EVALUATING AVOIDED CARBON EMISSION BENEFITS 
AT THE SANTA RITA JAIL

by

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May 2013

Masters project submitted in partial fulfillment of the requirements for the Master of Environmental Management degree in the Nicholas School of the Environment of Duke University

2013
Abstract

The Santa Rita Jail, located in the city of Dublin, California, is the 5th largest county jail in the country. The site encompasses approximately 45 ha and the main buildings cover a million square feet. It operates year-round and has stringent requirements for reliable power. To this end, the microgrid and distributed energy resources scientists and researchers at the Lawrence Berkeley National Laboratory have been involved in the Chevron Energy Services lead project to convert the various onsite distributed generation (DG) technologies at the Jail into a true microgrid. Currently, the Jail’s technologies include large-scale batteries, photovoltaics (PVs), fuel cells (FCs), and wind turbines. Several research papers and reports have already analyzed and described the performance, bill savings, and return on investment of the equipment individually or together as a microgrid. This document reports the results of the effort at quantifying the value of avoided carbon emissions by analyzing the PV and FC performance and energy data from 2007 to 2011. Using California’s recent cap and trade allowance auction settlement prices, estimates of the avoided value of carbon emissions from PV and FC during the 5-year period are presented and compared to the counter-factual emissions had the Jail purchased all of its electricity from the local utility. The estimated value of avoided emissions is between $116,000 and $177,000.
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Acknowledgements

The work described in this report was funded by the Office of Electricity Delivery and Energy Reliability’s Smart Grids Program in the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

I would like to thank my advisor Dr. Andrew Yates for proofreading my work and for his advice, and Dr. Chris Marnay and Dr. Michael Stadler for their guidance and support. I also want to acknowledge my current and past colleagues Johannes Thiemann, Nicholas DeForest, Carlos Dierckxsens, and Gonçalo Cardoso, for all their prior work ‘paving the road’ for me on the Santa Rita Jail dataset. Special thanks goes to Nicholas and Johannes for their always prompt replies to my panicked emails requesting help.

Thank you also to my family for their endless support, and last but not least, to Nate, you have made my last year of graduate school bearable.
Acronyms and abbreviations

CAISO California Independent System Operator
CARB California Air Resources Board
CIGRÉ International Council on Large Electric Systems
CPUC California Public Utilities Commission
DER distributed energy resources
DG distributed generation
DR demand response
EPA Environmental Protection Agency
FC fuel cell
GHG greenhouse gas(s), including carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), sulfur hexafluoride (SF6), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), nitrogen trifluoride (NF3), and other fluorinated greenhouse gases
GWP global warming potential
kWh kilowatt hour
MMTCO2E million metric tons of CO2 equivalent (abbreviation used by CARB)
MT CO2e metric tons of CO2 equivalent (from CARB)
MWh Megawatt hour
NREL National Renewable Energy Laboratory
PDP peak day pricing (an add-on to the TOU pricing structure)
PG&E Pacific Gas and Electric, the local utility
PV photovoltaic
RPS Renewable Portfolio Standard
SRJ Santa Rita Jail, or “the Jail”
T&D transmission and distribution
tCO2e metric tons of CO2 equivalent
TOU time-of-use (describes tariff structure)
U.S. DOE United States Department of Energy
WECC Western Electricity Coordinating Council
Introduction

The Santa Rita Jail (also referred to as SRJ or the Jail in this document), located in the city of Dublin, California, is the 5th largest county jail in the country. The site encompasses approximately 45 ha and the main buildings cover a million square feet. It has an inmate population of over 4,000 and operates year-round, so it has strong requirement for reliable power. To this end, the microgrid and distributed energy resources (DER) scientists and researchers at the Lawrence Berkeley National Laboratory (LBNL or Berkeley Lab) have been involved in the Chevron Energy Services lead project to convert the various onsite distributed generation (DG) technologies at the Jail into a true microgrid1. Currently, the Jail’s technologies include large-scale batteries, photovoltaics (PVs), fuel cells (FCs), and wind turbines.

Several research papers and reports have already analyzed and described the performance of the equipment individually or together as a microgrid see (Marnay, et al., 2012). This document reports the results of the effort at quantifying the avoided carbon emissions at the Jail by analyzing the PV and FC performance and energy data from 2007 to 2011. Using the recent cap and trade auction settlement prices, estimates of the PV and FC avoided emissions and carbon attributed to utility purchased electricity during the 5-year period will be presented and compared to the counter-factual emissions had the Jail purchased all of its electricity from the local utility.

This document is organized as follows:

• The discussion on carbon emissions section serves as an overview of the carbon market (cap and trade) in California and the need for greenhouse gas (GHG) accounting.

• The building and installed equipment section describes the energy characteristics of the Jail and its installed DER equipment.

• The methods section describes the dataset, the data calculations, and the caveats regarding the dataset. This section will also describe the jail’s tariff.

• The results section presents the results of the analysis.

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1 A microgrid as defined by the International Council on Large Electric Systems (CIGRÉ) Working Group 6.22: Microgrids Evolution Roadmap, “Microgrids are electricity distribution systems containing loads and distributed energy resources, (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, coordinated way either while connected to the main power network or while islanded” (CIGRÉ, 2012). The definition used by U.S. DOE is “A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that act as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode” (Smith, 2012).
Discussion on emissions and cap and trade in California

Background on California’s Assembly Bill 32 (AB 32), the Global Warming Solutions Act of 2006, and the cap and trade program are covered in this section as a way of introducing the potential of greenhouse gas accounting at the Jail, despite its relatively low emissions rate.

The genesis of cap and trade in California

Assembly Bill 32 (AB 32), the Global Warming Solutions Act of 2006, requires that California lower its greenhouse gas (GHG) emissions down to 427 million metric tons of carbon dioxide equivalent (mtCO$_2$e) by 2020, which is equivalent to its 1990 GHG emissions. In order to achieve this goal, the AB 32 Scoping Plan was prepared by the California Air Resources Board (CARB) that outlined the carbon reduction strategies to be implemented. These include increasing California’s renewable electricity generation, implementing more stringent building standards and energy efficiency programs, establishing transportation related emission standards, and last but not least, creating a cap and trade program for carbon emissions (California Air Resources Board, 2008). The cap and trade program requires that entities emitting over 25,000 tCO$_2$e per year be registered in the program and comply with mandatory reporting requirements. Non-covered entities, i.e., those in covered sectors but emitting less than 25,000 tCO$_2$e, or in sectors not covered, may voluntarily participate and obtain allowances that may be “banked” for future use, traded, used to comply with cap and trade regulation, or given back to CARB for retirement (California Air Resources Board, 2010). Figure 1 below shows the projected emissions with and without the cap, the cap and trade program timeline, and the participants for Phase 1 and 2. As of 2013, approximately 350 businesses representing 600 to 800 entities are covered by cap and trade, and 45 opt-in entities (California Air Resources Board, 2013b).

