headers to relieve the structural stress from thermal expansion of the piping, in accordance with ASME B31.3 code allowable composite pipe stress limits. (The composite pipe stress includes seismic and thermal stresses.) The header system diameters reduce from 5” to 3” as fluid enters each of the loops in order to keep the velocity within the standard practice range. This helps maintain pressure as the flow volume decreases; and thereby assists in balancing flow through the loops and their associated HCE. Flow balancing between the loops is also accomplished with globe valves at the entrance to each loop. Once flow balance is achieved during initial commissioning, these globe valves should not need adjusting. The piping in the loops is designed to allow movement due to collector tracking rotation and to absorb the thermal expansion from the receivers and headers. Therefore, the steel piping in the crossovers between collector rows, as well as from the collectors to the HTF distribution headers, employs ball joints.

- **Solar Field**

The solar heat was collected in a 6.4-acre solar field located southwest of the power plant and directly south of the coal haul road.

*Solar Collector Arrays.* The solar field consists of 7,822 sq. yd (6,540 m<sup>2</sup>) of parabolic trough collectors. This collector aperture (effective surface area) is provided by a total of eight (8), 164-yard-long (150-meter-long) collectors arranged in four (4) parallel flow loops with two (2) of these 150-meter-long collectors per loop. These are single-axis-tracking, parabolic trough solar collectors, meaning that the eight parallel rows of collectors are aligned on a north-south axis so that they may track the sun’s daily travel from east-to-west. Tracking the sun from east to west ensures that the maximum amount of the sun’s radiation is continuously focused on the HCE. Each “parabolic trough” solar collector has a linear, parabolic-shaped, mirrored surface that focuses the sun’s radiation on a linear receiver tube known as an HCE, located at the focus of the parabola. ASI used its Phoenix parabolic trough collector design for this project. Tracking the sun with the collectors requires a drive system. The drive system uses hydraulic rams powered by electric motors to position the collector. The closed-loop tracking system relies on a sun sensor or position feedback sensor for the precise alignment required to focus the maximum amount of solar radiation on the HCE during operation. The tracking is controlled by a local controller on each collector. The local controller also monitors the HTF temperature and reports operational status, alarms, and diagnostics to the main solar

field control computer in the control room. The collector is designed for normal operation in winds up to 40 miles per hour (mph) and safe operation in winds up to 85 mph. The collectors are designed to survive winds up to 85 mph when in their stowed position (the collector aimed approximately 10 degrees below eastern horizon).

*Mirrors.* The collectors are fitted with curved mirrors that were specifically engineered and manufactured for solar parabolic trough applications. The current state-of-the-art, low-iron glass mirrors are highly reliable. Development of a program for monitoring mirror reflectivity and washing mirrors is critical. Operations and Maintenance (“O&M”) procedures contained in the O&M manual address maintaining mirror reflectivity. The periodic monitoring of mirror reflectivity provides a valuable quality control tool for mirror washing and helps to optimize wash labor.

*Heat Collection Elements.* The HCE consists of a steel tube with a specialized coating, surrounded by an insulating, vacuum-tight glass tube. The coating on the steel tube gives it excellent selective heat transfer properties with a high solar absorptivity and low thermal emissivity. The vacuum enclosure serves primarily to protect the selective surface (coating) and to reduce heat losses by insulating the steel tube, while still allowing high transmissivity. The outer glass cylinder has an anti-reflective coating on the outer surfaces to improve transmissivity through the glass tube.

- **Solar Heat Exchanger**

Unlike the surrounding High-Pressure Feedwater Heaters, the solar heat exchanger heats the feedwater with the HTF – thermal energy from the solar field – rather than steam extractions from the high-pressure turbine. It adds up to 15 MMBtu/hr of solar energy to the system. When the temperature of the circulating HTF reaches feedwater temperature (~373 F), the temperature of the feedwater exiting feedwater heater #2 (E202), the HTF solenoid valve on the solar heat exchanger inlet line will open, and the solenoid valve on the bypass line will close, diverting the flow from the bypass line to the solar heat exchanger. The feedwater will continuously flow through the heat exchanger, whether the solar field is operational or not. The solar heat exchanger is a countercurrent flow shell-and-tube heat exchanger, with the lower pressure (~145 psig) HTF on the shell side, and the higher pressure (1,735 psig) feedwater on the tube side.

