

Energy Efficiency and Co-Benefits Assessment of Large Industrial Sources

Hydrogen Sector Public Report



**California Air Resources Board
Stationary Source Division
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Introduction and Summary

This report provides information regarding the data provided to the Air Resources Board (ARB or Board) by hydrogen production facilities subject to the Energy Efficiency and Co-Benefits Assessment of Large Industrial Facilities Regulation (EEA Regulation).¹ In this section, we provide background information on the EEA Regulation and a short summary of the types of energy efficiency improvements applicable to existing hydrogen plants. The limited number of facilities in this sector restricts the amount and type of energy efficiency project information that can be publically disclosed in a manner consistent with the public disclosure requirements under California Code of Regulations (CCR) §95610. Only three California hydrogen plants met the emissions threshold for being subject to the EEA Regulation. Consequently, the hydrogen sector consists of only three facilities owned by two different companies. There are additional hydrogen plants in California that did not meet the minimum emissions threshold for being subject to the EEA Regulation requirements and/or are associated with different California refineries and operate under the same air quality permit as the associated refinery. The reported emissions and identified energy efficiency projects from the hydrogen facilities operating under the same air quality permit as an associated refinery are included in the Refinery Sector Public Report in conjunction with the refinery which holds the operating permit. However, for the three facilities that were required to report as stand-alone facilities, any aggregated data would readily allow the two companies to determine their competitor's confidential business information. Thus, the more expanded disclosure of overall costs and emission reductions that is provided for other sectors cannot be disclosed for the hydrogen sector. Disclosing this information would compromise the confidential business information that was included in the Energy Efficiency Assessment Reports (EEA Reports).

Following the "Introduction and Summary," are two sections which provide information regarding the data submitted by the hydrogen plants. This information is presented in such a way as to be consistent with the public disclosure requirements under CCR §95610. The first section "Part I" provides a sector-wide view of energy efficiency improvement projects that are applicable to existing hydrogen facilities. The second section "Part II" summarizes limited information on projects identified by each of the three hydrogen facilities, consistent with the public disclosure requirements under CCR §95610. Emission inventories, both on a sector and facility-specific basis, are also provided for the 2009 base reporting year.

Based on the information provided to ARB, we have the following preliminary observations:

- The three hydrogen facilities that were required to report separately in the Mandatory Greenhouse Gas (GHG) Reporting Regulation and met the emissions threshold for the EEA Regulation identified 28 energy efficiency improvement projects.
- Hydrogen plant energy efficiency is primarily a function of the basic plant design. Once a plant is built, there are limited improvements that can be made. Major

¹ California Code of Regulations, title 17, sections 95600 to 95612.

industry energy efficiency improvements occur primarily with the retirement of older facilities and bringing new facilities on-line.

- These limited improvements could provide GHG reductions on the order of one to two percent (0.02 to 0.04 MMTCO_{2e}).
- While emitted emissions are public information, emission reductions associated with identified projects are being claimed as confidential business information for this sector due to the limited number of companies and facilities, and the linkage of emission reductions to fuel use reductions, the associated cost savings, and the resulting production cost impacts.

EEA Regulation Background

On July 22, 2010, the Board approved the EEA Regulation. The regulation requires operators of California's largest industrial facilities to conduct a one-time energy efficiency assessment. The regulation was approved by the Office of Administrative Law and became effective on July 16, 2011. All California facilities with 2009 GHG carbon-dioxide equivalent (CO_{2e}) emissions equal to or greater than 0.5 million metric tonnes (MMT) CO_{2e} are subject to the EEA Regulation. Also subject to the requirements are cement plants and transportation-fuel refineries that emitted at least 0.25 MMTCO_{2e} in 2009.

The regulation requires facility managers to conduct a one-time assessment of fuel and energy consumption, and provide estimates of GHG, criteria pollutants (CP), and toxic air contaminant (TAC or toxics) emissions. Facilities are further required to identify potential energy efficiency improvements for equipment, processes, and systems that cumulatively account for at least 95 percent of the facility's total GHG emissions. Energy Efficiency Assessment Reports (EEA Reports) were to be filed with the ARB by December 15, 2011. A total of 43 facilities were required to provide an EEA Report.²

To fulfill ARB's public disclosure requirements in the EEA Regulation, ARB staff developed five separate "Public Reports" for the following sectors: Refinery, Oil and Gas Production/Mineral Processing, Cement Manufacturing, Power Generation, and Hydrogen Production. The Public Reports summarize, by sector, the information provided in the EEA Reports submitted by the facilities. The reports strike a balance between full public disclosure of the information provided to ARB and our legal responsibility to protect confidential business information pursuant to CCR §95610. This report is the "Public Report" for the Hydrogen Production Sector.

The Public Reports do not present ARB staff's findings, conclusions, or recommendations. These will be presented in a subsequent report that will include all sectors. We intend to release this subsequent report once we have completed our

² Staff of the San Francisco State University Industrial Assessment Center is also under contract to provide a third-party review of a subset of the EEA Reports. Nine reports were provided to them to evaluate. Information from the third-party review is not yet available, and therefore is not reflected in this report.

review and analysis of the information provided in the EEA Report, the reports from the third party reviewer, and other applicable information. We anticipate releasing this subsequent report in 2013.

Summary of EEA Report Data for the Hydrogen Sector

Three hydrogen facilities were required to report separately in the Mandatory GHG Reporting Regulation and met the emissions threshold for the EEA Regulation. Additionally, there are other hydrogen facilities associated with California refineries which operate under the air quality permit of the refinery for which it provides hydrogen. The reported emissions and identified energy efficiency projects from these hydrogen facilities are included in the Refinery Sector Public Report in conjunction with the refinery which holds the operating permit. This report covers only the information submitted by those hydrogen facilities that operate under their own separately held permit. Below staff provides a summary of the 2009 GHG emissions from the Hydrogen Sector, including only the three separately permitted facilities.

The limited number of facilities in this sector restricts the amount and type of energy efficiency project information that can be publically disclosed. With only three facilities owned by two different companies, any aggregated data would readily allow the two companies to determine their competitor's information. Consequently, the more expanded disclosure of overall costs and emission reductions that is provided for other sectors cannot be disclosed for the hydrogen sector. Disclosing this information would not be consistent with the public disclosure requirements under CCR §95610.

GHG Emissions

Table IS-I shows the 2009 GHG emissions in MMTCO₂e per year from the three hydrogen production facilities subject to the EEA Regulation. This estimate comes from ARB's Mandatory GHG Reporting for 2009. The GHG emission estimates do not include any off-site emissions such as those associated with the production of electricity or steam which is not produced on-site. However, they include on-site production of exported steam and electricity, in addition to hydrogen. As shown in the table, the Hydrogen Sector total GHG emissions in 2009 were 1.8 MMTCO₂e per year.