The 25,000 mtCO$_2$e cutoff for covered entities

The 25,000 mtCO$_2$e emission threshold was selected for practical reasons. According to the US EPA’s Final Rule on Mandatory Reporting of Greenhouse Gases (US EPA, 2009), several GHG reporting thresholds on the national level were evaluated: 1,000 mtCO$_2$e, 10,000 mtCO$_2$e, 25,000 mtCO$_2$e, and 100,000 mtCO$_2$e. The 25,000 threshold was found to be the most suitable and pragmatic because it captures approximately 85% of national emissions. If 1,000 mtCO$_2$e were used, the number of entities

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2 Much of what is written in this section was previously submitted by the author for another course while at the the Nicholas School and also used in a report to the California Energy Commissions (Stadler, Groissböck, Cardoso, Müller, & Lai, 2013). The paper is attached in the appendix.

3 Covered greenhouse gases: carbon dioxide (CO$_2$), methane (CH$_4$), nitrous oxide (N$_2$O), sulfur hexafluoride (SF$_6$), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), nitrogen trifluoride (NF$_3$), and other fluorinated greenhouse gases (California Air Resources Board, 2011b).
reporting would grow by an order of magnitude while capturing less than 10% of the national emissions. If 10,000 mtCO2e were used, the number of reporting entities would double and capture only one more percent of national emissions. If 100,000 mtCO2e were used, certain key sectors of the economy would be excluded altogether.

Recognizing the lack of benefits from decreasing or increasing the threshold and to align with the US EPA’s national GHG reporting requirements, the Cal/EPA and CARB have set the mandatory emissions reporting as well as cap and trade enrollment threshold for California to 25,000 mtCO2e. Since the Jail contributes negligible amounts of GHG emissions via direct emissions, it would only be participating in cap and trade as an opt-in participant.

![Cap and trade program timeline and participants](image)

**Figure 1. Cap and trade program timeline and participants (cite myself)**

**Which sectors are the big emitters?**

According to CARB’s *California Greenhouse Gas Inventory for 2000-2009—by Category as Defined in the Scoping Plan*, as of 2009, the state of California emitted 456.77 million tCO2e per year, with transportation being the top emitter at 172.92 million tCo2e (37.9%), and electricity generation with 103.58 million tCO2e (22.7%) and industrial with 81.36 million tCO2e (17.8%), see Figure 2 (California Air Resources Board, 2011a). Note that the values reported account for direct emissions (defined in next section) only. This means that the majority contribution from the commercial and residential sectors, 42.92 million tCO2e (9.4%), is based on primary fuels (natural gas, coal, etc) that are combusted onsite, and the remainder from small commercial cogeneration and other fuels.

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4 While a Jail may appear to fall under the commercial and residential category, it is actually considered an industrial facility, and its utilities are billed at an industrial tariff rate.
Figure 2. Million tons of CO2e emitted in California for 2009. Graphic generated based on (California Air Resources Board, 2011a).

Direct, indirect, and other indirect emissions

According to the WRI/WBCSD GHG Protocol Corporate Standard, Revised Edition and the Climate Registry, GHG emissions are generally accounted for in three bins, or “scopes”: (1) direct emissions (excluding biogenic sources), (2) indirect emissions (those associated with the use of purchased electricity, steam, heating, and cooling), and (3) other indirect, e.g., employee commuting, outsourced activities, etc (WBCSD, 2004). Most of the Jail emissions are indirect, i.e., scope 2, those associated with utility purchases and not covered by the cap and trade program. The cut-off for being a covered entity for cap and trade in California is 25,000 metric tons of CO2 per year of direction emissions. Thus, excluding the indirect emissions generated by PG&E, any participation would have to be judged against the emissions from the Jail’s burning of natural gas.
Jail description

**Jail building (physical)**
The Jail opened in 1989 and is recognized as one of the most technologically advanced jails in the world (Alameda County Sheriff's Office, 2013). An aerial of the Santa Rita Jail is shown in the photo below. The 4,000 inmates are housed in the 18 chevron-shaped 2-story tall “pods” that surround the two central courtyards. The pods with PVs mounted appear to have black/gray roof tops.

![Aerial of the Santa Rita Jail](google maps)

**Jail energy and profile summary + tariffs**
The Jail is located within the Pacific Gas and Electric (PG&E) utility territory and serviced under its E-20 tariff (tariff for customers with maximum demand of 1 MW or more). The rate has a time-of-use (TOU) component and both a coincident maximum demand charge and a facility (non-coincident) demand charge. The tariffs, excluding fees and surcharges, for 2007 through 2011 are shown in Figure 4 below and Table 5 in appendix. Note that beginning in May 2010, PG&E’s Peak Day Pricing (PDP)\(^{5}\) structure came into effect for large commercial and industrial customers (PG&E, 2013a). The Jail opted-out of the program and remains to this day on E-20 with the TOU component only.

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\(^{5}\) Peak Day Pricing is a relatively new pricing plan that makes up a component of commercial/industrial and agricultural customer’s TOU tariffs. Peak days may be called between 9 and 15 times a year and the cost of energy for the peak hours of 2 pm to 6 pm (or optionally, 12 pm to 6 pm for small commercial) increases. In exchange for participation in the program, participants pay a lower energy rate ($/kWh) between May and October. High temperatures (98+), CAISO emergencies, and high market prices are all potential triggers for PDP being called, as well as for system testing purposes (PG&E, 2013a). For full details of program, please visit [http://www.pge.com/pdp](http://www.pge.com/pdp).
The Jail’s average electricity demand for the 5-year span was 1.6 MW, and a peak demand of about 4 MW. It is also Alameda county’s largest facility and largest utility liability, accounting for 30% of its utility budget (Ritchie, 2012).

**installed equipment and descriptions**

The analysis considers the contributions of the following DER installed onsite at the Jail (Alameda County Sheriff's Office, 2013; Nuniz, 2012; Thiemann, 2013):

- 1.2 MW of rooftop PV, installed in 2002. For detailed specs, refer to Table 7 in appendix. The cost of the PVs was approximately $9,000,000.
- 1 MW molten carbonate fuel cell with heat recovery (for facility hot water and space heating), installed in 2006. The cost of the FCs was approximately $3,500,000.

The DER listed below are not considered as they were installed after the time frame (2009 to 2011) covered by this analysis:

- 2 MW-4MWh Lithium Iron Phosphate battery, installed in 2011
- five 2.3 kW wind turbines, installed in 2012
- 275 kW of tracking PV, installed in 2012

Note that the 2.4 MW of emergency backup diesel generation is also not considered as there is no metered generator data available. Figure 5 shows the layout and locations of the installed DER equipment.