- **Expansion Vessel**

To accommodate the volumetric change that occurs when heating the HTF to the operating temperature, an expansion vessel is required. Nitrogen will be used to provide a blanket on the headspace of the expansion vessel. The nitrogen blanket prevents oxidation and contamination of the HTF by reducing its exposure to atmospheric air, as well as assists with meeting the net positive suction head requirements for the HTF pump. The HTF expansion tank is sized to minimize nitrogen venting during daily cyclical operations. The expansion vessel is a vertical, cylindrical pressure vessel rated to 150 psia. It has a capacity of 3,850 gallons and is designed to be 25% full at ambient temperature (77°F) and 75% at average operating temperature. The volume in the expansion vessel does not include the volume of HTF contained in the closed circuit, as it remains full, after initial filling. The total volume of HTF in the system is 5,940 gallons.

- **Nitrogen System**

Nitrogen will be used to blanket the expansion vessel. It will serve two main purposes, ensuring adequate minimum net positive suction head is available to the pump, especially for daily system startup, and also to prevent air from entering the system, thereby minimizing the degradation of the HTF. The nitrogen is supplied by a packaged system located near the expansion vessel.

## Basic Operation

- **Daily Start-Up**

Once the sun sensors at the solar field indicated that the Direct Normal Insolation (“DNI”) has reached 200 W/m<sup>2</sup>, the control room signals the pump to start circulating the HTF through the solar field. The collectors then begin tracking when the control room determines that adequate HTF flow is circulating through the solar field. In the absence of adequate flow, the collectors could overheat causing permanent damage to the receivers. The Solar Feed Water Heater is bypassed until the temperature of the HTF equals or exceeds the temperature of the feedwater exiting feedwater Heater #2 (typically, 373 F). Once the HTF reaches this threshold temperature, the solenoid valve on the heat exchanger inlet line opens and the bypass line closes, diverting the flow from the bypass line to the inlet of the heat exchanger.

The feedwater flows through the solar heat exchanger continuously, independently of the HTF temperature and route. Should the HTF temperature at any time fall below the feedwater temperature, the HTF flow would again be bypassed around the heat exchanger to avoid cooling the feedwater. However, once the HTF reaches the threshold temperature and starts flowing through the heat exchanger, the feedwater begins to extract the heat from the HTF and requires less heating in feedwater Heater #1. The collectors will be in operation as long as the DNI remains within the specified criteria. The collectors are programmed with a special timing provision to prevent the system from stowing (stopping tracking) while a cloud passes over. If the  $DNI \geq 200 \text{ W/m}^2$ , the system will continue to operate tracking the sun and pumping HTF. After a set amount of time of the  $DNI \leq 200 \text{ W/m}^2$ , the collector will assume it is night and go into the stow position.

- **Daily Shut-Down**

At the end of the day, when DNI drops below 200 W/m<sup>2</sup>, the collectors would move to the stow position, which is 30 degrees below the eastern horizon. Stowing protects the collectors from winds, and from unintentionally heating the HCE. After the collectors have been stowed, the HTF would continue to circulate as long as the HTF temperature is greater than the temperature of the feedwater to the heat exchanger. This maximizes the solar energy contribution to the feedwater heating system. Once the collectors have been stowed for a period and the HTF temperature has dropped to or below the feedwater



temperature to the heat exchanger, and therefore cannot contribute any more energy to the system, the pump would automatically shut off for the evening and the solenoid valves will switch back to bypassing the solar heat exchanger.