Table IS- I: 2009 Greenhouse Gas Emissions for the Three Independently Permitted Hydrogen Production Facilities Subject to EEA Regulation

Hydrogen Production Facility	2009 GHG Emissions (MMTCO ₂ e)
Air Liquide - El Segundo	0.54
Air Products - Carson	0.59
Air Products - Wilmington	0.69
Total	1.82

Energy Efficiency Projects and Estimated Potential Emission Reductions

The facility operators of California's three separately permitted hydrogen plants subject to the EEA Regulation identified 28 energy efficiency improvement projects and designated the project status as:

- Completed/Ongoing,
- Scheduled,
- Under Investigation, or
- Not Implementing.

For the Hydrogen Sector, many of the projects identified by the different facilities were similar in terms of the equipment impacted and the approach used to improve energy efficiency. Similar projects have been grouped and placed in one of the three "Equipment Category" listed in Table IS-2. Equipment Category refers to the equipment or a grouping of equipment (i.e. utilities equipment) that are associated with the hydrogen production process.

Table IS-2 summarizes the number of projects identified in the EEA Reports associated with the different equipment categories. The emission reductions associated with these projects are not included due to the linkage of emission reductions to fuel use reductions, the associated cost savings, and the resulting production cost impacts.

Table IS-2: Hydrogen Sector - Energy Efficiency Improvement Projects Identified in EEA Reports*

Equipment Category	Number of Projects	GHG (MMTCO₂e)	NO_x (Tons per day)	PM (Tons per day)
Thermal Equipment	10	CBI	CBI	CBI
Syngas Production Equipment	9	CBI	CBI	CBI
Utilities Equipment	4	CBI	CBI	CBI
Total*	23	CBI	CBI	CBI

*Includes all reported projects except those identified as Not Implementing.

CBI - Confidential Business Information pursuant to CCR §95610

Costs

Cost data cannot be provided for this sector due to the limited number of facilities and ownership by only two different companies. Any aggregated cost information could easily be deciphered by the two companies and would not be consistent with the public disclosure requirements under CCR §95610.

In the next two parts of this "Public Report," we provide more details on the information contained in the Hydrogen Sector EEA Reports. The information is presented consistent with the public disclosure requirements under CCR §95610.

Part I provides sector-wide information on the three separately permitted hydrogen facilities subject to the EEA Regulation including background information on the Hydrogen Sector; estimates of the GHG, criteria pollutant, and TAC emissions; and information on State, federal, and district regulations affecting hydrogen operations in California. Part I summarizes, on a sector-wide basis (limited to the three separately reported facilities), the types of energy efficiency improvement projects available for existing hydrogen production facilities. Details regarding estimates of the potential GHG, criteria pollutant, and TAC emission reductions associated with these projects cannot be disclosed due to the linkage of emission reductions to fuel use reductions, the associated cost savings, and the resulting production cost impacts.

Part II provides facility-specific information about each of the three separately permitted hydrogen plants submitting EEA Reports. Within each facility-specific section, there is information on the current (2009) emissions for GHG, criteria pollutants, and TACs from the specific facility. There is also a summary of the potential energy efficiency improvement projects that hydrogen plant staff identified in their EEA Report. The projects are categorized by Equipment Category and Equipment Sub-type. Equipment Sub-type provides a general description of the types of equipment but does not provide a detailed explanation of each of the 23 projects identified or plant-specific variations from the general description. In compliance with CCR §95610, information about cost and potential emission reductions of GHG, criteria pollutants, and TACs, summed for all the projects (by Equipment Category and Equipment Sub-type), is not provided due to the limited number of facilities and companies involved. While it is not possible to identify the specific details for each project a hydrogen facility has identified, it is possible to get a good indication of what action(s) are available for existing hydrogen plants by referring back to the sector-wide project information in Part I.

Part I – Hydrogen Sector Summary

I.0 Introduction

The information presented in this sector-wide summary is based on EEA Reports submitted by the three separately permitted hydrogen plants subject to the EEA Regulation. All information provided, including inventory data, is as reported by the facilities in their EEA Reports. Inventory data may not agree with other published data due to the inclusion of more recent data provided by the facility. The format and level of detail of the information presented strikes a balance between full public disclosure of the information provided to ARB and our responsibility to protect confidential business information in a manner consistent with ARB regulations. This report does not present ARB staff’s findings, conclusions, or recommendations. These will be presented in a subsequent report that will include all sectors. We intend to release this subsequent report once we have completed our review and analysis of the information provided in the EEA Reports, the reports from the third party reviewer, and other applicable information.³ We anticipate releasing this subsequent report in 2013.

I.1 Hydrogen Sector Description

There are three hydrogen production plants that were required to report separately in the Mandatory GHG Reporting Regulation and met the emissions threshold for the EEA Regulation. These hydrogen plants, identified in Table I-1, are in the South Coast Air Quality Management District. Additionally, there are hydrogen plants associated with different California refineries that operate under the same air quality permit as the associated refinery. The reported emissions and identified energy efficiency projects from these hydrogen facilities are included in the Refinery Sector Public Report in conjunction with the refinery which holds the operating permit. This report covers only the information submitted by those hydrogen facilities that operate under their own separately held permit.

Table I-1: Hydrogen Production Facilities Submitting EEA Reports and the Air Districts in Which They are Located

Hydrogen Plant	Air District
Air Liquide - El Segundo	South Coast Air Quality Management District
Air Products – Carson	
Air Products – Wilmington	

Overview of Hydrogen Production Processes

Hydrogen production facilities primarily produce hydrogen for refineries that manufacture transportation fuels. Hydrogen is also used in the manufacture of

³ The EEA Report submitted by one of the hydrogen plants was provided to staff of the Industrial Assessment Center of San Francisco State University. This group was contracted by ARB to provide a third-party review of a subset of the EEA reports. We anticipate that these third party reviewer reports will be completed later this year.

ammonia-based nitrogen fertilizer and in fuel cells for transportation or power generation. Hydrogen is an essential element of petroleum refining operations. It is used in the hydrotreating process to remove sulfur from fuels and in the hydrocracking process to make lighter fuels from crude oil. Due to the need to produce cleaner fuels requiring removal of sulfur from petroleum products and the need to refine heavier crude oil, the demand for hydrogen continues to increase. (Shumake, 2007)

Hydrogen plants are typically located either within a refinery or adjacent to a refinery property. Plants adjacent to a refinery are commonly referred to as an “over the fence” or “merchant” hydrogen plant. Merchant hydrogen plants may supply product to more than one refinery and are typically under separate operational control. New modern hydrogen plants may generate and supply power in addition to hydrogen and steam.

The three hydrogen production plants that reported under this regulation produce hydrogen using the process of steam methane reforming (SMR). SMR is the process of combining a hydrocarbon feed source [e.g. refinery fuel gas (RFG), methane, or natural gas] with superheated steam in the presence of a catalyst.

Hydrogen gas production consists of four basic process steps:

1. Feed stock hydrogenation and sulfur removal,
2. Reforming in the SMR,
3. Shift conversion, and
4. Hydrogen purification.

