PLANNING FOR CARBON-NEUTRAL DESALINATION IN CARLSBAD, CALIFORNIA

Nikolay S. Voutchkov, P.E., BCEE[1]

ABSTRACT

Greenhouse gas emissions (GHG) associated with production of desalinated seawater at the 50 MGD Carlsbad project in California are planned be mitigated by a portfolio of alternative technologies and measures including advanced energy reduction technologies, implementation of renewable energy projects, and carbon dioxide sequestration. This paper describes the methodology used to determine the carbon footprint for the Carlsbad desalination project and presents the scope and costs associated with the various GHG emission initiatives planned for this project.

INTRODUCTION

Over the past five years desalination has gained a significant momentum in California. With more than ten projects in various stages of environmental review, design and construction, desalination is planned to provide 400 MGD to 500 MGD of new fresh drinking water supplies for the state by year 2015.

One of the largest and most advanced projects under development today is the 50 MGD Carlsbad seawater desalination plant (Figure 1). This project is collocated with the Encina coastal power generation station which currently uses seawater for once-through cooling. The Carlsbad seawater desalination project is developed as a public-private partnership between Poseidon Resources and eight local utilities and municipalities.

Since 1999 a team of planners, scientists, engineers, equipment manufacturers and environmental experts have been working on the development and evaluation of the desalination project. The environmental impact assessment and local land use permit for the Carlsbad desalination project were approved in the first half of 2006. In August 2006 the project was granted ocean discharge permit for disposal of the high-salinity concentrate generated during the reverse osmosis membrane separation process, and in November of 2007 the California Coastal Commission confirmed project viability. Project permitting is planned to be completed by September of 2008 and construction is expected to begin by the end of this year. The Carlsbad project is targeted to be in operation by mid-2011 and to supply 6 to 8% of the drinking water in San Diego County. When completed, this project would be the largest seawater desalination plant in the USA.

GREENHOUSE GAS EMISSIONS OVERVIEW

Gases that trap heat in the atmosphere are referred to greenhouse gases (US EPA, 2006). Some greenhouse gases such as carbon dioxide occur naturally and are emitted to the atmosphere through natural processes and human activities. Other greenhouse gases (e.g., fluorinated gases) are created and emitted solely through human activities. The principal greenhouse gases that enter the atmosphere because of human activities are:

- **Carbon Dioxide (CO_2)**: Carbon dioxide enters the atmosphere through the burning of fossil fuels (oil, natural gas, and coal), solid waste, trees and wood products, and also as a result of other chemical reactions (e.g., manufacture of cement). Carbon dioxide is also removed from the atmosphere (or "sequestered") when it is absorbed by plants as part of the biological carbon cycle.
- **Methane (CH_4):** Methane is emitted during the production and transport of coal, natural gas, and oil. Methane emissions also result from livestock and other agricultural practices and by the decay of organic waste in municipal solid waste landfills.
- **Nitrous Oxide (N_2O):** Nitrous oxide is emitted during agricultural and industrial activities, as well as during combustion of fossil fuels and solid waste.
- **Fluorinated Gases:** Hydro fluorocarbons, per fluorocarbons, and sulfur hexafluoride are synthetic, powerful greenhouse gases that are emitted from a variety of industrial processes. These gases are typically emitted in smaller quantities, but because they are potent greenhouse gases, they are sometimes referred to as High Global Warming Potential gases ("High GWP gases").

Changes in the atmospheric concentrations of these greenhouse gases can alter the balance of energy transfers between the atmosphere, space, land, and the oceans and ultimately result in global and local climate variability and permanent changes (NRC, 2001). Many elements of human society and the environment are sensitive to climate variability and change. Human health, agriculture, natural ecosystems, coastal areas, and heating and cooling requirements are examples of climate-sensitive systems.

FIGURE 1 Carlsbad Sewater Desalination Project

The extent of climate change effects, and whether these effects prove harmful or beneficial, will vary by region, over time, and with the ability of different societal and environmental systems to adapt to or cope with the change.

Rising average temperatures are already affecting the environment. Some observed changes include shrinking of glaciers, thawing of permafrost, later freezing and earlier break-up of ice on rivers and lakes, lengthening of growing seasons, shifts in plant and animal ranges and earlier flowering of trees (IPCC, 2007).

Global temperatures are expected to continue to rise as human activities continue to add carbon dioxide, methane, nitrous oxide, and other greenhouse (or heat-trapping) gases to the atmosphere. Most of the United States is expected to experience an increase in average temperature as a result of increase in greenhouse gas emissions (IPCC, 2007).

According to a recent US EPA GHG emission inventory, the primary greenhouse gas emitted by human activities in the United States in 2006 was CO_2, representing approximately 84.8 percent of total greenhouse gas emissions (US EPA, 20008). The largest source of CO_2, and of overall greenhouse gas emissions was fossil-fuel based production of electricity. The second largest source was transportation.

Although production/distribution of drinking water is not one of the top ten energy users in the country, in California 19% of the electric energy used state-wide is associated with water transfers and production (CEC, 2005). The main reason for this unusually high energy demand associated with water supply is that a large portion of the water used in southern California is delivered via long-distance in-state and out-of-state water transfers. To address the increasing global greenhouse emissions challenge, California enacted the Global Warming Solutions Act of 2006 which aims to reduce the greenhouse gas (GHG) emissions of the state to 1990 levels by year 2020. In response to this legislation, Poseidon made the commitment to completely offset the carbon footprint associated with desalination plant operations. The Climate Action Plan described herein outlines a portfolio of operational and design technologies and measures; green energy supply alternatives and carbon emission offset initiatives. The key components of the Climate Action Plan are described below.

ASSESSING PROJECT GROSS CARBON FOOTPRINT

The carbon footprint of the seawater desalination plant is the amount of greenhouse gases that would be released into the air from the power generation sources that will supply electricity for the plant. Usually, carbon footprint is measured in pounds (lbs) or metric tons of carbon dioxide (CO_2) emitted per year. The total plant carbon footprint is dependent on two key factors: (1) how much electricity is used by the desalination plant; and (2) what sources (fossil fuels, wind, sunlight, etc.) are used to generate the electricity supplied to the plant. Both of these factors could be variable over time and therefore, the Climate Action Plan has to have the flexibility to incorporate such changes.