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6 The PVs were installed at the same time as the Jail’s chiller replacement and other minor upgrades and insufficient information was provided for separating the costs. The total for all improvements made at the time was nine million and is the number used here, but obviously an overestimate of the actual PV-only costs.
Methods
This section describes the data, their origins, assumptions, shortcomings and defects, and what data cleaning and analyses were performed on them.

Data sources

Metered data and utility bills from the Jail
Raw equipment performance data and total utility purchase information for between 2007 and 2011 have been supplied by the Jail. The data are metered at 15-minute intervals in units of power generated (kW) for PVs and FC and in units of demand (kW) for PG&E purchases. For 2007 through 2010, no utility billing cycles coincided with actual calendar months; for 2011, no billing cycle data was supplied by SRJ.

data cleaning and calibration
Much of the data had been cleaned and sanity checked as part of another project and master’s thesis which examined the Jail’s potential for demand response (DR) participation, (Thiemann, 2013). The work performed by Thiemann are shown in Figure 17 in Appendix.
As a result of prior work by others, minimal data cleaning was necessary for this project. The work included:

Figure 5. Layout of equipment at the Santa Rita Jail, modified from (Smith, 2012).
• converting 15-minute readings (approximately 131,400 data points per year per equipment) to hourly and daily readings (8760 and 365 data points per year per equipment).
• setting negative FC meter readings (negative power generation) to zero (no output). Negative readings are possibly due to meter malfunction.

Figure 6 through Figure 10 show the energy profile of the Jail for years 2007 through 2011. All values are in energy units (kWh), and the “savings” (avoided utility purchases) are the sum of the area of the PVs and FCs.

![Energy Profile Chart](image)

**Figure 6.** Jail PV, FC, and utility purchase profile for 2007
Figure 7. Jail PV, FC, and utility purchase profile for 2008

Figure 8. Jail PV, FC, and utility purchase profile for 2009
Figure 9. Jail PV, FC, and utility purchase profile for 2010

Figure 10. Jail PV, FC, and utility purchase profile for 2011

Yearly utility bills
Table 1 shows the annual utility bill at the SRJ. Of note is the trade off between natural gas and electricity purchases. In 2011, when the FC was minimally operational, more electricity and natural gas had to be purchased to meet the Jail’s needs.
### Table 1. The Jail’s utility costs

<table>
<thead>
<tr>
<th>Year</th>
<th>Electricity purchased ($)</th>
<th>Natural gas for FC ($, rounded)</th>
<th>Natural gas for all others ($, rounded)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>$981,000</td>
<td>$422,000</td>
<td>$474,000</td>
</tr>
<tr>
<td>2008</td>
<td>$1,121,000</td>
<td>$466,000</td>
<td>$514,000</td>
</tr>
<tr>
<td>2009</td>
<td>$998,000</td>
<td>$406,000</td>
<td>$403,000</td>
</tr>
<tr>
<td>2010</td>
<td>$1,127,000</td>
<td>$317,000</td>
<td>$420,000</td>
</tr>
<tr>
<td>2011</td>
<td>$1,366,000</td>
<td>$130,000</td>
<td>$459,000</td>
</tr>
</tbody>
</table>

### GHG emission factors comparisons: marginal vs average, and CO2 vs CO2e

Greenhouse gas emission factor (also referred to as emission rate or emissions coefficient) is the amount of emissions associated with converting a fuel into electricity, generally given in terms of lb/MWh or metric tons/MWh (Bruso, 2011). Coal and natural gas have different CO2 emissions factors and renewable sources such as wind, solar, nuclear, are considered to have emission factors of zero. Marginal emission factor represents the emission factor of the last generation resource to be dispatched to meet demand, which can vary depending on time of day and season. Average emission factor is the total amount of energy generated divided by total emissions.

Emissions can be expressed in terms of CO2 or CO2e. Figure 11 shows a schematic of the difference between CO2 and CO2e (UNEP, 2010). Emission factors for CH4 and N2O vary not only based on fuel combusted but also on the plant size, efficiency, vintage, and maintenance and operation practices. The CH4 and N2O emission factors are then multiplied by the CH4 or N2O Global Warming Potential (GWP) values to arrive at their respective CO2e values. Accounting in terms of CO2e, while more complete, is not always possible due to the lack of information on CH4 and N2O emission factors.

![Figure 11. CO2e calculation example, graphic copied and modified from (UNEP, 2010)](image)

Several emission factors for electricity generation were compared as part of the analysis and summarized in Table 2 below. Not surprisingly, average factors tend to decrease over time to account for overall improvements in generation efficiency, the marginal factors⁷ are more resistant to change over time.

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⁷ The last generators to be dispatched, those on the margin and most expensive in terms of energy generated per dollar, tend to stay consistent. According to (Mahone, Price, & Morrow, 2009), natural gas power plants are most often the marginal generators, though it is possible that coal or hydro will be dispatched last for a few hours a year.
Based on a nation-wide study of marginal and average emission factors for the year 2007, the emission factors in the area covered by the Western Electricity Coordinating Council (WECC) were determined to be 0.464 metric tons of CO2/MWh for marginal emission and 0.462 metric tons of CO2/MWh for average (Siler-Evans, Azevedo, & Morgan, 2012). The same study reports the average marginal emissions factor for 2006 through 2011 as 0.486 metric tons of CO2/MWh.

Emission factors from eGrid based on WECC “subregions” were also reported. In this case, the CAMX subregion emission factors were 0.309 and 0.299 metric tons of CO2/MWh for 2007 and 2009, respectively. Emission factors of 0.310 and 0.300 for 2007 and 2009 in units of metric tons of CO2e were also reported by eGrid (US EPA, 2011, 2012a).

Another study performed by NREL/openEI disaggregated the average emissions in the CAMX subregion down to monthly hourly values, i.e., each of the 24 hours of a month has a different emissions factor, and a year has 24 hours * 12 months = 288 emissions values (OpenEI, 2011). The advantage of hourly disaggregation is that the temporal effects of marginal generation may be observed, and for this work, the benefits of the PV and FC can be better estimated.

PG&E estimates of its own average emission factors and the range is between 0.254 and 0.291 metric tons of CO2/MWh (Bruso, 2011).

Yet another source of estimates was from Energy and Environmental Economics, Inc (E3), a consulting company that has reported extensively on GHG emissions to CARB and the CEC. E3 derived estimates for marginal and average emissions for CAMX as part of its work in developing a GHG tool for buildings in California, as well as a building-specific marginal emissions factor for 2008 (Mahone, et al., 2009). The results that are based on eGrid are fundamentally different than those calculated by Mahone, et al.