Figure I-1 shows a process flow diagram for an SMR hydrogen plant. The hydrocarbon feedstock is pretreated through hydrogenation and desulfurization to remove catalyst-poisoning sulfur prior to SMR. SMR is a catalytic, endothermic reaction conducted under high temperature and pressure. The process involves releasing hydrogen (H₂) from both steam (water, H₂O) and methane (CH₄) and is carried out in a reforming reaction through a gas-fired heater filled with multiple nickel catalyst tubes. The SMR is followed by a water-gas shift conversion to increase the hydrogen yield. The end result of these two reactions is the production of hydrogen and carbon dioxide (CO₂). The crude hydrogen gas is purified through pressure swing adsorption (PSA) to remove water, methane, carbon dioxide, carbon monoxide (CO), and nitrogen to produce a high purity product. (Air Products, 2012)

Two chemical reactions occur in the SMR:

1. Reformation of Feed Stock

The first step causes the hydrocarbon feedstock to react with steam to produce a synthesis gas (syngas), a mixture made up of hydrogen and carbon monoxide. Heat for the reaction is supplied by gas-fired burners in the furnace.

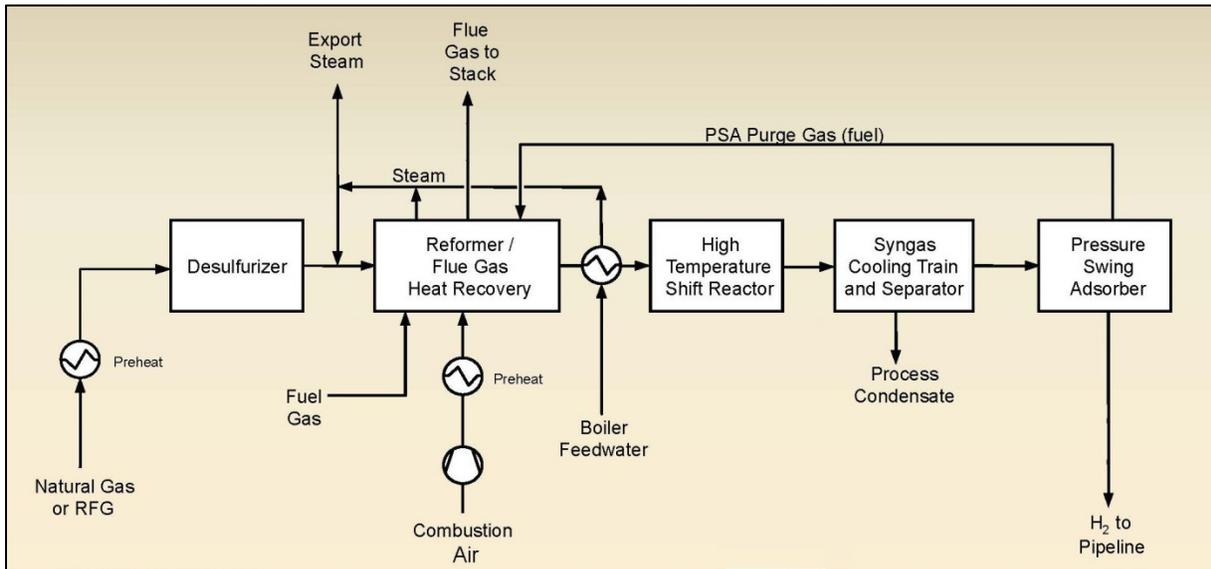


2. Water-Gas Shift Conversion

The second step is mildly exothermic and is known as the water-gas shift conversion. In this step the carbon monoxide that was produced in the first reaction is reacted with steam over a catalyst to form hydrogen and carbon dioxide. (Nyserda.org)



Figure I-1: Process Flow Diagram for SMR Hydrogen Plant



(Air Products, 2012)

Hydrogen plants operate several auxiliary systems to support the hydrogen gas production, such as: waste heat boilers, cooling towers, steam turbine/generator systems, and boiler make-up water treatment systems (filter, softener, reverse osmosis, and ion exchange). Steam is generated in the hydrogen plant's steam generating system by heat recovery from the reforming heater flue gas and from the reforming heater process gas. Some of the steam generated is sent to the steam turbine where it produces electricity. The boiler make-up water treatment system produces high quality water for use in the plant's steam generating system and for export to a local refinery customer. The make-up water treatment system consists of multi-media filters, water softener, reverse osmosis, and ion-exchange units. (Air Products, 2012)

I.2 Emissions and Fuel Use

Emissions

The estimated GHG emissions from the three independently permitted hydrogen production facilities subject to the EEA Regulation are provided below. Table I-2 shows that the total GHG emissions from these facilities in 2009 were 1.8 MMTCO₂e. This estimate comes from ARB's Mandatory GHG Reporting for 2009. The GHG emission estimates do not include off-site emissions associated with the production of electricity which is not produced on-site. As mentioned in the overview of the hydrogen production process, production of exported steam and electricity are included in the processes that generate GHG.

Table I-2: Greenhouse Gas Emissions for Three Independently Permitted Hydrogen Plants Submitting EEA Reports (2009)

Hydrogen Plant	2009 GHG Emissions (MMTCO ₂ e/year)
Air Liquide - El Segundo	0.54
Air Products - Carson	0.59
Air Products - Wilmington	0.69
Total	1.82

Table I-3 provides the estimated criteria pollutant emissions from the three independently permitted hydrogen production plants. The emission estimates were provided by the facilities and are primarily based on emissions estimation methodologies used by the local air district in which the facility is located. The reporting of criteria pollutants may vary with local air district. These totals represent the totals of the reported values.

Table I-3: 2009 Total Criteria Pollutant Emissions for Three Independently Permitted Hydrogen Plants Submitting EEA Reports

Criteria Pollutant	Total Mass Emissions (tons/day)
Reactive Organic Gases (ROG)	0.23
Carbon monoxide (CO)	0.1
Oxides of Nitrogen (NO _x)	0.2
Sulfur Oxides (SO _x)	0.01
Particulate Matter (PM)	0.04

Table I-4 shows the estimated TAC emissions for the three independently permitted hydrogen plants. The emission estimates were provided by the hydrogen plants and are primarily based on emissions estimation methodologies used by the local air district in which the plant is located. Also, the Air Toxics "Hot Spots" Information and Assessment Act (AB 2588), enacted in 1987, requires stationary sources to periodically provide more comprehensive reporting, resulting in variations in the TACs reported. These totals represent the totals of the reported values. The TACs are ranked

according to potential public health impact based on the combination of mass emissions and cancer potency. The cancer potency factors (CPF) used are approved by California's Office of Environmental Health Hazard Assessment and can be found on the web at http://www.oehha.ca.gov/air/hot_spots/tsd052909.html (OEHHA, 2009)

To identify the TACs of greatest potential concern, the TACs for each facility were ranked using the reported emissions for each pollutant and their cancer potency factor. Pound for pound, not all pollutants are equal in terms of potential health impacts to the public. Specifically, the ranking (R) for each pollutant is determined by multiplying the reported emissions (E) and the pollutant-specific inhalation cancer potency factor (CPF). The equation for ranking each pollutant is: $R = E \times CPF$.