- **Field Temperature Control**

With sufficient solar radiation levels and the field of collectors tracking the sun, the temperature of the HTF exiting the solar field would reach at a maximum of 576°F. When the exit temperature exceeds the maximum safe temperature, the solar field automatically defocuses to a stand-by position. The collector would continue following the sun, but with a sufficient lag angle to reduce the concentration of solar radiation on the HCE, thus preventing the HTF from further increasing in temperature and overheating. Normal tracking was resumed when conditions considered safe were restored.

## **Section 4 Solar Integration Discussion and Knowledge Gained**

The solar thermal energy was added to the feedwater prior to entering the boiler. As shown on Exhibit 2, the solar heat exchanger was installed between the two high pressure feedwater heaters. As feedwater enters the feedwater heater, steam is automatically drawn out or extracted from the steam turbine steam cycle to heat the feedwater. When the solar heat is added to the feedwater less steam is extracted from the steam turbine which either reduces coal input, increases the unit electrical output or both.

The results of the integration were very positive. There were no coal unit outages or de-rates caused by the solar thermal heating during the seven month test period. Unit 2's impact on the solar field was also minimal. The coal unit availability was 98.4%. There were two days of forced outage and two days the unit did not operate because its generation was not needed due to wind generation.

The new feedwater piping to the solar heat exchanger included manual and motor controlled valves. The heat exchanger remained in-service once it was commissioned. It was not isolated each night when the solar field was off line. The heat exchanger was designed to be isolated if there were a tube leak in the heat exchanger. A tube leak could have filled the approximately 145 psi shell side (HTF side) of the heat exchanger with 1,735 psi feedwater. There were no such events.

There was minimal impact on plant operation. The solar system had to be manually started by the control operator each day. The HTF pump was started once the solar incidence was high enough to enable heat to the HTF. The HTF was by-passed around the heat exchanger until the temperature was 5 degree F above the feedwater temperature and rising. There were unit operating permissives that had to be met before heat exchanger was placed in service. The unit had to be operating at 20 MW or greater and feedwater flow had to exceed 150,000 lb/hr. Once the feedwater temperature was exceeded and the permissives were met the HTF heat exchanger isolation valves were opened and then the by-pass valve closed.

The only detrimental effect caused by the solar system was power consumption required to operate the solar system. This was about 0.4% of the equivalent kw-hr output. A majority of the power was used by the heat transfer fluid pump. There was a very small increase in boiler feed pump power due to the increased pressure drop caused by the feedwater circulating through solar heat exchanger. This was so small (4 psi pressure drop in the 1,735 psi system) that it was assumed negligible.

Abengoa elected to have an employee on site at all times the solar system was in operation. Their activities included, but were not limited to, witness or startup of the solar field each morning, training Public Service operators on the solar field operation, resolving control system alarms as required, implementing software revisions, implementing Abengoa office design changes, field repairs as required, and supervising mirror cleanings.

## **Section 5 System Performance**

A reduction in fuel and emissions was expected from three operational changes brought on by the solar heat addition. The three operational changes that contribute to fuel and emissions reduction are: a reduction of high pressure steam extraction, increased available steam for generation, and supplemental heating of feedwater.

### **Reduced High Pressure Steam Extraction**

A feedwater heater increases the temperature or heat content of feedwater. Steam extractions from the turbine provide the necessary heat for feedwater heating. These steam extractions are self-regulating or self adjusting determined from the temperature difference between the steam temperature and the feedwater temperature. A steam extraction will increase or decrease flow from turbine to the feedwater heater. The temperature or heat content of the feedwater determines the steam extraction flow. When the temperature of the feedwater is low, the feedwater heater will increase the steam extraction. Likewise, a high feedwater temperature will reduce the steam extraction.

As the solar heat exchanger adds heat to the feedwater, a reduced extraction flow is expected from the turbine. A reduced steam extraction from the turbine provides a savings in heat. The savings in heat translate to savings in heat source or coal fuel. With less coal used, emissions would be reduced.