The Carlsbad seawater desalination plant is planned to be operated continuously, 24 hours a day and 365 days per year, and to produce an average annual drinking water flow of 50 MGD (1.89 x10^5 m^3/day). When the plant was originally conceived over five years ago, the total baseline power use for this plant was projected at 31.3 megawatts (MW) or 3.96 KWh/m^3 (15.03 KWh/1,000 gallons) of drinking water. This power use incorporates both production of fresh drinking water and conveyance, and delivery of this water to the distribution systems of the individual utilities and municipalities served by the plant.

However over the lengthy period of project permitting, the seawater desalination technology has evolved. By taking advantage of the most recently available state-of-the art technology for energy recovery and by advancing the design to accommodate latest high efficiency reverse osmosis system feed pumps and membranes, the actual project power use was reduced down to 13.48 KWh/1,000 gallons of drinking water. As a result, the total annual energy consumption for the Carlsbad seawater desalination project used to determine the plant carbon footprint is 246,000 MWh/yr. This energy use is determined for an annual average plant production capacity of 50 MGD. As actual production capacity may vary from year to year, so would the total energy use.

Next, in order to convert the desalination plant annual energy use into carbon footprint (CF), this use is multiplied by the electric grid emission factor (Emission Factor), which is the amount of greenhouse gasses emitted during the production of unit electricity consumed from the power transmission and distribution system:

$$CF\ (lbsCO_2/yr) = \text{Annual Plant Electricity Use (MWh/yr)} \times \text{Emission Factor (lbs of } CO_2/MWh)$$

The actual value of the Emission Factor is specific to the actual supplier of electricity for the project, which is San Diego Gas and Electric (SDG&E) for the Carlsbad plant. Similar to other power suppliers in California, SDG&E determines their Emission Factor based on a standard protocol developed by the California Climate Action Registry (CCAR). CCAR was created by California Legislature (SB 1771) in 2001 as a non-profit voluntary registry for GHG emissions and is the authority in California that sets forth the rules by which GHG emissions are determined and accounted for.

Based on information provided in their most recent emissions report (CCAR, 2008) the SDG&E emission factor is 546.46 lbs of CO_2 per MWh of delivered electricity. At 246,000 MWh/yr of energy use and 546.46 lbs CO_2/MWh, the total carbon footprint for the Carlsbad seawater desalination project is calculated at 134.4 million lbs of CO_2 per year (61,100 metric tons CO_2/yr). This carbon footprint is reflective of the latest energy efficient design of the desalination plant. A more conventional desalination plant design (274,000 MWh/yr) would have a carbon footprint of 68,100 tons CO_2/yr.

It is important to note that the value of the emission factor is reduced with the increase of the portion of renewable power sources in power supplier's energy resource portfolio. Because of the statewide initiatives and legislation to expand the use of renewable sources of electricity, the emission factors of all California power suppliers are expected to decrease measurably in the future. For example, currently approximately 10% of SGD&E's retail electricity is generated from renewable sources (solar radiation, wind, geothermal heat, etc.). In their most-recent Long-term Energy Resource Plan, SDG&E has committed to increase energy from renewable sources by 1% each year, reaching 20% by year 2017. This reduction will certainly reduce the Carlsbad desalination plant carbon footprint over time, especially taking into consideration that the plant will not be fully operational before mid 2011.

OFFSETTING CARBON FOOTPRINT BY REDUCED WATER IMPORTS

Currently, San Diego County imports 90% of its water from two sources – the Sacramento Bay – San Joaquin River Delta, traditionally known as the "Bay-Delta", and the Colorado River. This imported water is captured, released and conveyed via a complex system of intakes, dams, reservoirs, aqueducts and pump stations (State Water Project), and treated in conventional water treatment plants prior to its introduction to the water distribution system. The total amount of electricity needed to deliver this water to San Diego County via the State Water Project facilities is 10.45 KWh/1,000 gallons (2.76 KWh/m^3), which includes 9.93 KWh/1,000 gallons (2.62 KWh/m^3) for delivery, 0.21 KWh/1,000 gallons (0.06 kWh/m^3) for evaporation losses, and 0.31 KWh/1000 gallons (0.08 KWh/m^3) for treatment.

