# TECHNICAL REPORT

## Potential Cost-effective GHG Reduction Opportunities at Ecopetrol's Barrancabermeja Oil Refinery

### PREPARED FOR


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## EXECUTIVE SUMMARY

An emissions measurement and performance evaluation program was completed at the Barrancabermeja Refinery. The purpose of the study was to identify and quantify, in terms of magnitude and economic value, opportunities to reduce greenhouse gas (GHG) emissions and improve energy efficiencies. The field work was conducted during the period of 29 January to 9 February 2013.

The commodity prices used in this analysis are based on data provided by Ecopetrol for specific application to the refinery. The applied prices are summarized in the table below. All prices presented in the report are expressed in US dollars (USD).

**Table i: Applied commodity prices.**

| Commodity | Value | Units of Measure |
|---|---|---|
| Natural Gas | 4.35 | USD/GJ |
| Ethane | 80.84 | USD/m$^3$ (Liquid) |
| LPG | 0.25 | USD/L |
| NGL | 566.08 | USD/m$^3$ (Liquid) |
| Hydrogen | 1.00 | USD/kg |
| | 0.09 | USD/m$^3$ |
| Electricity | 0.10 | USD/kW·h |

The value of any potential marketable GHG credits was not considered but would have a positive impact on the practicability of each opportunity. A discount rate of 12% has been used in the economic evaluations.

The relative value of the different commodities on an equivalent-energy basis for the pricing indicated above is as follows:

**Table ii: Relative commodity price index expressed on an gross energy basis (HHV).**

| Commodity | Value Relative to Processed Natural Gas |
|---|---|
| Natural Gas | 1.0 |
| Ethane | 1.0 |
| LPG | 2.3 |
| NGL | 3.7 |
| Hydrogen | 1.6 |
| Electricity | 6.4 |

Throughout this report, emissions and potential emission reductions are reported in units of tonnes per annum, while process activity levels, natural gas losses and methane losses are all expressed in cubic metres per day. The volumetric flows are referenced at standard conditions of 101.325 kPa and 15ºC. The value of avoidable commodity losses and energy consumption are expressed on an annualized basis. All reported GHG emissions include contributions due to $CH_{4,}$ $CO_2$ and $N_2O$ emissions. The impact on emissions of selected criteria air pollutants is also considered, including volatile organic compounds (VOCs), $SO_2$, $NO_x$, CO, particulate matter [PM]).

All emissions calculations, economic-valuations and detailed analyses of measurement results were performed using Clearstone's web-based source-simulation and data-management application, CSimOnLine. This program features rigorous process simulation utilities, emission factor libraries, and calculations for detailed benchmarking of process systems and units. Moreover, it provides entry-time quality assurance checks of all input data as well as standardized reporting of the results. All cost estimates were prepared by a senior cost estimator and are Class 5 estimates (AACE RP No. 18R-97).

**Measurement and Testing Program**

The emissions measurement and performance testing work comprised:

- Collection of process data and the application of rigorous engineering calculations needed to evaluate opportunities to reduce steam losses from the refinery's utility system as well of the practicability of converting the flares from steam assist to air assist.
- Evaluation of a waste heat recovery opportunity associated with Plant UOP 1.
- Evaluation of opportunities to optimize the performance of the refinery's steam boilers.
- Evaluation of the impacts of fuel switching and/or processing on the refinery's fuel gas system.
- Screening, using a hydrocarbon vapour imaging infrared (IR) camera, of selected storage tanks for potential emissions issues.

**Current Emissions**

A rigorous assessment of GHG emissions by the refinery was not conducted. The key sources considered included flaring and fuel use by the steam boilers, but did not include contributions by the steam-methane reformers or due to fugitive equipment leaks.

The assessed sources contribute 1.730 Mt CO2E GHG emissions annually. As depicted in Figure i. These are almost entirely due to fuel use by the boilers.

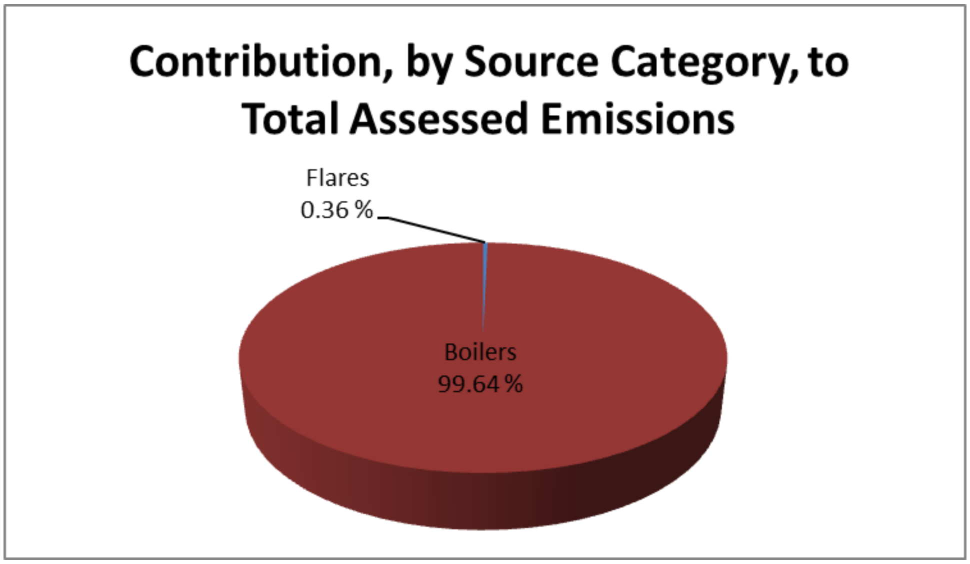


**Figure i: A pie chart depicting the percentage contribution, by primarysource category, to the total uncontrolled direct GHG emissions from these sources (1.730 Mt $CO_2E$/y).**

**Emissions Reduction and Energy Efficiency Opportunities**

Roughly 51.4 million USD/y in potential opportunities to reduce GHG emissions and improve energy efficiencies at the Barrancabermeja Refinery were identified. These opportunities offer 396.6 kty of $CO_2E$ emission reductions. The key opportunities include the following and their percentage contribution to the total reduction opportunity is depicted in Figure ii and Figure iii:

- Implementing product recovery systems or improved operating procedures to preclude losses of hydrogen and valuable LPG and NGLs into the fuel gas system.
- Improved maintenance and tuning of the process boilers.
- Improved management of the steam system to bring steam losses at the refinery in line with industry standards.
- Conversion from the use of steam to air as the flare assist gas.
- Improved monitoring and maintenance of floating roof seals.
- Management of leakage into the flare systems and optimization of purge gas consumption.
- Implementation of a waste heat recovery system in UOP I to produce low pressure steam.

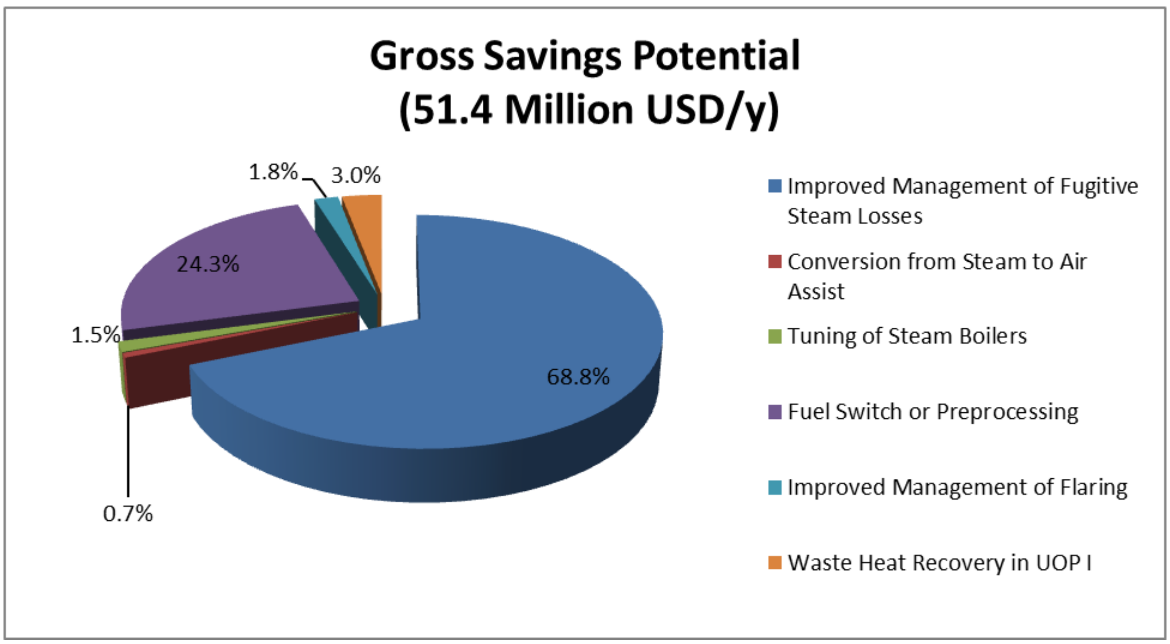


**Figure ii: A pie chart depicting the percentage contribution, by priamry source category, to the total gross savings potential of the assessed control opportunities relating to these sources.**

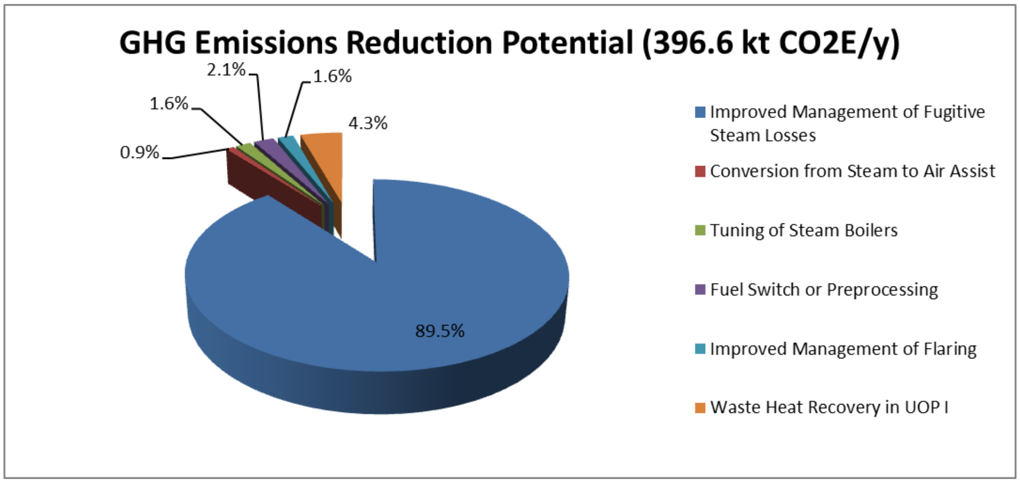


**Figure iii: A pie chart depicting the percentage contribution, by primary source category, to the total assessed GHG redcution potential for these sources.**

**Implementation Cost**

Preliminary capital costs have been assessed for identified opportunities to reduce energy consumption or emissions. Additional analysis of these opportunities may be appropriate after they have been confirmed and prioritized.

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## ACKNOWLEDGEMENTS

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- Edgar Eduardo Yañez Angarita (Ecopetrol).
- Staff at the Barrancabermeja Refinery.
- Michael Layer (Natural Resources Canada).

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## LIST OF ACRONYMS

| | | |
|---|---|---|
| CAPP | - | Canadian Association of Petroleum Producers |
| GHG | - | Greenhouse Gas ($CO_2$, $CH_4$, $N_2O$, $SF_6$) |
| HHV | - | Higher Heating Value |
| LHV | - | Lower Heating Value |
| MJ | - | Megajoule |
| ng | - | Nanogram |
| NPV | - | Net Present Value |
| RISE | - | Research Institute of Safety and Environmental Technology |
| THC | - | Total Hydrocarbons |
| USD | - | US Dollars |

# 1 INTRODUCTION

This report presents the results of a study to identify and evaluate opportunities to reduce greenhouse gas (GHG) emissions and improve energy efficiencies at Ecopetrol's Barrancabermeja Refinery in Colombia. The completed study is in support of efforts to develop a nationally appropriate mitigation action (NAMA) plan to reduce GHG emissions in Colombia's oil and natural gas sector. The specific opportunities considered at the refinery consisted of management of steam losses, waste heat recovery opportunities, fuel switching or pre-processing for the refinery's fuel gas system, and management of storage losses.

The key benefits of these opportunities include increased profits, improved overall energy efficiencies, conservation of a valuable non-renewable resource, reduced GHG emissions, reduced air pollution and both national and international recognition.

Some of the key reasons that significant cost-effective GHG reduction and energy efficiency improvement opportunities may exist are:

- Changes in operating conditions from initial design values.
- Progressive deterioration of equipment performance.
- Outdated designs that are based on previous low energy prices.
- Use of outdated technologies.
- Lack of quantitative data to build business cases for improvement opportunities.

The main advantages of conducting an independent integrated energy and emissions review are:

- Fresh views and insights coupled with knowledge and experience of the review team.
- Increased probability of identifying significant cost-effective emission reduction opportunities through a comprehensive facility examination.
- Potential synergies between disciplines for improved opportunity identification.
- Maximum utilization of the review team's expertise.
- Independent verification of the facility's performance.
- Transparent third-part determination of the emissions baseline and other data needed for the design of carbon credit projects.
- Opportunity for technology transfer to, and training of, facility staff.
- Access to specialized testing, measurement and analytical technologies that may not be readily available to the facility staff.

Additionally, the review provides the means to monitor performance over the long term by comparing performance against the baseline established at the time of the initial facility survey. This process, or benchmarking, can be applied at the facility level as well as at the individual process unit level. The following sections present a description of the surveyed facility (Section 2), a summary and discussion of the key evaluation results (Section 3), conclusions and recommendations (Section 4), and references cited (Section 0). A glossary of relevant key terminology is provided in Appendix A. Details of the methodology used to conduct economic evaluations are presented in Appendix B. The remaining appendices delineate the applied evaluation methodology and detailed calculation results for the primary source categories evaluated.

## 2 FACILITY DESCRIPTION

The Barrancabermeja Refinery currently has a processing capacity of 250,000 bbl/d, and supplies nearly 80% of the fuels consumed in Colombia. However, the refinery is scheduled to undergo a major modernization program at a cost of US$3 billion-plus to increase the refinery capacity to 300,000 bbl/d by 2016.

The specific upgrades will include heavy crude processing capability to take advantage of the available domestic heavy sour crudes, and a processing configuration to meet the projected 2013 Colombian clean fuels product specifications, which will eliminate fuel oil production.

The project will enable the country's largest refinery to increase the conversion factor from 76% to 95%, which means that it will be possible to obtain more products, such as gasoline and diesel.

The scope of the modernization project includes addition of the following new units: a crude unit, delayed coker, hydrocracker unit (80,000 bbl/d), coker naphtha hydrotreating unit, hydrogen unit, sour water strippers, amine regeneration unit, and sulfur recovery unit, plus associated utilities and offsite units. The project will also include revamps to the diesel hydrotreater, gasoline hydrotreater and dismantling of two existing atmospheric and vacuum distillation units.

A photograph of the refinery is presented in Figure 1 below.

**Figure 1: Photograph of the Barrancabermeja Refinery.**

# 3 PERFORMANCE EVALUATIONS

## 3.1 Fuel System

Table 1 presents, by fuel gas mix drum, a summary of the total amount of fuel consumed by boilers at the refinery, and shows the recoverable commodities present in the fuel. Several different scenarios are considered to reflect the potential range in gas compositions that many occur for each fuel gas mix drum. Each scenario for a given fuel gas mix drum has the same energy flow rate. Table 2 summarizes the total direct emissions associated with consumption of this fuel, and Table 3 indicates the direct emissions reductions potential from recovering the valuable non-methane fractions of the fuel gas and then replacing these fractions using an equivalent energy flow of residue natural gas instead. The economics associated with this proposed fuel switching are delineated in Table 4. The detailed analysis results are presented in Appendix G.

At a minimum, consideration should be given to processing the current refinery gas to recover the valuable condensable fractions (i.e., LPG and NGL). Additionally, there is some $H_2$ being used as fuel. The direct emissions from the combustion of $H_2$ are zero; however, significant energy is expended in generating the $H_2$, which makes it a noteworthy source of indirect emissions. It is much more appropriate to produce only as much hydrogen as is needed for the hydro treaters and use residue gas as boiler fuel. Burning produced hydrogen as fuel instead of using it for its intended purpose represents a potential refinery bottleneck. Accordingly, it is recommended that improved controls be installed to better manage the hydrogen production rates in accordance with process demands.

The emissions reduction potential shown in Table 3 only considers direct emissions, which is why there are some negative reductions in $CO_2$E GHG emissions shown in Table 3 (i.e., the current fuel mix contains noteworthy amounts of hydrogen from the hydrogen plants, which reduces the fuel carbon content but does not consider the emissions associated with initially producing that hydrogen). Insufficient data were available to assess the indirect emission contribution from the use of hydrogen as fuel. Still, a total GHG emissions reduction of at least 8.4 kt/y $CO_2$E could be achieved.

A preliminary assessment of the combined costs of pre-processing the refinery gas to recover LPG and NGL, and of implementing controls to avoid excessive hydrogen production is provided in Table 4. The overall results show a substantial economic incentive to pursuing this opportunity (i.e., approximately 12.5 million USD annually). Not considered in the economic evaluation is the fact the current rich fuel mixtures are contributing to external fouling of the boiler tubes due to soot accumulation. This fouling reduces the fuel efficiency of the boilers and contributes to increased fuel requirements and maintenance costs. Consideration of these additional costs would further enhance the economics of the opportunity.