### **Reduced Extraction Increased Generation**

A reduction of steam extraction from the turbine increases the amount of steam inside the turbine. Generation will increase as more steam flows through the turbine. Higher generation will lower the stack emissions for each MW of generation produced.

### **Well Heated Feedwater into Boiler**

The addition of the solar heat exchanger will provide one more feedwater heating source. With the feedwater properly heated by the solar heat exchanger and the final feedwater

heater, the boiler will add less heat to the feedwater in the process of converting feedwater to steam. The reduced boiler heat requirement reduces the amount of coal consumed. The less coal consumed the lower emissions. Therefore with less coal consumption there are lower emissions.

## Section 6 Performance Testing

A plant performance test was conducted to measure the performance with and without the solar heating. McHale & Associates tested Cameo Unit 2 on October 28, 2010.

### Cameo Unit 2 Solar Performance Test

The test gathered operational data for two periods for comparison purposes. The first period gathered data for four hours operating with the solar heating. The second data collection gathered data for two hours without solar heating.

The testing data was collected while the unit maintained a net generation level of 29 MW. The operation of Cameo Unit 2 was kept the same for both tests. The only operational change done was the addition of solar heating to the feedwater.

### McHale's Performance Test Results

The following are results from McHale's performance test. The extraction to feedwater (six) was reduced by 3,068lb/hr. The generation increased 300 kW with the solar heat input, and the heat rate was reduced by -185Btu/kWh or 1.33%. A lower heat rate represents less coal consumption and less emissions for a unit of generation.

| Description                                   | Units   | Test 1<br>with<br>Solar<br>Heat<br>Input | Test 2<br>without<br>Solar<br>Heat<br>Input | Change<br>due to<br>Solar |
|---|---------|--|---|---------------------------|
| <b>OUTPUT RESULTS</b>                         |         |  |   |                           |
| Measured Net Electrical Output                | kW      | 29230                                    | 28930                                       | 300                       |
| <b>HEAT RATE RESULTS</b>                      |         |  |   |                           |
| Net Unit Heat Rate, HHV (As-tested)           | Btu/kWh | 13877                                    | 13872                                       | 5                         |
| Gross Turbine Heat Rate (As-tested)           | Btu/kWh | 9978                                     | 10025                                       | -47                       |
| Gross Turbine Heat Rate (Corrected to Design) | Btu/kWh | 9635                                     | 9758  | -123                      |
| <b>HEATER 5 RESULTS</b>                       |         |  |   |                           |
| Extraction Steam Flow                         | lbm/hr  | 12538                                    | 12226                                       | 312                       |
| <b>HEATER 6 RESULTS</b>                       |         |  |   |                           |
| Extraction Steam Flow                         | lbm/hr  | 13930                                    | 16998                                       | -3068                     |
| <b>SOLAR HEAT EXCHANGER</b>                   |         |  |   |                           |
| Solar Heat Exchanger Feedwater Pressure Drop  | psia    | 2.55                                     | 7.57  | -5.02                     |

|   |          |       |       |       |
|---|----------|-------|-------|-------|
| Solar Heat Exchanger Temperature Rise             | °F       | 13.78 | -     | 13.78 |
| Solar Heat Exchanger Energy Added                 | MMBtu/hr | 4.4   | -     | 4.4   |
| Heat Rate Impact at Test Load HHV (~29 NMW)       | Btu/kWh  | 190   | -     | -190  |
| Heat Rate Impact at 100% Load, HHV (50 NMW)       | Btu/kWh  | 111   | -     | -111  |
| Heat Rate Impact at Summer Solstice, HHV (50 NMW) | Btu/kWh  | 159   | -     | -159  |
| Heat Rate Impact at Winter Solstice, HHV (50 NMW) | Btu/kWh  | 99    | -     | -99   |
| <b>OVERALL RESULTS</b>                            |          |       |       |       |
| Coal-Based Heat Rate, HHV                         | Btu/kWh  | 13687 | 13872 | -185  |

## Public Service's Performance Test Results

McHale's test results used as-tested values when comparing tests. This assumes that both test operated exactly the same with the exception of the solar heat input. Boiler maintenance is required while generating which includes soot blowing. Soot blowing was done in between testing periods as to avoid introducing variations in operating conditions.