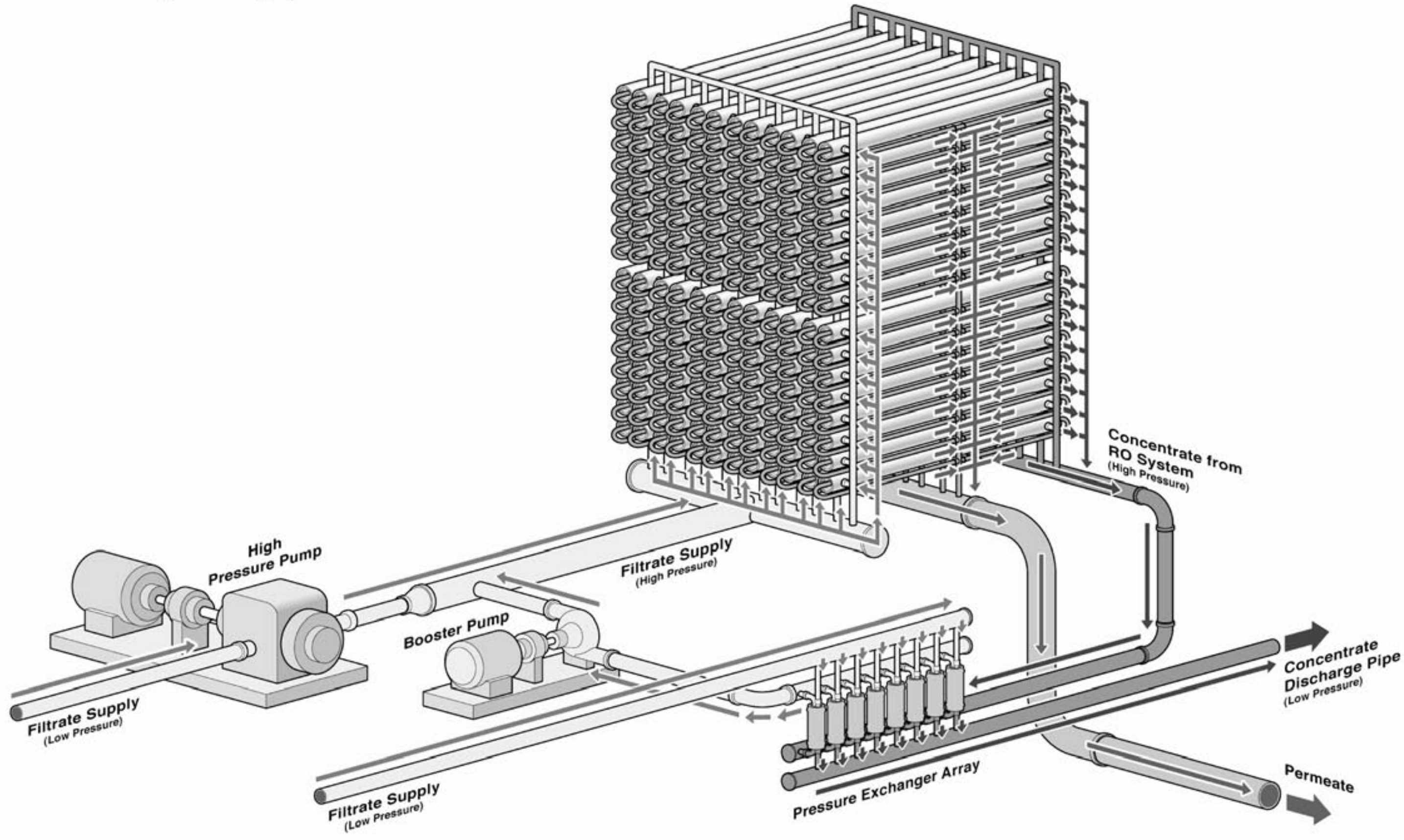
Over the past decade the availability of imported water from the State Water Project has been in steady decline due to prolonged drought, climate change patterns and environmental, and population growth pressures. One of the key reasons for the

TABLE 1 Desalination Project Net GHG Emission Zero Balance

Source	Total Annual Power Use (MWh/year)	Total Annual Emissions (tons CO_2/year)
Carbon Dioxide Emission Generation		
1. Seawater Desalination and Product Water Delivery – High Energy Efficiency Design	246,00	61,100
2. Carbon Emission Reduction Due to Reduced Water Imports	190,700	47,400
3. Total Net Power Use & Carbon Emissions (Item 1 - Item 2)	**55,300**	**13,700**
On-Site Carbon Dioxide Emissions Reductions		
4. Energy Efficient Plant Design	Accounted for in Item 1	Accounted for in Item 1
5. Use of Warm Cooling Water	(12,300)	(3,100)
6. Green Building Design	(500)	(124)
7. On-site Solar Power Generation	(777)	(193)
8. Use of CO_2 for Water Production	NA	(2,100)
9. Reduced Energy for Water Reclamation	(1,950)	(484)
10. Subtotal On-site Power/GHG Emission Reduction (Sum of Items 4 through 9)	(15,527)	(6,001)
Off-site Carbon Dioxide Emission Mitigation		
11. CO_2 Sequestration by Re-vegetation of Wildfire Zones	(NA)	(166)
12. CO_2 Sequestration in Coastal Wetlands	(NA)	(304)
13. Regional Green Power Generation Projects (*see Table 3*)	(2,260)	(561)
14. Other Carbon Offset Projects and Purchase of Renewable Credits	(37,513)	(6,668)
15. Subtotal Off-site Power/GHG Mitigation Reduction (Sum of Items 11 through 14)	(39,773)	(7,699)
Total Net CHG Emission Balance (Item 3 - Item 9 - Item 14)		0

Notes: NA – Not Applicable. Numbers in Parentheses Indicate Reduction.

FIGURE 2 Energy Recovery System for the Carlsbad Seawater Desalination Plant



development of the Carlsbad seawater desalination project is to replace 50 MGD of the water imported via the State Water Project with fresh drinking water produced locally by tapping the ocean as an alternative drought-proof source of water supply. Since the desalination project will offset the import of 50 MGD of water via the State Water Project, once in operation, this project will also offset the electricity consumption of 10.45 KWh/1,000 gallons, and the GHG emissions associated with pumping, treatment and distribution of this imported water. The annual energy use for importing 50 MGD of State Water Project water is therefore, 190,700 MWh/yr. At 546.46 lbs CO_2/MWh, the total carbon footprint of the water imports that will be offset by desalinated water is therefore, 104.2 million lbs of CO_2 per year (47,400 metric tons CO_2/yr).

Taking under consideration that the gross carbon footprint of the desalination plant is 61,100 metric tons CO_2/yr, and that 47,400 metric tons CO_2/yr (77.4%) of these GHG emissions would be offset by reduction of 50 MGD of water imports to San Diego County, the Carlsbad desalination plant's net carbon footprint is estimated at 13,700 metric tons CO_2/yr. Lines 1-3 of Table 1 summarize the total annual power use and emissions, the power and emission reduction attributable to reduced water imports, and the net power use and net annual emissions.

CLIMATE ACTION PLAN FOR NET CARBON FOOTPRINT REDUCTION

The main purpose of the Climate Action Plan (CAP) for the Carlsbad seawater desalination project is to eliminate plant's net carbon footprint by implementing measures for: energy efficient facility design and operations; green building design; use of carbon dioxide for water production; on-site solar power generation; carbon dioxide sequestration by creation of coastal wetlands and reforestation; funding renewable power generation projects, and acquisition of renewable energy credits. Project carbon neutrality would be achieved by a balanced combination of these measures.