This method for ranking pollutants is a simplistic tool used to rank the reported emissions according to potential health impacts. All of the pollutants reported for the sector were ranked using the equation above. The ten pollutants with the highest ranking are listed in the table. The location of a pollutant on the list in the table is a combination of the reported emissions and the presence and/or relative magnitude of the CPF. The pollutant with the highest ranking is listed first. While the CPF is typically used in health risk assessments to estimate potential cancer risk, this ranking is not a risk assessment. The list in Table I-5 simply provides a method for placing the reported pollutants in a relative ranking based on mass and the cancer potency of the pollutant. This ranking shows that emissions of polycyclic aromatic hydrocarbons (PAH), cadmium, and benzene are the top three pollutants of potential concern.

Table I-4: 2009 Toxic Air Contaminant Emissions for Three Independently Permitted Hydrogen Plants Submitting EEA Reports

Toxic Air Contaminant*	Total Mass Emissions (pounds/year)
Polycyclic Aromatic Hydrocarbons (PAH)**	13
Cadmium	1
Benzene	143
Arsenic	2
Formaldehyde	413
Nickel	8
Beryllium	< 1
Naphthalene	2
Lead	4
1,3-Butadiene	< 1

*Top ten TACs listed in rank order based on mass times cancer potency.

**Without the individual components that are reported separately.

Fuel Use

The fuels used for the hydrogen production process include by-product fuels (including PSA purge gas and RFG), diesel, natural gas, methane, and electricity. Fuels are used as both feedstock for hydrogen production and as energy sources. The fuels used for feed stock include RFG, methane, and natural gas. Energy sources for the reformer

furnace include RFG and PSA purge gas. Fuels are also used as energy sources to run the auxiliary systems that support the hydrogen gas production. Specific fuel use data cannot be provided in a manner consistent with the public disclosure requirements under CCR §95610 due to the limited number of facilities and companies that contributed to these data.

I.3 Regulatory Requirements

Hydrogen plants subject to the EEA Regulation are also subject to a variety of State, local, and federal air pollution control regulations and emissions reduction programs. These regulations and programs are mainly designed to reduce criteria and toxic air emissions from refineries. Three complementary State regulations focusing on GHG emission reductions that hydrogen plants are subject to are the Mandatory Reporting of GHG Emissions (Mandatory Reporting) Regulation, the Cap-and-Trade (C&T) Regulation, and the Cost of Implementation Fee Regulation. California's air quality management and air pollution control districts develop, implement, and enforce specific criteria and toxics regulations and programs at the local level. The United States Environmental Protection Agency (U.S. EPA) develops criteria and toxic regulations and programs at the federal level. Below is a brief summary of the Mandatory Reporting, C&T, and the Cost of Implementation Fee Regulations. Also provided are the local air district regulations for the district in which the reporting hydrogen plants are located as well as information regarding federal hydrogen plant regulations. The discussion below focuses on some of the key air-related regulations and programs impacting hydrogen production facilities. However, it is not a complete listing of all of the State, local, and federal air regulations or programs that hydrogen plants are required to meet.

Mandatory Reporting of GHG Emissions (title 17, CCR, sections 95100 to 95158)

In January 2012, amendments to the Mandatory Reporting of GHG Emissions Regulation became effective. In the revised regulation, hydrogen plants are identified as a source category that is subject to the regulation (section 95114). The revised regulation affects all hydrogen production facilities in California where GHG emissions equal or exceed 10,000 MTCO_{2e} annually, whether stand-alone merchant facilities or production units within larger facilities. The Mandatory Reporting Regulation was amended in 2013 to further support benchmarking, allocation of allowances, and the covered emissions calculation under the Cap-and-Trade Regulation, as well as to ensure that reported GHG emissions data is accurate and complete in order to support California's other climate and GHG reduction programs. These amendments became effective January 1, 2014. Operators are required to report stationary combustion and process emissions as well as amounts of carbon dioxide captured and transferred off-site. Operators are required to sample feedstocks (other than natural gas) daily, but solid and liquid samples can be composited to produce a monthly sample for carbon content analysis. The ARB MRR is very similar to US EPA reporting regulations with some modifications by ARB to support Cap-and-Trade. For more information about the Mandatory Reporting Program, please go to:

http://www.arb.ca.gov/cc/reporting/ghg-rep/guidance/ghg_applicability.pdf

Cap-and-Trade Program (title 17, CCR, sections 95800 to 96022)

Cap-and-Trade is one of the strategies California will use to reduce GHG emissions. The program will help California meet its goal of reducing GHG emissions to 1990 levels by 2020. Under Cap-and-Trade, an overall limit on GHG emissions from capped sectors has been established by the Cap-and-Trade Program and facilities subject to the cap will be able to trade compliance instruments (allowances and offsets). Hydrogen facilities are subject to the Cap-and-Trade Regulation and will have to either reduce on-site GHG emissions or obtain GHG compliance instruments equal to their compliance obligation. For more information about the Cap-and-Trade Program, please go to <http://www.arb.ca.gov/cc/capandtrade/capandtrade.htm>

Cost of Implementation Fee Regulation (title 17, CCR, sections 95200 to 95207)

The AB 32 Cost of Implementation Fee Regulation was finalized on June 17, 2010 and became effective on July 17, 2010. Amendments were adopted in 2011 and 2012 to better align it with the Mandatory Reporting Regulation and the Cap-and-Trade Regulation. AB 32 authorized the ARB to adopt a schedule of fees to be paid by sources of GHG emissions. Money collected from these fees will be used to fund the State's costs of implementing AB 32. Entities subject to these fees include large natural gas distributors and large users of natural gas including refineries, suppliers and importers of gasoline and diesel fuel, electricity importers and in-state generating facilities, facilities that combust coal and petroleum coke, and cement manufacturers. There are approximately 300 facilities subject to this fee.

Fees are determined based on the annual budget for the program and the cost to repay start-up loans. The regulation is designed so that invoices are sent after the budget is approved ensuring that each year ARB collects only the amount authorized to run the program and repay the startup loans. The fees are based on a uniform cost for each metric ton of carbon dioxide subject to the regulation. This uniform cost is referred to as the Common Carbon Cost (CCC) and is calculated as the total amount of funding to be collected divided by the total number of emissions subject to the Regulation. For more information about the Cost of Implementation Fee Regulation, please go to: <http://www.arb.ca.gov/cc/adminfee/adminfee.htm>

Local Air Quality Management District Rules

The local air pollution control and air quality management district's require Best Available Control Technology (BACT) be used in the hydrogen plants. All three of the hydrogen plants subject to the EEA Regulation are located in the South Coast Air Quality Management District (SCAQMD) and subject to local permitting requirements. The SCAQMD has two rules specifically affecting hydrogen plants:

- SCAQMD Rule 1189 – Emissions from Hydrogen Process Vents: The purpose of this rule is to reduce emissions of volatile organic compounds (VOCs) from

hydrogen plant process vents. The rule applies to all hydrogen plants that produce any hydrogen for use in petroleum refining operations.

- SCAQMD Rule 1189 (c)(3) states that after January 1, 2003, the total VOC emissions from all process vents of the hydrogen SMR plant combined, are to be less than 2.5 pounds of VOCs per million standard cubic feet of hydrogen.
- SCAQMD Rule 1118 – Control of Emissions from Refinery Flares: The purpose of Rule 1118 is to monitor and record data on refinery and related flaring operations, and to control and minimize flaring and flare related emissions.