| Table 1: Commodity content of fuel mix scenarios at the Barrancabermeja Refinery. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Source** | **Tag No.** | **Date** | **Fuel Mix Scenario** | **Value of Fuel Consumed (USD/y)** | **Raw Fuel Consumed ($m^3$/h)** | **Residue Gas ($10^3$ $m^3$/d)** | **Ethane ($m^3$/d liq)** | **LPG ($m^3$/d liq)** | **NGL ($m^3$/d)** | **Hydrogen ($m^3$/d)** |
| Balance Mix Drum | D-2953 | 2013-02-02 | Current Mix | 66,487,230 | 40,961.67 | 904.42 | 144.70 | 60.87 | 9.84 | 15,548.45 |
| | | N/A | Dry Natural Gas | 61,942,368 | 43,109.45 | 1,034.63 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 2013-02-06 | Gas de Campos | 65,012,359 | 40,017.82 | 880.52 | 231.57 | 44.43 | 6.82 | 0.00 |
| | | 2013-02-02 | Normal Operation | 71,846,931 | 41,300.77 | 810.94 | 157.07 | 155.32 | 9.84 | 78,944.80 |
| Caldaers Nuevas Mix Drum | D-940 | 2013-02-01 | Current Mix | 5,681,591 | 2,718.33 | 26.26 | 21.64 | 25.52 | 1.89 | 24,147.43 |
| | | N/A | Dry Natural Gas | 3,860,944 | 2,687.06 | 64.49 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 2013-02-06 | Gas de Campos | 4,052,300 | 2,494.36 | 54.88 | 14.43 | 2.77 | 0.43 | 0.00 |
| | | 2013-02-01 | Refinery gas @ 100% | 5,681,591 | 2,718.33 | 26.26 | 21.64 | 25.52 | 1.89 | 24,147.43 |
| | | 2013-01-31 | Refinery gas @ 50% | 5,920,876 | 2,538.69 | 20.69 | 25.40 | 32.59 | 1.57 | 20,341.95 |
| | | 2013-02-04 | Refinery gas @ 85% | 5,697,605 | 2,673.26 | 26.18 | 20.87 | 26.04 | 1.96 | 23,559.95 |
| | | 2013-02-01 | Normal Operation | 5,780,935 | 2,697.42 | 24.29 | 22.50 | 27.39 | 1.92 | 24,658.31 |
| | | 2013-01-31 | HDT, Orthoflow and Mod IV | 5,930,443 | 2,506.52 | 20.42 | 25.75 | 32.51 | 1.58 | 21,065.68 |
| | | 2013-02-04 | Normal Operation | 5,841,485 | 2,695.59 | 23.33 | 21.63 | 28.45 | 1.97 | 25,797.15 |
| Central Norte Mix Drum | D-2421 | 2013-02-01 | Current Mix | 56,164,894 | 35,615.25 | 789.44 | 157.08 | 33.70 | 5.77 | 0.00 |
| | | N/A | Dry Natural Gas | 53,769,387 | 37,421.37 | 898.11 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 2013-02-06 | Gas de Campos | 56,434,308 | 34,737.67 | 764.34 | 201.02 | 38.57 | 5.92 | 0.00 |
| | | 2013-02-01 | Normal Operation | 60,934,957 | 45,700.61 | 598.22 | 306.48 | 48.54 | 9.49 | 311,278.28 |
| | | 2013-02-04 | Normal Operation | 58,547,839 | 35,547.94 | 756.66 | 154.82 | 65.05 | 10.53 | 18,233.32 |
| Distral Mix Drum | D 968 | 2013-02-01 | Current Mix | 29,868,440 | 15,000.00 | 251.24 | 92.57 | 107.10 | 5.18 | 40,248.48 |
| | | N/A | Dry Natural Gas | 23,450,130 | 16,320.37 | 391.69 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 2013-02-06 | Gas de Campos | 24,612,367 | 15,149.94 | 333.35 | 87.67 | 16.82 | 2.58 | 0.00 |
| | | 2013-02-04 | Normal Operation | 27,550,212 | 16,803.62 | 270.09 | 115.10 | 47.71 | 7.21 | 68,803.81 |
| Foster Mix Drum | D-942 | 2013-02-04 | Current Mix | 11,460,675 | 6,680.00 | 81.55 | 32.09 | 34.38 | 3.29 | 58,299.08 |
| | | N/A | Dry Natural Gas | 8,550,922 | 5,951.10 | 142.83 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 2013-02-06 | Gas de Campos | 8,974,723 | 5,524.32 | 121.55 | 31.97 | 6.13 | 0.94 | 0.00 |
| | | 2013-02-01 | Normal Operation | 11,218,594 | 6,640.86 | 85.85 | 31.71 | 31.07 | 3.04 | 53,997.62 |

| Table 2: Estimated emissions per scenario by the boilers at the Barrancabermeja Refinery. | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | Tag No. | Date | Fuel Mix Scenario | Total (Direct and Indirect) Emissions (t/y) | | | | | | | | | |
| | | | | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | $NO_x$ | $SO_2$ | PM |
| Balance Mix Drum | D-2953 | 2013-02-02 | Current Mix | 14.29 | 712,407 | 12.86 | 716,693 | 32.86 | 499.99 | 1,685.70 | 0.00 | 11.43 |
| | | N/A | Dry Natural Gas | 14.32 | 702,897 | 12.89 | 707,194 | 32.94 | 501.26 | 1,689.96 | 0.00 | 11.46 |
| | | 2013-02-06 | Gas de Campos | 14.27 | 716,870 | 12.85 | 721,151 | 32.83 | 499.55 | 1,684.20 | 0.00 | 11.42 |
| | | 2013-02-02 | Normal Operation | 14.28 | 709,728 | 12.85 | 714,013 | 32.85 | 499.91 | 1,685.42 | 0.00 | 11.43 |
| Caldaers Nuevas Mix Drum | D-940 | 2013-02-01 | Current Mix | 0.89 | 42,726 | 0.80 | 42,993 | 2.05 | 31.21 | 105.22 | 0.00 | 0.71 |
| | | N/A | Dry Natural Gas | 0.89 | 43,812 | 0.80 | 44,080 | 2.05 | 31.24 | 105.34 | 0.00 | 0.71 |
| | | 2013-02-06 | Gas de Campos | 0.89 | 44,683 | 0.80 | 44,950 | 2.05 | 31.14 | 104.98 | 0.00 | 0.71 |
| | | 2013-02-01 | Refinery gas @ 100% | 0.89 | 42,726 | 0.80 | 42,993 | 2.05 | 31.21 | 105.22 | 0.00 | 0.71 |
| | | 2013-01-31 | Refinery gas @ 50% | 0.89 | 44,285 | 0.80 | 44,551 | 2.04 | 31.06 | 104.72 | 0.00 | 0.71 |
| | | 2013-02-04 | Refinery gas @ 85% | 0.89 | 42,899 | 0.80 | 43,166 | 2.05 | 31.19 | 105.16 | 0.00 | 0.71 |
| | | 2013-02-01 | Normal Operation | 0.89 | 42,851 | 0.80 | 43,119 | 2.05 | 31.19 | 105.16 | 0.00 | 0.71 |
| | | 2013-01-31 | HDT, Orthoflow and Mod IV | 0.89 | 44,139 | 0.80 | 44,405 | 2.04 | 31.07 | 104.76 | 0.00 | 0.71 |
| | | 2013-02-04 | Normal Operation | 0.89 | 42,749 | 0.80 | 43,016 | 2.05 | 31.20 | 105.17 | 0.00 | 0.71 |
| Central Norte Mix Drum | D-2421 | 2013-02-01 | Current Mix | 12.40 | 620,602 | 11.16 | 624,321 | 28.51 | 433.88 | 1,462.80 | 0.00 | 9.92 |
| | | N/A | Dry Natural Gas | 12.43 | 610,153 | 11.19 | 613,883 | 28.59 | 435.12 | 1,466.98 | 0.00 | 9.95 |
| | | 2013-02-06 | Gas de Campos | 12.39 | 622,282 | 11.15 | 625,999 | 28.50 | 433.64 | 1,461.98 | 0.00 | 9.91 |
| | | 2013-02-01 | Normal Operation | 12.49 | 582,702 | 11.24 | 586,449 | 28.72 | 437.08 | 1,473.60 | 0.00 | 9.99 |
| | | 2013-02-04 | Normal Operation | 12.39 | 622,257 | 11.15 | 625,974 | 28.50 | 433.69 | 1,462.16 | 0.00 | 9.91 |
| Distral Mix Drum | D 968 | 2013-02-01 | Current Mix | 5.39 | 273,926 | 4.85 | 275,543 | 12.40 | 188.69 | 636.17 | 0.00 | 4.31 |
| | | N/A | Dry Natural Gas | 5.42 | 266,103 | 4.88 | 267,729 | 12.47 | 189.77 | 639.79 | 0.00 | 4.34 |
| | | 2013-02-06 | Gas de Campos | 5.40 | 271,392 | 4.86 | 273,013 | 12.43 | 189.12 | 637.60 | 0.00 | 4.32 |
| | | 2013-02-04 | Normal Operation | 5.41 | 265,948 | 4.87 | 267,572 | 12.45 | 189.50 | 638.88 | 0.00 | 4.33 |
| Foster Mix Drum | D-942 | 2013-02-04 | Current Mix | 1.99 | 90,700 | 1.79 | 91,296 | 4.57 | 69.52 | 234.39 | 0.00 | 1.59 |
| | | N/A | Dry Natural Gas | 1.98 | 97,032 | 1.78 | 97,626 | 4.55 | 69.20 | 233.29 | 0.00 | 1.58 |
| | | 2013-02-06 | Gas de Campos | 1.97 | 98,961 | 1.77 | 99,552 | 4.53 | 68.96 | 232.50 | 0.00 | 1.58 |
| | | 2013-02-01 | Normal Operation | 1.99 | 91,128 | 1.79 | 91,724 | 4.57 | 69.50 | 234.32 | 0.00 | 1.59 |

**Table 3: Estimated emissions reduction per scenario by the boilers at the Barrancabermeja Refinery.**

| Source | Tag No. | Date | Fuel Mix Scenario | Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | $NO_x$ | $SO_2$ | PM |
| Balance Mix Drum | D-2953 | N/A | Dry Natural Gas | -0.04 | 9,510 | -0.03 | 9,499 | -0.08 | -1.27 | -4.27 | 0.00 | -0.03 |
| | | 2013-02-06 | Gas de Campos | 0.01 | -4,462 | 0.01 | -4,458 | 0.03 | 0.44 | 1.50 | 0.00 | 0.01 |
| | | 2013-02-02 | Normal Operation | 0.00 | 2,679 | 0.00 | 2,680 | 0.01 | 0.08 | 0.28 | 0.00 | 0.00 |
| Caldaers Nuevas Mix Drum | D-940 | N/A | Dry Natural Gas | 0.00 | -1,087 | 0.00 | -1,087 | 0.00 | -0.04 | -0.12 | 0.00 | 0.00 |
| | | 2013-02-06 | Gas de Campos | 0.00 | -1,957 | 0.00 | -1,957 | 0.00 | 0.07 | 0.24 | 0.00 | 0.00 |
| | | 2013-02-01 | Refinery gas @ 100% | 0.00 | 0 | 0.00 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 2013-01-31 | Refinery gas @ 50% | 0.00 | -1,559 | 0.00 | -1,558 | 0.01 | 0.15 | 0.50 | 0.00 | 0.00 |
| | | 2013-02-04 | Refinery gas @ 85% | 0.00 | -173 | 0.00 | -173 | 0.00 | 0.02 | 0.06 | 0.00 | 0.00 |
| | | 2013-02-01 | Normal Operation | 0.00 | -125 | 0.00 | -125 | 0.00 | 0.02 | 0.06 | 0.00 | 0.00 |
| | | 2013-01-31 | HDT, Orthoflow and Mod IV | 0.00 | -1,413 | 0.00 | -1,412 | 0.01 | 0.14 | 0.46 | 0.00 | 0.00 |
| | | 2013-02-04 | Normal Operation | 0.00 | -23 | 0.00 | -23 | 0.00 | 0.01 | 0.04 | 0.00 | 0.00 |
| Central Norte Mix Drum | D-2421 | N/A | Dry Natural Gas | -0.04 | 10,448 | -0.03 | 10,438 | -0.08 | -1.24 | -4.18 | 0.00 | -0.03 |
| | | 2013-02-06 | Gas de Campos | 0.01 | -1,681 | 0.01 | -1,678 | 0.02 | 0.24 | 0.82 | 0.00 | 0.01 |
| | | 2013-02-01 | Normal Operation | -0.09 | 37,899 | -0.08 | 37,872 | -0.21 | -3.20 | -10.79 | 0.00 | -0.07 |
| | | 2013-02-04 | Normal Operation | 0.01 | -1,655 | 0.00 | -1,654 | 0.01 | 0.19 | 0.64 | 0.00 | 0.00 |
| Distral Mix Drum | D 968 | N/A | Dry Natural Gas | -0.03 | 7,823 | -0.03 | 7,814 | -0.07 | -1.07 | -3.62 | 0.00 | -0.02 |
| | | 2013-02-06 | Gas de Campos | -0.01 | 2,534 | -0.01 | 2,530 | -0.03 | -0.43 | -1.44 | 0.00 | -0.01 |
| | | 2013-02-04 | Normal Operation | -0.02 | 7,978 | -0.02 | 7,971 | -0.05 | -0.81 | -2.71 | 0.00 | -0.02 |
| Foster Mix Drum | D-942 | N/A | Dry Natural Gas | 0.01 | -6,333 | 0.01 | -6,330 | 0.02 | 0.32 | 1.09 | 0.00 | 0.01 |
| | | 2013-02-06 | Gas de Campos | 0.02 | -8,261 | 0.01 | -8,257 | 0.04 | 0.56 | 1.89 | 0.00 | 0.01 |
| | | 2013-02-01 | Normal Operation | 0.00 | -429 | 0.00 | -428 | 0.00 | 0.02 | 0.07 | 0.00 | 0.00 |

| Table 4: Economic analysis of fuel switching or pre-processing at the Barrancabermeja Refinery. | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Source** | **Tag No.** | **Date** | **Fuel Mix Scenario** | **Application Life Expectancy (y)** | **Capital Cost ($10^3$ USD)** | **Net Present Salvage Value (USD)** | **Net Operating Cost (USD/y)** | **Value of Conserved Energy (USD/y)** | **NPV ($10^3$ USD)** | **ROI (%)** | **Payback Period (y)** |
| Balance Mix Drum | D-2953 | N/A | Dry Natural Gas | 20 | 91,250 | 0 | 0 | 4,544,863 | -57,774 | 5.0 | 20.08 |
| | | 2013-02-06 | Gas de Campos | 20 | 91,250 | 0 | 0 | 1,474,871 | -80,386 | 1.6 | 61.87 |
| | | 2013-02-02 | Normal Operation | 20 | 0 | 0 | 0 | -5,359,701 | -39,478 | 0.0 | NA |
| Caldaers Nuevas Mix Drum | D-940 | N/A | Dry Natural Gas | 20 | 3,938 | 0 | 0 | 1,820,648 | 9,472 | 46.2 | 2.16 |
| | | 2013-02-06 | Gas de Campos | 20 | 3,938 | 0 | 0 | 1,629,291 | 8,063 | 41.4 | 2.42 |
| | | 2013-02-01 | Refinery gas @ 100% | 20 | 0 | 0 | 0 | 0 | 0 | 0.0 | NA |
| | | 2013-01-31 | Refinery gas @ 50% | 20 | 0 | 0 | 0 | -239,285 | -1,763 | 0.0 | NA |
| | | 2013-02-04 | Refinery gas @ 85% | 20 | 0 | 0 | 0 | -16,014 | -118 | 0.0 | NA |
| | | 2013-02-01 | Normal Operation | 20 | 0 | 0 | 0 | -99,343 | -732 | 0.0 | NA |
| | | 2013-01-31 | HDT, Orthoflow and Mod IV | 20 | 0 | 0 | 0 | -248,851 | -1,833 | 0.0 | NA |
| | | 2013-02-04 | Normal Operation | 20 | 0 | 0 | 0 | -159,894 | -1,178 | 0.0 | NA |
| Central Norte Mix Drum | D-2421 | N/A | Dry Natural Gas | 20 | 78,530 | 0 | 0 | 2,395,507 | -60,885 | 3.1% | 32.78 |
| | | 2013-02-06 | Gas de Campos | 20 | 78,530 | 0 | 0 | -269,414 | -80,514 | -0.3 | NA |
| | | 2013-02-01 | Normal Operation | 20 | 0 | 0 | 0 | -4,770,063 | -35,135 | 0.0 | NA |
| | | 2013-02-04 | Normal Operation | 20 | 0 | 0 | 0 | -2,382,945 | -17,552 | 0.0 | NA |
| Distral Mix Drum | D 968 | N/A | Dry Natural Gas | 20 | 33,410 | 0 | 0 | 6,418,310 | 13,866 | 19.2 | 5.21 |
| | | 2013-02-06 | Gas de Campos | 20 | 33,410 | 0 | 0 | 5,256,073 | 5,305 | 15.7 | 6.36 |
| | | 2013-02-04 | Normal Operation | 20 | 0 | 0 | 0 | 2,318,228 | 17,075 | 0.0 | 0.00 |
| Foster Mix Drum | D-942 | N/A | Dry Natural Gas | 20 | 10,586 | 0 | 0 | 2,909,754 | 10,846,59 6 | 27.5 | 3.64 |

| Table 4: Economic analysis of fuel switching or pre-processing at the Barrancabermeja Refinery. | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Source** | **Tag No.** | **Date** | **Fuel Mix Scenario** | **Application Life Expectancy (y)** | **Capital Cost ($10^3$ USD)** | **Net Present Salvage Value (USD)** | **Net Operating Cost (USD/y)** | **Value of Conserved Energy (USD/y)** | **NPV ($10^3$ USD)** | **ROI (%)** | **Payback Period (y)** |
| | | 2013-02-06 | Gas de Campos | 20 | 10,586 | 0 | 0 | 2,485,952 | 7,724,970 | 23.5 | 4.26 |
| | | 2013-02-01 | Normal Operation | 20 | 0 | 0 | 0 | 242,081 | 1,783,118 | 0.0 | 0.00 |

### 3.2 <u>Boilers</u>

Most of the steam boilers at the refinery were subjected to a combustion test to determine any opportunities to optimize their performance through tuning. While all of the boilers have $O_2$ sensors on the flue gas stacks for use in automated excess-air control, it was noted that some of the $O_2$ sample lines were plugged and in need of servicing. Thus, the affected boilers had incorrect $O_2$ control.

The results of the combustion tests indicated tuning of the boilers would result in 0.754 million USD annually in fuel savings (see Table 5) and 6.2 kt/y in $CO_2E$ emission reductions (see Table 6). The economics of implementing an improved control system that adjusts the air-to-fuel ratio based on both the fuel quality and that includes regular manual checking of the thermal efficiencies using a portable combustion analyzer is presented in Table 7. The detailed analysis results are presented in Appendix C.

**Table 5: Commodity losses due to tuning opportunities for the process boilers at the Barrancabermeja Refinery.**

| Source | Value of Avoidable Fuel Consumption (USD/y) | Total Avoidable Fuel Consumption ($m^3$/h) | Residue Gas ($10^3$ $m^3$/d) | Ethane ($m^3$/d liq) | LPG ($m^3$/d liq) | NGL ($m^3$/d) | Hydrogen ($m^3$/d) |
|---|---|---|---|---|---|---|---|
| Balance Boiler 1 | 25,998 | 16.02 | 0.35 | 0.06 | 0.02 | 0.00 | 6.08 |
| Balance Boiler 2 | 3,710 | 2.29 | 0.05 | 0.01 | 0.00 | 0.00 | 0.87 |
| Balance Boiler 3 | 9,450 | 5.82 | 0.13 | 0.02 | 0.01 | 0.00 | 2.21 |
| Balance Boiler 4 | 2,312 | 1.42 | 0.03 | 0.01 | 0.00 | 0.00 | 0.54 |
| Balance Boiler 5 | 10,200 | 6.28 | 0.14 | 0.02 | 0.01 | 0.00 | 2.39 |
| Calderas Nuevas Boiler | 537,116 | 256.98 | 2.48 | 2.05 | 2.41 | 0.18 | 2,282.81 |
| Central Norte Boiler 1 | 18,602 | 11.80 | 0.26 | 0.05 | 0.01 | 0.00 | 0.00 |
| Central Norte Boiler 2 | 15,954 | 10.12 | 0.22 | 0.04 | 0.01 | 0.00 | 0.00 |
| Central Norte Boiler 3 | 32,723 | 20.75 | 0.46 | 0.09 | 0.02 | 0.00 | 0.00 |
| Central Norte Boiler 4 | 479 | 0.30 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| Distral Boiler 4 | 48,427 | 24.32 | 0.41 | 0.15 | 0.17 | 0.01 | 65.26 |
| Distral Boiler 5 | 32,590 | 16.37 | 0.27 | 0.10 | 0.12 | 0.01 | 43.92 |
| Distral Boiler 6 | 980 | 0.49 | 0.01 | 0.00 | 0.00 | 0.00 | 1.32 |
| Foster Boiler B | 7,246 | 4.22 | 0.05 | 0.02 | 0.02 | 0.00 | 36.86 |
| Foster Boiler D | 7,770 | 4.53 | 0.06 | 0.02 | 0.02 | 0.00 | 39.52 |
| Total | 753,557 | 381.71 | 4.93 | 2.64 | 2.84 | 0.21 | 2,481.77 |