The size and priority of the individual projects included in the Climate Action Plan will be determined based on a life-cycle cost-benefit analysis and overall benefit for the local community. Implementation of energy efficiency measures for water production, green building design, and carbon dioxide sequestration projects in the vicinity of the project site will be given the highest priority.

The project Climate Action Plan is a living document that has to be updated periodically in order to reflect the dynamics of development of desalination and green energy generation technologies; and the efficiency and cost-effectiveness of various carbon footprint reduction and offset alternatives. Once the Carlsbad seawater desalination plant is operational, the actual carbon footprint will be verified at the time of plant startup and will be updated periodically to account for changes in power supplier's Emission Factor, and for the actual performance of the already implemented carbon footprint reduction initiatives. Periodic assessment and re-prioritization of activities that keep the desalination plant operations "green" is a very essential component of the Climate Action Plan because both desalination technology and

FIGURE 3 Tampa Bay Desalination Plant Pelton Wheel Energy Recovery System

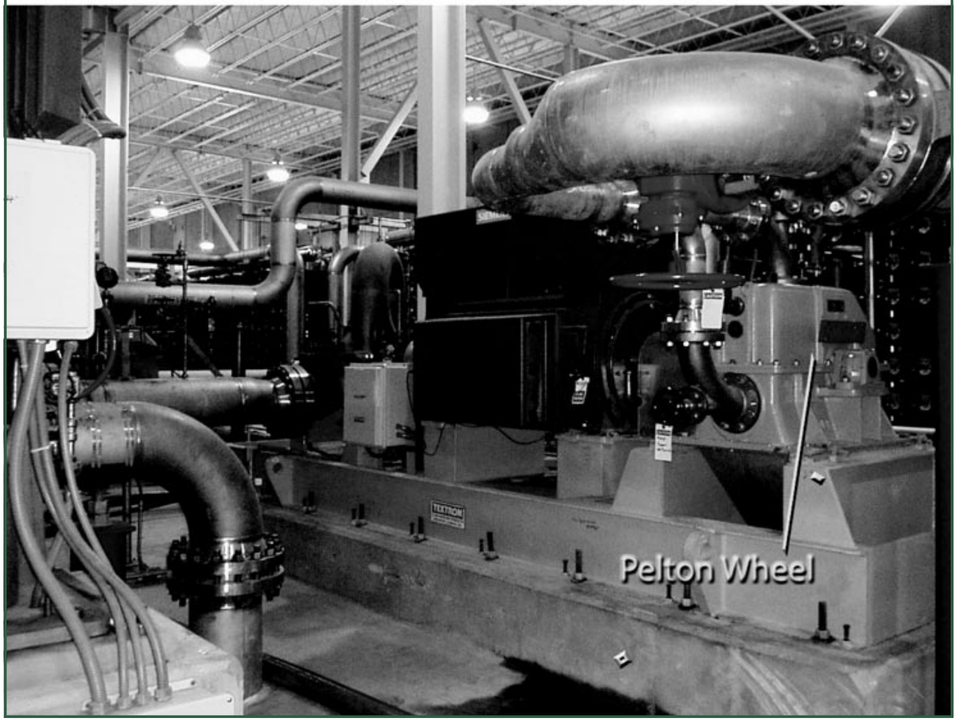


TABLE 2 Unit Costs of Carbon Footprint Reduction Alternatives

Alternative	Unit Cost (US$/ton CO_2 reduced)
Green Building Design	3,400
On-site Solar Power Generation	1,900
CO_2 Sequestration in Coastal Wetlands	400
CO_2 Sequestration by Re-vegetation of Wildfire Zones	200
Use of CO_2 for Water Production	70

green power generation (i.e., solar, wind and bio-fuel-based power) are expected to undergo accelerated development over the next decade as they evolve from marginal to mainstream sources of water supply and power supply, respectively. The specific carbon footprint reduction measures incorporated in the Carlsbad Climate Action Plan, and their key benefits and constraints are discussed below.

Energy Efficient Design and Operations

Over 50% of the energy used at the Carlsbad seawater desalination plant is applied for salt-fresh water separation by reverse osmosis. The seawater desalination project design incorporates a number of features minimizing plant energy consumption. One of them is a state-of-the art pressure exchanger-based energy recovery system that allows recovering and reusing 33.9% of the total initial energy applied for salt separation. After membrane separation, most of the energy applied for desalination is retained in the concentrated stream ("brine") that also contains the salts removed from the seawater. This energy bearing stream (shown as the high pressure condensate from the RO system in Figure 2) is applied to the back side of the pistons of cylindrical isobaric chambers (shown as the Pressure Exchanger Array in Figure 2). These pistons pump approximately 45 to 50% of the seawater fed into the reverse osmosis membranes for desalination. Since a small amount of energy (4 to 6%) is lost during the energy transfer from the concentrate to the feed water, this energy is added back to feed flow by small booster pumps. The reminder (45 to 50%) of the feed flow is pumped by high-pressure centrifugal pumps equipped with high-efficiency motors.

The pressure exchanger energy recovery system is projected to recover 10,200 hp (7.6 MW) of power and yield 2,650 hp (1.98 MW) of additional power savings as compared to the energy that could be recovered using standard energy recovery equipment (pelton wheels). Pelton wheels are presently employed at most large seawater desalination plants worldwide, including at the 25 MGD seawater desalination plant in Tampa, Florida (see Figure 3).