Average emission values from eGrid are actual metered or reported emissions data associated with generating facilities in the areas specified. In simple terms, emissions in CAMX is summed up and divided by the amount of energy generated, and this ignores the effects of imported electricity. The values from Mahone, et al. are the simulated results from PLEXOS®, an advanced Mixed Integer Programming (MIP) simulation and optimization software (PLEXOS, 2012). A dispatch of every power plant in WECC is simulated and the emissions of each plant that generates in California or imports into California is summed up and divided by the energy generated. This latter method tends to result in higher estimates of average emissions since imports on average emit at a higher rate compared to California-based generators.

Marginal emission values are not directly available from eGrid because the operations data from all plants do not show the dispatch order or which plant operates on the margin. However, a “non-baseload output emissions rate” is calculated and described as “a slice of the system total mix, with a greater weight given to plants that operate coincident with peak demand for electricity” (Rothschild & Diem, 2009). The
capacity factor of the plant is used to determine whether it operates coincident with peak demand; those with low capacity factors (c.f. ≤ 0.2) are assumed to be non-baseload (Diem, 2009; Diem & Quiroz, 2012; Rothschild & Diem, 2009). While the non-baseload output emission rates are not referred to as marginal emissions rate in eGrid, their use and applicability is similar, i.e., both are appropriate for estimations of reduced emissions from energy efficiency and renewable energy projects. As reference, maps showing the WECC, CAMX, and PG&E territory are shown in Figure 18 in Appendix.

Table 2. Comparison of GHG emissions factors in units of average, marginal, or non-baseload CO2 or CO2e

<table>
<thead>
<tr>
<th>Area: data source (source)</th>
<th>units (metric tons of ? / MWh)</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAMX: eGrid (US EPA, 2011, 2012a)</td>
<td>CO2 (avg)</td>
<td>0.309</td>
<td>0.299</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CO2e (avg)</td>
<td>0.310</td>
<td>0.300</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAMX: eGrid (Diem &amp; Quiroz, 2012; US EPA, 2011)</td>
<td>CO2 (“non-baseload”)</td>
<td>0.474</td>
<td>0.451</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAMX: Plexos® (Mahone, et al., 2009)</td>
<td>CO2 (avg)</td>
<td></td>
<td></td>
<td>0.244</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CO2 (marginal)</td>
<td></td>
<td></td>
<td>0.490</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WECC: eGrid (Siler-Evans, et al., 2012)</td>
<td>CO2 (avg)</td>
<td>0.462</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CO2 (marginal)</td>
<td>0.464</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CO2 (marginal, avg of 2006-2011)</td>
<td>0.486</td>
<td>0.486</td>
<td>0.486</td>
<td>0.486</td>
<td>0.486</td>
</tr>
<tr>
<td>WECC: eGrid (hr avg, OpenEI 2011)</td>
<td>CO2 (avg)</td>
<td></td>
<td></td>
<td>0.369</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WECC: eGrid (peak hr.ly avg, OpenEI)</td>
<td>CO2 (avg)</td>
<td></td>
<td></td>
<td>0.345</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PG&amp;E area: PG&amp;E (Bruso, 2011)</td>
<td>CO2 (avg)</td>
<td>0.288</td>
<td>0.291</td>
<td>0.261</td>
<td>0.254</td>
<td>0.254</td>
</tr>
<tr>
<td>CA bldgs: Plexos® (Mahone, et al., 2009)</td>
<td>CO2 (marginal)</td>
<td>0.535</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: “non-baseload” assumed to be equivalent to marginal.

Figure 12 graphically shows the various emission factors. The emission factor for natural gas is inserted for comparison purposes.

![Comparison of Emission Factors](image)

Figure 12. Comparison of emission factors, non-baseload grouped with marginal (note y-axis starts at 0.2).
To summarize, the marginal emissions range is 0.451 to 0.535, and the average emissions range is 0.244 to 0.369. Assuming the “real” emissions factor is somewhere within this range, the minimum of 0.244 and maximum of 0.535 have been used in the calculations to derive the range for potential benefits.

**Determining “avoided grid generation”**

For every unit of energy the Jail generates energy onsite, it displaces the same amount in utility purchases and an even greater amount of generation at the power plant. This avoided grid generation takes into account the losses in transmission and distribution (T&D). *The Greenhouse Gas Protocol: Guidelines for Quantifying GHG Reductions from Grid-Connected Electricity Projects* by WRI outlines the following formula for determining avoided grid generation (Broekhoff, 2007):

\[
GEN_{proj,t} = \frac{S_t}{(1-L)}
\]

Where:

- \(GEN_{proj,t}\) = over time period, \(t\), total grid generation avoided for project \(proj\);
- \(S_t\) = over time period, \(t\), total electricity savings; and
- \(L\) = average T&D loss in territory reported as a fraction.

\(S_t\) is calculated from the time series metered data. \(L\) varies by time period (on peak, mid peak, or off peak, season, and year) and distance from generation. For simplicity, a loss factor of 1.109 (loss rate of 9.83%) loss is assumed for this analysis (Wong, 2011).^8^  

**Natural gas emission factor**

Unlike electricity generation, there is little variation in natural gas emission factor since it is the actual fuel being combusted for electricity (or heat) generation. An emission factor of 0.508 metric tons per MWh is used for analysis based on the estimate from (US EIA, 2013).

**Avoided NG purchases**

The yearly avoided natural gas purchases is calculated as follows:

\[
NG_{avoided} = (FCNG_{purchased} \times 0.60) - (FC_{energy\_generated} / 0.0293)
\]

---

^8^ Depending on the type of analysis, different loss factors may be more appropriate. According to table ES-1 of (Wong, 2011) and accompanying text, 1.109 can be used as the factor for avoided cost calculations for DER/DR. Since the savings from PV will occur mostly on peak, the 1.109 factor corresponding to a loss rate of 9.83% for the PG&E territory is deemed more appropriate in this analysis than, for example, the 7.8% loss used by CARB for its in-state California-wide emissions reduction calculations.
where:

\[ NG_{avoided} = \text{avoided NG purchases, in therms}; \]

\[ FCNG_{purchased} = \text{NG purchased for FC, in therms}; \]

\[ 0.60 = \text{total efficiency of FC}; \]

\[ FC_{energy\ generated} = \text{electricity generated by FC, in MWh}; \] and

\[ 0.0293 = \text{therm to MWh conversion factor} \]

**The cost of PV and FC**

The PVs (and other efficiency improvements that were put in place at the same time) were approximately $9,000,000 in 2002. Assuming a 20 year life and 3% rate, the PVs cost approximately $587k per year. The fuel cell cost $3,500,000 in 2006. Assuming a 15 year life and 3% rate, the FCs cost approximately $421k per year. Together at $1,008k per year, these costs are to be compared to the value of avoided generation for electricity and avoided purchases for natural gas, avoided carbon emissions, and the cost of carbon under the cap and trade program.