**Table 6: Estimated emissions reduction potential due to tuning opportunities for the process boilers at the Barrancabermeja Refinery.**

| Source Name | $CH_4$ (t/y) | $CO_2$ (t/y) | $N_2O$ (t/y) | $CO_2E$ (t/y) | VOC (t/y) | CO (t/y) | $NO_x$ (t/y) | $SO_2$ (t/y) | PM (t/y) |
|---|---|---|---|---|---|---|---|---|---|
| Balance Boiler 1 | 0.01 | 278.57 | 0.01 | 280.25 | 0.01 | 0.00 | 0.23 | 0.00 | 0.00 |
| Balance Boiler 2 | 0.00 | 39.76 | 0.00 | 40.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 |

| Table 6: Estimated emissions reduction potential due to tuning opportunities for the process boilers at the Barrancabermeja Refinery. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Source Name** | **$CH_4$ (t/y)** | **$CO_2$ (t/y)** | **$N_2O$ (t/y)** | **$CO_2E$ (t/y)** | **VOC (t/y)** | **CO (t/y)** | **$NO_x$ (t/y)** | **$SO_2$ (t/y)** | **PM (t/y)** |
| Balance Boiler 3 | 0.00 | 101.26 | 0.00 | 101.86 | 0.00 | 0.00 | 0.11 | 0.00 | 0.00 |
| Balance Boiler 4 | 0.00 | 24.77 | 0.00 | 24.92 | 0.00 | 0.01 | 0.02 | 0.00 | 0.00 |
| Balance Boiler 5 | 0.00 | 109.29 | 0.00 | 109.95 | 0.01 | 0.08 | 0.11 | 0.00 | 0.00 |
| Calderas Nuevas Boiler | 0.08 | 4,039.14 | 0.08 | 4,064.43 | 0.19 | 101.28 | 9.95 | 0.00 | 0.07 |
| Central Norte Boiler 1 | 0.00 | 205.55 | 0.00 | 206.78 | 0.01 | 0.00 | 0.12 | 0.00 | 0.00 |
| Central Norte Boiler 2 | 0.00 | 176.28 | 0.00 | 177.34 | 0.01 | 0.12 | 0.15 | 0.00 | 0.00 |
| Central Norte Boiler 3 | 0.01 | 361.58 | 0.01 | 363.74 | 0.02 | 0.00 | 0.21 | 0.00 | 0.01 |
| Central Norte Boiler 4 | 0.00 | 5.29 | 0.00 | 5.32 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Distral Boiler 4 | 0.01 | 444.13 | 0.01 | 446.75 | 0.02 | 0.02 | 0.37 | 0.00 | 0.01 |
| Distral Boiler 5 | 0.01 | 298.88 | 0.01 | 300.65 | 0.01 | 0.00 | 0.25 | 0.00 | 0.00 |
| Distral Boiler 6 | 0.00 | 8.99 | 0.00 | 9.04 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 |
| Foster Boiler B | 0.00 | 57.35 | 0.00 | 57.72 | 0.00 | 0.04 | 0.05 | 0.00 | 0.00 |
| Foster Boiler D | 0.00 | 61.49 | 0.00 | 61.89 | 0.00 | 0.05 | 0.06 | 0.00 | 0.00 |
| Total | 0.13 | 6,212.32 | 0.11 | 6,250.65 | 0.29 | 101.60 | 11.67 | 0.00 | 0.10 |

| Table 7: Economic analysis of implementing a program to provide improved control of the boilers and provide regular verification of their performance at the Barrancabermeja Refinery. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Source Name** | **Application Life Expectancy (y)** | **Capital Cost (USD)** | **Net Present Salvage Value (USD)** | **Net Operating Cost (USD/y)** | **Value of Conserved Energy (USD/y)** | **NPV (USD)** | **ROI (%)** | **Payback Period (y)** |
| Balance Boiler 1 | 20 | 149,063 | 0 | 4,375 | 22,883 | -$12,735 | 12.42% | 8.1 |
| Balance Boiler 2 | 20 | 149,063 | 0 | 4,375 | 3,396 | -$156,277 | None | N/A |
| Balance Boiler 3 | 20 | 149,063 | 0 | 4,375 | 4,309 | -$149,550 | None | N/A |
| Balance Boiler 4 | 20 | 149,063 | 0 | 4,375 | 2,054 | -$166,156 | None | N/A |
| Balance Boiler 5 | 20 | 149,063 | 0 | 4,375 | 9,396 | -$112,077 | 3.37% | 29.7 |
| Calderas Nuevas Boiler | 20 | 149,063 | 0 | 4,375 | 414,756 | $2,873,714 | 275.31% | 0.4 |
| Central Norte Boiler 1 | 20 | 149,063 | 0 | 4,375 | 16,685 | -$58,393 | 8.26% | 12.1 |
| Central Norte Boiler 2 | 20 | 149,063 | 0 | 4,375 | 14,128 | -$77,222 | 6.54% | 15.3 |
| Central Norte Boiler 3 | 20 | 149,063 | 0 | 4,375 | 29,269 | $34,301 | 16.70% | 6.0 |
| Central Norte Boiler 4 | 20 | 149,063 | 0 | 4,375 | 364 | -$178,607 | None | N/A |
| Central Norte Boiler 5 | 20 | 149,063 | 0 | 4,375 | 0 | -$181,288 | None | N/A |
| Distral Boiler 4 | 20 | 149,063 | 0 | 4,375 | 44,080 | $143,395 | 26.64% | 3.8 |
| Distral Boiler 5 | 20 | 149,063 | 0 | 4,375 | 29,120 | $33,202 | 16.60% | 6.0 |
| Distral Boiler 6 | 20 | 149,063 | 0 | 4,375 | 888 | -$174,744 | None | N/A |
| Foster Boiler B | 20 | 149,063 | 0 | 4,375 | 6,465 | -$133,671 | 1.40% | 71.3 |
| Foster Boiler D | 20 | 149,063 | 0 | 4,375 | 6,681 | -$132,078 | 1.55% | 64.6 |
| Total | 20 | 2,385,008 | 0 | 70,000 | 604,474 | 1,551,814 | --- | --- |

### 3.3 Steam System

The results from analysis of the steam system are presented in Table 8, Table 9 and Table 10. Two opportunities are considered: (1) improved management of steam losses due to blowdowns and fugitive leaks to bring the amount of losses in line with industry benchmarks for similar systems, and (2) converting from the use of steam to air as the assist gas for the flare stacks. The total reported amount of fuel consumption and corresponding direct emissions produced by the steam system are summarized in Table 1 and Table 2. Table 8 presents the estimated amount of fuel consumption that could be avoided through each of the proposed steam management options and Table 9 presents the associated emission reductions that could be achieved. An economic evaluation of two steam management options is presented in Table 10. The detailed results are presented in Appendix D.

The results indicate that up to 35.4 million USD in annual fuel costs could be eliminated through improved management of steam losses through implementation of a formal leak detection and repair program. This would also reduce GHG emissions by 354.9 kt/y. A more detailed review of the individual steam leaks is warranted to better evaluate the costs of such a program. Use of the VPAC acoustical leak detector is one potential option that may be used to estimate the amount of leakage from individual components.

The amount of steam used as assist gas for the flare stacks costs $0.339 million annually in fuel and contributes 3.403 kt/y of $CO_2E$. The cost of converting from steam assist to air assist is estimated at 1.03 million USD and the payback period is 3.2 years. The cost costs of implementing a formal program to manage steam leaks is based on typical data for other industrial facilities with appropriate scaling to account for differences in size. Despite an estimated capital cost of 195 thousand USD, an annual operating cost of 1.7 million USD, and an assumed control efficiency of 70%, the payback period is less than one month.

| Table 8: Fuel consumption associated with current steam losses and use of steam for flare assist gas at the Barrancabermeja Refinery. | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Source** | **Value of Avoidable Fuel Consumption (USD/y)** | **Total Avoidable Fuel Consumption ($m^3$/h)** | **Residue Gas ($10^3$ $m^3$/d)** | **Ethane ($m^3$/d liq)** | **LPG ($m^3$/d liq)** | **NGL ($m^3$/d)** | **Hydrogen ($m^3$/d)** |
| Steam Generation System (Refinery) | 35,373,300 | 20,607.73 | 395.24 | 103.47 | 68.02 | 5.58 | 41,683.46 |
| Flaring Steam Assist (Medium-pressure Steam) | 339,133 | 197.57 | 3.79 | 0.99 | 0.65 | 0.05 | 399.63 |
| Total | 35,712,432 | 20,805.30 | 399.03 | 104.47 | 68.68 | 5.63 | 42,083.09 |

| Table 9: Estimated incremental emissions associated with avoidable steam losses at the Barrancabermeja Refinery. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Source Name** | **$CH_4$ (t/y)** | **$CO_2$ (t/y)** | **$N_2O$ (t/y)** | **$CO_2E$ (t/y)** | **VOC (t/y)** | **CO (t/y)** | **$NO_x$ (t/y)** | **$SO_2$ (t/y)** | **PM (t/y)** |
| Steam Generation System (Refinery) | 7.09 | 352,788.70 | 6.38 | 354,916.73 | 16.31 | 505.12 | 268.56 | 0.00 | 5.67 |
| Flaring Steam Assist (Medium-pressure Steam) | 0.07 | 3,382.27 | 0.06 | 3,402.68 | 0.16 | 4.84 | 2.57 | 0.00 | 0.05 |
| Total | 7.16 | 356,170.97 | 6.45 | 358,319.41 | 16.47 | 509.97 | 271.13 | 0.00 | 5.73 |

| Table 10: Economic analysis of converting from steam-assist to air-assist for the flares and implement an enhanced program for managing steam leaks at the Barrancabermeja Refinery. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Source Name and Recommended Control Measure** | **Application Life Expectancy (y)** | **Capital Cost (USD)** | **Net Present Salvage Value (USD)** | **Net Operating Cost (USD/y)** | **Value of Conserved Energy (USD/y)** | **NPV (USD)** | **ROI (%)** | **Payback Period (y)** |
| Steam Generation System (Refinery): Implementation of an Enhanced Leak Management Program | 20 | 195,000 | 0 | 1,680,000 | 26,529,975 | 182,844,368 | 12,743 | 0.0 |
| Flaring Steam Assist (Medium-pressure Steam): Conversion to Air Assist | 20 | 1,025,283 | 0 | 0 | 318,566 | 1,321,203 | 31 | 3.2 |

### 3.4 Storage Tanks

Several refined-product storage tanks were screened using a hydrocarbon vapour-imaging IR camera to check for noteworthy product evaporation losses. Copies of the IR images were submitted separately. While the emissions are not quantified using this approach, the method does provides a qualitative indication of the amount of leakage and allows the viewer to see exactly where the emissions are occurring (i.e., appreciably from the rim seal and some of the deck fittings). The seals on these tanks should be repaired. If this does not resolve the problem then the volatility of the stored product should be examined and consideration should be given to either adjusting the product vapour pressure or installing a vapour control system on the affected tanks.

The refinery would benefit from having its own camera and should consider purchasing one to conduct its own screening programs. The camera could also be used to screen for fugitive equipment leaks and other forms of hydrocarbon releases. The cost of a hydrocarbon imaging infrared campers is approximately 70 thousand USD.

### 3.5 Flares

The refinery has relatively low flaring rates amounting to just under 1.0 million USD in energy losses (see Table 11) and emissions of 6.225 kt $CO_2E$ (see Table 12) annually. Still, there may be some potential to optimize the flare purge gas consumption and reduce purge rates as leakage rates increase. A discussion of best practices for managing flare valve leakage and purge gas consumptions are presented in Appendix E. The potential economics of implementing such management program is provided in Table 13. The detailed results are presented in Appendix E.

**Table 11: Commodity losses due flaring at the Barrancabermeja Refinery.**

| Source | Value of Avoidable Product Losses (USD/y) | Total Avoidable Product Loss ($m^3$/h) | Residue Gas ($10^3$ $m^3$/d) | Ethane ($m^3$/d liq) | LPG ($m^3$/d liq) | NGL ($m^3$/d) | Hydrogen ($m^3$/d) |
|---|---|---|---|---|---|---|---|
| Flare TEA-1 | 167,445 | 17.74 | 0.02 | 0.07 | 1.23 | 0.25 | 19.38 |
| Flare TEA-2 | 349,338 | 55.46 | 0.18 | 0.45 | 1.72 | 0.78 | 210.25 |
| Flare TEA-3 | 82,918 | 30.96 | 0.16 | 0.52 | 0.34 | 0.09 | 270.39 |
| Flare TEA-4 | 97,740 | 40.68 | 0.02 | 3.21 | 0.01 | 0.00 | 26.51 |
| Flare TEA-6 | 191,429 | 64.00 | 0.57 | 0.80 | 1.27 | 0.04 | 329.85 |
| Flare TEA-7 | 39,651 | 6.64 | 0.02 | 0.06 | 0.32 | 0.03 | 20.04 |
| Total | 928,520 | 215.48 | 0.97 | 5.12 | 4.90 | 1.19 | 876.43 |

| Table 12: Estimated emissions associated with flaring at the Barrancabermeja Refinery. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Source Name | $CH_4$ (t/y) | $CO_2$ (t/y) | $N_2O$ (t/y) | $CO_2E$ (t/y) | VOC (t/y) | CO (t/y) | $NO_x$ (t/y) | $SO_2$ (t/y) | PM (t/y) |
| Flare TEA-1 | 0.09 | 984.47 | 0.00 | 986.90 | 0.36 | 2.55 | 0.47 | 0.26 | 0.91 |
| Flare TEA-2 | 0.22 | 1,940.21 | 0.00 | 1,945.87 | 0.72 | 5.17 | 0.95 | 0.00 | 1.85 |
| Flare TEA-3 | 0.20 | 572.49 | 0.00 | 577.12 | 0.25 | 1.81 | 0.33 | 0.00 | 0.65 |
| Flare TEA-4 | 0.02 | 1,273.13 | 0.00 | 1,274.24 | 0.50 | 3.53 | 0.65 | 0.00 | 1.27 |
| Flare TEA-6 | 0.70 | 1,490.45 | 0.00 | 1,506.02 | 0.61 | 4.34 | 0.80 | 0.00 | 1.56 |
| Flare TEA-7 | 0.02 | 254.27 | 0.00 | 254.89 | 0.10 | 0.70 | 0.13 | 8.20 | 0.25 |
| Total | 1.27 | 6,515.02 | 0.01 | 6,545.03 | 2.54 | 18.10 | 3.32 | 8.45 | 6.48 |

| Table 13: Economic analysis of implementing a program to leakage into the flare systems at the Barrancabermeja Refinery. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Source Name | Application Life Expectancy (y) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
| Flare TEA-1 | 20 | 17,500 | 0 | 36,000 | 117,211 | 580,684 | 464.06 | 0.2 |
| Flare TEA-2 | 20 | 17,500 | 0 | 36,000 | 244,537 | 1,518,533 | 1191.64 | 0.1 |
| Flare TEA-3 | 20 | 17,500 | 0 | 36,000 | 58,043 | 144,863 | 125.96 | 0.8 |
| Flare TEA-4 | 20 | 17,500 | 0 | 36,000 | 68,418 | 221,285 | 185.25 | 0.5 |
| Flare TEA-6 | 20 | 17,500 | 0 | 36,000 | 134,000 | 704,346 | 560.00 | 0.2 |
| Flare TEA-7 | 20 | 17,500 | 0 | 36,000 | 27,756 | -78,227 | None | N/A |
| Total | 20 | 105,000 | 0 | 216,000 | 649,965 | 3,091,484 | --- | --- |

### 3.6 UOP I

Plant UOP I does not fully recover all the usable heat from the coke it combusts. The opportunity to implement a waste heat recovery system to produce low-pressure steam was investigated. The recoverable heat amounts to a potential fuel savings worth approximately $1.6 million (see Table 14). The associated emissions reduction would be 17.1 kt/y of $CO_2E$ (see Table 15). The payback is estimated at 0.6 years making this a very financially attractive project to consider (see Table 16). The detailed analysis results are presented in Appendix F.

**Table 14: Avoidable fuel consumption from implementing a waste heat recovery project at Plant UOPI at the Barrancabermeja Refinery.**

| Source | Value of Avoidable Fuel Consumption (USD/y) | Total Avoidable Fuel Consumption ($m^3/h$) | Residue Gas ($10^3$ $m^3/d$) | Ethane ($m^3/d$ liq) | LPG ($m^3/d$ liq) | NGL ($m^3/d$) | Hydrogen ($m^3/d$) |
|---|---|---|---|---|---|---|---|
| UOP I | 1,551,914 | 955.27 | 21.02 | 5.53 | 1.06 | 0.16 | 0.00 |
| Total | 1,551,914 | 955.27 | 21.02 | 5.53 | 1.06 | 0.16 | 0.00 |

**Table 15: Estimated emissions reductions from implementing a waste-heat recovery project in Plant UOP I at the Barrancabermeja Refinery.**

| Source Name | $CH_4$ (t/y) | $CO_2$ (t/y) | $N_2O$ (t/y) | $CO_2E$ (t/y) | VOC (t/y) | CO (t/y) | $NO_x$ (t/y) | $SO_2$ (t/y) | PM (t/y) |
|---|---|---|---|---|---|---|---|---|---|
| UOP I | 0.34 | 17,112.43 | 0.31 | 17,214.65 | 0.78 | 11.92 | 14.31 | 0.00 | 0.27 |
| Total | 0.34 | 17,112.43 | 0.31 | 17,214.65 | 0.78 | 11.92 | 14.31 | 0.00 | 0.27 |

**Table 16: Economic analysis of installing a waste-heat recovery project in Plant UOP I at the Barrancabermeja Refinery.**

| Source Name | Application Life Expectancy (y) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| UOP I | 20 | 1,002,500 | $0 | $0 | $1,551,914 | $10,428,549 | 154.80% | 0.6 |

# 4 CONCLUSIONS AND RECOMMENDATIONS

## 4.1 Conclusions

There are a number of potentially large cost-effective opportunities to reduce GHG emissions and improve energy efficiencies at the Barrancabermeja Refinery. The key opportunities are delineated in Table 17 and include:

- Implement product recovery systems or improved controls to preclude losses of hydrogen and valuable LPG and NGLs into the fuel gas system (12.5 million USD/y in gross savings potential and 8.4 kt/y $CO_2E$ emissions reduction without considering indirect emission contributions).
- Improved tuning and control of the process boilers (0.604 million USD/y gross savings potential and 5.0 kt/y $CO_2E$ emissions reduction), with a payback period of 4.5 years.
- Improved management of the steam system to bring steam losses at the refinery in line with industry standards (35.4 million USD/y gross savings potential and 354.9 kt/y $CO_2E$ emissions reduction, with a payback of <0.1years).
- Conversion from the use of steam to air as the flare assist gas (0.339 million USD/y gross savings potential and 3.4 kt/y $CO_2E$ emissions reduction and an estimated payback period of 3.2 years).
- Improved monitoring and maintenance of floating roof seals.
- Management of leakage unto the flare systems and optimization of purge gas consumption (0.928 million USD/y gross savings potential and 6.5 kt/y $CO_2E$ emissions reduction, with an estimated payback period of 0.2 years).
- Implementation of a waste heat recovery system in UOP I to produce low pressure steam (1.6 million USD/y gross savings potential and 17.2 kt/y $CO_2E$ emissions reduction, with an estimated payback period of 0.6 years).

## 4.2 Recommendations

Each of the opportunities should be subjected to a refined analysis to build a strong business case to proceed with the best of these opportunities. The refined analysis should identify and evaluate all key site-specific constraints and consider local labour and material costs.

| Table 17: Summary of evaluated opportunities and recommended actions. | | | | | | |
|---|---|---|---|---|---|---|
| **Opportunity** | **Potential Gross Savings (Million USD/y)** | **Potential GHG Reduction (kt/y)** | **Recommended Control Measures or Actions** | **Capital Costs (Million USD)** | **Payback Period (Years)** | **Comments** |
| Fuel Switching or Preprocessing | 12.5 | 8.4 | Review existing control systems to develop a practicable strategy to avoid producing excess hydrogen in the hydrogen plants. As well, consider installing a gas processing facility to recovery LPG and NGL from the produced refinery gas before using it as a fuel. | 48.034 | 3.8 | The fuel gas being burned in the steam boilers is rich in valuable LPG and NGL fractions as well as hydrogen. These valuable fractions should be recovered before using the gas as fuel. Additionally, there are potentially significant swings in the fuel gas composition which is believed to be adversely affecting the performance of the boilers. |
| Tuning of Steam Boilers | 0.753 | 6.2 | Implement a formal program to regularly validate online boiler $O_2$ analyzers. This would comprise performing independent manual checks using a portable combustion analyzer. | 2.385 | 4.5 | Some of the $O_2$ sampling ports for the continuous online analyzers were plugged. Thus, at a minimum the current maintenance |

| Table 17: Summary of evaluated opportunities and recommended actions. | | | | | | |
|---|---|---|---|---|---|---|
| **Opportunity** | **Potential Gross Savings (Million USD/y)** | **Potential GHG Reduction (kt/y)** | **Recommended Control Measures or Actions** | **Capital Costs (Million USD)** | **Payback Period (Years)** | **Comments** |
| | | | | | | procedures for these systems should be reviewed to develop a strategy for avoiding future occurrences. |
| Conversion from Steam to Air Assist Flares | 0.339 | 3.4 | Converting to from steam to air assist would involve replacing the flare tip, installing a blower and possibly modifying the assist gas piping. This work would have to be deferred until a scheduled facility shutdown. | 1.025 | 3.2 | Many facilities are tending to convert from steam assist to air assist to reduce operating costs. |
| Improved Management of Fugitive Steam Losses | 35.373 | 354.9 | Numerous instances of steam losses were observed throughout the refinery. These losses are sufficient to warrant a formal program to regularly detect and repair steam leaks. A review of these losses is needed to identify and focus efforts on the primary causes of these losses. | 0.195 | <0.1 | None |
| Improved Management of Flaring | 0.929 | 6.5 | Overall, the flares appeared to be well managed; however, there is still an opportunity for improved management of these sources through measures such as | 0.105 | <0.8 | None |

| Table 17: Summary of evaluated opportunities and recommended actions. | | | | | | |
|---|---|---|---|---|---|---|
| **Opportunity** | **Potential Gross Savings (Million USD/y)** | **Potential GHG Reduction (kt/y)** | **Recommended Control Measures or Actions** | **Capital Costs (Million USD)** | **Payback Period (Years)** | **Comments** |
| | | | optimizing purge gas consumption and managing leakage into the flare headers (for example, using a VPAC system). | | | |
| Waste Heat Recovery in UOP I | 1.552 | 17.2 | This opportunity would involve installing a heat exchange to recover waste heat from the flue gas to produce low-pressure steam. | 1.002 | 0.6 | None |
| Total | 51.446 | 396.6 | --- | 52.746 | --- | None |

## 5 REFERENCES CITED

None.