In addition to the state-of-the-art pressure exchanger energy recovery technology, the Carlsbad desalination plant design incorporates variable frequency drives on seawater intake pumps, filter effluent transfer pumps, and product water pumps as well as premium efficiency motors for all large pumps in continuous operation. Installation of premium-efficiency motors and variable frequency drives on large pumps would result in additional 1.26 MW (4%) power savings. Harnessing, transferring and reusing the energy applied for salt separation at very high efficiency by the pressure exchangers allows reducing the overall amount of electric power used for seawater desalination with over 11.5% (3.24 MW) as compared to standard designs of similar facilities. These savings correspond to a total annual electricity use reduction of 28,380 MWh/yr and a carbon footprint reduction of 7,000 tons of CO_2/yr and, as shown in Line 4 of Table 1, are already accounted for by the High Energy Efficiency Design figures used in Line 1 of Table 1.

Over 80% of the desalination plant piping would be made of low-friction fiberglass reinforced plastic (FRP) and high-density polyethylene (HDPE) materials, which in turns would yield additional energy savings for seawater conveyance. The desalination plant operations will be fully automated, which would allow to reduce plant staff requirements and associated GHG emissions for staff transportation and services.

Use of Warm Cooling Water

Osmotic pressure that has to be overcome in order to produce fresh drinking water decreases with the increase of seawater temperature. Therefore, desalination of warmer seawater requires less energy. The Carlsbad seawater desalination plant will be collocated with the Encina power plant (see Figure 1) and its intake will be connected to the cooling water canal to take advantage of the warmer seawater discharged by the power plant. The difference between the

FIGURE 4 Solar Panel Rooftop System

TABLE 3 Regional Carbon Footprint Offset Projects

Desalination Project Public Partner (Proponent of Green Power Generation Facility)	Green Power Project Description	Annual Capacity of Green Energy Projected to be Generated by the Project (MWh/yr)
City of Encinitas	95 KW Solar Panel System Installed on City Hall Roof	160
Valley Center Municipal Water District	1,000 KW Solar Panel System	1,680
Rainbow Municipal Water District	250 KW Solar Panel System	420
	Total Green Power Generation Capacity (MWh/yr)	2,260

average annual temperatures of the ambient ocean seawater and the warm seawater which will be used as source water for the desalination plant is 5.5° C. Based on pilot testing results, this temperature increment is projected to result in 5% of additional energy savings and carbon footprint reduction, as compared to desalinating cold seawater of ambient temperature. Because of this, 5% of additional energy savings and respective carbon footprint reduction (12,300 MWh/yr and 3,100 tons/CO_2 per year) are projected to be achieved by using warm cooling water from the Encina Power Generation Station as source seawater for the desalination plant. These savings in power and emissions are shown in Line 5 of Table 1.

There are no additional capital and operations costs to use warm water from the power plant once-trough cooling system. Therefore, when the power plant is operational the desalination plant will use only warm cooling water. When the power plant is down the desalination plant intake is designed to collect cold seawater from the same intake.

Green Building Design

The desalination plant will be located on a site currently occupied by a dilapidated fuel oil storage tank which in no longer used by the power plant. This tank and its content will be removed and the site will be reclaimed and reused to construct the desalination plant. Reclaiming the land will reduce project imprint on the environment as compared to using new undisturbed site for the desalination plant.

A key "green" feature of the Carlsbad seawater desalination plant design is its compactness. The desalination plant facilities will be configured as series of structures sharing common walls, roofs and equipment which would allow significant reduction of its physical footprint. The total area occupied by the desalination plant facilities would be less than 5 acres. When built, this would be the smallest footprint desalination plant in the world per unit production capacity (5 acres per 50 MGD). For comparison, the 25 MGD Tampa Bay seawater desalination plant occupies 8 acres; the 73 MGD Orange County Groundwater Recharge Project, which also uses reverse osmosis system, occupies approximately 40 acres; and the 86 MGD Ashkelon, Israel seawater desalination plant, which currently is the largest seawater reverse osmosis facility in the world, occupies 24 acres. A plant with a smaller physical footprint would also yield a smaller construction-related carbon footprint: lower construction material expenditures and GHG emissions from construction equipment due to smaller volume of excavation and concrete works. A reduced construction site footprint also generates less dust emissions and requires less water for dust control.

A large portion of the desalination plant facilities and equipment will be located in several buildings. Building design will follow the principles of the Leadership in Energy and Environmental Design (LEED) program. This is a program of the United States Green Building Council and is developed to promote construction of sustainable buildings that reduce the overall impact of building construction and functions on the environment by: (1) sustainable site selection and development; (2) energy efficiency; (3) materials selection; (4) indoor environmental quality, and (5) water savings.

Consistent with the principles of the LEED program, the desalination plant buildings will include features and materials that allow minimizing energy use for lighting, air conditioning and ventilation. For example, a portion of the walls of the main desalination plant building will be equipped with translucent panels to maximize daylight use and views to the outside. Non-emergency interior lighting will be automatically controlled to turn-off in unoccupied rooms and facilities. A monitoring system will ensure that the ventilation in the individual working areas in the building is maintained at its design minimum requirements. In addition, building design will incorporate water conserving fixtures (lavatory faucets, showers, water closets, urinals, etc.) for plant staff service facilities and for landscape irrigation.

The green desalination plant buildings will incorporate low-emitting materials and thus pose less risk to the natural environment and building's occupants. Low emitting paints, coatings, adhesives, sealants and carpet systems are planned to be used on the interior of the buildings. Building design team will include professional engineers that have achieved the LEED Accredited Professional designation and are well experienced with the design and construction of green buildings.

The additional costs associated with the implementation of the green building design as compared to the costs for a standard building are estimated at US$5 million and the potential energy savings are approximately 500 MWh/yr. The potential carbon footprint reduction associated with this design is 124 tons of CO_2 per year (0.9% of the net power plant footprint). The unit cost of carbon footprint reduction associated with green building design was estimated for project life of 30 years and 6.5% interest (capital recovery factor of 0.07657). At capital costs of US$5 million, the annualized cost of this capital investment is US$382,850/yr. Because of the higher level of complexity and automation of the "green building" design, as compared to conventional design, the additional O&M costs associated with the "green" systems of the building are US$34,650/yr. Therefore, the total annual costs associated with this design are estimated at US$417,500/yr. At 124 tons of CO_2 reduction per year, this annualized cost corresponds to unit carbon footprint reduction cost of US$3,400/ton CO_2 as shown in Table 2.