**The cost of carbon**

The first two cap and trade auctions in California took place in November 2012 and February 2013. The settlement prices for 2013 allowances, $10.09 and $13.63 from the two auctions are used as proxy for the value of carbon for this analysis. The auction and settlement results are in Table 3. The percentage not purchased by covered entities is the percentage purchased by opt-in entities. The Jail would be considered an opt-in if it were to participate in cap and trade.

**Table 3. Results of the first two cap and trade allowance auctions (California Air Resources Board, 2012, 2013a)**

<table>
<thead>
<tr>
<th></th>
<th>2012-Nov auction</th>
<th>2013-Feb auction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2013 allowances</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>reserve</td>
<td>$10.00</td>
<td>$10.71</td>
</tr>
<tr>
<td>settlement price</td>
<td>$10.09</td>
<td>$13.62</td>
</tr>
<tr>
<td>allowances available (millions)</td>
<td>23.1</td>
<td>12.9</td>
</tr>
<tr>
<td>% sold</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>% purchased by covered entities</td>
<td>94%</td>
<td>88.15%</td>
</tr>
<tr>
<td><strong>2015 allowances</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>reserve</td>
<td>$10.00</td>
<td></td>
</tr>
<tr>
<td>settlement price</td>
<td>$10.00</td>
<td></td>
</tr>
<tr>
<td>allowances available (millions)</td>
<td>39.5</td>
<td></td>
</tr>
<tr>
<td>% sold</td>
<td>14%</td>
<td></td>
</tr>
<tr>
<td>% purchased by covered entities</td>
<td>91%</td>
<td></td>
</tr>
<tr>
<td><strong>2016 allowances</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>reserve</td>
<td></td>
<td>$10.71</td>
</tr>
<tr>
<td>settlement price</td>
<td></td>
<td>$10.71</td>
</tr>
<tr>
<td>allowances available (millions)</td>
<td>9.6</td>
<td></td>
</tr>
<tr>
<td>% sold</td>
<td>46%</td>
<td></td>
</tr>
<tr>
<td>% purchased by covered entities</td>
<td></td>
<td>100%</td>
</tr>
</tbody>
</table>
Data and analysis limitations

Equipment not performing at rated power and meter malfunctions
The performance of the PVs and FCs vary throughout the 5-year time frame. The 1.2 MW PVs have historically output at a max rate of 600 kW, about half of rated, and the 1 MW FCs has had long stretches of down time. In addition, the metering equipment at the jail has been at times unreliable. For example, for more than half a year in 2011, the readings for FCs were unavailable. Thus, it is unclear if the FCs were operating at the time and how much they were generating. The analysis looks at the avoided purchases based on metered performance and data at hand, inclusive of the under-performance and meter malfunctions. No attempts were made to reconcile or fix these types of data deficiencies.

Weather and temperature variability
The peaks in demand may be caused by extreme weather or temperatures. Unless otherwise noted, the analysis assumes the weather for these five years are typical and the savings are typical as well.

Existing Load shifting or shedding and demand response behaviors
The analysis assumes that the Jail’s utility purchases take into account PG&E’s high demand charge during summer peak hours, lowest in 2008 at $10.51/kW and highest in 2009 at $12.62/kW. In other words, the Jail may be purchasing less energy during certain hours due to load shifting or load shedding as well as due to onsite generation, but the analysis cannot account for these savings.

Emissions from natural gas consumption
The avoided emissions calculations are based on electricity only. The natural gas purchases and associated emissions are not considered.

Efficiency measures installed between 2007 and 2011
The Jail introduced several energy efficiency measures during the years of the analysis. These included retrofitting of toilets, showers, and values, and also retrofits of both indoor and outdoor lighting (cite matt’s cheat sheet). The savings (both $ and carbon avoided) of these efficiency measures are aggregated in with the energy savings from the installation of the DG equipment and cannot be easily separated.

Billing cycles not aligned with calendar months
The utility billing cycles are not aligned with the calendar months, and the number of billing days vary between 15 and 40 days per bill. No efforts were made to shift the dates of the billing cycles to match calendar months. All calculations of avoided savings are based on calendar months or on annual basis.
Results and conclusions

Avoided electricity generation and avoided natural gas purchase

Figure 13 compares the yearly avoided generation results of installed PV and FC at the Jail with the purchases. Both the avoided and purchased natural gas values have been converted from therms to GWh to facilitate comparison and presentation on the same graphic with electricity. The avoided generation for electricity is the onsite PV generated values multiplied by the 1.109 T&D loss factor, and for natural gas is the avoided purchases for domestic hot water due to FC waste heat utilization. Years 2007 and 2008 are similar; the avoided values are approximately 16% of the total yearly energy requirements. The best performing year, 2010, saw 5.975 GWh avoided, which was enough to offset close to 19% of total energy requirements. The second best year, 2009, had 5.891 GWh avoided, which offset over 20% of total energy requirements (the total requirements were lower in 2009). The worst year, 2011, was caused by the fuel cells’ subpar performance; avoided generation was around 11% of total energy requirements.

Figure 13. Avoided generation at the Jail
**Avoided carbon emissions**

Using the avoided generation values from the previous section, annual low and high estimates for avoided carbon emissions were calculated using emission factors of 0.244 (lowest of the average emission factors) and 0.535 (highest of the marginal emission factors) metric tons of CO2/MWh for electricity and 0.508 metric tons of CO2/MWh for natural gas, see Figure 14. Note that since there is only one emission factor estimate for natural gas, the low and high estimates are the same. Not surprisingly, the years with higher avoided generation also have higher avoided emissions, and vice versa.

![Avoided carbon emissions](chart.png)

**Figure 14. Avoided carbon emissions at the Jail**

**Estimates for value avoided carbon emissions**

Estimates for the value of avoided carbon emissions were calculated by multiplying the low and high (0.244 and 0.535) emission estimates from the previous section with the low and high ($10.09 and $13.62) cap and trade settlement prices, see Table 4. The lowest estimate of the value of avoided carbon emissions is the product of the lower emissions rate and the lower carbon price, shown in column e, and the highest estimate is the product of the higher emissions rate and the higher carbon price, shown in column h.
Table 4. Estimated values of avoided carbon based on low and high cap and trade settlement prices