Federal Regulations

40 CFR Part 98 Mandatory Greenhouse Gas Reporting, Subpart P – Hydrogen Production

I.4 Energy Efficiency Improvement Opportunities

The energy efficiency improvements available for implementation in existing hydrogen plants are limited to minor improvements. This is because the overall energy efficiency of a hydrogen plant is primarily a function of the original plant design. It is estimated that these minor improvements could provide GHG reductions on the order of one to two percent (0.02 to 0.04 MMTCO_{2e}). The information provided in the Tables I-5 through I-8 gives an overview of the types of improvements available to existing hydrogen production facilities. These are consistent with the projects identified in the EEA Reports. The numbers of projects that were identified as Completed/Ongoing, Scheduled, or Under Investigation are included in the numbers of projects listed in each equipment category. Projects that were identified as Not Implementing were not included. Each of the Tables I-6 through I-8 covers a broad category of equipment or processes identified in the table title and referred to as “Equipment Category.” The equipment categories for these tables are listed in Table I-5 along with a brief description of the type of projects in each specific category. Tables I-6 through I-8 provide additional information regarding how the efficiency improvements are achieved, such as installing variable frequency drives on motors.

As noted in Section I.5 discussed later in the report, about 85% of the projects identified in this section have already occurred or will occur over the next few years. Additionally, approximately 60% of the projects occurred prior to 2010.

Table I-5: Listing of Equipment Categories and Projects Descriptions of Types of Projects

Table Number	Equipment Category	Description of Types of Projects
Table I-6	Thermal	Projects dealing with thermal equipment such as furnaces and heat exchangers
Table I-7	Syngas Production	Projects dealing with equipment used in the process to produce the syngas
Table I-8	Utility	Projects dealing with equipment in the auxiliary systems to produce steam and electricity

Within each table, the types of improvements are provided under the “Efficiency Improvement Method” group (column 1). The “Efficiency Improvement Method” is the approach, action, or mechanism that would result in energy efficiency improvements, and are as follows:

- Changes in plant operation
- Maintenance practices
- Improvement in monitoring and process control
- Investment in same but more efficient technologies
- Investment in new technologies

A more detailed description of the types of projects associated with the “Efficiency Improvement Method” is provided in Tables I-6, I-7, and I-8 under the column entitled “Project Description.” The emissions and cost data are not provided as it cannot be provided in a manner consistent with the public disclosure requirements under CCR §95610 due to the limited number of facilities in this sector.

Thermal Equipment

There are ten projects identified for thermal equipment. The efficiency improvement methods that are available for these projects include:

- Changes in plant operation.
- Improvement in monitoring and process control.
- Investment in same but more efficient technologies.

Table I-6: Thermal Equipment – Energy Efficiency Improvement Opportunities

Efficiency Improvement Method	Project Description	Potential GHG Reductions (metric tons/year)	One Time Cost (\$)	Annual Cost (\$/year)	Annual Savings (\$/year)	Potential NO _x Reduction (tons/day)	Potential PM Reduction (tons/day)
<ul style="list-style-type: none"> Changes in plant operation, Improvement in monitoring and process control 	<ul style="list-style-type: none"> Furnace temperature optimization 	CBI	CBI	CBI	CBI	CBI	CBI
<ul style="list-style-type: none"> Investment in same but more efficient technologies 	<ul style="list-style-type: none"> Low level heat recovery 	CBI	CBI	CBI	CBI	CBI	CBI

CBI - Confidential Business Information pursuant to CCR §95610

Syngas Production

There are nine projects identified for equipment used in syngas production at the hydrogen production facilities. The efficiency improvement methods available for these projects include:

- Changes in plant operation.
- Maintenance practices.
- Improvement in monitoring and process control.
- Investment in same but more efficient technologies.
- Investment in new technologies.

Table I-7: Syngas Production – Energy Efficiency Improvement Opportunities

Efficiency Improvement Method	Project Description	Potential GHG Reductions (metric tons/year)	One Time Cost (\$)	Annual Cost (\$/year)	Annual Savings (\$/year)	Potential NO _x Reduction (tons/day)	Potential PM Reduction (tons/day)
<ul style="list-style-type: none"> Changes in plant operation, Maintenance practices, Improvement in monitoring and process control, Investment in same but more efficient technologies, Investment in new technologies 	<ul style="list-style-type: none"> Catalyst improvements, Purification process improvements 	CBI	CBI	CBI	CBI	CBI	CBI

CBI - Confidential Business Information pursuant to CCR §95610

Utilities

Utilities include projects involving the auxiliary systems to produce steam and electricity at hydrogen production facilities. There are four projects identified for equipment categorized as utilities. These projects include changes in maintenance practices, improvements in monitoring and process control, and investment in the same or more efficient technologies.

Table I-8 Utilities – Energy Efficiency Improvement Opportunities

Efficiency Improvement Method	Project Description	Potential GHG Reductions (metric tons/year)	One Time Cost (\$)	Annual Cost (\$/year)	Annual Savings (\$/year)	Potential NO _x Reduction (tons/day)	Potential PM Reduction (tons/day)
<ul style="list-style-type: none"> Maintenance practices, Improvements in monitoring and process control 	<ul style="list-style-type: none"> Reduce steam trap losses, Compressor operating improvements 	CBI	CBI	CBI	CBI	CBI	CBI
<ul style="list-style-type: none"> Investment in same but more efficient technologies 	<ul style="list-style-type: none"> Install variable frequency drives on motors, Compressor design retrofit improvements, Small-scale steam turbine electricity cogeneration 	CBI	CBI	CBI	CBI	CBI	CBI

CBI - Confidential Business Information pursuant to CCR §95610

Summary

Table I-9 summarizes the number of projects by “Equipment Category” for the energy efficiency improvement projects identified in the EEA Reports.

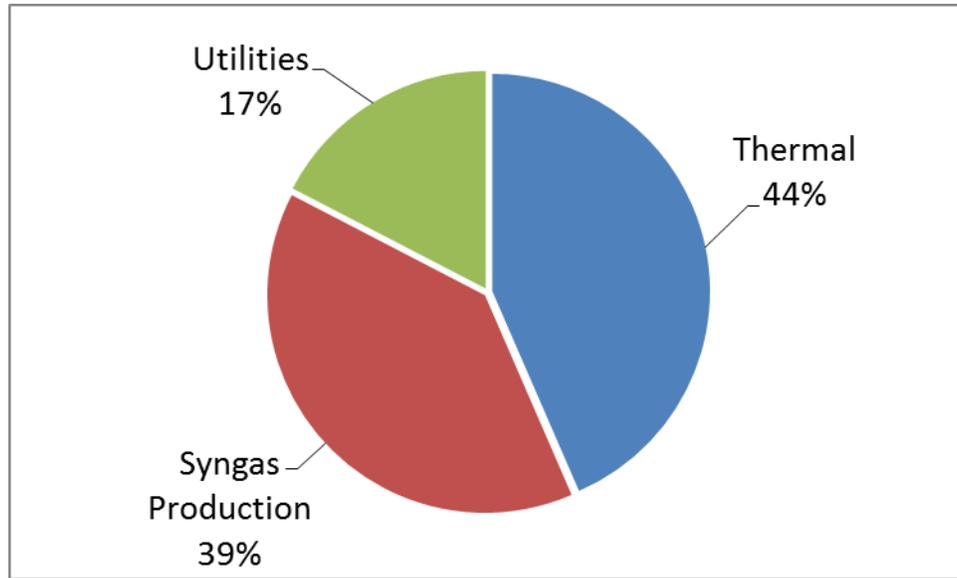
Table I-9: Number of Energy Efficiency Improvement Projects Identified in EAA Reports*