The total actual energy reduction that would result from green building design will be verified during plant commissioning, which will incorporate a LEED-compliance review process (i.e., by mid-2011). The LEED-review process will be completed by an independent third party consultant certified to complete such reviews.

On-site Solar Power Generation

One enhancement of the green building design is the installation of rooftop photovoltaic (PV) system for solar power generation (see Figure 4). The main desalination plant building would have a roof surface of approximately 50,000 square feet, which would be adequate to house a solar panel system that could generate approximately 777 MWh/yr of electricity and reduce the net carbon footprint of the desalination plant by 193 metric tons of CO_2 per year, which is approximately 1.4% of the net desalination plant carbon footprint of 13,700 tons of CO_2 per year.

The construction cost of the rooftop solar power system is estimated at US$4.1 million. The annualized capital cost of power generation using this alternative is US$313,937/yr (@ 30 years and 6.5%). In addition, the annual operation and maintenance costs for this system are estimated at US$52,763/yr. Therefore, the total annual costs for operation of this system are estimated at US$366,700/yr, which /yr which corresponds to unit cost of generated electricity of 47.2 cents/kWh (US$366,700/ yr /(777,000 KWh/yr = US$47.19/KWh). This unit cost is approximately five times higher than the cost of power supply from the electric grid. The unit cost of carbon footprint reduction for this alternative is US$1,900/ton of CO_2 as shown in Table 2.

Use of Carbon Dioxide for Water Production

Approximately 2,100 tons of CO_2 per year are planned to be used at the desalination plant for post-treatment of the fresh water (permeate) produced by the reverse osmosis (RO) system. Carbon dioxide in a gaseous form will be added to the RO permeate in combination with calcium hydroxide or calcium carbonate in order to form soluble calcium bicarbonate which adds hardness and alkalinity to the drinking water for distribution system corrosion protection. In this post-treatment process of RO permeate stabilization, gaseous carbon dioxide is sequestered into soluble form of calcium bicarbonate. Because the pH of the drinking water distributed for potable use is in a range of 8.3 to 8.5 at which CO_2 in a soluble bicarbonate form, the carbon dioxide introduced in the RO permeate would remain permanently sequestered in this form and ultimately would be consumed with the drinking water.

A small quantity of carbon dioxide used in the desalination plant post-treatment process is sequestered directly from the air when the pH of the source seawater is adjusted by addition of sulfuric acid in order to prevent RO membrane scaling. However, a large amount is typically delivered to the desalination plant site by commercial supplier. Depending on the supplier, carbon dioxide is of one of two origins: (1) a CO_2 Generating Plant or (2) a CO_2 Recovery Plant. CO_2 Generating Plants use various fossil fuels (natural gas, kerosene, diesel oil, etc.) to produce this gas by fuel combustion. CO_2 Recovery Plants produce carbon dioxide by recovering it from the waste streams of other industrial production facilities which emit CO_2-rich gasses: breweries, commercial alcohol (i.e., ethanol) plants; hydrogen and ammonia plants, etc. Typically, if these gases are not collected via CO_2 Recovery Plant and used in other facilities, such as the desalination plant, they are emitted to the atmosphere and therefore, constitute a GHG release.

The Carlsbad desalination plant is planned to use only carbon dioxide produced in a CO_2 Recovery Plant. This requirement will be enforced by requiring the commercial supplier of carbon dioxide for the desalination plant operations to provide a certificate of origin of each load of this water treatment chemical delivered to the plant site. This would encourage and incentivize the commercial suppliers and manufacturers of CO_2 to recover this gas from industrial waste streams rather than to generate new gas by combustion, and thereby to prevent its release to the atmosphere. Sequestration of CO_2 at the desalination plant by its conversion from gaseous to chemically bounded soluble form is therefore considered a desalination plant carbon footprint reduction alternative. By sequestering 2,100 tons of CO_2 per year in the desalination plant post-treatment process (see line 8 of Table 1), the net carbon footprint of the plant (13,700 tons of CO_2/yr would be reduced by 15.3%). At annual expenditure for carbon dioxide supply of approximately US$147,000/yr, this carbon footprint reduction alternative is very cost-competitive (US$70/ton CO_2) as shown in Table 2.

Carbon Emissions Offset by Reducing Energy Needs for Water Reclamation

The Carlsbad Municipal Water District owns and operates a 4 MGD water reclamation plant which consists of advanced tertiary treatment facilities for the entire flow and of 1 MGD brackish reverse osmosis water desalination system, which at present uses 1,950 MWh of electricity per year. The purpose of the brackish water desalination plant is to reduce the salinity of the treated effluent from 1,400 mg/L to below 1,000 mg/l in order to make the effluent suitable for irrigation. The current high level of salinity of the reclaimed water is mainly due to the relatively high salinity of the City's drinking water which could reach 1,000 mg/l at times.

Once the Carlsbad seawater desalination plant is in operation and completely replaces the existing high-salinity drinking water, the salinity of the City's reclaimed water is projected to be reduced by half. Therefore, the replacement of the existing City high-salinity imported water supply with desalinated water would eliminate the need for operation of the 1 MGD brackish water desalination plant at the Carlsbad Water Recycling Facility. This in turns would reduce the carbon footprint of the Carlsbad Water Reclamation Facility by 1,950 MWh x 546.46 lbs of CO_2 /MWh = 1,065,957 lbs of CO_2/yr (484 tons of CO_2/yr). Since this GHG reduction is directly credited to the seawater desalination plant operations, the Carlsbad desalination plant's carbon footprint could be reduced by 3.5%. The carbon footprint credit associated with reduced energy for water reclamation is presented in line 9 of Table 1.