<table>
<thead>
<tr>
<th>Cost of PV+FC</th>
<th>avoided emissions (metric tons CO2/MWh)</th>
<th>value of avoided emissions ($, rounded to thousand)</th>
</tr>
</thead>
<tbody>
<tr>
<td>($, rounded)</td>
<td>low (0.244)</td>
<td>high (0.535)</td>
</tr>
<tr>
<td></td>
<td>low (0.244)</td>
<td>high (0.535)</td>
</tr>
<tr>
<td></td>
<td>low (0.244)</td>
<td>high (0.535)</td>
</tr>
<tr>
<td>2007 $1,008,000</td>
<td>2,099</td>
<td>4,322</td>
</tr>
<tr>
<td></td>
<td>$21,000</td>
<td>$25,000</td>
</tr>
<tr>
<td></td>
<td>$29,000</td>
<td>$33,000</td>
</tr>
<tr>
<td>2008 $1,008,000</td>
<td>2,272</td>
<td>2,605</td>
</tr>
<tr>
<td></td>
<td>$23,000</td>
<td>$26,000</td>
</tr>
<tr>
<td></td>
<td>$31,000</td>
<td>$35,000</td>
</tr>
<tr>
<td>2009 $1,008,000</td>
<td>2,704</td>
<td>3,022</td>
</tr>
<tr>
<td></td>
<td>$27,000</td>
<td>$30,000</td>
</tr>
<tr>
<td></td>
<td>$37,000</td>
<td>$41,000</td>
</tr>
<tr>
<td>2010 $1,008,000</td>
<td>2,783</td>
<td>3,061</td>
</tr>
<tr>
<td></td>
<td>$28,000</td>
<td>$31,000</td>
</tr>
<tr>
<td></td>
<td>$38,000</td>
<td>$42,000</td>
</tr>
<tr>
<td>2011 $1,008,000</td>
<td>1,596</td>
<td>1,908</td>
</tr>
<tr>
<td></td>
<td>$16,000</td>
<td>$19,000</td>
</tr>
<tr>
<td></td>
<td>$22,000</td>
<td>$26,000</td>
</tr>
<tr>
<td>Total $5,040,000</td>
<td>11,453</td>
<td>13,028</td>
</tr>
<tr>
<td></td>
<td>$116,000</td>
<td>$131,000</td>
</tr>
<tr>
<td></td>
<td>$156,000</td>
<td>$177,000</td>
</tr>
</tbody>
</table>

Note: the low and high emission rates apply for electricity avoided (PV) and that a 0.508 emission factor, not shown, applies to natural gas (FC).

**Conclusion: participation in cap and trade unlikely**

While the Jail is not a covered entity under the California cap and trade program, it can elect to be an opt-in participant. However, its low annual emissions rate translates to rather insignificant earnings relative to its utility costs (Table 1), and so participation in the program would be unrealistic.
Appendices

Prior paper on cap and trade

Summary of the cap and trade program
in California

ENV 535: Air Quality Management
2012 November 19, 2012

Judy Lai
Introduction: the genesis of cap and trade in California

Assembly Bill 32 (AB 32), the Global Warming Solutions Act of 2006, requires that California lower its greenhouse gas (GHG) emissions down to 1990 levels by 2020, which is equivalent to its 1990 GHG emissions. In order to achieve this goal, the AB 32 Scoping Plan was prepared by the California Air Resources Board (CARB) that outlined the carbon reduction strategies to be implemented. Those include increasing California’s renewable electricity generation, implementing more stringent building standards and energy efficiency programs, establishing transportation related emission standards, and last but not least, creating a cap and trade program for carbon emissions (CARB 2008a). As the administrator of California’s greenhouse gas reduction (GHG) and climate change programs, CARB has distributed the emission allowances and allowed first carbon offsets auction to take place. This paper summarizes the cap and trade program and the results of the first auction.

---

The fundamentals of the cap and trade program

Who is covered?

The program covers sources (referred to as covered entity, participant, or facility in later sections of this paper) that are responsible for approximately 85% of the emissions in California (CARB 2010a). Mandatory GHG reporting requirements, emissions regulations, as well as penalties for non-compliance have been adopted and are overseen by CARB (CARB 2007). There are two phases to the program: Phase 1 began in 2012, and covered entities for both Phase 1 and 2 must register for the program by end of January 2012 (CARB 2012a). The first compliance period starts in 2013 and includes electricity generation/importer and large industrial emitters that exceeded 25,000 metric tons yearly from 2008 to 2012 (CARB 2012a). Phase 2 will begin in 2015 and, in addition to the existing participants of Phase 1, include fuel distributors under 25,000 metric tons. The overall cap will also be increased to accommodate the new entrants (CARB 2010b, EPA 2009, CARB 2011a, CARB 2012a).

In all, enrollment in the cap and trade program is mandatory for approximately 350 businesses representing 600 to 800 facilities. Non-covered entities (those in covered sectors but emitting less than 25,000 metric tons, in sectors not covered) may voluntarily participate and obtain allowances that may be “banked” for future use, traded, used to comply with cap and trade regulation, or given back to CARB for retirement (CARB 2010b).

---

*Covered greenhouse gases: carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), sulfur hexafluoride (SF₆), hydrofluorocarbons (HFCs), perfluorocarbons (PFCS), nitrogen trifluoride (NF₃), and other fluorinated greenhouse gases. (CARB 2010b)*

---

*1 A compliance period is defined as “the length of time for which covered entities must submit compliance instruments equal to their verified emissions.” (CARB 2010b)*
Why are they covered?

The 25,000 mtcO2e emission threshold was selected for practical reasons. According to the US EPA’s Final Rule on Mandatory Reporting of Greenhouse Gases (EPA 2009), several GHG reporting thresholds on the national level were evaluated: 1,000 mtcO2e, 10,000 mtcO2e, 25,000 mtcO2e, and 100,000 mtcO2e. The 25,000 threshold was found to be the most suitable and pragmatic because it captures approximately 85% of national emissions. If 1,000 mtcO2e were used, the number of entities reporting would grow by an order of magnitude while capturing less than 10% of the national emissions. If 10,000 mtcO2e were used, the number of reporting entities would double and capture only one percent of national emissions. If 100,000 mtcO2e were used, certain key sectors of the economy would be excluded all together.

Recognizing the lack of benefits from decreasing or increasing the threshold and to align with the US EPA’s national GHG reporting requirements7, the Cal/EP A and CARB have set the mandatory emissions reporting as well as cap and trade enrollment threshold for California to 25,000 mtcO2e.

The cap and allowances: how are these set?

The initial cap will be set at 162.8 million mtcO2e and decline until 2015. In 2015, the cap will be raised to 394.5 million mtcO2e to accommodate the newly covered entities

---

1 Yearly emissions monitoring and reporting to the EPA is required of certain industries. Facilities over 25,000 mtcO2e/yr for five consecutive years, facility can cease reporting. If under 15,000 mtcO2e/yr for three years, facility can cease reporting. Non-covered facilities reporting is required so that facilities can learn of their emissions (must be under the 25,000 mtcO2e/yr threshold). Participants can earn “fill two-thirds with one emission”, with the monitoring efforts being applicable for both EPA and cap and trade regulations.

and again decline until 2020 (CARB 2011b). Note that in Phase 1, the cap decreases by approximately 2% a year whereas in Phase 2 the cap decreases between 3.1% and 3.5% a year. A total of 2.7 billion allowances (one allowance = one metric ton of CO2 equivalent) will be issued for the duration of program8.