Equipment Category	Number of Projects	GHG (MMTCO ₂ e)	NO _x (tons per day)	PM (tons per day)
Thermal Equipment	10	CBI	CBI	CBI
Syngas Production	9	CBI	CBI	CBI
Utilities	4	CBI	CBI	CBI
Total	23	CBI	CBI	CBI

*Includes all reported projects except those identified as “Not Implementing.”
CBI - Confidential Business Information pursuant to CCR §95610

Figure 1-2 shows pictorially the relative contribution of each equipment category to the total number of projects.

Figure I-2 Number of Identified Projects by Equipment Category



As mentioned previously, the costs associated with the aggregated projects identified by the three hydrogen facilities cannot be provided in a manner consistent with the public disclosure requirements under CCR §95610.

Table I-10 Summary of Estimated Costs and Savings for Energy Efficiency Improvement Projects*

Number of Projects	One time Cost (million \$)	Annual Cost (million \$.year)	Annual Savings (million \$/year)
23	CBI**	CBI	CBI

* Includes all projects identified as Completed/Ongoing, Scheduled, or Under Investigation. Does not include projects identified as “Not Implementing.”

** CBI - Confidential Business Information pursuant to CCR§95610

I.5 Implementation Status of Energy Efficiency Improvement Opportunities

Hydrogen plants subject to the EEA Regulation identified 28 energy efficiency improvement projects and assigned these projects to one of four categories:

- Completed/Ongoing
- Scheduled
- Under Investigation or
- Not Implementing

As mentioned previously, hydrogen plant energy efficiency is primarily a function of the basic plant design and once a plant is built, there are limited improvements that can be made. Consequently, the GHG reductions, and associated co-benefits, that would be achieved with these limited improvements are not significant. These values are not being disclosed because the limited number of facilities and companies that contributed to the data set for the hydrogen sector restricts the amount and type of energy efficiency project information that can be publically disclosed in a manner consistent with the public disclosure requirements under CCR §95610. And, while emitted emissions are public information, emission reductions associated with identified projects are being claimed as confidential business information for this sector due to the linkage of emission reductions to fuel use reductions, the associated cost savings, and the resulting production cost impacts. Consequently, this section provides only information regarding the numbers of projects identified and the associated timing.

Table I-11 shows the number of energy efficiency improvement projects identified in the EEA Reports as either Completed, Ongoing, Scheduled, or Under Investigation. The numbers of projects associated with the Completed/Ongoing projects were divided into two subcategories based on if the projects were completed before 2010 or during/after 2010. This was done to indicate projects that occurred before 2010 for which any associated emission reductions should already be reflected in the 2009 GHG Mandatory Reporting. The five projects identified as Not Implementing are not included in this table.

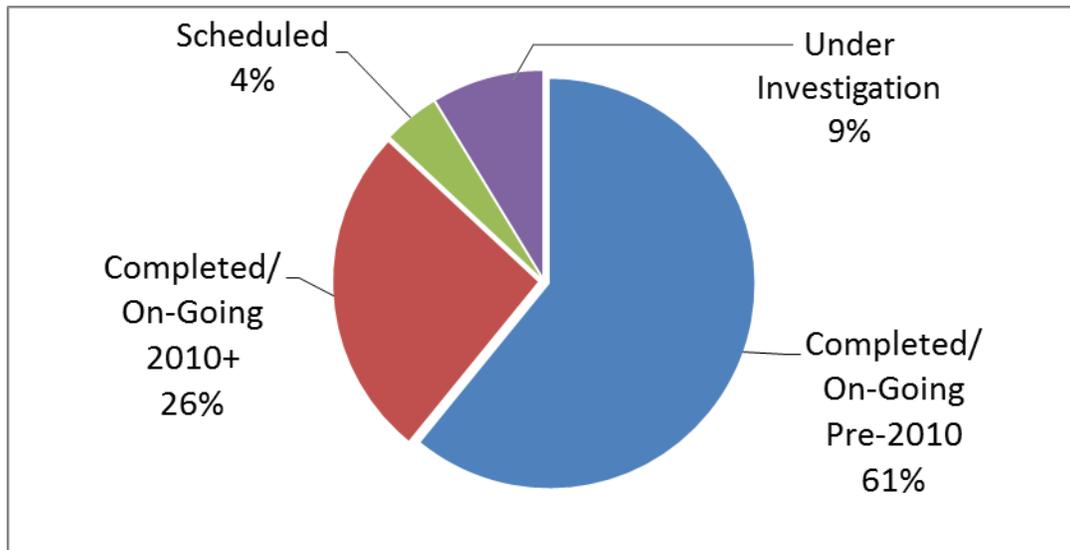
Table I-11: Hydrogen Estimated GHG, NO_x, and PM Emission Reductions by Project Status

Project Status	Number of Projects (% of total)	GHG MMTCO _{2e} (% of total)	NO _x tons per day (% of total)	PM tons per day (% of total)
Completed/Ongoing (C/O) Pre-2010	14	CBI	CBI	CBI
Completed/Ongoing 2010+	6	CBI	CBI	CBI
Subtotal C/O	20 (87%)	CBI	CBI	CBI
Scheduled	1 (4%)	CBI	CBI	CBI
Under Investigation	2 (9%)	CBI	CBI	CBI
Subtotal Pre-2010	14 (61%)	CBI	CBI	CBI
Subtotal 2010+	9 (39%)	CBI	CBI	CBI
Total	23	CBI	CBI	CBI

CBI - Confidential Business Information pursuant to CCR §95610

Two things of note in Table I-11 are that over 85 percent of the projects are Completed/Ongoing projects and that about 60 percent of all projects occurred before 2010. This is shown pictorially in Figure I-3.

Figure I-3. Number of Projects by Project Status



It should be noted, that the number of projects listed assumes that all of the energy efficiency improvement projects identified in the EEA Reports will be implemented, except for those identified as “Not Implementing.” This assumption is accurate for projects that were reported as Completed/Ongoing, which make up about 85 percent of the identified projects. However, implementation of some projects reported as Scheduled or Under Investigation may preclude the implementation of other projects that deal with the same equipment or processes. Therefore, these numbers of projects listed in this report do not necessarily represent readily achievable on-site reductions. As stated in the Introduction and Summary, ARB staff will be developing a subsequent report that will include all sectors. We intend to release this subsequent report once we have completed our review and analysis of the information provided in the EEA Report, the reports from the third party reviewer, and other applicable information. We anticipate releasing this subsequent report in 2013.