## APPENDIX A GLOSSARY

### General Terminology

Air Toxics - air pollutants that are either known or believed to have an adverse effect on human health. For many such compounds 15-minute, 1-hour and 8-hour occupational exposure limits have been established but acceptable limits for prolonged low-concentration exposure are uncertain.

Acid Precipitation - acid precipitation (or acid rain) results from the atmospheric emission of $SO_x$ and $NO_x$. Both types of pollutants are products of combustion. In the air, these substances react with atmospheric moisture to produce sulphuric ($H_2SO_4$) and nitric ($HNO_3$) acid, respectively. Eventually, these substances are carried to earth by precipitation (rain or snow).

The precursors of acid rain may produce respiratory and other internal disease when inhaled in high concentrations. Also, acid rain has potentially serious indirect effects on human health. The two major concerns regarding indirect health effects are: (1) the leaching of toxic chemicals by acidified waters leading to contamination of drinking water supplies, and (2) the contamination of edible fish by toxic chemicals, principally mercury. Acid rain has also been known to damage aquatic ecosystems (National Research Council, 1981).

Choked Flow - occurs where the local fluid velocity is equal to the speed of sound in that fluid at its flowing temperature and pressure. Under these conditions the fluid flow is too fast for decompression waves to travel upstream. Consequently, there is no longer any driving force for further increases in the flow rate and the flow is therefore choked.

Combustion Efficiency - the extent to which all input combustible material has been completely oxidized (i.e., to produce $H_2O$, $CO_2$ and $SO_2$). Complete combustion is often approached but is never actually achieved. The main factors that contribute to incomplete combustion include thermodynamic, kinetic, mass transfer and heat transfer limitations. In fuel rich systems, oxygen deficiency is also a factor.

Criteria Air Pollutants - pollutants for which ambient air quality objectives have been promulgated. These typically include $SO_2$, $NO_x$, PM, and CO. Additionally, VOCs also may be a criteria air pollutant in some jurisdictions.

Destruction Efficiency - the extent to which a target substance present in the input combustibles has been destroyed (i.e., converted to intermediate, partially-oxidized and fully-oxidized products of combustion).

Fugitive Emissions - unintentional leaks from piping and associated equipment components (e.g., from seals, packings or gaskets, or leaks from underground pipelines [resulting from corrosion, faulty connection, etc.]). Fugitive sources tend to be continuous emitters and have low to moderate emission rates.

Global Warming Potential (GWP) - the amount of radiative forcing on the climate produced per unit mass of a specific greenhouse gas relative to that produced by $CO_2$. For example, $CO_2$ has a GWP of 1 while $CH_4$ and $N_2O$ have GWPs of 21 and 310, respectively. These values include both direct and indirect effects.

Greenhouse Gases - these are substances that cause radiative forcing on the climate (i.e., contribute to global warming) when emitted into the atmosphere. Current focus is on those greenhouse gases increasing in atmospheric due to human activities, primarily $CO_2$, $CH_4$, CFCs and $N_2O$.

Continued global warming could be expected to result in a significant rise in the present sea level, altered precipitation patterns and changed frequencies of climatic extremes. The potential effects of these changes include altered distribution and seasonal availability of fresh water resources, reduced crop yields and forest productivity and increased potential for tropical cyclones.

Heat Rate - the amount of heat energy (based on the net or lower heating value of the fuel) which must be input to a combustion device to produce the rated power output. Heat rate is usually expressed in terms of net J/kW·h.

Kinetics and Thermodynamics - thermodynamic equilibrium defines the maximum extent to which a chemical reaction, such as combustion, may proceed (i.e., the point at which there is no further tendency for change).

Chemical kinetics determines the rate at which a chemically reacting system will approach the point of thermodynamic equilibrium.

Methane Content of Natural Gas - volume of methane contained in a unit volume of natural gas at 15°C 101.325 kPa.

Nitrogen Oxides ($NO_x$) - the total of all forms of oxidized nitrogen at a given measurement point. The primary form of $NO_x$ emitted by combustion devices is $NO_2$; however, other forms may include NO, $N_2O$, $NO_3$, $N_2O_4$ and $N_2O_5$. Convention is to express total $NO_x$ in terms of equivalent $NO_2$.

There are three mechanisms for the formation of $NO_x$ in combustion processes: thermal fixation of nitrogen from the combustion air (thermal $NO_x$), oxidation of fuel-bound nitrogen compounds (chemical $NO_x$), and the formation of CN compounds in the flame zone which subsequently react to form NO (prompt $NO_x$). Thermal $NO_x$ is the predominant form of $NO_x$ produced from natural gas combustion. The conditions that govern the formation of thermal $NO_x$ are the peak temperature, residence time at the peak temperature and the availability of oxygen while that temperature exists.

Fuel-bound nitrogen is an important source of $NO_x$ where appreciable amounts of such fuels are used. The extent of conversion of fuel-bound nitrogen to NO is nearly independent of the parent fuel molecule, but is strongly dependent on the local combustion environment and on the initial amount of fuel-bound nitrogen.

Prompt $NO_x$ is associated with the combustion of hydrocarbons. The maximum formation of prompt $NO_x$ is reached on the fuel-rich side of stiochiometric, it remains high through a fuel-rich region, and then drops off sharply when the fuel-air ratio is about 1.4 times the value at stiochiometric.

$NO_x$ controls can be classified into types: post combustion methods and combustion control techniques. Post combustion methods address $NO_x$ emissions after formation while combustion control techniques prevent the formation of $NO_x$ during the combustion process. Post combustion methods tend to be more expensive than combustion control techniques.

Post combustion control methods include selective non-catalytic reduction, and selective catalytic reduction.

Combustion control techniques depend on the type of combustion device and fuel. Nonetheless, they generally are designed to achieve lower combustion temperatures without significantly affecting combustion efficiency and power output, and to avoid/minimize the use of nitrogen containing fuels.

Particulate Matter (PM) - particulate matter is that portion of the flue gas which exists as a solid or liquid droplet when it leaves the stack and cools to ambient conditions. Carbonaceous particulate that forms from gas-phase processes is generally referred to as soot, and that developed from pyrolysis of liquid hydrocarbon fuels is referred to as coke or cenospheres.

The potential for particulate emissions is generally dependent on the composition of the fuel and the type of combustion device. Combustion of natural gas produces very small amounts of particulate emissions compared to other types of fuels. Nonetheless, the amount of particulate emissions will tend to increase with the molecular weight of the gas. Also, reciprocating engines produce the most particulate matter while heaters and boilers produce the least. Most of the particulate matter emitted by reciprocating engines is reportedly due to lubricating oil leakage past the piston rings.

Particulate emissions generally are classified as PM, $PM_{10,}$ $PM_{2.5}$ and $PM_1$ according to the maximum diameter of the material, namely, total PM, and PM with a diameter less than 10, 2.5 and 1 microns, respectively. $PM_{10}$ and smaller particulate matter are of greatest concern because of their ability to bypass the body's natural filtering system.

Photochemical Oxidants - photochemical oxidants are a class of pollutants produced by the reaction of VOCs and $NO_x$ in the presence of solar radiation which accumulate in the air near ground level. Ozone ($O_3$) is the principal oxidant produced; however, significant levels of peroxyacetyl nitrate (PAN) and nitrogen dioxide ($NO_2$) also occur.

Exposure to increased ozone concentrations can cause short-term impairment of the respiratory system and is suspected of playing a role in the long-term development of chronic lung disease.

Damage to vegetation caused by ozone is reported (Wilson et al., 1984) to be greater than that caused by commonly occurring air contaminants such as $SO_2$, $NO_2$, or acidic precipitation. Also, elevated ozone concentrations produce smog and cause deterioration and cracking of rubber products.

Pipeline Leak - fugitive emission through a small opening in the wall of the pipeline or from valves, fittings or connectors attached to that pipeline.

Power Output - for engines it is the net shaft power available after all losses and power take-offs (e.g., ignition-system power generators, cooling fans, turbo chargers and pumps for fuel, lubricating oil and liquid coolant) have been subtracted. For heaters and boilers it is the net heat transferred to a target process fluid or system.

Products of Incomplete Combustion - these are any compounds, excluding $CO_2$, $H_2O$, $SO_2$, HCl and HF, that contain C, H, S, Cl or F and occur in the flue gas stream. These compounds may result from thermodynamic, kinetic or transport limitations in the various combustion zones. All input combustibles are potential products of incomplete combustion. Intermediate substances formed by dissociation and recombination effects may also occur as products of incomplete combustion (CO is often the most abundant combustible formed).

Residual Flare Gas - the sum of the flare purge gas flow and any leakage into the flare header. This is the total gas flow rate that occurs in the header to an intermittent flare during the periods between flaring events.

Standard Reference Conditions - most equipment manufacturers reference flow, concentration and equipment performance data at ISO standard conditions of 15°C, 101.325 kPa, sea level and 0.0 percent relative humidity.

The following equation shows how to correct pollutant concentrations measured in the exhaust to 3 percent oxygen (15% excess air) for comparison and regulatory compliance purposes:

$$ppm(3\%) = \frac{21-3}{21-O_2(actual)} \; x \; ppm(actual)$$

Subsonic Flow - flow where the local fluid velocity is less the speed of sound in that fluid at its flowing temperature and pressure.

Sulphur Oxides ($SO_x$) - usually almost all sulphur input to a combustion process as part of the fuel or waste materials being burned is converted to $SO_x$. Only a few percent of the available sulphur is emitted as sulphate particulate and other products of incomplete combustion. The produced $SO_x$ is comprised mostly of $SO_2$ (typically 95 percent) with the rest being $SO_3$. For simplification purposes it is assumed throughout this document that all input sulphur is converted to $SO_2$.

Thermal Efficiency - the percentage or portion of input energy converted to useful work or heat output. For combustion equipment, typical convention is to express the input energy in terms of the net (lower) heating value of the fuel. This results in the following relation for thermal efficiency:

$$\eta = \mathit{Thermal\ Efficiency} = \frac{\mathit{Useful\ Work/Heat\ Output}}{\mathit{Net\ Heat/Energy\ Input}}\ x\ 100\%$$

Alternatively, thermal efficiency may be expressed in terms of energy losses as follows:

$$\eta = \left(1 - \frac{\Sigma \mathit{Energy\ Losses}}{\mathit{Net\ Heat/Energy\ Input}}\right) x\ 100\%$$

Losses in thermal efficiency occur due to the following potential factors:

- exit combustion heat losses (i.e, residual heat value in the exhaust gases),
- heat rejected through coolant and lube oil cooling systems (where applicable),
- heat losses from the surface of the combustion unit to the atmosphere (i.e., from the body and associated piping of a heater, boiler or engine),
- air infiltration,
- incomplete combustion, and
- mechanical losses (e.g., friction losses and energy needed to run cooling fans and lubricating-oil pumps).

Total Hydrocarbons - all compounds containing at least one hydrogen atom and one carbon atom.

Total Volatile Organic

| | |
|---|---|
| Compounds (TOC) - | all VOCs plus all non-reactive organic compounds (i.e., methane, ethane, methylene chloride, methyl chloroform, many fluorocarbons, and certain classes of per fluorocarbons). |
| Vented Emissions - | vented emissions are releases to the atmosphere by design or operational practice, and may occur on either a continuous or intermittent basis. The most common causes or sources of these emissions are pneumatic devices that use natural gas as the supply medium (e.g., compressor starter motors, chemical injection and odourization pumps, instrument control loops, valve actuators, and some types of glycol circulation pumps), equipment blowdowns and purging activities, and venting of still-column off-gas by glycol dehydrators. |
| Volatile Organic Compounds (VOC) - | any compounds of carbon, excluding carbon monoxide, and carbon dioxide, which participate in atmospheric chemical reactions. This excludes methane, ethane, methylene chloride, methyl chloroform, many fluorocarbons, and certain classes of per fluorocarbons. |
| Waste Gas - | any gas that leaks into the environment or is vented or flared. |

## APPENDIX B ECONOMIC EVALUATION METHODOLOGY

### B.1 Basic Valuations

(1) Value of an energy stream (USD/y)

The value of an energy stream is assessed using the following relation:

$$V = (Q_{V_{CH4}} \cdot p_{CH4} + Q_{L_{LPG}} \cdot p_{LPG} + Q_{L_{NGL}} \cdot p_{NGL} + Q_{H2} \cdot p_{H2} + e \cdot p_e) \cdot g_c$$

**Equation 1**

Where,

| | | |
|---|---|---|
| V | = | value of a stream (USD/y) |
| p | = | commodity price (USD/unit of flow measure) |
| e | = | electric power consumption (kW·h) |
| $g_c$ | = | constant of proportionality |
| | = | 365 d/y |

(2) Value of Certified Carbon Credits

$$V_{CCC} = VER_{CO2E} \cdot p_{CO2E} \cdot g_c$$

**Equation 2**

Where,

| | | |
|---|---|---|
| $V_{CCC}$ | = | Value of certified carbon credits (USD/y) |
| $VER_{CO2E}$ | = | Verified $CO_2E$ emission reductions achieved (t $CO_2E$/y) |

(3) Net Present Value (NPV)

$$NPV = -CC + SV_{RE} + \frac{SV_{CE}}{(1+i)^N} + \sum_{n=1}^{n=N} \frac{((V_{Losses} \cdot \eta - OC + OCS)}{(1+i)^n}$$

**Equation 3**

Where,

n = a variable indicating the number of years since the start of the project (y),

| | | |
|---|---|---|
| N | = | life expectancy of the project or life expectancy of the control technology, whichever is less (y). |
| i | = | discount rate (expressed as a fractional value). |
| $V_{Losses}$ | = | value of avoidable product losses or energy consumption (\$/y). For the purposes of these calculations, the value of the product losses is assumed to remain constant with time, but would actually tend to increase due to inflation and supply and demand considerations. Also, the costs of any required processing have not been considered in assessing the value of the product losses (these costs are assumed to be small). |
| $\eta$ | = | Control efficiency of the considered control technology (dimensionless fractional value). |
| OC | = | Operating cost of the considered control technology (\$). For the purposes of these calculations, the operating cost is assumed to remain constant; however, these would tend to increase with time due to inflation. |
| OCS | = | Operating and maintenance savings from discontinued use of the replaced System (USD/y) |
| CC | = | Capital cost of the considered control technology (USD). |
| $SV_{RE}$ | = | Net salvage value of any equipment removed when the control technology is installed (USD). |
| $SV_{CE}$ | = | Net salvage value of the control equipment at the end of the project life or at the end of the life of the control technology, whichever occurs first (USD). |

Overall, the actual value of avoided hydrocarbon losses is very site-specific and depends on many factors. Some important considerations are listed below:

- Cost to find, develop, produce, treat/upgrade/process/refine, and deliver the sales product,
- Parts of the system where emission reductions are achieved; for instance, gas conserved before processing is less valuable than gas conserved after processing.
- Impact of emission reductions on specific energy consumption, equipment life, workplace safety, operability, reliability and deliverability.
- Supply and Demand Constraints (Conserved gas often becomes reserve production that is not sold until the reservoir and market conditions change to the point where demand exceeds supplied; this time lag reduces the present value of such gas.)
- Market prices and current contract requirements.
- Government taxes and royalties.

(4) Net Operating Costs

$$NOC = OC + OCS$$

**Equation 4**

Where,

| | | |
|---|---|---|
| NOC | = | net operating costs (USD/y) |
| OC | = | Operating cost of the considered control technology (USD). For the purposes of these calculations, the operating cost is assumed to remain constant; however, these would tend to increase with time due to inflation. |
| OCS | = | Operating and maintenance savings from discontinued use of the replaced System (USD/y) |

(5) Net Present Salvage Value

$$NPSV = SV_{RE} + \frac{FSV_{CE}}{(1+i)^N}$$

**Equation 5**

Where,

| | | |
|---|---|---|
| NPSV | = | Net present salvage value (USD). |
| $SV_{RE}$ | = | Net salvage value of any equipment removed when the control technology is installed (USD). |
| $SV_{CE}$ | = | Net salvage value of the control equipment at the end of the project life or at the end of the life of the control technology, whichever occurs first (USD). |
| N | = | life expectancy of the project or life expectancy of the control technology, whichever is less (y). |

(6) Return on Investment (ROI)

$$ROI = \frac{(V_{Losses} \cdot \eta - OC + OCS)}{CC - SV_{RE}} \cdot 100\%$$

**Equation 6**

Where,

| | | |
|---|---|---|
| $V_{Losses}$ | = | Value of avoidable product losses or energy consumption (USD/y). |
| $\eta$ | = | Efficiency of the selected control measure in reducing product losses and avoidable fuel consumption (fractional dimensionless value). |
| OC | = | Operating cost of the considered control technology (USD). |
| CC | = | Capital cost of the considered control technology (USD). |

(7) Payback Period

$$PP = \frac{CC - SV_{RE}}{V_{Losses} \cdot \eta - OC + OCS}$$

**Equation 7**

## B.2 Avoid Production Losses or Fuel Consumption

Avoided product or commodity losses, reduced fuel requirements, and displacement of wellhead natural gas production through capture and production of waste gas streams is all classified as conserved product and is assessed an economic value. The value of the product depends on the type of product and where in the system it is conserved, the quality of the conserved product, and the applicable regulatory and contract incentives. Generally, the value of natural gas decreases in moving upstream due to increasing treating, processing and transport requirements. One exception to this occurs on some parts of the gas transmission system where existing contracts between producers and pipeline companies offer no incentive for transmission companies to conserve gas. Consequently, for these sections of pipeline, the gas effectively has no value.

Overall, the actual value of avoided hydrocarbon losses is very site-specific and depends on many factors. Some important considerations are listed below:

- Cost to find, develop, produce, treat/upgrade/process/refine, and deliver the sales product,
- Parts of the system where emission reductions are achieved; for instance, gas conserved before processing is less valuable than gas conserved after processing.
- Impact of emission reductions on specific energy consumption, equipment life, workplace safety, operability, reliability and deliverability.
- Supply and Demand Constraints (Conserved gas often becomes reserve production that is not sold until the reservoir and market conditions change to the point where demand exceeds supplied; this time lag reduces the present value of such gas.)
- Market prices and current contract requirements.
- Government taxes and royalties.

## B.3 Capital Costs

Capital costs may include the following major expense categories:

- Public Consultation and Regulatory Approvals,
- Engineering, Procurement and Project-management Services,
- Equipment and Materials,
- Construction Services, and
- Installation of Utility Services (e.g., electric power, fuel gas, water, telecommunications, and roadways).

The applicability and relative contribution of each expense category to total costs depends on the type of control technology being implemented and the specific application.

In assessing the capital costs for each technology it is assumed, for simplicity, that the costs are incurred all in the first year. This may be true for low-capital-cost options but for more capital-intensive options the cost would normally be incurred in phases over several years to help minimize risks. In many applications the total capital cost of a control technology is substantially greater than the direct costs of the basic control devices. For example, the end control device (e.g., an incinerator) for a large-scale vapour collection application may represent less that 10 percent of the total capital cost for the total vapour collection and control system.

Many of the control options considered are add-on devices that have about the same installed cost no matter if it is a new or retrofit application. Where the differences are potentially significant, a weighted cost is used to reflect the anticipated mix of new and retrofit applications. Technologies which may only be feasible in new applications (for example, field upgrading) are priced in terms of the incremental cost relative to a conventional system and are assumed to have fewer potential applications. Where one control device may service a number of different sources at a site (such as a flare system), only a single unit is priced.

The level of specificity and rigor used to assess capital costs varied according to the control technology and the available information. The specific cost elements considered, either directly or indirectly, in each case included the following:

- **Labour** - Labour hours are directly related to the quantities of materials. The relative efficiency of labour depends on the availability of skilled craftsmen and the relative site conditions. Weather conditions may also be important if significant outside work is planned. Remote sites or areas with infrequent workloads may have problems maintaining a reasonable number and selection of qualified crafts people. If adequate numbers of skilled people are not available, training is an option if the project is large enough; or else craftsmen can be imported from other locations. Subsistence and travel pay usually is required when importing crafts people.