Carbon Dioxide Sequestration by Re-vegetation in Wildfire Zones

Almost every year parts of San Diego County are exposed to measurable loss of forest, urban and suburban trees due to large wildfires. For example, in 2007 San Diego wildfires burned over 35,000 acres, including forests, tree farms, urban forestry. A specific annual carbon offset program required by the California Coastal Commission is the revegetation of areas in the San Diego region impacted by the wildfires that occurred during the fall of 2007. In response to this program Poseidon has committed to investing US$1.0 million in reforestation activities.

More specifically, when Poseidon updates Carlsbad desalination plant's net carbon footprint for the preceding year, it will calculate the cost of offsetting that year's net carbon emissions at a rate equal to the purchase of such carbon offsets through a Green-e type process. Poseidon will then pay the amount resulting from this calculation to either the San Diego County Air Pollution Control District or another entity identified by the California Coastal Commission as responsible for administering a San Diego area wildfire revegetation program. Poseidon will continue making its annual offset payments to the revegetation program until the cumulative total of such payments equals $1 million, at which time Poseidon may elect to direct annual offset payments to other projects, so long as those projects satisfy accepted standards for offsetting carbon emissions.

According to the Tree Guidelines for Coastal Southern California Communities issued by the USDA Forest Service (McPherson, et. al., 2000) the average annual costs for tree planting and care increase with mature tree size and for medium-size trees range between US$16 and 23 per tree (avg. US$19.5/tree). Average annual maintenance costs for trees are estimated at US$3 to US$5 (avg. US$4/tree). Updated for inflation, the year 2008 average tree planting cost is US$26.7/tree and the average annual maintenance cost is US$5.5/tree. Assuming tree maintenance costs for 25 years @ US$5.5/tree, the total lifecycle maintenance expenditure per tree is US$137.5. When added to the three planting cost of US$26.7, the total cost for planting and maintaining of the trees included in the reforestation project would be US$164.2/tree. At commitment of US$1.0 MM ($35,000/yr averaed over 30 years) and total costs of US$164.2/tree, the total amount of trees planned to be replanted is 6,090 (204 per year). At an annual tree sequestration rate of 60 lbs/tree over 25--year period of the desalination plant operations, the total annual carbon footprint reduction associated with the tree sequestration project is estimated at 365,400 lbs (166 metric tons) of CO_2 per year as shown in Line 11 of Table 1. This is approximately 1.2% reduction of the net desalination plant footprint. At annual expenditure for tree reforestation of approximately US$33,500/yr, the unit carbon footprint reduction cost for this alternative would be US$200/ton of CO_2 as shown in Table 2.

Carbon Dioxide Sequestration in Coastal Wetlands

As a part of the Carlsbad seawater desalination project, Poseidon Resources is planning to develop 37 acres of new coastal wetlands in San Diego County. These wetlands will be designed to create habitat for marine species similar to these found in the Agua Hedionda Lagoon (see Figure 1), from which source seawater is collected for the power plant and for desalination plant operations. Once the wetlands are fully developed, they will be maintained and monitored over the life of the desalination plant operations. The cost of the wetland restoration project is estimated at US$3.0 million.

In addition to the benefit of marine habitat restoration and enhancement, coastal wetlands also act as a "sink" of carbon dioxide. Tidal wetlands are very productive habitats that remove significant amounts of carbon from the atmosphere, a large portion of which is stored in the wetland soils. While freshwater wetlands also sequester CO_2, they are often a measurable source of methane emissions. For comparison, coastal wetlands and salt marshes release negligible amounts of greenhouse gases and therefore, their carbon sequestration capacity is not measurably reduced by methane production.

Based on a detailed study completed in a coastal lagoon in Southern California (Brevik & Homburg, 2004) the average annual rate of sequestration of carbon in coastal wetland soils is estimated at 0.03 kg of C/m^2.yr. Another source (Truilio, 2007) indicates that in addition to accumulating CO_2 in the soils, central and southern California tidal marshes could also sequester 0.45 kg of C/m^2.yr in the macrophytes growing in the marshes and 0.34 to 0.63 kg of C/m^2.yr in the algal biomass. Taking under consideration that the total area of the proposed wetland project is 37 acres (149,739 square meters) and the maximum sequestration capacity of the coastal wetlands could be 1.11 kg of C/m^2.yr, the wetland carbon sequestration capacity would be up to 83 tons of C/yr. With a conversion factor from carbon to carbon dioxide of 3.664 the estimated offset of the desalination plant carbon footprint by the wetland project is estimated at 304 tons of CO_2/year as shown in Line 12 of Table 3 (a 2.2% reduction of the net carbon footprint). At a total annual cost for wetland development and maintenance of approximately US$120,000/yr, the unit carbon footprint reduction cost for this alternative would be US$400/ton of CO_2) as shown in Table 2.

Site-specific research is planned to be completed in order to quantify the actual carbon sequestration capacity of the new wetland system proposed to be developed as a part of the Carlsbad seawater desalination project, once the wetland project is completed and is fully functional. Typically it takes three to five years for a coastal wetland project to be fully functional and to begin to yield enhanced habitat and GHG sequestration benefits.

Carbon Emission Offsets by Investing in Regional Renewable Energy Projects

Poseidon plans to invest in a number of green power projects with its public partners who will be receiving desalinated water from the Carlsbad seawater desalination Plant. Table 3 presents the various green power project opportunities and associated GHG offsets that would ultimately be applied against the carbon footprint of the Carlsbad seawater desalination project.

Based on the projects described in Table 2, the total carbon footprint offset for the desalination plant is projected at 2,260 MWh/yr or 561 tons of CO_2/year (4.1% of net carbon footprint). This credit is shown in Line 13 of Table 1.

Other Carbon Offset Projects and Renewable Credits

For the remainder of the Project's carbon emissions, Poseidon will purchase a combination of carbon offset projects and Renewable Energy Credits (RECs). Contracts for offset projects provide more price stability and are typically established for longer terms (10-20 years) then RECs (1-3 years).