References

- (Air Products, 2012) Personal communication with Jim Reebel and Scot Govert of Air Products via email. May 16-17, and 24, 2012.
- (OEHHA, 2009) Technical Support Document for Cancer Potency Factors: Methodologies for derivation, listing of available values and adjustments to allow for early life stage exposures, California Environmental Protection Agency Office of Environmental Health Hazard Assessment Air Toxicology and Epidemiology Branch, May 2009.
- (Shumake, 2007) Shumake, G., and Coleman, A. *Optimize Your Hydrogen Plant Operations: Proper Unit Monitoring Is Necessary To Achieve This Goal. Hydrocarbon Processing*. September 2007. Printed on August 19, 2009 from CBI website. <http://www.cbi.com/about/articles/default.aspx>

Part II – Facility Specific Information for Hydrogen Production Facilities

II.0 Introduction

Part II of this report provides specific information about each of the three hydrogen production facilities submitting EEA Reports. Each hydrogen production facility has a separate section that provides information on the current (2009) emissions for GHG, criteria pollutants, and TACs from the specific facility and a summary of the energy efficiency improvement projects that hydrogen facility staff identified in their EEA Report. The projects are grouped by timing or status (whether they are Completed/Ongoing, Scheduled, or Under Investigation). The numbers of projects are then provided for each Equipment Category/Equipment Sub-type.

Equipment Sub-type provides a general description of the types of equipment affected by the improvement project but does not provide an explanation of each of the 23 projects noted or facility-specific variations from the general description. Information about cost and estimated emission reductions of GHG, criteria pollutants, and TACs is not provided due to the small number of facilities in this sector, in compliance with the confidentiality requirement under CCR §95610. While it is not possible to release the details for each project a facility has identified, it is possible to get an indication of what equipment and timeframe were considered.

II.1 Air Liquide - El Segundo

General Information

This hydrogen plant currently supplies hydrogen and steam to the Chevron Refinery. The facility may also sell a portion of its hydrogen production to other customers in the Los Angeles area. A portion of the steam is used in the hydrogen production process, but most is transported by pipeline to other units within the Chevron Refinery. (AQMD, 2003)

The hydrogen plant produces both hydrogen and steam. The design basis for the hydrogen plant is steam reforming of multiple types of feedstock. Generally, the process passes feed gas and steam over a catalyst to produce hydrogen. Medium pressure steam, produced by heat recovery in the hydrogen plant, is generated and distributed to other units and used within the hydrogen plant. (AQMD, 2003)

Emissions

Table II-1 provides the 2009 GHG emissions reported by Air Liquide – El Segundo in compliance with ARB’s GHG Mandatory Reporting Regulation. Air Liquide – El Segundo is the second largest GHG emitter of the three hydrogen production facilities subject to the EEA Regulation and contributes 30 percent of the total GHG emissions for the three independently permitted hydrogen plants submitting EEA Reports.

Table II-1: Air Liquide – El Segundo 2009 Greenhouse Gas Emissions

Pollutant	2009 Annual Emissions (MMTCO ₂ e)
Greenhouse Gas Emissions	0.54

In addition, the facility reported the following emissions of criteria pollutants as shown in Table II-2.

Table II-2: Air Liquide – El Segundo 2009 Criteria Pollutant Emissions

Criteria Pollutant	2009 Annual Emissions (tpd)
Reactive Organic Gases (ROG)	0.05
Carbon monoxide (CO)	0.016
Oxides of Nitrogen (NO _x)	0.052
Oxides of Sulfur (SO _x)	0.0025
Particulate Matter (PM)	0.009

Table II-3 lists the TACs identified for this facility, ranked according to the combined mass TAC emissions and cancer potency factor, as described in Section 1.2.

Table II-3: Air Liquide – El Segundo 2009 Prioritized Toxic Air Contaminant Emissions

Toxic Air Contaminant*	2009 Emissions (pounds/year)
Cadmium	1
Arsenic	0.74
Benzene	77
Nickel	8
Formaldehyde	175
Beryllium	< 1
Naphthalene	1,100
Lead	4.4
1,3-Butadiene	0.01

* Listed in rank order based on mass times cancer potency

Energy Efficiency Improvement Options

The Air Liquide facility identified six projects addressing the energy efficiency of either furnaces or heat exchangers. All six projects have either been completed or are ongoing. The projects are grouped by equipment category (including thermal) and by equipment sub-type (furnace, and heat exchangers). Additionally, specific ways that the projects improve energy efficiency as well as information about cost and estimated emission reductions of GHG, criteria pollutants, and TACs, are not provided in Table II-4 due to the small number of facilities in this sector and in compliance with the confidentiality requirements under CCR §95610. However, it is possible to get an indication of what equipment and timeframe were considered.

Table II-4: Number of Air Liquide – El Segundo Energy Efficiency Options Reported as Completed/Ongoing

Status	Equipment Category	Equipment Sub-type	Number of Projects	Potential GHG Reductions (metric tons/year)	One Time Cost (\$)	Annual Cost (\$/year)	Annual Savings (\$/year)	Potential NO _x Reduction (tons/day)	Potential PM Reduction (tons/day)
Completed/ Ongoing	Thermal	Furnace, heat exchangers	6	CBI	CBI	CBI	CBI	CBI	CBI

CBI - Confidential Business Information pursuant to CCR §95610

The Air Liquide facility identified one project addressing heat exchangers that is not being implemented because the project was not cost effective and did not achieve the energy efficiency as anticipated. This project is listed in Table II-5.

Table II-5: Air Liquide – El Segundo Energy Efficiency Options Reported as Not Being Implemented

Equipment Category	Equipment Sub-type	Number of Projects	Reason Why Project Not Being Implemented
Thermal	Heat Exchanger	1	Not Cost-effective; not as energy efficient as anticipated.

Reference:

AQMD, 2003. Final Negative Declaration for: Chevron Products Company Refinery Proposed Hydrogen Plant Project. SCH#2003051116. South Coast Air Quality Management District. July, 2003.

II.2 Air Products – Carson

General Information

Air Products and Chemicals, Inc. Carson Hydrogen Plant produces gaseous hydrogen by reacting hydrocarbon feedstock with steam. The hydrocarbon feedstock at the Carson plant is commercial pipeline natural gas. The plant exports hydrogen gas and steam to local refineries. (Air Products, 2012)

The Air Products Carson plant has been in continuous operation since November 1999. There have been no major overhauls to the facility. The facility is located on a 14.5 acre parcel. (Air Products, 2012)

Emissions

Table II-6 provides the 2009 GHG emissions reported by Air Products - Carson in compliance with ARB's GHG Mandatory Reporting Regulation. The Air Products – Carson Hydrogen Production Facility contributes 32 percent of the total GHG emissions for the three independently permitted hydrogen plants submitting EEA Reports.

Table II-6: Air Products – Carson 2009 Greenhouse Gas Emissions

Pollutant	2009 Annual Emissions (MMTCO ₂ e)
Greenhouse Gas Emissions	0.59

In addition, the facility reported the following emissions of criteria pollutants as shown in Table II-7.