- **Excavation/Civil** - Soil conditions and the required depth of any underground systems may have a significant impact on costs. Compaction is also more difficult to achieve in certain situations and this increases the hours needed for backfill operations. Other matters to consider are the presence of rock, high water tables, poor soil conditions requiring removal, availability of import fill, site access for equipment, degree of hand excavation or backfill required, and constraints on pile driving due to close proximity of sensitive operating equipment and buried piping.

- **Concrete** - Foundation costs can be substantial. If piling is required, then the cost of the concrete for pile caps is less than for a spread footing type foundation but the combined cost of piling and pile caps is usually higher. The depth of foundation needed to avoid frost lines is also a factor that can increase the amount of concrete required. Designing for earthquake zones increases the size of the foundations, rebar and anchor bolts and can add 20 to 30 percent to concrete costs. Additionally, soil and environmental conditions which attack concrete may require special mixes of concrete costing more and special coating or treatment of rebar and anchor bolts. Pouring and curing of concrete may require expensive heating and hoarding if done during severe winter conditions.

- **Structural Steel** - Structural steel is required for aboveground piping systems, equipment bases, access platforms, stairs and handrails. Some structural work may be done at fabrication shops and then shipped to the site for reduced costs. Typical company specifications require all structural steel work to be sandblasted, primed and painted.

- **Winterization of Equipment and Piping** - Winterization requirements can drive up costs if heat tracing or additional shelters are required.

- **System Reliability, Operability, Maintainability and Safety** - The reliability, operability, maintainability and risks associated with each option should be clearly identified and considered in the evaluation process. Special safeguarding measures and instrumentation controls may often be required and can add substantially to the overall cost.

- **Spacing** - Facilities that are space-limited may not be able to accommodate combustion-based control equipment due to their spacing requirements (usually at least 25 m). In some such cases it may be possible to acquire additional lease space for a price.

- **Public Response/Perception** - Particular concerns are the potential for off-site noise, visible flames, and odours, especially where the facility may be observed from residential areas, or nearby high-traffic roadways or navigable waterways.

## B.4 Conserved or Displaced Electricity

The amount of utility power avoided through conservation measures or displaced by power production from waste gas streams is assessed and assigned a value based on the commercial price for electricity.

Actual costs may include both a demand and an energy charge, and the applicable rates vary with the size and type of service application. Lower rates are available to large general-service customers.

## B.5 Removal Costs

Removal costs are separate from installation costs and apply where a process unit must be removed and replaced by an alternative unit (e.g., removing gas operating pumps and replacing them with electric powered units).

## B.6 Salvage Value

This is the value of the installed emission control equipment at the end of the project life, and of any equipment removed as part of a control measure (e.g., changing out oversized compressors for improved energy efficiency). It is assumed that each control device has essentially zero salvage value at the end of the analysis period. The decline in value is attributed to a combination of equipment depreciation, obsolescence and high salvage costs.

### B.7 R&D Costs

Some emerging and embryonic control technologies may be assessed a research and development cost. For simplicity, it is assumed that these costs are all incurred in the first year; however, they would normally be incurred over a much longer period of time (e.g., 5 to 10 years).

### B.8 Project Life

The life of a given control option is application dependent and tied directly to the remaining economic life of the associated wells or upstream facilities. Traditionally, new oil and gas developments have been assessed based on a 20-year life expectancy. As the industry ages, however, the quality of finds in the Western Canadian sedimentary basin is gradually declining leading to reduced life expectancies for new projects. As well, average remaining life of existing facilities is declining. In some parts of the industry, such as heavy oil and shallow gas production, the average economic lives of wells has always been relatively low. A typical heavy oil well may only have 2 to 4 years of economic life through application of primary production techniques and an additional 4 to 6 years with subsequent application of enhanced recovery techniques.

### B.9 Operating Cost

The operating amount is the cost of energy consumption, labour, parts, consumables (e.g., filters, replacement parts, lube oil, etc.), environmental reporting, on-going management and supervision, lease payments, insurance premiums, and other associated expenses (e.g., vehicles, subsistence, etc.) that may be required. If a control option is simply to employ a more environmentally-friendly method of performing a required process function, only incremental operating costs are considered.

In most cases, a bottom-up approach has been used to estimate operating costs. The amount of energy consumption is calculated based on the average amount of work done in controlling the target emissions and the efficiency of the process. All other costs are assessed in varying degrees of detail depending on the available information and nature of the control option. Typically, these efforts included compilation of pricing data from technology vendors and service companies, discussions with individual technology users and estimates of application-specific material and labour requirements by expense categories.

### B.10 Financial Discount Rate

The discount rate and opportunity cost of equity in the upstream petroleum industry is usually taken to be a value in the range of 6 to 12 percent, depending on the segment of the industry. Typically, the discount rate increases in moving upstream through the industry in accordance with increasing financial risks. Accordingly, differing values within this range are applied herein.

In comparison, a non-redeemable guaranteed interest certificate (GIC) currently yields a 3.900 to 4.450 percent rate of return for a 1-year term, and a 5.150 percent return for a 10-year GIC. The prime interest rate is presently 6.250 percent. Most oil and gas ventures are expected to yield better than bank interest to compensate for the added risk involved.

### B.11 Other Discount Rates

In addition to the overall financial discount rate, further discount factors may be applied to the relevant cost and revenue accounts for each control option to account for the applicable taxes, tax shields and royalties.

### B.12 Inflation Rates

An average inflation rate may be assumed for the time series.

### B.13 Value of GHG Reduction

The value of a GHG emission reduction option is simply calculated as the equalized annual value divided by the average annual $CO_2$ reduction. For now, this is set to zero.

# APPENDIX C HEATERS AND BOILERS

## C.1 Introduction

The purpose of natural gas-fuelled heaters and boilers is to provide useful thermal work at the best possible energy conversion efficiency.

## C.2 Background

Equipment design and operating data are collected during field surveys and input into a proprietary Clearstone software program to facilitate the calculation of the required parameters. The design and operating data includes equipment make, model, capacity, recommended settings, actual settings, and operating flow rates, temperatures, pressures and, where measured, fuel and exhaust (flue) gas composition. Measured fuel and exhaust gas compositions are used to determine the air-to-fuel and exhaust-to-fuel ratios.

A material balance is performed, on a mole basis, using the following stoichiometric relation:

$$Fuel + a \cdot Air \rightarrow b \cdot Flue + c \cdot H_2O$$

**Equation 8**

The mole balances used include nitrogen to determine *a*, carbon to determine *b* and hydrogen to determine *c*. These coefficients were used to determine the flow rates of the unknown streams from the known (measured) flow rates.

The information gap in the field measurement data are completed using either the manufacturer's data for the equipment or the typical default parameters provided by Clearstone software.

The stack gas heat loss is determined by Clearstone Software as the potential energy that can be recovered by cooling the stack gas from the measured stack gas temperature to 10°C above its dew point or 15°C whichever is greater. The rest of the heat content in flue gas is considered as unrecoverable losses. The economic value is assigned only to the recoverable energy.

For the purpose of combustion and thermal efficiency analyses, the stack gas temperature must be measured as close to the exhaust manifold of the combustion chamber as possible. In cases where the exhaust gases are used to preheat air or fuel, the stack gas temperature measurement should be performed after the heat exchanger.

### C.2.1 Definitions

Combustion Efficiency and Energy Efficiency are assessed in the evaluation of process heaters and boilers.

### C.2.1.1 Combustion Efficiency (CE)

Combustion efficiency is defined as the total enthalpy contained in the reactants minus the total enthalpy contained in the products divided by the energy content of the fuel. This may be written as follows:

$$\frac{\left(\dot{m}_{FUEL} \cdot h^{f}_{FUEL} + \dot{m}_{AIR} \cdot h^{f}_{AIR} - \dot{m}_{FLUE} \cdot h^{f}_{FLUE}\right)}{\dot{m}_{FUEL} \cdot LHV}$$

**Equation 9**

Where:

| | |
|---|---|
| $\dot{m}$ | is the molar flow rate of the stream (i.e., fuel, air, or flue gas) (kmole/h), |
| $h^{f}$ | is the heat of formation of the stream (MJ/kmole), and |
| $LHV$ | is the lower heating value of the fuel gas stream (MJ/kmole) |

For heaters and boilers, expected combustion efficiencies are in the range of 99 to 99.99 percent.

### C.2.1.2 Excess Air (EA)

Excess air is defined as the amount of supplied combustion air that is in excess of the stoichiometric amount required. Stoichiometric (or theoretical) combustion is a process which burns all the carbon (C) to $CO_2$, all hydrogen (H) to $H_2O$ and all sulphur (S) to $SO_2$. Excess air is a function of the air-to-fuel ratio and, as a result, may be controlled with a mechanical or electronic link to the fuel gas flow control valve.

Typical excess air values vary on whether is a natural or forced draft design, the manufacturer and the model number. Typical values used in the evaluation of natural gas-fuelled heaters and boilers are based on the following criteria:

| | |
|---|---|
| **Heaters and Boilers** | Excess air of 10 to 15 percent for natural draft and 5 to 10 percent for forced draft operations |

### C.2.1.3 Energy Efficiency (EF)

While combustion efficiency is useful in demonstrating how much of the energy in the fuel is converted to heat, it does not provide a complete description of how effectively the equipment is utilizing this energy.

Heat lost to exhaust is a function of combustion efficiency and the quantity of combustion air that is required for efficient operation. Useful work is whatever is left over after all losses have been accounted for. Since heat losses from the external surfaces of a heater or boiler are normally relatively small, the amount of heat lost up the stack is a good indication of whether or not the unit is being operated in an efficient manner.

A typical energy balance based on manufacturers' heat load data yields:

- Energy from Fuel 100 %
- Useful Work 70 to 85 %
- Radiation 2 to 5 %
- Exhaust 15 to 25 %

#### C.2.1.4 Recoverable Stack Heat

Stack heat losses are calculated using a simplified heat balance. The equation used is:

$$Fraction\ of\ \ Heat\ Lost = \frac{Stack\ Losses}{Heat\ Input}$$

**Equation 10**

where

*Heat Input = Energy Content of Fuel + Sensible Heat in Fuel + Sensible Heat in Combustion Air*

*Stack Losses = Energy Content of the Exhaust Gas + Convective Stack Losses + Sensible Heat in the Exhaust Gas*

## C.3 Performance Evaluation Methodology

Combustion systems are analysed, using proprietary software, based on field operating data collected or measured. The results are compared to manufacturer's data or to equipment benchmark values as stated in the previous section.

The testing done on each unit involved analyzing the flue gas composition, measuring the flue gas temperature, obtaining the fuel gas composition, and where possible, measuring the flow rate of one or more of the following: fuel gas, combustion air and flue gas. Additionally, the make and model of each unit, and ambient temperature and barometric pressure at the site were recorded where available.

### C.3.1 Calculation of Fuel Consumption Rate of Crude Oil Heater

Assuming the heater is solely used to provide heat for a crude oil heating process, the fuel consumption rate of the heater is estimate based on the amount of process heating that is required for that purpose.

After obtaining the inlet temperature, $T_{in,}$ and outlet temperature, $T_{out}$, of the crude oil, the fuel consumption rate of the heater is calculated as following:

$$Q \times HHV \times 10^6 = mC_p (T_{out} - T_{in}) / eff$$

**Equation 11**

Where:

| | | |
|---|---|---|
| Q | → | fuel consumption rate ($m^3$/day); |
| HHV | → | the gross heating value of the fuel gas ($MJ/m^3$); |
| *eff* | → | the efficiency of the heater (assume 85%); |
| m | → | the crude oil mass production rate (kg/day); |
| $C_p$ | → | the specific heat of the crude oil. |

The crude oil specific heat (But/(lb)($^oF$)) is calculated using the following equation [Perry & Chilton, 1973]:

$$C_p = \frac{0.388 + 0.00045t}{s}$$

**Equation 12**

Where:

| | | |
|---|---|---|
| t | → | the average temperature of the inlet and outlet ($^oF$); |
| s | → | the specific gravity of the crude oil. |

A similar approach is applied for other heated fluids such as heat mediums and water.

### C.3.2 Fuel Costs and Fuel Cost Savings Results

Fuel costs associated with the improper operation of combustion units are made up of two components:

- Any unburned fuel in the exhaust gas, and
- Incremental fuel associated with operating at excessive air-to-fuel ratios.

The value of unburned fuel is determined by calculating the heating value of the unburned or partially burned components of the exhaust gas, determining the fuel gas equivalent volume using the energy content of the natural gas used as fuel, and the assigned monetary value per unit of energy (typically in $/GJ).

The cost associated with operations using too much excess air is determined by comparing the measured air-to-fuel ratio with typical values specified by the equipment manufacturer or best management practice (BMP) values appropriate for the equipment being assessed. The cost is calculated by determining the amount of heat required to heat the excess air from ambient temperature to the exhaust stack temperature and applying the assigned monetary value of the energy.

The optimum air-to-fuel depends on the type of air supply (i.e., natural or forced draft), type of fuel, style of burner system and unit loading. Specific manufacturers' values are used wherever possible. In the absence of manufactures' data, average values for the types of units tested are used.

### C.3.3 Excess Emission and Emission Reduction Results

Excessive emissions and potential emissions reductions are determined and expressed in terms of fuel gas ($10^3$ $m^3$/d), methane (tonnes $CH_4$/y) and total green house gases (GHG) (tonnes $CO_2E$/y). The Global Warming Potential of Methane is taken as 21 for purposes of calculation GHG emissions.

### C.3.4 Fuel Gas Composition

Where possible, a fuel gas analysis is obtained from the facility operator. If wide fluctuations in fuel gas composition are typical for a facility, an analysis that is consistent with the equipment performance and flue gas measurements is required for use in all efficiency calculations. Where one is not available, a sample of the fuel is collected from the fuel gas line and sent to a suitable laboratory for analysis.

### C.3.5 Flue Gas Composition

The flue gas analyses are conducted using a Testo 350 Portable Combustion Analyzer, or equivalent analyzer, equipped with detectors for $O_2$, CO, $CO_2$, $NO_x$, $SO_2$, and combustibles, and thermocouples for measuring ambient and stack-gas temperatures. A typical measurement is depicted in Figure 2. The flue gas is sampled either through a convenient sampling port on the exhaust stack or at the top of the stack. The flue gas temperature is measured close to the combustion chamber exit. All results are corrected to account for the actual fuel gas composition.


**Figure 2: Photographs of combustion test being conducted using a portable combustion analyzer.**

### C.3.6 Data Evaluation

- Carbon Dioxide – Actual $CO_2$ emissions based on flue gas measured are compared to maximum possible $CO_2$ emissions based on fuel gas composition to determine combustion efficiency and potential loss of input energy due to incomplete combustion and the formation of CO. Actual emission values should not be compared to typical U.S. EPA AP-42 or CAPP values unless they are corrected for fuel gas composition.

- Carbon Monoxide – Measured CO emissions per unit of energy input, expressed as nanogram per Joule (ng/J), are compared to regulatory requirements, manufacturer's specifications or typical values provided by U.S. EPA AP-42 or CAPP for various types of combustion equipment. Significantly greater actual values may be caused by insufficient combustion air (e.g., due to fouling of the air intake or incorrect setting of the air intake dampers), faulty burners or poor mixing.
- Oxides of Nitrogen - Measured $NO_x$ emissions per unit of energy input, expressed as ng/J, are compared to regulatory requirements, manufacturer's specifications or typical values provided by U.S. EPA AP-42 or CAPP for various types of combustion equipment. Significantly greater actual values may be caused by burner design causing high flame temperatures (heater/boiler), poor mixing or use of fuels containing high concentrations of organically bonded nitrogen.
- Methane ($CH_4$) - Measured $CH_4$ emissions per unit of energy input, expressed as ng/J, are compared to regulatory requirements, manufacturer's specifications or typical values provided by U.S. EPA AP-42 or CAPP for various types of combustion equipment. Significantly greater actual values may be caused by insufficient combustion air (e.g., due to fouling of the air intake or incorrect setting of the air intake dampers), faulty burners or poor mixing.

## C.4 Energy Management and Emission Control Options

The opportunities for improving the performance of heaters and boilers address the losses associated with the combustion of fuel and the transfer of the energy from the flue gases to the material to be heated. Key improvement areas include:

- Temperature control.
- Flame failure detection.
- Air-to-fuel ratio control (typically, 5 to 25 percent potential savings).
- Preheating of combustion air or oxidant (typically 15 to 30 percent savings).

### C.4.1 Temperature Control

Heaters and boilers that are operated using on/off control and experience frequent on/off cycling will experience inefficiencies due to poor combustion during the initial stages of burner firing, particularly for natural draft units. The implementation of modulating temperature control, or the adjustment of on/off setpoints to minimize on/off cycling is recommended in these situations.

### C.4.2 Flame Failure Detection

Flame failure detection is a standard feature on large modern process heaters and boilers, but is absent on many of the smaller and medium sized units. In the absence of a flame failure detection system, if the burner pilot or flame is out when there is heat demand, the temperature control system will continue to supply gas to the burner which will then be exhausted up the flue stack unburned. In fact, the temperature control system will tend to maximize the supply rate of fuel to the burner in these cases. Often a thermocouple and automatic fuel shutoff valve can be installed to avoid this problem. This is particularly beneficial for unmanned field equipment and process units with multiple burner trains.

### C.4.3 Air-to-Fuel Ratio Control

Ensuring the proper air-to-fuel ratio is maintained typically offers energy savings of 5 to 25 percent through improved combustion efficiencies and reduced stack losses. Stoichiometric combustion is not practical, since perfect mixing of the air and fuel would be needed to achieve complete fuel combustion. Without excess air, unburned hydrocarbons can enter the exhaust gas stream which can be both dangerous and environmentally harmful. Too much excess air is also undesirable since it carries away heat.

Caution should be used when reducing excess air. Although this is often an opportunity worth considering, it is important to maintain a certain amount of excess air. Excess air is essential to maintaining safe combustion. It is also used to carry heat to the material to be heated. As a result, operators should be careful to establish the proper amount of excess air according to the requirements of the burner and furnace. Important factors for setting the proper excess air include:

- Type of fuel used.
- Type of burner used.
- Process conditions.
- Process temperature.

Automatic air-to-fuel ratio control systems can be readily retrofit to natural draft systems. This requires the installation of an oxygen sensor in the flue gas stream, a forced-air supply system and a controller. Generally, the more practicable option is to manually check and adjust the air-to-fuel ratio on a regular basis. At a minimum, this should be done at the start of each season to adjust for changes in the air density. To facilitate regular tests to determine the air-to-fuel ratio, it is recommended that a ¼” diameter hole be drilled at a convenient location near the base of the vertical portion of the stack.

The air-to-fuel ratio on a natural draft furnace may be adjusted by either changing the damper position on the air intake (if applicable) or changing the setpoint on the fuel gas pressure regulator, or some combination thereof. If there is no adjustable damper on the air intake, consideration should be given to installing one.

The following is a brief checklist or potential problems to watch for in furnaces equipped with forced air systems:

- Combustion air leaks downstream of the air intake.

- Loose or worn linkages on forced air control systems (this could lead to poor control of the fuel air mixture over the range of operating conditions).
- Poor flame stability (this indicates improper fuel air control).
- Fouling of the air intake arrestor or screen (e.g., by bugs and airborne debris such as fine sand, dust, lant seeds and leaves).

The last two points also apply to natural draft furnaces.

### C.4.4 Preheating Combustion Air

Recovering waste heat from the flue gas and using it to preheat the combustion air for the furnace can result in energy savings of 15 to 30 percent. If the unit is housed in a building and it is impracticable to install a waste heat recovery system, a simple approach which offers some savings is to draw all the combustion air from inside the building. This helps to recover some of the radiant heat losses from the body of the furnace and cool the building for the benefit of workers.

## C.5 References

CAPP. 2003. *Calculating Greenhouse Gas Emissions*. Publication No. 2003-0003, Canadian Association of Petroleum Producers.

CETAC-West. 2008. *Efficient Use of Fuel Gas in Fired Heaters*. Fuel Gas Best Management Practices Module 6 of 17. CAPP Report, Calgary.

U.S. Environmental Protection Agency. 1998. *Compilation of Pollution Emission Factors, Vol.1, Station and Point Area Sources, AP-42(5$^{th}$ Edition)*. North Carolina. (http://www.epa.gov/ttn/chief/ap42/ch13/final/c13s05.pdf)

Perry & Chilton. 1973. Heat Generation and Transport: Liquid Petroleum Fuels. *Chemical Engineers' Handbook*. Fifth Edition, McGraw Hill, pp9-11.