The initial allowance allocation by CARB to the participants is based on the following formula (CARB 2010c, CARB 2010d, CARB 2011b):

\[
\text{Allocation} = \text{output} \times \text{leakage risk assistance factor} \times \text{product benchmark} \times \text{declining cap factor}
\]

Where:

- \text{output} = \text{the amount of product produced, e.g., barrels of oil or tons of cement/glass/etc. produced};
- \text{leakage risk assistance factor} = \text{a multiplier that tries to account for the risk that decreasing emissions in California leads to increasing emissions in neighboring states. High risk entities have a factor of 1 in all three compliance periods while medium and low risk entities face (1.00, 0.75, and 0.50) and (1.00, 0.50, and 0.30) factors in subsequent compliance periods, respectively};
- \text{product benchmark} = \text{a comparison of an entity with its peers. A higher multiplier applies to those that are more efficient than the benchmark and can be viewed as a “reward” for those that have adopted efficient processes voluntarily prior to the cap and trade; and}
- \text{declining cap factor} = \text{value decreases proportionally with overall cap decline (from 0.981 in 2013 to 0.851 in 2020)}.

---

7 Non-covered entities (those in covered sectors but emitting less than 25,000 mtcO2e or in sectors not covered) may participate and obtain allowances that may be “banked” for future use, traded, used to comply with cap and trade regulations, or have ARB register as CARB 2011b.

8 Note: covered entities include covered sectors but emitting less than 25,000 mtcO2e or in sectors not covered.
Note that extra allowances were allocated to the electricity generators and natural gas distributors initially as a way of protecting the Californian utility customers from near future rate hikes. Even with the extra allowances, the utilities will still need to participate in the auction so that future emission allowances can be acquired (CARB 2011b). In addition, since the 162.8 million cap is lower than the forecasted emissions of all the facilities combined, it is almost certain that no participant was allocated enough allowances initially that it can opt out of the auction.

**Buying and selling allowances**

The total issued allowances in each compliance period equals the cap for that period, and so an entity requiring more than its allocation has to buy excess allowances from another that has emitted less. In addition, all new entities starting operation during any compliance period would need to obtain allowances in order to emit. In this way, the cap is preserved.

**Offsets**

An offset is a "credit" that is equivalent to one MtCO2e of GHG reduction or sequestration that is obtained outside of the allowances framework of cap and trade. The current offset opportunities are: carbon sequestration in the form of planting for urban forests; reforestation or forest management projects; methane reduction via livestock biogas capture or methane digester installation; and the destruction of ozone depleting substances (those with high global warming potential) (CARB 2011c, CARB

---

**Graphical comparison of forecasted emissions with cap and trade program**

Figure 1 below shows the total forecasted emissions for 2013 to 2020 (dashed red line) and the proposed cap and trade emissions limits (solid black line).

![Graph showing forecasted GHG emissions and cap and trade allowances](image)

**Figure 1:** Graphic showing forecasted GHG emissions and cap and trade allowances. Sources: CARB 2011b, CARB 2012, and CARB 2012a.

The two phases as well as the three compliance periods are also shown. Note that the total forecasted emissions values include emitters under 25,000 metric tons of CO2e/yr, and represent the business-as-usual scenario if cap and trade does not exist. The solid
black cap and trade allowances line is the cap that applies to the covered entities, i.e.,
emitters above 25,000 mCO₂e in phase 1, and inclusive of fuel distributors regardless
of size in phase 2. As can be seen, a dramatic decrease in emissions can be achieved
with a cap and trade program relative to the BAU case.

Emissions auction

Background

The first emissions auction took place on November 14th, 2012. In total, 23,126,110 of
2013 vintage and 39,450,000 of 2015 vintage allowances were available at a reserve
price of $10/allowance, and bids were allowed in 1,000 increments (CARB 2012c,
CARB 2012d). Purchase limits were set at 40% for electric utilities, 15% for other
covered and opt-in entities, and 4% for voluntary entities (CARB 2012c).

Auction results

As of November 19, 2012, only the summary results for the auction have been posted
by CARB. In all, 73 qualified bidders participated in the auction and all 23,126,110 of the
2013 vintage allowances were sold while 5,576,000 out of 39,450,000 of the 2015
vintage allowances were sold.

<table>
<thead>
<tr>
<th>Table 1. Summary of first CIRG allowance auction</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013 Vintage</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Total allowances available</td>
</tr>
<tr>
<td>Total allowances sold</td>
</tr>
<tr>
<td>Auction reserve price</td>
</tr>
<tr>
<td>Auction settlement price</td>
</tr>
<tr>
<td>summary statistics</td>
</tr>
<tr>
<td>Max bid price</td>
</tr>
<tr>
<td>Min bid price</td>
</tr>
<tr>
<td>Mean bid price</td>
</tr>
<tr>
<td>Median bid price</td>
</tr>
<tr>
<td>Revenue (allowance * settlement price)</td>
</tr>
</tbody>
</table>

source: CARB 2012c.

Revenue from auction

To date, there has been no clear indication of how the revenue from the auction will be
used. A portion of the revenue will be used to offset CARB’s costs of administering the
cap and trade and clean air programs, and the Legislative Analyst’s Office of California
recommends that remaining funds be used on new or expanded programs (LAO 2012).
This uncertainty has been one of the main driving forces behind the lawsuit initiated by
the California Chamber of Commerce, along with the belief that the business impacts of
increased energy costs will significantly harm the state’s economy while providing no
additional environmental benefits (California Chamber of Commerce, 2012).
Conclusion

The cap and trade program in California has been six years in the making, ever since AB 32, the Global Warming Solutions Act of 2006 was passed. While cap and trade is not the only strategy for reducing California’s emissions in 2020 to 1990 levels, it is perhaps the most contentious. The program has two phases: phase 1 including electricity generators and large industrial emitters over 25,000 mtCO₂eq/yr, and phase 2 including those from phase 1 as well as fuel distributors under 25,000 mtCO₂eq/yr. In all, approximately 85% of all greenhouse gas emissions can be captured by the above two classes of emitters. The compliance periods are of 3- or 2-year increments and participants need to verify their emissions within each period and turn in the appropriate number of allowances. In November 2012, the first allowance auction took place and the summary results showed that 100% and 14% of available allowances were sold for 2013 and 2015 vintages, respectively. To date, there is still unclear how the revenue from the auction, which totalled $289,102,450, will be used for the benefit of California.