Company personnel corrected for variations in process conditions. Correcting process conditions allows for a comparison of one test to another, capturing only the effects of supplemented solar heating. The difference in heat rate between both corrected tests is -187Btu/kWh or 1.38%. These values match closely with the as-tested values McHale arrived at.

## Section 7 Coal Savings and Emissions Reduction

Coal consumption was reduced due to the additional heat input from the solar heat exchanger. The amount of coal saved was calculated by knowing the operating conditions of the heat exchanger. The emission reduction was calculated based on the offset coal fuel.

### Coal Savings

From the feedwater temperature rise, the net heat input into the feedwater from solar heat was calculated. An equivalent amount of coal needed to produce the same temperature rise was calculated and compared to the amount of coal needed with the solar heating feedwater. The total coal savings for the project was 524,760lbs.

### CO<sub>2</sub>, NO<sub>x</sub> and SO<sub>2</sub> Reduction

The relationship between emissions and the amount coal consumed captures the reduced emissions obtained by integrating the solar heating. We calculated the emission reduction by determining the amount of coal saved (524,760 lbs). This amount of coal savings correlates directly to the emissions reductions of 1,162,953 lbs of CO<sub>2</sub>, 1,954 lbs of NO<sub>x</sub> and 5,400 lbs SO<sub>2</sub>.

## Project Solar Thermal Delivery Results

The following table shows Abengoa's expected thermal energy delivery from the field to the actual thermal energy delivery observed.

| Month | Abengoa<br>Predicted Solar<br>Field Thermal<br>Delivery<br>(MMBtu) | Actual Solar<br>Thermal<br>Delivery<br>(MMBtu) |
|-------|--|--|
| Jan   | 920  |  |
| Feb   | 1,232  |  |
| Mar   | 2,106  |  |
| Apr   | 2,490  |  |
| May   | 3,159  |  |
| Jun   | 3,827  | 965  |
| Jul   | 3,604  | 2,280  |
| Aug   | 2,902  | 1,516  |
| Sep   | 2,524  | 1,653  |
| Oct   | 1,709  | 739  |
| Nov   | 955  | 277  |
| Dec   | 803  | 143  |
| TOTAL | 26,231   | 7,573  |

The table below shows the expected coal reduction and emissions savings based on Abengoa predicted solar field delivery, assuming no heat loss in from the solar field to the heat exchanger and a coal heating value of 10,800 Btu/lb.

| Month | Abengoa<br>Predicted<br>Solar Field<br>Thermal<br>Delivery<br>(MMBtu) | Expected<br>Coal<br>Savings<br>(lb) | Expected<br>CO <sub>2</sub><br>Savings<br>(lb) | Expected<br>NO <sub>x</sub><br>Reduced<br>(lb) | Expected<br>SO <sub>2</sub><br>Reduced<br>(lb) |
|-------|---|-------------------------------------|--|--|--|
| Jan   | 920   | 851,852                             | 188,784  | 395  | 877  |
| Feb   | 1,232   | 1,140,741                           | 252,807  | 529  | 1,174  |
| Mar   | 2,106   | 1,950,000                           | 432,152  | 904  | 2,007  |
| Apr   | 2,490   | 2,305,556                           | 510,949  | 1,069  | 2,373  |
| May   | 3,159   | 2,925,000                           | 648,228  | 1,357  | 3,010  |
| Jun   | 3,827   | 3,543,519                           | 785,302  | 1,644  | 3,647  |
| Jul   | 3,604   | 3,337,037                           | 739,542  | 1,548  | 3,434  |
| Aug   | 2,902   | 2,687,037                           | 595,491  | 1,246  | 2,765  |
| Sep   | 2,524   | 2,337,037                           | 517,926  | 1,084  | 2,405  |
| Oct   | 1,709   | 1,582,407                           | 350,687  | 734  | 1,628  |
| Nov   | 955   | 884,259                             | 195,966  | 410  | 910  |
| Dec   | 803   | 743,519                             | 164,776  | 345  | 765  |
| Total | 26,231  | 24,287,963                          | 5,382,610                                      | 11,265   | 24,994   |