About one-and-half-to-two years before operations begin, Poseidon will develop and issue a request for proposal (RFP) for carbon offset projects and renewable energy credits. Poseidon will then select the best mix from the responses and contract for their acquisition or development. The exact nature and cost of the offset projects and RECs will be known once the RFP process is complete. The offset purchases and REC's are estimated as 6,668 tons CO_2/year as shown in Line 14 of Table 1. Offsets or RECs would be used as the swing mitigation option to "true-up" annual changes to the project's net carbon footprint.

PROJECT ANNUAL NET-ZERO CARBON EMISSION BALANCE

Table 1 summarizes the total and net carbon footprint estimates of the Carlsbad seawater desalination project and quantifies GHG emission reduction and mitigation options which are planned to be implemented in order to reduce the plant net carbon emission footprint to zero. Analysis of data presented in Table 1 indicates that up to 40% of the GHG emissions associated with seawater desalination and drinking water delivery will be reduced by on-site reduction measures and the remainder will be mitigated by off-site mitigation projects and purchase of renewable energy credits. It should be noted that the contribution of on-site GHG reduction activities is expected to increase over the useful life (i.e., in the next 30 years) of the project because of the following key reasons:

- The power supplier (SDG&E) is planning to increase significantly the percentage of green power sources in its electricity supply portfolio, which in turn will reduce its Emission Factor and the net desalination plant carbon footprint.
- Advances in seawater desalination technology are expected to yield further energy savings and carbon footprint reductions. Over the last 20 years the use of power for production of one gallon of fresh water by seawater desalination has decreased by more than 50%. This trend is projected to continue in the future.

The mitigation costs of the various alternatives are summarized in Table 2. The lowest unit cost of carbon footprint reduction can be achieved by using carbon dioxide for post-treatment of the desalinated water (US$70/ton CO_2). The most costly carbon footprint reduction options are green building design (US$3,400/ton CO_2) and installation of rooftop solar power generation system (US$1,900/ton CO_2). Development of new coastal wetlands is a very promising carbon footprint reduction option (US$400/ton CO_2. Similarly, reforestation could also be a cost-competitive GHG reduction alternative (US$200/ton CO_2). As compared to green power generation alternatives (solar and wind power) reforestation and wetland mitigation have added environmental benefits. For example, the new coastal wetlands developed in relation to seawater desalination project could be designed to create habitat for species that are impacted by the intake operations of the desalination plant via impingement and entrainment of these species on the intake screens.

SUMMARY AND CONCLUSIONS

Greenhouse gas emissions associated with production of desalinated seawater at the Carlsbad seawater desalination project in Southern California are planned be mitigated by a portfolio of alternative technologies and measures: including use of carbon dioxide for water production, green building design, advanced energy recovery technology, green energy projects and carbon dioxide sequestration by reforestation and new coastal wetlands. The mix of GHG reduction alternatives will be prioritized and implemented under a Carbon Action Plan which defines a roadmap for carbon-neutral seawater desalination.

The total gross carbon footprint of conventional desalination plant design for this project is 68,100 tons of CO_2/yr. Approximately 69.6% of the total carbon footprint will be offset by reduction of water transfers from Northern California. Energy efficient design and use of advanced energy recovery technologies eliminate an additional 10.3% of the gross carbon footprint. The remaining net carbon footprint of 13,700 tons of CO_2/yr is planned to be offset by using warm water from the power plant with which the desalination plant is collocated (22.6% of net footprint); by sequestering CO_2 in the water production process (15.3% of net footprint); and by various off-site and on-site renewable energy generation projects (9% of the total footprint). In addition, the project will employ green building design, and carbon dioxide sequestration by reforestation and wetland development to offset another 4.3% of the net carbon footprint. The remaining 48.8% of the net footprint (9.9% of the gross footprint) of the project will be offset by purchasing renewable credits and investing in off-site renewable energy projects.

Estimates of the costs of CO_2 emission offsets indicate that use of warm cooling water is most cost effective because it does not require additional expense. Use of CO_2 for water production is also very cost effective at US$70/ton of reduced CO_2. Green building design and solar power generation were least cost effective at US$3,400/ton and US$1,900/ton, respectively.

ABOUT THE AUTHOR

Senior Vice President – Technical Services, Poseidon Resources Corporation
1055 Washington Boulevard, Stamford, CT 06901, tel. 203-327-7740, ext. 126
e-mail: nvoutchkov@poseidon1.com

REFERENCES

US EPA (2006). U.S. Climate Action Plan (available online at: www.state.gov/g/oes/rls/rpts/car/, accessed May 2008).

NRC (2001). *Climate Change Science: An Analysis of Some Key Questions*. Committee of the Science of Climate Change, National Research Council (NRC). (Available online at http://books.nap.edu/html/climatechange, accessed May 2008).

IPCC (2007) Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Parry, Martin L., Canziani, Osvaldo F., Palutikof, Jean P., van der Linden, Paul J., and Hanson, Clair E. (eds.)]. Cambridge University Press, Cambridge, United Kingdom, 1000 pp.

US EPA (2008) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006. (USEPA#430-R-08-005).

CEC (2005). California's Water-Energy Relationship, Final Staff Report, November 2005. (CEC-700-2005-011-SF).

CCAR(2008) Annual Emissions Report, San Diego Gas and Electric, 2006, California Climate Action Registry. (www.climateregistry.org/CARROT/Public/reports.aspx, accessed May 2008)

McPherson, G.E., K. I. Scott, J.R. Simpson, Q. Xiao, P.J. Peper (2000) Tree Guidelines for Coastal Southern California Communities, USDA Forest Service, Pacific Southwest Research Station (http://www.ufei.org/files/pubs/cufr_48.pdf accessed May 2008)

Brevik, E.C., J.A. Homburg (2004) A 5000 Year Record of Carbon Sequestration from a Coastal Lagoon and Wetland Complex, Southern California, USA, Catena, 57, pp.221-322.

Truilio, L. (2007) Notes on Carbon Sequestration and Tidal Salt Marsh Restoration (www.sfbayjv.org/tools/climate/CarbonWtlandsSummary_07_Trulio.pdf accessed May 2008)