## C.6 Results

Results of calculations performed for the analysis of the process heaters and boilers at the surveyed facilities are presented below:

# Heater and Boiler Index

| Facility Name | Device Category | Tag Number | Name | Device Type | Service |
|---|---|---|---|---|---|
| Barancabermeja Refinery | Heaters and Boilers | B-2401 | Central Norte Boiler 1 | Wall-fired (<=29 MW) Uncontrolled | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-2401 | Central Norte Boiler 1 | Wall-fired (<=29 MW) Uncontrolled | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-2401 | Central Norte Boiler 1 | Wall-fired (<=29 MW) Uncontrolled | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-2402 | Central Norte Boiler 2 | Wall-fired (<=29 MW) Uncontrolled | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-2402 | Central Norte Boiler 2 | Wall-fired (<=29 MW) Uncontrolled | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-2403 | Central Norte Boiler 3 | Wall-fired (<=29 MW) Uncontrolled | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-2403 | Central Norte Boiler 3 | Wall-fired (<=29 MW) Uncontrolled | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-2403 | Central Norte Boiler 3 | Wall-fired (<=29 MW) Uncontrolled | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-2404 | Central Norte Boiler 4 | Wall-fired (>29 MW) Uncontrolled Pre-NSPS | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-2404 | Central Norte Boiler 4 | Wall-fired (>29 MW) Uncontrolled Pre-NSPS | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-2404 | Central Norte Boiler 4 | Wall-fired (>29 MW) Uncontrolled Pre-NSPS | Steam Generator |

| | | | | | |
|---|---|---|---|---|---|
| Barancabermeja Refinery | Heaters and Boilers | B-2405 | Central Norte Boiler 5 | Wall-fired (>29 MW) Uncontrolled Pre-NSPS | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-2951 | Balance Boiler 1 | Wall-fired (>29 MW) Uncontrolled Pre-NSPS | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-2951 | Balance Boiler 1 | Wall-fired (>29 MW) Uncontrolled Pre-NSPS | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-2951 | Balance Boiler 1 | Wall-fired (>29 MW) Uncontrolled Pre-NSPS | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-2952 | Balance Boiler 2 | Wall-fired (>29 MW) Uncontrolled Pre-NSPS | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-2952 | Balance Boiler 2 | Wall-fired (>29 MW) Uncontrolled Pre-NSPS | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-2952 | Balance Boiler 2 | Wall-fired (>29 MW) Uncontrolled Pre-NSPS | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-2953 | Balance Boiler 3 | Wall-fired (>29 MW) Uncontrolled Pre-NSPS | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-2953 | Balance Boiler 3 | Wall-fired (>29 MW) Uncontrolled Pre-NSPS | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-2953 | Balance Boiler 3 | Wall-fired (>29 MW) Uncontrolled Pre-NSPS | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-2954 | Balance Boiler 4 | Wall-fired (>29 MW) Uncontrolled Pre-NSPS | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-2954 | Balance Boiler 4 | Wall-fired (>29 MW) Uncontrolled Pre-NSPS | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-2955 | Balance Boiler 5 | Wall-fired (>29 MW) Uncontrolled Pre-NSPS | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-2955 | Balance Boiler 5 | Wall-fired (>29 MW) Uncontrolled Pre-NSPS | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-901 B | Foster Boiler B | Wall-fired (<=29 MW) Uncontrolled | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-901 B | Foster Boiler B | Wall-fired (<=29 MW) Uncontrolled | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-901 D | Foster Boiler D | Wall-fired (<=29 MW) Uncontrolled | Steam Generator |

| | | | | | |
|---|---|---|---|---|---|
| Barancabermeja Refinery | Heaters and Boilers | B-901 D | Foster Boiler D | Wall-fired (<=29 MW) Uncontrolled | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-952 | Calderas Nuevas Boiler | Wall-fired (>29 MW) Uncontrolled Pre-NSPS | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-952 | Calderas Nuevas Boiler | Wall-fired (>29 MW) Uncontrolled Pre-NSPS | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-952 | Calderas Nuevas Boiler | Wall-fired (>29 MW) Uncontrolled Pre-NSPS | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-954 | Distral Boiler 4 | Wall-fired (<=29 MW) Uncontrolled | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-954 | Distral Boiler 4 | Wall-fired (<=29 MW) Uncontrolled | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-954 | Distral Boiler 4 | Wall-fired (<=29 MW) Uncontrolled | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-955 | Distral Boiler 5 | Wall-fired (<=29 MW) Uncontrolled | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-955 | Distral Boiler 5 | Wall-fired (<=29 MW) Uncontrolled | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-955 | Distral Boiler 5 | Wall-fired (<=29 MW) Uncontrolled | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-956 | Distral Boiler 6 | Wall-fired (<=29 MW) Uncontrolled | Steam Generator |
| Barancabermeja Refinery | Heaters and Boilers | B-956 | Distral Boiler 6 | Wall-fired (<=29 MW) Uncontrolled | Steam Generator |

# Combustion Analysis
# Report Summary

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Device | |
|---|---|
| **Name** | Central Norte Boiler 1 |
| **ID** | B-2401 |
| **On Site Location** | Barrancabermeja |
| **Category** | Heaters and Boilers |
| **Type** | Wall-fired (<=29 MW) Uncontrolled |
| **Service** | Steam Generator |
| **Manufacturer** | N/A |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |

| Report Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Alfonso Garcia |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 2013/09/08 |

| Applied Emission Factors (ng/J) | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor** | 1.00 | US EPA AP-42 |
| **$N_2O$ Emission Factor** | 0.90 | US EPA AP-42 |
| **VOC Emission Factor** | 2.30 | US EPA AP-42 |
| **CO Emission Factor** | 0.31 | User Entered |
| **PM Emission Factor** | 0.80 | US EPA AP-42 |
| **$NO_x$ Emission Factor** | 30.03 | User Entered |

| Device Comments and Assumptions |
|---|
| Boiler |

| Data Comments and Assumptions |
|---|
| N/A |

## Combustion Analysis Input

| Gas Stream Conditions | | | |
|---|---|---|---|
| **Stream** | **Temperature ($^oC$)** | **Flow (m3/h @ STP)** | **Relative Humidity (%)** |
| **Ambient Air** | 30.0 | | 60.0 |
| **Fuel** | 30.0 | 4,600.1 | 0.0 |
| **Combustion Air** | 30.0 | 0.0 | 60.0 |
| **Flue Gas** | 156.7 | 0.0 | N/A |

| General Simulation Data | |
|---|---|
| **Analysis Method** | Fuel Flow And Stack Gas |
| **Flue Gas Type** | Dry |
| **Local Barometric Pressure (kPa)** | 95.8 |
| **Nominal Rated Power Output (kW)** | 24,400 |
| **Assumed Efficiency (%)** | 80 |
| **Assumed Loading (%)** | 100 |
| **Fuel Cost (USD/GJ)** | 3.66 |

| Stack Gas Analysis | |
|---|---|
| **Component** | **Concentration (On A Dry Volume Basis)** |
| **Oxygen (%)** | 3.00 |
| **Carbon Monoxide (ppm)** | 1.00 |
| **Total Combustible (ppm)** | 0.00 |
| **Unburnt Fuel (calculated) (ppm)** | 0.00 |
| **Nitric Oxide (ppm)** | 89.00 |
| **Nitrogen Dioxide (ppm)** | 0.60 |
| **Sulfur Dioxide (ppm)** | 1.00 |

| Fuel Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.001190 | 0.001180 | 0.001193 |
| Ethane | 0.051599 | 0.051157 | 0.051731 |
| Isobutane | 0.000822 | 0.000815 | 0.000824 |
| Isopentane | 0.000292 | 0.000290 | 0.000293 |
| Methane | 0.921223 | 0.913340 | 0.923574 |
| n-Butane | 0.000988 | 0.000980 | 0.000991 |
| n-Heptane | 0.000464 | 0.000460 | 0.000465 |
| n-Hexane | 0.000187 | 0.000185 | 0.000187 |
| Nitrogen | 0.020589 | 0.020413 | 0.011806 |
| n-Pentane | 0.000282 | 0.000280 | 0.000283 |
| Oxygen | 0.002364 | 0.002344 | 0.000000 |
| Propane | 0.008631 | 0.008557 | 0.008653 |
| **Total** | **#VALUE!** | **1.000000** | **1.000000** |

## Combustion Analysis Output

| Fuel Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 17.3 |
| Quality (inlet condition) (%) | 1.0 |
| Gross Heating Value ($MJ/m^3$) | 39.7 |
| Net Heating Value ($MJ/m^3$) | 35.3 |
| Theoretic Combustion Air Requirement (kmol/kmol) | 10.3 |

| Material Balance | |
|---|---|
| Stream | Flow Rate ($10^3m^3/d$) |
| Fuel | 110.40 |
| Air | 1301.38 |
| Stack Gas | 1416.16 |

| Excess Air | |
|---|---|
| Type | Amount (%) |
| Actual | 15.0 |
| Recommended Lower Limit | 5.0 |
| Recommended Upper Limit | 10.0 |

| Energy Balance | |
|---|---|
| Type | Amount (kW) |
| Gross Input Energy | 51,142.4 |
| Net Input Energy | 41,017.1 |

| Avoidable Energy Consumption (Losses) | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| High Excess Air | 0.3 | 105.0 |
| Unburnt Fuel | 0.0 | 0.2 |
| Recoverable Heat in Flue Gas[1] | 4.8 | 1967.4 |

| Unavoidable Energy Comsumption Losses | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| Unrecoverable Heat in Flue Gas[1] | 16.3 | 6,669.6 |

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C. The unrecoverable portion is the energy still left in the flue gas at that temperature.

| Efficiencies | |
|---|---|
| Efficiency Type | Amount (%) |
| Apparent Thermal Efficiency | 78.9 |
| Carbon Combustion Efficiency | 100.0 |

| Stack Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 27.60 |
| Dew Temperature (°C) | 57.4 |

| Determined Flue Gas Emission Factors[2] | |
|---|---|
| Component | Amount (ng/J) |
| Carbon Monoxide | 0.3 |
| Carbon Dioxide | 50,060.9 |
| Methane | 0.0 |
| Ethane | 0.0 |
| Total VOC | 0.0 |
| Total Hydrocarbons | 0.0 |
| Nitric Oxide | 29.7 |
| Nitrogen Dioxide | 0.3 |
| Total Oxides of Nitrogen | 30.0 |
| Hydrogen Sulfide | 0.0 |
| Sulfur Dioxide | 0.9 |
| Carbon Disulfide | 0.0 |
| Carbonyl Sulfide | 0.0 |
| Total TRS | 0.0 |

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The $SO_2$ emission factor is based on the concentration measured in the flue gas.

| Dry Flue Gas Analysis | |
|---|---|
| **Component** | **Mole Fraction** |
| nitrogen | 0.867735 |
| carbon_dioxide | 0.102174 |
| oxygen | 0.030000 |
| nitric_oxide | 0.000089 |
| carbon_monoxide | 0.000001 |
| nitrogen_dioxide | 0.000001 |
| **Total** | **#VALUE!** |

## Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Switch Fuel Source | Switching to field gas | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0.23 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | 0 | 0 | 0 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0 | 4,375 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Switch Fuel Source | Switching to field gas | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 42.00 | N/A |
| Tuning | Upgrade Fuel Drum and Boilers | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

## Control Technology Input Streams

| Technology type | Application Description | Use | Temperature ($^{o}C$) | Pressure (kPa) | Line Name | Cross Sectional Shape |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | 25 | 101 | | Circular |

**Stream Pipe/Duct Cross-sectional Flow Area Dimension**

| Technology type | Application Description | Use | Pipe Outside Diameter (mm) | Pipe Wall Thickness (mm) | Pipe Rectangular Length (mm) | Pipe Rectangular Width (mm) |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | | | | |

**Stream Flow Rate**

| Technology type | Application Description | Use | Measurement Type | Reading Type | Measurement Date | Velocity (m/s) | Flow Rate ($m^3/h$) | Standard Flow Rate ($m^3/h$) |
|---|---|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Back Calculated Based on Measured Unit Output | Flow Rate (Standard Conditions) | | | | 4515.61 |

**Stream Composition**

| Technology type | Application Description | Use | Composition Name | Sample ID |
|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Gas de Campos | 47 |

## Simulation Results

| Source Name | Source Tag No. | Service Type | Value of Fuel/Loss Stream (USD/y) | Total Product Loss Flow ($m^3$/h) | Total Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3m^3$/d) | Ethane ($m^3$/d liq) | LPG ($m^3$/d liq) | NGL ($m^3$/d) | Hydrogen ($m^3$/d) |
| Central Norte Boiler 1 | B-2401 | Steam Generator | 7,254,154 | 4,600.0 | 101.96 | 20.29 | 4.35 | 0.75 | 0.00 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| 1.6 | 80,156 | 1.44 | 80,636 | 3.7 | 0.5 | 48.1 | 0.0 | 1.3 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Tuning | 0.23 | 149,063 | 0 | 4,375 | 16,685 | -58,393 | 8.26 | 12.11 |
| Switch Fuel Source | 100.00 | 0 | 0 | 0 | -81,839 | -602,806 | NA | NA |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| Tuning | 0.00 | 184 | 0.00 | 185 | 0.01 | 0.00 | 0.11 | 0.00 | 0.00 |
| Switch Fuel Source | -0.01 | -736 | -0.01 | -739 | -0.02 | -55.87 | -19.56 | 0.00 | -0.01 |

# Capital Cost Details

| Control Technology Type | Application description |
| --- | --- |
| Tuning | Upgrade Fuel Drum and Boilers |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
| --- | --- | --- | --- | --- | --- |
| Construction | Other Constuction Cost | Per Burner Installation. | 80,000.00 | 0.0 | 0 |
| | | Process GC installation (per drum) | 30,000.00 | 7.0 | 210,000 |
| Material | Instruments | CO Analyzer (per boiler) | 50,000.00 | 16.0 | 800,000 |
| | | Combustion Analyzer (per site) | 15,000.00 | 1.0 | 15,000 |
| | | Per Boiler Instrumentation | 50,000.00 | 16.0 | 800,000 |
| | | Process GC for Gas Anal. & A/F Control (per drum) | 80,000.00 | 7.0 | 560,000 |
| | Other Material Cost | High Efficiency Burners (4x per boiler) | 80,000.00 | 0.0 | 0 |

| | |
| --- | --- |
| **Total** | 2,385,000 |

# Combustion Analysis Report Summary

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Device | |
|---|---|
| **Name** | Central Norte Boiler 2 |
| **ID** | B-2402 |
| **On Site Location** | Barrancabermeja |
| **Category** | Heaters and Boilers |
| **Type** | Wall-fired (<=29 MW) Uncontrolled |
| **Service** | Steam Generator |
| **Manufacturer** | N/A |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |

| Report Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Alfonso Garcia |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 2013/09/08 |

| Applied Emission Factors (ng/J) | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor** | 1.00 | US EPA AP-42 |
| **$N_2O$ Emission Factor** | 0.90 | US EPA AP-42 |
| **VOC Emission Factor** | 2.30 | US EPA AP-42 |
| **CO Emission Factor** | 35.00 | US EPA AP-42 |
| **PM Emission Factor** | 0.80 | US EPA AP-42 |
| **$NO_x$ Emission Factor** | 42.00 | US EPA AP-42 |

| Device Comments and Assumptions |
|---|
| Boiler |

| Data Comments and Assumptions |
|---|
| N/A |

# Combustion Analysis Input

| Gas Stream Conditions | | | |
|---|---|---|---|
| **Stream** | **Temperature ($^{o}C$)** | **Flow (m3/h @ STP)** | **Relative Humidity (%)** |
| **Ambient Air** | 30.0 | | 60.0 |
| **Fuel** | 30.0 | 5,270.1 | 0.0 |
| **Combustion Air** | 30.0 | 0.0 | 60.0 |
| **Flue Gas** | 164.0 | 0.0 | N/A |

| General Simulation Data | |
|---|---|
| **Analysis Method** | Fuel Flow And Stack Gas |
| **Flue Gas Type** | Dry |
| **Local Barometric Pressure (kPa)** | 95.8 |
| **Nominal Rated Power Output (kW)** | 24,400 |
| **Assumed Efficiency (%)** | 80 |
| **Assumed Loading (%)** | 100 |
| **Fuel Cost (USD/GJ)** | 3.66 |

| Stack Gas Analysis | |
|---|---|
| **Component** | **Concentration (On A Dry Volume Basis)** |
| **Oxygen (%)** | 2.76 |
| **Carbon Monoxide (ppm)** | 0.00 |
| **Total Combustible (ppm)** | 0.00 |
| **Unburnt Fuel (calculated) (ppm)** | 0.00 |
| **Nitric Oxide (ppm)** | 0.00 |
| **Nitrogen Dioxide (ppm)** | 0.00 |
| **Sulfur Dioxide (ppm)** | 0.00 |

| Fuel Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.001190 | 0.001180 | 0.001193 |
| Ethane | 0.051599 | 0.051157 | 0.051731 |
| Isobutane | 0.000822 | 0.000815 | 0.000824 |
| Isopentane | 0.000292 | 0.000290 | 0.000293 |
| Methane | 0.921223 | 0.913340 | 0.923574 |
| n-Butane | 0.000988 | 0.000980 | 0.000991 |
| n-Heptane | 0.000464 | 0.000460 | 0.000465 |
| n-Hexane | 0.000187 | 0.000185 | 0.000187 |
| Nitrogen | 0.020589 | 0.020413 | 0.011806 |
| n-Pentane | 0.000282 | 0.000280 | 0.000283 |
| Oxygen | 0.002364 | 0.002344 | 0.000000 |
| Propane | 0.008631 | 0.008557 | 0.008653 |
| **Total** | **1.008631** | **1.000000** | **1.000000** |

# Combustion Analysis Output

| Fuel Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 17.3 |
| Quality (inlet condition) (%) | 1.0 |
| Gross Heating Value ($MJ/m^3$) | 39.7 |
| Net Heating Value ($MJ/m^3$) | 35.3 |
| Theoretic Combustion Air Requirement (kmol/kmol) | 10.3 |

| Material Balance | |
|---|---|
| Stream | Flow Rate ($10^3 m^3/d$) |
| Fuel | 126.48 |
| Air | 1472.72 |
| Stack Gas | 1604.22 |

| Excess Air | |
|---|---|
| Type | Amount (%) |
| Actual | 13.6 |
| Recommended Lower Limit | 5.0 |
| Recommended Upper Limit | 10.0 |

| Energy Balance | |
|---|---|
| Type | Amount (kW) |
| Gross Input Energy | 59,276.5 |
| Net Input Energy | 47,681.4 |

| Avoidable Energy Consumption (Losses) | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| High Excess Air | 0.2 | 91.5 |
| Recoverable Heat in Flue Gas[1] | 5.1 | 2409.5 |

| Unavoidable Energy Comsumption Losses | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| Unrecoverable Heat in Flue Gas[1] | 16.0 | 7,627.0 |

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C. The unrecoverable portion is the energy still left in the flue gas at that temperature.

| Efficiencies | |
|---|---|
| Efficiency Type | Amount (%) |
| Apparent Thermal Efficiency | 79.0 |
| Carbon Combustion Efficiency | 100.0 |

| Stack Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 27.59 |
| Dew Temperature (°C) | 57.6 |

| Determined Flue Gas Emission Factors[2] | |
|---|---|
| Component | Amount (ng/J) |
| Carbon Monoxide | 0.0 |
| Carbon Dioxide | 50,061.4 |
| Methane | 0.0 |
| Ethane | 0.0 |
| Total VOC | 0.0 |
| Total Hydrocarbons | 0.0 |
| Nitric Oxide | 0.0 |
| Nitrogen Dioxide | 0.0 |
| Total Oxides of Nitrogen | 0.0 |
| Hydrogen Sulfide | 0.0 |
| Sulfur Dioxide | 0.0 |
| Carbon Disulfide | 0.0 |
| Carbonyl Sulfide | 0.0 |
| Total TRS | 0.0 |

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The $SO_2$ emission factor is based on the concentration measured in the flue gas.

| Dry Flue Gas Analysis | |
|---|---|
| **Component** | **Mole Fraction** |
| nitrogen | 0.868837 |
| carbon_dioxide | 0.103563 |
| oxygen | 0.027600 |
| **Total** | **1.000000** |

## Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Switch Fuel Source | Switching to field gas | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0.17 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | 0 | 0 | 0 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0 | 4,375 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Switch Fuel Source | Switching to field gas | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 42.00 | N/A |
| Tuning | Upgrade Fuel Drum and Boilers | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