The following table shows the actual amount of solar generation, coal savings, and emissions reduction for individual months.

|              | <b>Solar<br/>Generation<br/>(MWh)</b> | <b>Coal<br/>Savings<br/>(lb)</b> | <b>CO<sub>2</sub> Reduced<br/>(lb)</b> | <b>NO<sub>x</sub><br/>Reduced<br/>(lb)</b> | <b>SO<sub>2</sub><br/>Reduced<br/>(lb)</b> |
|--------------|---------------------------------------|----------------------------------|--|--|--|
| May          | 6                                     | 7,604                            | 16,853                                 | 37   | 78   |
| June         | 54                                    | 73,803                           | 163,559                                | 341  | 759  |
| July         | 114                                   | 154,376                          | 342,122                                | 726  | 1,589                                      |
| Aug          | 71                                    | 97,650                           | 216,409                                | 453  | 1,005                                      |
| Sep          | 89                                    | 124,346                          | 275,570                                | 85   | 1,280                                      |
| Oct          | 34                                    | 46,951                           | 104,051                                | 219  | 483  |
| Nov          | 11                                    | 14,951                           | 33,133                                 | 69   | 154  |
| Dec          | 4                                     | 5,078                            | 11,255                                 | 24   | 52   |
| <b>TOTAL</b> | <b>384</b>                            | <b>524,760</b>                   | <b>1,162,953</b>                       | <b>1,954</b>                               | <b>5,400</b>                               |

The following table shows the amount of heat delivered to the feedwater.

| <b><u>Solar Energy Input into Feedwater</u></b> | <b><u>(MMBtu)</u></b> |
|---|-----------------------|
| May   | 82                    |
| June  | 797                   |
| July  | 1,667                 |
| August  | 1,055                 |
| September                                       | 1,343                 |
| October   | 507                   |
| November  | 161                   |
| December  | 55                    |
| <b><u>Total Solar Input</u></b>                 | <b><u>(MMBtu)</u></b> |
| May – December                                  | 5,667                 |

## Lessons Learned

### Performance

Overall the performance related to coal and emissions savings were not as good as Abengoa predicted or what Public Service expected. There is reason to believe that these results are attributable to the small scope of the project as a demonstration project. However, the integration into the feedwater cycle of an existing fossil facility was successful. The project was not designed to maximize efficiency or performance. For example, to minimize costs, less insulation was used than what would have been installed for a 20 year design. Mirror washings were less frequent than would typically be performed to reduce O&M expense. As previously mentioned, Abengoa took this opportunity to test a new collector frame design; however, the results were that the redesigned system did not provide the anticipated solar energy collection efficiency instead the efficiency actually decreased.

### Future Deployment

At this time, Public Service believes that it would be best to take a “wait and see” approach before deciding on further deployments of solar integration with fossil fuel feedwater systems. Though the Company believes it achieved a successful integration of the solar heating into the feedwater system, the situation regarding costs and efficiencies is fluid, making it difficult to make any definitive recommendations regarding future deployments at this time. Based on our costs for Cameo, the Company would conclude that the cost on an equivalent MWH basis is much higher than wind or PV solar. However, as discussed below in more detail, technological changes have occurred and it is likely that costs will come down. The Company believes that the best approach at this time is to continue to monitor developments relating to CSP technology, as well as other renewable technologies, before deciding on any future deployment of CSP technology.