References

PG&E E-20 TOU Tariff, primary voltage

The time-of-use tariff for the Jail is shown in Table 5 below. Note that the rates shown exclude fees, taxes, and surcharges, and the fixed costs ($26.83/day through December 2007 and $32.85/day through December 2011).

Table 5. PG&E E-20 tariff for 2007 through 2011 (PG&E, 2013b)

<table>
<thead>
<tr>
<th>Month</th>
<th>Summer only Max Peak demand ($/kW)</th>
<th>Part-Peak demand ($/kW)</th>
<th>Max demand ($/kW)</th>
<th>Summer only Max Peak energy ($/kWh)</th>
<th>Part-Peak energy ($/kWh)</th>
<th>Off-Peak energy ($/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>Jan</td>
<td>$0.83</td>
<td>$4.57</td>
<td>$0.08300</td>
<td>$0.06865</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Feb</td>
<td>$0.83</td>
<td>$4.57</td>
<td>$0.08300</td>
<td>$0.06865</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mar</td>
<td>$0.80</td>
<td>$5.04</td>
<td>$0.08266</td>
<td>$0.06832</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Apr</td>
<td>$0.80</td>
<td>$5.04</td>
<td>$0.08266</td>
<td>$0.06832</td>
<td></td>
</tr>
<tr>
<td></td>
<td>May</td>
<td>$11.88</td>
<td>$2.72</td>
<td>$5.04</td>
<td>$0.12385</td>
<td>$0.09183</td>
</tr>
<tr>
<td></td>
<td>Jun</td>
<td>$11.88</td>
<td>$2.72</td>
<td>$5.04</td>
<td>$0.12385</td>
<td>$0.09183</td>
</tr>
<tr>
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**NREL/openEI hourly emission factors by month**

Figure 15 shows hourly emission factors as calculated by NREL and shown in openEI for 2008. The hours during which the PVs are most useful are also the hours when the emission factors tend to be lower. The average emissions using this method is 0.369 metric tons/MWh. Blue vertical lines block off the peak demand hours. Figure 16 shows the emission factor variation for the peak hours only, and the average for peak hours is 0.345 metric tons/MWh.

![Figure 15. Comparison of monthly hourly emissions factors from openEI (OpenEI, 2011).](image1)

![Figure 16. Comparison of monthly hourly emissions factors from openEI, peak hours only (OpenEI, 2011).](image2)
Figure 17. Data cleaning and calibration performed by Thiemann prior to the work performed in this analysis (Thiemann, 2013)

Table 6. Summary table of the Jail’s yearly onsite generation (PV and FC), avoided generation, and PG&E purchases (all values in MWh)

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Data from all billing cycles involving 2007

- Dates: 12/16/2006 - 1/16/2008
- Bili: 188 - 200
- Timestep: 15 minutes
- Content: PG&E, FC, PV
- Rows: 15040 data sets in 2003
- Watch out:
  - Average PV power was calculated as non-rolling 30-min-average PV power generated in 112 sets -> corrected
  - Average FC power generated was calculated as non-rolling 30-min-average FC power generated in 176 datasets -> corrected
- PG&E and PG&E average data off by factor 5 (kWh vs kW in 15 min steps) in 8332 data sets -> marked in blue
- FC data for 02-07 to 02-08 is missing (was filled in using 02-08 to 02-09 twice) -> Wrong data set to 0 for 02-07 to 02-08
- Daylight saving time not considered correctly. All data in standard time. Corrected non-aligned FC data in spring time change
- Total demand is negative in 11 data sets -> marked in dark blue

Data from all billing cycles involving 2008

- Dates: 12/14/2007 - 1/14/2009
- Bili: 200 - 212
- Timestep: 15 minutes
- Content: PG&E, FC, PV
- Rows: 15136 data sets in 2008 (kip year)
- Watch out: No switch to daylight saving time. Measurement all year long in standard time? [Switching dates 2008 03-09 and 11-02]
- No switch to daylight saving time. Missing data for one hour in spring switch (03-08) and no “double hour” in autumn (11-01)
- Total demand is zero or negative in 14 data sets -> marked in dark blue

Data from all billing cycles involving 2009

- Dates: 12/14/2008 - 1/14/2010
- Bili: 212 - 224
- Timestep: 15 minutes
- Content: PG&E, FC, PV
- Rows: 15040 data sets in 2009
- Watch out: No switch to daylight saving time; missing data for one hour in spring switch (03-08) and no “double hour” in autumn (11-01)
- No switch to daylight saving time; missing data for one hour in spring switch (03-08) and no “double hour” in autumn (11-01)
- Total demand is zero or negative in 12 data sets -> marked in dark blue

Data from all billing cycles involving 2010

- Dates: 12/16/2009 - 12/31/2010
- Bili: 224 - 235
- Timestep: 15 minutes
- Content: PG&E, FC, PV
- Rows: 15040 data sets in 2010
- Watch out: December data not complete. Missing first 2011 bill -> corrected
- Total demand is zero or negative in 16 data sets -> marked in dark blue

Data from all billing cycles involving 2011

- Bili: no billing data available
- Timestep: 15 minutes
- Content: PG&E, FC, PV
- Rows: 15040 data sets in 2011
- Watch out: All timesteps corrected -> corrected with 2009 data
- No switch to daylight saving time. Measurement all year long in standard time? [Switching dates 2010 03-11 and 11-04]
- No switch to daylight saving time. Measurement all year long in standard time? [Switching dates 2010 03-11 and 11-04]
- No switch to daylight saving time. Measurement all year long in standard time? [Switching dates 2010 03-11 and 11-04]
- Total demand is zero or negative in 15 data sets -> marked in dark blue
- No billing cycle information available!
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Table 7. Specification of the Jail PV system (HU = housing unit) (Dierckxsens, 2009)

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</tr>
<tr>
<td>Inverter Rating (kWdc)</td>
<td>266</td>
<td>259</td>
<td>274</td>
</tr>
<tr>
<td>Number of Modules</td>
<td>2046</td>
<td>1728</td>
<td>3420</td>
</tr>
<tr>
<td>Module Peak Power Voltage (V)</td>
<td>18.9</td>
<td>34</td>
<td>32.3</td>
</tr>
<tr>
<td>Module Peak Power Current (A)</td>
<td>6.9</td>
<td>4.45</td>
<td>2.48</td>
</tr>
<tr>
<td>Array Peak Power (kW)</td>
<td>267</td>
<td>261</td>
<td>274</td>
</tr>
</tbody>
</table>

Figure 18. Left to right: WECC territory, CAMX subregion, and PG&E territory (white area only) (US EPA, 2012b)
References


California Air Resources Board (2011b). Final Regulation Order.