Table II-7: Air Products – Carson 2009 Criteria Pollutant Emissions

Criteria Pollutant	2009 Annual Emissions (tpd)
Reactive Organic Gases (ROG)	0.04
Carbon monoxide (CO)	0.34
Oxides of Nitrogen (NO _x)	0.04
Oxides of Sulfur (SO _x)	0.0006
Particulate Matter (PM)	0.013

Table II-8 lists the TACs identified for this facility, ranked according to the combined mass TAC emissions and cancer potency factor, as described in Section 1.2.

Table II-8: Air Products - Carson 2009 Prioritized Toxic Air Contaminant Emissions

Toxic Air Contaminant*	2009 Annual Emissions (pounds per year)
Polycyclic Aromatic Hydrocarbons (total)**	6
Formaldehyde	177
Benzene	37

* Listed in rank order based on mass times cancer potency

** Without the individual components that are reported separately.

Energy Efficiency Improvement Options

Table II-9 provides information on the nine potential energy efficiency improvement projects identified in the Air Products - Carson EEA Report. Eight of the projects were identified as completed and one is scheduled. The projects are grouped by equipment category (including thermal, syngas production and utilities) and by equipment sub-type (furnace, heat exchangers, compressors, steam turbine, and generator). Additionally, specific ways that the projects improve energy efficiency as well as information about cost and estimated emission reductions of GHG, criteria pollutants, and TACs, are not provided in this table due to the small number of facilities in this sector, in compliance with the confidentiality requirements under CCR §95610. However, it is possible to get an indication of what equipment and timeframe were considered.

Table II-9: Number of Air Products - Carson Energy Efficiency Options Reported as Completed, and Scheduled

Status	Equipment Category	Equipment Sub-type	Number of Projects	Potential GHG Reductions (metric tons/year)	One Time Cost (\$)	Annual Cost (\$/year)	Annual Savings (\$/year)	Potential NO _x Reduction (tons/day)	Potential PM Reduction (tons/day)
Completed	Thermal	Furnace, heat exchangers	2	CBI	CBI	CBI	CBI	CBI	CBI
Completed	Syngas Production	compressors, heat exchangers	4	CBI	CBI	CBI	CBI	CBI	CBI
Completed	Utilities	steam turbine, generator	2	CBI	CBI	CBI	CBI	CBI	CBI
Scheduled	Thermal	Furnace, heat exchangers	1	CBI	CBI	CBI	CBI	CBI	CBI
Total			9	CBI	CBI	CBI	CBI	CBI	CBI

CBI - Confidential Business Information pursuant to CCR §95610

Reference:

Air Products, 2012. Personal communication with Jim Reebel and Scot Govert of Air Products via email. May 16-17, and 24, 2012.

II.3 Air Products – Wilmington

General Information

Air Products and Chemicals, Inc. Wilmington Hydrogen Plant produces gaseous hydrogen by reacting hydrocarbon feedstock with steam. The hydrocarbon feedstock at the Wilmington plant utilizes a combined refinery fuel gas feedstock from local refinery customers. The plant exports hydrogen gas and steam to local refineries. The Wilmington plant also exports electricity and boiler make-up water to one of the local refineries.

The Air Products Wilmington plant has been in continuous operation since January 1996. There have been no major overhauls to the facility. The facility is located on a nine acre parcel. (Air Products, 2012)

Emissions

Table II-10 provides the 2009 GHG emissions reported by Air Products - Wilmington in compliance with ARB's GHG Mandatory Reporting Regulation. The Air Products – Wilmington Hydrogen Production Facility contributes 38 percent of the total GHG emissions for the three independently permitted hydrogen plants submitting EEA Reports.

Table II-10: Air Products – Wilmington 2009 Greenhouse Gas Emissions

Pollutant	2009 Annual Emissions (MMT _{CO2e})
Greenhouse Gas Emissions	0.69

In addition, the facility reported the following emissions of criteria pollutants as shown in Table II-11.

Table II-11: Air Products – Wilmington 2009 Criteria Pollutant Emissions

Criteria Pollutant	2009 Annual Emissions (tpd)
Reactive Organic Gases (ROG)	0.14
Carbon monoxide (CO)	0.05
Oxides of Nitrogen (NO _x)	0.07
Oxides of Sulfur (SO _x)	0.006
Particulate Matter (PM)	0.02

Table II-12 lists the three TACs identified for this facility, ranked according to the combined mass TAC emissions and cancer potency factor, as described in Section I.2.

Table II-12: Air Products – Wilmington 2009 Prioritized Toxic Air Contaminant Emissions

Toxic Air Contaminant*	2009 Annual Emissions (pounds per year)
Polycyclic Aromatic Hydrocarbons (total)**	7
Benzene	29
Formaldehyde	61

* Listed in rank order based on mass times cancer potency.

**Without the individual components that are reported separately.

Energy Efficiency Improvement Options

Table II-13 provides information on the eight potential energy efficiency improvement projects identified in the Air Products - Wilmington EEA Report. Six of the projects were identified as completed and two are under investigation. The projects are grouped by equipment category (including thermal, syngas production and utilities) and by equipment sub-type (furnace, heat exchangers, compressors, steam turbine, and generator). Additionally, specific ways that the projects improve energy efficiency as well as information about cost and estimated emission reductions of GHG, criteria pollutants, and TACs, are not provided in this due to the small number of facilities in this sector and in order to be in compliance with the confidentiality requirements under CCR §95610. However, it is possible to get an indication of what equipment and timeframe were considered.

Table II-13: Number of Air Products – Wilmington Energy Efficiency Options Reported as Completed or Under Investigation

Status	Equipment Category	Equipment Sub-type	Number of Projects	Potential GHG Reductions (metric tons/year)	One Time Cost (\$)	Annual Cost (\$/year)	Annual Savings (\$/year)	Potential NO _x Reduction (tons/day)	Potential PM Reduction (tons/day)
Completed	Thermal	furnace, heat exchangers	1	CBI	CBI	CBI	CBI	CBI	CBI
Completed	Syngas Production	compressors, heat exchangers	3	CBI	CBI	CBI	CBI	CBI	CBI
Completed	Utilities	steam turbine, generator	2	CBI	CBI	CBI	CBI	CBI	CBI
Under Investigation	Syngas Production	compressors, heat exchangers	2	CBI	CBI	CBI	CBI	CBI	CBI
Total			8	CBI	CBI	CBI	CBI	CBI	CBI

CBI - Confidential Business Information pursuant to CCR §95610

The Air Products - Wilmington facility identified four projects addressing compressors, heat exchangers, steam turbines, and generators that are not being implemented

because the projects are not cost effective and would not achieve the energy efficiency anticipated. These projects are listed in Table II-14.

Table II-14: Air Products – Wilmington Energy Efficiency Options Reported as Not Being Implemented

Equipment Category	Equipment Sub-type	Number of Projects	Reason Why Projects not Being Implemented
Syngas Production	compressors, heat exchangers	2	Energy savings smaller than anticipated.
Utilities	steam turbine, generator	2	Not cost-effective; not as energy efficient as anticipated.

Reference:

Air Products, 2012. Personal communication with Jim Reebel and Scot Govert of Air Products via email. May 16-17, and 24, 2012.