The optimum location for solar thermal technology would be in the San Luis Valley. However, the Company does not have generation facilities in this area. Notwithstanding that present recommendation, the Company gained vital information, knowledge and expertise about concentrating solar system design. In the event we employ this technology in the future we will be much more informed regarding the design details and its impact on solar energy collection efficiency.

The following table compares the Cameo site and the San Luis Valley’s solar resource to the present location of our fossil fuel units.

| <b>Plant Name</b> | <b>Ref Temp ('C)</b> | <b>Ref DNI (W/m2)</b> | <b>Ref Wind (m/s)</b> | <b>Plant Size (MWe)</b> | <b>Annual Plant Output (MWh)</b> | <b>Compared to Cameo Site</b> | <b>Compared to San Luis Valley</b> |
|-------------------|----------------------|-----------------------|-----------------------|-------------------------|----------------------------------|-------------------------------|------------------------------------|
| Cameo             | 9.6                  | 950                   | 3.8                   | 1.00                    | 1,397,724                        | 100.00%                       | 77.91%                             |
| Comanche          | 12.5                 | 950                   | 2.7                   | 1.00                    | 1,590,111                        | 113.76%                       | 88.63%                             |
| Ft St Vrain       | 11.9                 | 925                   | 3.3                   | 0.97                    | 1,392,156                        | 99.60%                        | 77.60%                             |
| Hayden            | 9.2                  | 960                   | 4.7                   | 1.01                    | 1,289,782                        | 92.28%                        | 71.89%                             |
| Pawnee            | 11.9                 | 920                   | 3.4                   | 0.97                    | 1,374,492                        | 98.34%                        | 76.61%                             |
| Rocky Mtn Energy  | 12.6                 | 925                   | 2.5                   | 0.97                    | 1,392,312                        | 99.61%                        | 77.61%                             |
| San Luis Valley   | 7.5                  | 990                   | 2.2                   | 1.05                    | 1,794,086                        | 128.36%                       | 100.00%                            |

### Future of Concentrating Solar Technology

Similar to wind and solar photovoltaic technologies, the Company expects the installed cost of concentrating solar power technology to drop and the performance of such technology to improve. For example, a significant improvement that was not available even two years ago is the direct heating of water into superheated steam with a heat exchanger or heat transfer fluid. This design is much more efficient, and utilizes less equipment, than the design employed at Cameo. We would expect the overall project cost using this design would be less than the solar thermal system integrated at Cameo. Technology suppliers are developing three dimensional tracking systems that should be available in the near future. These and other developments in concentrating solar power technology are a primary factor in making it difficult for the Company to draw any definitive conclusions at this time regarding future utilization of this technology, leading it to believe that a wait and see approach would be best.

### Cameo Solar System Future

The company continues to consider alternatives for future use of the Cameo solar equipment installed for the Cameo demonstration. Based on analysis of the data associated with the Cameo demonstration, it does not appear cost effective to install a full-size turbine, generator, and associated power block components to create a stand alone solar plant for long-term electricity generation at the Cameo site. Also, relocation of the entire solar field to a different site appears cost-prohibitive. Potentially it would cost more to move the Cameo Solar system than the original cost of construction. Nevertheless, we plan to continue investigating these options in more detail. The solar equipment also could be recycled: the mirrors, receiver tubes, and aluminum structures have commercial value that could be extracted.

















**CERTIFICATE OF SERVICE**  
**09A-015E**

I hereby certify that on this 2<sup>nd</sup> day of March 2011, the foregoing **“PUBLIC SERVICE COMPANY OF COLORADO FINAL REPORT INNOVATIVE CLEAN TECHNOLOGY “COLORADO INTEGRATED SOLAR PROJECT””** was e-filed with the Colorado Public Utilities Commission in accordance in accordance with applicable law upon:

Doug Dean, Director  
Colorado Public Utilities Commission  
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And a copy was electronically served in Adobe .pdf format, or mailed, via U.S. mail, postage prepaid, and addressed to the following:

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Handwritten signature of William H. Hight, written in black ink over a horizontal line.