# Control Technology Input Streams

| Technology type | Application Description | Use | Temperature (°C) | Pressure (kPa) | Line Name | Cross Sectional Shape |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | 25 | 101 | | Circular |

**Stream Pipe/Duct Cross-sectional Flow Area Dimension**

| Technology type | Application Description | Use | Pipe Outside Diameter (mm) | Pipe Wall Thickness (mm) | Pipe Rectangular Length (mm) | Pipe Rectangular Width (mm) |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | | | | |

**Stream Flow Rate**

| Technology type | Application Description | Use | Measurement Type | Reading Type | Measurement Date | Velocity (m/s) | Flow Rate ($m^3$/h) | Standard Flow Rate ($m^3$/h) |
|---|---|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Back Calculated Based on Measured Unit Output | Flow Rate (Standard Conditions) | | | | 5173.31 |

**Stream Composition**

| Technology type | Application Description | Use | Composition Name | Sample ID |
|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Gas de Campos | 47 |

## Simulation Results

| Source Name | Source Tag No. | Service Type | Value of Fuel/Loss Stream (USD/y) | Total Product Loss Flow ($m^3$/h) | Total Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3 m^3$/d) | Ethane ($m^3$/d liq) | LPG ($m^3$/d liq) | NGL ($m^3$/d) | Hydrogen ($m^3$/d) |
| Central Norte Boiler 2 | B-2402 | Steam Generator | 8,310,737 | 5,270.0 | 116.81 | 23.24 | 4.99 | 0.85 | 0.00 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| 1.8 | 91,831 | 1.65 | 92,381 | 4.2 | 64.2 | 77.0 | 0.0 | 1.5 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Tuning | 0.17 | 149,063 | 0 | 4,375 | 14,128 | -77,222 | 6.54 | 15.28 |
| Switch Fuel Source | 100.00 | 0 | 0 | 0 | -93,745 | -690,506 | NA | NA |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| Tuning | 0.00 | 156 | 0.00 | 157 | 0.01 | 0.11 | 0.13 | 0.00 | 0.00 |
| Switch Fuel Source | -0.01 | -843 | -0.01 | -846 | -0.02 | -0.38 | -0.45 | 0.00 | -0.01 |

# Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Tuning | Upgrade Fuel Drum and Boilers |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Construction | Other Constuction Cost | Per Burner Installation. | 80,000.00 | 0.0 | 0 |
| | | Process GC installation (per drum) | 30,000.00 | 7.0 | 210,000 |
| Material | Instruments | CO Analyzer (per boiler) | 50,000.00 | 16.0 | 800,000 |
| | | Combustion Analyzer (per site) | 15,000.00 | 1.0 | 15,000 |
| | | Per Boiler Instrumentation | 50,000.00 | 16.0 | 800,000 |
| | | Process GC for Gas Anal. & A/F Control (per drum) | 80,000.00 | 7.0 | 560,000 |
| | Other Material Cost | High Efficiency Burners (4x per boiler) | 80,000.00 | 0.0 | 0 |

| | |
|---|---|
| **Total** | 2,385,000 |

# Combustion Analysis
# Report Summary

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Device | |
|---|---|
| **Name** | Central Norte Boiler 3 |
| **ID** | B-2403 |
| **On Site Location** | Barrancabermeja |
| **Category** | Heaters and Boilers |
| **Type** | Wall-fired (<=29 MW) Uncontrolled |
| **Service** | Steam Generator |
| **Manufacturer** | N/A |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |

| Report Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Alfonso Garcia |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 2013/09/08 |

| Applied Emission Factors (ng/J) | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor** | 1.00 | US EPA AP-42 |
| **$N_2O$ Emission Factor** | 0.90 | US EPA AP-42 |
| **VOC Emission Factor** | 2.30 | US EPA AP-42 |
| **CO Emission Factor** | 0.09 | User Entered |
| **PM Emission Factor** | 0.80 | US EPA AP-42 |
| **$NO_x$ Emission Factor** | 28.84 | User Entered |

| Device Comments and Assumptions |
|---|
| Boiler |

| Data Comments and Assumptions |
|---|
| N/A |

# Combustion Analysis Input

| Gas Stream Conditions | | | |
|---|---|---|---|
| **Stream** | **Temperature ($^oC$)** | **Flow (m3/h @ STP)** | **Relative Humidity (%)** |
| **Ambient Air** | 30.0 | | 60.0 |
| **Fuel** | 30.0 | 5,800.1 | 0.0 |
| **Combustion Air** | 30.0 | 0.0 | 60.0 |
| **Flue Gas** | 188.0 | 0.0 | N/A |

| General Simulation Data | |
|---|---|
| **Analysis Method** | Fuel Flow And Stack Gas |
| **Flue Gas Type** | Dry |
| **Local Barometric Pressure (kPa)** | 95.8 |
| **Nominal Rated Power Output (kW)** | 24,400 |
| **Assumed Efficiency (%)** | 80 |
| **Assumed Loading (%)** | 100 |
| **Fuel Cost (USD/GJ)** | 3.66 |

| Stack Gas Analysis | |
|---|---|
| **Component** | **Concentration (On A Dry Volume Basis)** |
| **Oxygen (%)** | 3.10 |
| **Carbon Monoxide (ppm)** | 0.30 |
| **Total Combustible (ppm)** | 0.00 |
| **Unburnt Fuel (calculated) (ppm)** | 0.00 |
| **Nitric Oxide (ppm)** | 84.50 |
| **Nitrogen Dioxide (ppm)** | 0.90 |
| **Sulfur Dioxide (ppm)** | 2.90 |

| Fuel Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.001190 | 0.001180 | 0.001193 |
| Ethane | 0.051599 | 0.051157 | 0.051731 |
| Isobutane | 0.000822 | 0.000815 | 0.000824 |
| Isopentane | 0.000292 | 0.000290 | 0.000293 |
| Methane | 0.921223 | 0.913340 | 0.923574 |
| n-Butane | 0.000988 | 0.000980 | 0.000991 |
| n-Heptane | 0.000464 | 0.000460 | 0.000465 |
| n-Hexane | 0.000187 | 0.000185 | 0.000187 |
| Nitrogen | 0.020589 | 0.020413 | 0.011806 |
| n-Pentane | 0.000282 | 0.000280 | 0.000283 |
| Oxygen | 0.002364 | 0.002344 | 0.000000 |
| Propane | 0.008631 | 0.008557 | 0.008653 |
| **Total** | **1.008631** | **1.000000** | **1.000000** |

# Combustion Analysis Output

| Fuel Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 17.3 |
| Quality (inlet condition) (%) | 1.0 |
| Gross Heating Value ($MJ/m^3$) | 39.7 |
| Net Heating Value ($MJ/m^3$) | 35.3 |
| Theoretic Combustion Air Requirement (kmol/kmol) | 10.3 |

| Material Balance | |
|---|---|
| Stream | Flow Rate ($10^3 m^3/d$) |
| Fuel | 139.20 |
| Air | 1649.22 |
| Stack Gas | 1793.94 |

| Excess Air | |
|---|---|
| Type | Amount (%) |
| Actual | 15.6 |
| Recommended Lower Limit | 5.0 |
| Recommended Upper Limit | 10.0 |

| Energy Balance | |
|---|---|
| Type | Amount (kW) |
| Gross Input Energy | 64,488.2 |
| Net Input Energy | 51,719.2 |

| Avoidable Energy Consumption (Losses) | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| High Excess Air | 0.4 | 185.0 |
| Unburnt Fuel | 0.0 | 0.1 |
| Recoverable Heat in Flue Gas[1] | 6.5 | 3381.4 |

| Unavoidable Energy Comsumption Losses | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| Unrecoverable Heat in Flue Gas[1] | 16.3 | 8,416.0 |

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C. The unrecoverable portion is the energy still left in the flue gas at that temperature.

| Efficiencies | |
|---|---|
| Efficiency Type | Amount (%) |
| Apparent Thermal Efficiency | 77.2 |
| Carbon Combustion Efficiency | 100.0 |

| Stack Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 27.60 |
| Dew Temperature ($^{o}C$) | 57.3 |

| Determined Flue Gas Emission Factors[2] | |
|---|---|
| Component | Amount (ng/J) |
| Carbon Monoxide | 0.1 |
| Carbon Dioxide | 50,061.2 |
| Methane | 0.0 |
| Ethane | 0.0 |
| Total VOC | 0.0 |
| Total Hydrocarbons | 0.0 |
| Nitric Oxide | 28.4 |
| Nitrogen Dioxide | 0.5 |
| Total Oxides of Nitrogen | 28.8 |
| Hydrogen Sulfide | 0.0 |
| Sulfur Dioxide | 2.5 |
| Carbon Disulfide | 0.0 |
| Carbonyl Sulfide | 0.0 |
| Total TRS | 0.0 |

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The $SO_2$ emission factor is based on the concentration measured in the flue gas.

| Dry Flue Gas Analysis | |
|---|---|
| **Component** | **Mole Fraction** |
| nitrogen | 0.867306 |
| carbon_dioxide | 0.101608 |
| oxygen | 0.031000 |
| nitric_oxide | 0.000085 |
| nitrogen_dioxide | 0.000001 |
| carbon_monoxide | 0.000000 |
| **Total** | **1.000000** |

## Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Switch Fuel Source | Switching to field gas | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0.32 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | 0 | 0 | 0 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0 | 4,375 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Switch Fuel Source | Switching to field gas | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 42.00 | N/A |
| Tuning | Upgrade Fuel Drum and Boilers | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

## Control Technology Input Streams

| Technology type | Application Description | Use | Temperature ($^{o}C$) | Pressure (kPa) | Line Name | Cross Sectional Shape |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | 25 | 101 | | Circular |

**Stream Pipe/Duct Cross-sectional Flow Area Dimension**

| Technology type | Application Description | Use | Pipe Outside Diameter (mm) | Pipe Wall Thickness (mm) | Pipe Rectangular Length (mm) | Pipe Rectangular Width (mm) |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | | | | |

**Stream Flow Rate**

| Technology type | Application Description | Use | Measurement Type | Reading Type | Measurement Date | Velocity (m/s) | Flow Rate ($m^3/h$) | Standard Flow Rate ($m^3/h$) |
|---|---|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Back Calculated Based on Measured Unit Output | Flow Rate (Standard Conditions) | | | | 5693.59 |

**Stream Composition**

| Technology type | Application Description | Use | Composition Name | Sample ID |
|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Gas de Campos | 47 |

## Simulation Results

| Source Name | Source Tag No. | Service Type | Value of Fuel/Loss Stream (USD/y) | Total Product Loss Flow ($m^3/h$) | Total Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3 m^3/d$) | Ethane ($m^3/d$ liq) | LPG ($m^3/d$ liq) | NGL ($m^3/d$) | Hydrogen ($m^3/d$) |
| Central Norte Boiler 3 | B-2403 | Steam Generator | 9,146,542 | 5,800.0 | 128.56 | 25.58 | 5.49 | 0.94 | 0.00 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| 2.0 | 101,066 | 1.82 | 101,672 | 4.6 | 0.2 | 58.2 | 0.0 | 1.6 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Tuning | 0.32 | 149,063 | 0 | 4,375 | 29,269 | 34,301 | 16.70 | 5.99 |
| Switch Fuel Source | 100.00 | 0 | 0 | 0 | -103,180 | -759,998 | NA | NA |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| Tuning | 0.01 | 323 | 0.01 | 325 | 0.01 | 0.00 | 0.19 | 0.00 | 0.01 |
| Switch Fuel Source | -0.01 | -928 | -0.01 | -931 | -0.03 | -70.89 | -27.07 | 0.00 | -0.01 |

## Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Tuning | Upgrade Fuel Drum and Boilers |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Construction | Other Constuction Cost | Per Burner Installation. | 80,000.00 | 0.0 | 0 |
| | | Process GC installation (per drum) | 30,000.00 | 7.0 | 210,000 |
| Material | Instruments | CO Analyzer (per boiler) | 50,000.00 | 16.0 | 800,000 |
| | | Combustion Analyzer (per site) | 15,000.00 | 1.0 | 15,000 |
| | | Per Boiler Instrumentation | 50,000.00 | 16.0 | 800,000 |
| | | Process GC for Gas Anal. & A/F Control (per drum) | 80,000.00 | 7.0 | 560,000 |
| | Other Material Cost | High Efficiency Burners (4x per boiler) | 80,000.00 | 0.0 | 0 |
| | | | | **Total** | 2,385,000 |

# Combustion Analysis
# Report Summary

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Device | |
|---|---|
| **Name** | Central Norte Boiler 4 |
| **ID** | B-2404 |
| **On Site Location** | Barrancabermeja |
| **Category** | Heaters and Boilers |
| **Type** | Wall-fired (>29 MW) Uncontrolled Pre-NSPS |
| **Service** | Steam Generator |
| **Manufacturer** | N/A |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |

| Report Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Alfonso Garcia |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 2013/09/08 |

| Applied Emission Factors (ng/J) | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor** | 1.00 | US EPA AP-42 |
| **$N_2O$ Emission Factor** | 0.90 | US EPA AP-42 |
| **VOC Emission Factor** | 2.30 | US EPA AP-42 |
| **CO Emission Factor** | 1.87 | User Entered |
| **PM Emission Factor** | 0.80 | US EPA AP-42 |
| **$NO_x$ Emission Factor** | 31.49 | User Entered |

| Device Comments and Assumptions |
|---|
| Boiler |

| Data Comments and Assumptions |
|---|
| N/A |

## Combustion Analysis Input

| Gas Stream Conditions | | | |
|---|---|---|---|
| Stream | Temperature ($^oC$) | Flow (m3/h @ STP) | Relative Humidity (%) |
| **Ambient Air** | 30.0 | | 60.0 |
| **Fuel** | 30.0 | 10,991.4 | 0.0 |
| **Combustion Air** | 30.0 | 0.0 | 60.0 |
| **Flue Gas** | 217.2 | 0.0 | N/A |

| General Simulation Data | |
|---|---|
| **Analysis Method** | Fuel Flow And Stack Gas |
| **Flue Gas Type** | Dry |
| **Local Barometric Pressure (kPa)** | 95.8 |
| **Nominal Rated Power Output (kW)** | 37,900 |
| **Assumed Efficiency (%)** | 80 |
| **Assumed Loading (%)** | 100 |
| **Fuel Cost (USD/GJ)** | 3.5 |

| Stack Gas Analysis | |
|---|---|
| Component | Concentration (On A Dry Volume Basis) |
| **Oxygen (%)** | 2.10 |
| **Carbon Monoxide (ppm)** | 6.30 |
| **Total Combustible (ppm)** | 0.00 |
| **Unburnt Fuel (calculated) (ppm)** | 0.00 |
| **Nitric Oxide (ppm)** | 99.00 |
| **Nitrogen Dioxide (ppm)** | 0.00 |
| **Sulfur Dioxide (ppm)** | 0.00 |

| Fuel Analysis Results | | | |
|---|---|---|---|
| Component Name | Mole Fraction | | |
| | Entered | Normalized | Air Free |
| Carbon monoxide | 0.001190 | 0.001180 | 0.001193 |
| Ethane | 0.051599 | 0.051157 | 0.051731 |
| Isobutane | 0.000822 | 0.000815 | 0.000824 |
| Isopentane | 0.000292 | 0.000290 | 0.000293 |
| Methane | 0.921223 | 0.913340 | 0.923574 |
| n-Butane | 0.000988 | 0.000980 | 0.000991 |
| n-Heptane | 0.000464 | 0.000460 | 0.000465 |
| n-Hexane | 0.000187 | 0.000185 | 0.000187 |
| Nitrogen | 0.020589 | 0.020413 | 0.011806 |
| n-Pentane | 0.000282 | 0.000280 | 0.000283 |
| Oxygen | 0.002364 | 0.002344 | 0.000000 |
| Propane | 0.008631 | 0.008557 | 0.008653 |
| **Total** | **1.008631** | **1.000000** | **1.000000** |

## Combustion Analysis Output

| Fuel Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 17.3 |
| Quality (inlet condition) (%) | 1.0 |
| Gross Heating Value ($MJ/m^3$) | 39.7 |
| Net Heating Value ($MJ/m^3$) | 35.3 |
| Theoretic Combustion Air Requirement (kmol/kmol) | 10.3 |

| Material Balance | |
|---|---|
| Stream | Flow Rate ($10^3m^3/d$) |
| Fuel | 263.79 |
| Air | 2974.55 |
| Stack Gas | 3248.81 |

| Excess Air | |
|---|---|
| Type | Amount (%) |
| Actual | 10.0 |
| Recommended Lower Limit | 5.0 |
| Recommended Upper Limit | 10.0 |

| Energy Balance | |
|---|---|
| Type | Amount (kW) |
| Gross Input Energy | 122,131.3 |
| Net Input Energy | 97,974.9 |

| Avoidable Energy Consumption (Losses) | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| High Excess Air | 0.0 | 0.4 |
| Unburnt Fuel | 0.0 | 2.3 |
| Recoverable Heat in Flue Gas[1] | 7.8 | 7615.6 |

| Unavoidable Energy Comsumption Losses | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| Unrecoverable Heat in Flue Gas[1] | 16.2 | 15,831.6 |

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C. The unrecoverable portion is the energy still left in the flue gas at that temperature.

| Efficiencies | |
|---|---|
| Efficiency Type | Amount (%) |
| Apparent Thermal Efficiency | 76.1 |
| Carbon Combustion Efficiency | 100.0 |

| Stack Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 27.56 |
| Dew Temperature (°C) | 58.2 |

| Determined Flue Gas Emission Factors[2] | |
|---|---|
| Component | Amount (ng/J) |
| Carbon Monoxide | 1.9 |
| Carbon Dioxide | 50,058.5 |
| Methane | 0.0 |
| Ethane | 0.0 |
| Total VOC | 0.0 |
| Total Hydrocarbons | 0.0 |
| Nitric Oxide | 31.5 |
| Nitrogen Dioxide | 0.0 |
| Total Oxides of Nitrogen | 31.5 |
| Hydrogen Sulfide | 0.0 |
| Sulfur Dioxide | 0.0 |
| Carbon Disulfide | 0.0 |
| Carbonyl Sulfide | 0.0 |
| Total TRS | 0.0 |

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The $SO_2$ emission factor is based on the concentration measured in the flue gas.

| Dry Flue Gas Analysis | |
|---|---|
| **Component** | **Mole Fraction** |
| nitrogen | 0.871617 |
| carbon_dioxide | 0.107278 |
| oxygen | 0.021000 |
| nitric_oxide | 0.000099 |
| carbon_monoxide | 0.000006 |
| **Total** | **1.000000** |

## Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Switch Fuel Source | Switching to field gas | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0.00 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | 0 | 0 | 0 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0 | 4,375 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Switch Fuel Source | Switching to field gas | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |
| Tuning | Upgrade Fuel Drum and Boilers | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

# Control Technology Input Streams

| Technology type | Application Description | Use | Temperature (°C) | Pressure (kPa) | Line Name | Cross Sectional Shape |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | 25 | 101 | | Circular |

**Stream Pipe/Duct Cross-sectional Flow Area Dimension**

| Technology type | Application Description | Use | Pipe Outside Diameter (mm) | Pipe Wall Thickness (mm) | Pipe Rectangular Length (mm) | Pipe Rectangular Width (mm) |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | | | | |

**Stream Flow Rate**

| Technology type | Application Description | Use | Measurement Type | Reading Type | Measurement Date | Velocity (m/s) | Flow Rate ($m^3/h$) | Standard Flow Rate ($m^3/h$) |
|---|---|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Back Calculated Based on Measured Unit Output | Flow Rate (Standard Conditions) | | | | 10789.6 |

**Stream Composition**

| Technology type | Application Description | Use | Composition Name | Sample ID |
|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Gas de Campos | 47 |

## Simulation Results

| Source Name | Source Tag No. | Service Type | Value of Fuel/Loss Stream (USD/y) | Total Product Loss Flow ($m^3$/h) | Total Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3 m^3$/d) | Ethane ($m^3$/d liq) | LPG ($m^3$/d liq) | NGL ($m^3$/d) | Hydrogen ($m^3$/d) |
| Central Norte Boiler 4 | B-2404 | Steam Generator | 17,333,091 | 10,991.3 | 243.63 | 48.48 | 10.40 | 1.78 | 0.00 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| 3.8 | 191,524 | 3.44 | 192,672 | 8.8 | 7.2 | 120.5 | 0.0 | 3.1 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Tuning | 0.00 | 149,063 | 0 | 4,375 | 364 | -178,607 | NA | NA |
| Switch Fuel Source | 100.00 | 0 | 0 | 0 | -195,532 | -1,440,247 | NA | NA |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| Tuning | 0.00 | 4 | 0.00 | 4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Switch Fuel Source | -0.02 | -1,758 | -0.02 | -1,765 | -0.05 | -127.53 | -333.62 | 0.00 | -0.02 |

# Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Tuning | Upgrade Fuel Drum and Boilers |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Construction | Other Constuction Cost | Per Burner Installation. | 80,000.00 | 0.0 | 0 |
| | | Process GC installation (per drum) | 30,000.00 | 7.0 | 210,000 |
| Material | Instruments | CO Analyzer (per boiler) | 50,000.00 | 16.0 | 800,000 |
| | | Combustion Analyzer (per site) | 15,000.00 | 1.0 | 15,000 |
| | | Per Boiler Instrumentation | 50,000.00 | 16.0 | 800,000 |
| | | Process GC for Gas Anal. & A/F Control (per drum) | 80,000.00 | 7.0 | 560,000 |
| | Other Material Cost | High Efficiency Burners (4x per boiler) | 80,000.00 | 0.0 | 0 |
| | | | | **Total** | 2,385,000 |

# Combustion Analysis
# Report Summary

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Device | |
|---|---|
| **Name** | Central Norte Boiler 5 |
| **ID** | B-2405 |
| **On Site Location** | Barrancabermeja |
| **Category** | Heaters and Boilers |
| **Type** | Wall-fired (>29 MW)<br>Uncontrolled Pre-NSPS |
| **Service** | Steam Generator |
| **Manufacturer** | N/A |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |

| Report Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Alfonso Garcia |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 2013/09/08 |

| Applied Emission Factors (ng/J) | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor** | 1.00 | US EPA AP-42 |
| **$N_2O$ Emission Factor** | 0.90 | US EPA AP-42 |
| **VOC Emission Factor** | 2.30 | US EPA AP-42 |
| **CO Emission Factor** | 35.00 | US EPA AP-42 |
| **PM Emission Factor** | 0.80 | US EPA AP-42 |
| **$NO_x$ Emission Factor** | 118.00 | US EPA AP-42 |

| Device Comments and Assumptions |
|---|
| Boiler |

| Data Comments and Assumptions |
|---|
| Simulation with O2 level |

## Combustion Analysis Input

| Gas Stream Conditions | | | |
|---|---|---|---|
| **Stream** | **Temperature ($^oC$)** | **Flow (m3/h @ STP)** | **Relative Humidity (%)** |
| **Ambient Air** | 30.0 | | 60.0 |
| **Fuel** | 30.0 | 8,954.1 | 0.0 |
| **Combustion Air** | 30.0 | 0.0 | 60.0 |
| **Flue Gas** | 225.2 | 0.0 | N/A |

| General Simulation Data | |
|---|---|
| **Analysis Method** | Fuel Flow And Stack Gas |
| **Flue Gas Type** | Dry |
| **Local Barometric Pressure (kPa)** | 95.8 |
| **Nominal Rated Power Output (kW)** | 37,900 |
| **Assumed Efficiency (%)** | 80 |
| **Assumed Loading (%)** | 100 |
| **Fuel Cost (USD/GJ)** | 3.66 |

| Stack Gas Analysis | |
|---|---|
| **Component** | **Concentration (On A Dry Volume Basis)** |
| **Oxygen (%)** | 1.59 |
| **Carbon Monoxide (ppm)** | 0.00 |
| **Total Combustible (ppm)** | 0.00 |
| **Unburnt Fuel (calculated) (ppm)** | 0.00 |
| **Nitric Oxide (ppm)** | 0.00 |
| **Nitrogen Dioxide (ppm)** | 0.00 |
| **Sulfur Dioxide (ppm)** | 0.00 |

| Fuel Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.001190 | 0.001180 | 0.001193 |
| Ethane | 0.051599 | 0.051157 | 0.051731 |
| Isobutane | 0.000822 | 0.000815 | 0.000824 |
| Isopentane | 0.000292 | 0.000290 | 0.000293 |
| Methane | 0.921223 | 0.913340 | 0.923574 |
| n-Butane | 0.000988 | 0.000980 | 0.000991 |
| n-Heptane | 0.000464 | 0.000460 | 0.000465 |
| n-Hexane | 0.000187 | 0.000185 | 0.000187 |
| Nitrogen | 0.020589 | 0.020413 | 0.011806 |
| n-Pentane | 0.000282 | 0.000280 | 0.000283 |
| Oxygen | 0.002364 | 0.002344 | 0.000000 |
| Propane | 0.008631 | 0.008557 | 0.008653 |
| **Total** | **1.008631** | **1.000000** | **1.000000** |

## Combustion Analysis Output

| Fuel Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 17.3 |
| Quality (inlet condition) (%) | 1.0 |
| Gross Heating Value ($MJ/m^3$) | 39.7 |
| Net Heating Value ($MJ/m^3$) | 35.3 |
| Theoretic Combustion Air Requirement (kmol/kmol) | 10.3 |

| Material Balance | |
|---|---|
| Stream | Flow Rate ($10^3 m^3/d$) |
| Fuel | 214.90 |
| Air | 2364.90 |
| Stack Gas | 2588.32 |

| Excess Air | |
|---|---|
| Type | Amount (%) |
| Actual | 7.4 |
| Recommended Lower Limit | 5.0 |
| Recommended Upper Limit | 10.0 |

| Energy Balance | |
|---|---|
| Type | Amount (kW) |
| Gross Input Energy | 100,584.4 |
| Net Input Energy | 80,921.4 |

| Avoidable Energy Consumption (Losses) | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| Recoverable Heat in Flue Gas[1] | 7.9 | 6393.0 |

| Unavoidable Energy Comsumption Losses | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| Unrecoverable Heat in Flue Gas[1] | 15.9 | 12,851.6 |

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C. The unrecoverable portion is the energy still left in the flue gas at that temperature.

| Efficiencies | |
|---|---|
| Efficiency Type | Amount (%) |
| Apparent Thermal Efficiency | 76.2 |
| Carbon Combustion Efficiency | 100.0 |

| Stack Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 27.54 |
| Dew Temperature (°C) | 58.6 |

| Determined Flue Gas Emission Factors[2] | |
|---|---|
| Component | Amount (ng/J) |
| Carbon Monoxide | 0.0 |
| Carbon Dioxide | 50,061.4 |
| Methane | 0.0 |
| Ethane | 0.0 |
| Total VOC | 0.0 |
| Total Hydrocarbons | 0.0 |
| Nitric Oxide | 0.0 |
| Nitrogen Dioxide | 0.0 |
| Total Oxides of Nitrogen | 0.0 |
| Hydrogen Sulfide | 0.0 |
| Sulfur Dioxide | 0.0 |
| Carbon Disulfide | 0.0 |
| Carbonyl Sulfide | 0.0 |
| Total TRS | 0.0 |

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The $SO_2$ emission factor is based on the concentration measured in the flue gas.

| Dry Flue Gas Analysis | |
|---|---|
| **Component** | **Mole Fraction** |
| nitrogen | 0.873894 |
| carbon_dioxide | 0.110206 |
| oxygen | 0.015900 |
| **Total** | **1.000000** |

## Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Switch Fuel Source | Switching to field gas | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0.00 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | 0 | 0 | 0 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0 | 4,375 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Switch Fuel Source | Switching to field gas | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |
| Tuning | Upgrade Fuel Drum and Boilers | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

# Control Technology Input Streams

| Technology type | Application Description | Use | Temperature (°C) | Pressure (kPa) | Line Name | Cross Sectional Shape |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | 25 | 101 | | Circular |

**Stream Pipe/Duct Cross-sectional Flow Area Dimension**

| Technology type | Application Description | Use | Pipe Outside Diameter (mm) | Pipe Wall Thickness (mm) | Pipe Rectangular Length (mm) | Pipe Rectangular Width (mm) |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | | | | |

**Stream Flow Rate**

| Technology type | Application Description | Use | Measurement Type | Reading Type | Measurement Date | Velocity (m/s) | Flow Rate ($m^3/h$) | Standard Flow Rate ($m^3/h$) |
|---|---|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Back Calculated Based on Measured Unit Output | Flow Rate (Standard Conditions) | | | | 8789.48 |

**Stream Composition**

| Technology type | Application Description | Use | Composition Name | Sample ID |
|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Gas de Campos | 47 |

## Simulation Results

| Source Name | Source Tag No. | Service Type | Value of Fuel/Loss Stream (USD/y) | Total Product Loss Flow ($m^3/h$) | Total Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3 m^3/d$) | Ethane ($m^3/d$ liq) | LPG ($m^3/d$ liq) | NGL ($m^3/d$) | Hydrogen ($m^3/d$) |
| Central Norte Boiler 5 | B-2405 | Steam Generator | 14,120,369 | 8,954.0 | 198.47 | 39.49 | 8.47 | 1.45 | 0.00 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| 3.1 | 156,025 | 2.80 | 156,960 | 7.2 | 109.1 | 367.8 | 0.0 | 2.5 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Tuning | 0.00 | 149,063 | 0 | 4,375 | 0 | -181,288 | NA | NA |
| Switch Fuel Source | 100.00 | 0 | 0 | 0 | -158,890 | -1,170,348 | NA | NA |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| Tuning | 0.00 | 0 | 0.00 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Switch Fuel Source | -0.02 | -1,428 | -0.02 | -1,433 | -0.04 | -0.64 | -2.15 | 0.00 | -0.01 |

## Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Tuning | Upgrade Fuel Drum and Boilers |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Construction | Other Constuction Cost | Per Burner Installation. | 80,000.00 | 0.0 | 0 |
| | | Process GC installation (per drum) | 30,000.00 | 7.0 | 210,000 |
| Material | Instruments | CO Analyzer (per boiler) | 50,000.00 | 16.0 | 800,000 |
| | | Combustion Analyzer (per site) | 15,000.00 | 1.0 | 15,000 |
| | | Per Boiler Instrumentation | 50,000.00 | 16.0 | 800,000 |
| | | Process GC for Gas Anal. & A/F Control (per drum) | 80,000.00 | 7.0 | 560,000 |
| | Other Material Cost | High Efficiency Burners (4x per boiler) | 80,000.00 | 0.0 | 0 |
| | | | | **Total** | 2,385,000 |

# Combustion Analysis Report Summary

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Device | |
|---|---|
| **Name** | Balance Boiler 1 |
| **ID** | B-2951 |
| **On Site Location** | Barrancabermeja |
| **Category** | Heaters and Boilers |
| **Type** | Wall-fired (>29 MW)<br>Uncontrolled Pre-NSPS |
| **Service** | Steam Generator |
| **Manufacturer** | N/A |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |

| Report Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Alfonso Garcia |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 2013/09/08 |

| Applied Emission Factors (ng/J) | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor** | 1.00 | US EPA AP-42 |
| **$N_2O$ Emission Factor** | 0.90 | US EPA AP-42 |
| **VOC Emission Factor** | 2.30 | US EPA AP-42 |
| **CO Emission Factor** | 0.83 | User Entered |
| **PM Emission Factor** | 0.80 | US EPA AP-42 |
| **$NO_x$ Emission Factor** | 41.21 | User Entered |

| Device Comments and Assumptions |
|---|
| Boiler |

| Data Comments and Assumptions |
|---|
| N/A |

## Combustion Analysis Input

| Gas Stream Conditions | | | |
|---|---|---|---|
| **Stream** | **Temperature ($^oC$)** | **Flow (m3/h @ STP)** | **Relative Humidity (%)** |
| **Ambient Air** | 30.0 | | 60.0 |
| **Fuel** | 30.0 | 7,420.1 | 0.0 |
| **Combustion Air** | 30.0 | 0.0 | 60.0 |
| **Flue Gas** | 150.6 | 0.0 | N/A |

| General Simulation Data | |
|---|---|
| **Analysis Method** | Fuel Flow And Stack Gas |
| **Flue Gas Type** | Dry |
| **Local Barometric Pressure (kPa)** | 95.8 |
| **Nominal Rated Power Output (kW)** | 0 |
| **Fuel Cost (USD/GJ)** | 3.66 |

| Stack Gas Analysis | |
|---|---|
| **Component** | **Concentration (On A Dry Volume Basis)** |
| **Oxygen (%)** | 2.90 |
| **Carbon Monoxide (ppm)** | 2.70 |
| **Total Combustible (ppm)** | 0.00 |
| **Unburnt Fuel (calculated) (ppm)** | 0.00 |
| **Nitric Oxide (ppm)** | 124.30 |
| **Nitrogen Dioxide (ppm)** | 0.00 |
| **Sulfur Dioxide (ppm)** | 38.00 |

| Fuel Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Ethane | 0.040830 | 0.040830 | 0.041435 |
| Hydrogen (normal) | 0.015585 | 0.015585 | 0.015816 |
| Isobutane | 0.002245 | 0.002245 | 0.002278 |
| Isopentane | 0.000680 | 0.000680 | 0.000690 |
| Methane | 0.906545 | 0.906545 | 0.919985 |
| n-Butane | 0.002460 | 0.002460 | 0.002496 |
| n-Heptane | 0.000360 | 0.000360 | 0.000365 |
| n-Hexane | 0.000260 | 0.000260 | 0.000264 |
| Nitrogen | 0.016140 | 0.016140 | 0.004689 |
| n-Pentane | 0.000585 | 0.000585 | 0.000594 |
| Oxygen | 0.003090 | 0.003090 | 0.000000 |
| Propane | 0.011220 | 0.011220 | 0.011386 |
| **Total** | **1.000000** | **1.000000** | **1.000000** |

## Combustion Analysis Output

| Fuel Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 17.1 |
| Quality (inlet condition) (%) | 1.0 |
| Gross Heating Value ($MJ/m^3$) | 39.8 |
| Net Heating Value ($MJ/m^3$) | 35.3 |
| Theoretic Combustion Air Requirement (kmol/kmol) | 10.3 |

| Material Balance | |
|---|---|
| Stream | Flow Rate ($10^3m^3/d$) |
| Fuel | 178.08 |
| Air | 2090.78 |
| Stack Gas | 2275.21 |

| Excess Air | |
|---|---|
| Type | Amount (%) |
| Actual | 14.4 |
| Recommended Lower Limit | 5.0 |
| Recommended Upper Limit | 10.0 |

| Energy Balance | |
|---|---|
| Type | Amount (kW) |
| Gross Input Energy | 82,650.6 |
| Net Input Energy | 66,262.6 |

| Avoidable Energy Consumption (Losses) | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| High Excess Air | 0.2 | 142.3 |
| Unburnt Fuel | 0.0 | 0.7 |
| Recoverable Heat in Flue Gas[1] | 4.4 | 2936.5 |

| Unavoidable Energy Comsumption Losses | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| Unrecoverable Heat in Flue Gas[1] | 16.3 | 10,784.7 |

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C. The unrecoverable portion is the energy still left in the flue gas at that temperature.

| Efficiencies | |
|---|---|
| Efficiency Type | Amount (%) |
| Apparent Thermal Efficiency | 79.3 |
| Carbon Combustion Efficiency | 100.0 |

| Stack Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 27.58 |
| Dew Temperature ($^oC$) | 57.6 |

| Determined Flue Gas Emission Factors[2] | |
|---|---|
| Component | Amount (ng/J) |
| Carbon Monoxide | 0.8 |
| Carbon Dioxide | 49,867.3 |
| Methane | 0.0 |
| Ethane | 0.0 |
| Total VOC | 0.0 |
| Total Hydrocarbons | 0.0 |
| Nitric Oxide | 41.2 |
| Nitrogen Dioxide | 0.0 |
| Total Oxides of Nitrogen | 41.2 |
| Hydrogen Sulfide | 0.0 |
| Sulfur Dioxide | 33.0 |
| Carbon Disulfide | 0.0 |
| Carbonyl Sulfide | 0.0 |
| Total TRS | 0.0 |

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The $SO_2$ emission factor is based on the concentration measured in the flue gas.

| Dry Flue Gas Analysis | |
|---|---|
| **Component** | **Mole Fraction** |
| nitrogen | 0.868332 |
| carbon_dioxide | 0.102541 |
| oxygen | 0.029000 |
| nitric_oxide | 0.000124 |
| carbon_monoxide | 0.000003 |
| **Total** | **1.000000** |

## Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Switch Fuel Source | Switching to field gas | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0.19 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | 0 | 0 | 0 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0 | 4,375 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Switch Fuel Source | Switching to field gas | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |
| Tuning | Upgrade Fuel Drum and Boilers | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

## Control Technology Input Streams

| Technology type | Application Description | Use | Temperature (°C) | Pressure (kPa) | Line Name | Cross Sectional Shape |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | 25 | 101 | | Circular |

**Stream Pipe/Duct Cross-sectional Flow Area Dimension**

| Technology type | Application Description | Use | Pipe Outside Diameter (mm) | Pipe Wall Thickness (mm) | Pipe Rectangular Length (mm) | Pipe Rectangular Width (mm) |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | | | | |

**Stream Flow Rate**

| Technology type | Application Description | Use | Measurement Type | Reading Type | Measurement Date | Velocity (m/s) | Flow Rate ($m^3$/h) | Standard Flow Rate ($m^3$/h) |
|---|---|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Back Calculated Based on Measured Unit Output | Flow Rate (Standard Conditions) | | | | 7272.68 |

**Stream Composition**

| Technology type | Application Description | Use | Composition Name | Sample ID |
|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Gas de Campos | 47 |

## Simulation Results

| Source Name | Source Tag No. | Service Type | Value of Fuel/Loss Stream (USD/y) | Total Product Loss Flow ($m^3/h$) | Total Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3 m^3/d$) | Ethane ($m^3$/d liq) | LPG ($m^3$/d liq) | NGL ($m^3/d$) | Hydrogen ($m^3/d$) |
| Balance Boiler 1 | B-2951 | Steam Generator | 12,043,827 | 7,420.0 | 163.83 | 26.21 | 11.03 | 1.78 | 2,816.52 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| 2.6 | 129,049 | 2.33 | 129,825 | 6.0 | 2.1 | 106.6 | 0.0 | 2.1 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Tuning | 0.19 | 149,063 | 0 | 4,375 | 22,883 | -12,735 | 12.42 | 8.05 |
| Switch Fuel Source | 100.00 | 0 | 0 | 0 | 228,739 | 1,684,839 | NA | 0.00 |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| Tuning | 0.00 | 245 | 0.00 | 247 | 0.01 | 0.00 | 0.20 | 0.00 | 0.00 |
| Switch Fuel Source | -0.01 | -1,232 | -0.01 | -1,234 | -0.01 | -88.64 | -199.44 | 0.00 | -0.00 |

## Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Tuning | Upgrade Fuel Drum and Boilers |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Construction | Other Constuction Cost | Per Burner Installation. | 80,000.00 | 0.0 | 0 |
| | | Process GC installation (per drum) | 30,000.00 | 7.0 | 210,000 |
| Material | Instruments | CO Analyzer (per boiler) | 50,000.00 | 16.0 | 800,000 |
| | | Combustion Analyzer (per site) | 15,000.00 | 1.0 | 15,000 |
| | | Per Boiler Instrumentation | 50,000.00 | 16.0 | 800,000 |
| | | Process GC for Gas Anal. & A/F Control (per drum) | 80,000.00 | 7.0 | 560,000 |
| | Other Material Cost | High Efficiency Burners (4x per boiler) | 80,000.00 | 0.0 | 0 |

| | |
|---|---|
| **Total** | 2,385,000 |

# Combustion Analysis Report Summary

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Device | |
|---|---|
| **Name** | Balance Boiler 2 |
| **ID** | B-2952 |
| **On Site Location** | Barrancabermeja |
| **Category** | Heaters and Boilers |
| **Type** | Wall-fired (>29 MW) Uncontrolled Pre-NSPS |
| **Service** | Steam Generator |
| **Manufacturer** | N/A |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |

| Report Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Alfonso Garcia |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 2013/09/08 |

| Applied Emission Factors (ng/J) | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor** | 1.00 | US EPA AP-42 |
| **$N_2O$ Emission Factor** | 0.90 | US EPA AP-42 |
| **VOC Emission Factor** | 2.30 | US EPA AP-42 |
| **CO Emission Factor** | 0.59 | User Entered |
| **PM Emission Factor** | 0.80 | US EPA AP-42 |
| **$NO_x$ Emission Factor** | 35.57 | User Entered |

| Device Comments and Assumptions |
|---|
| Boiler |

| Data Comments and Assumptions |
|---|
| N/A |

## Combustion Analysis Input

| Gas Stream Conditions | | | |
|---|---|---|---|
| **Stream** | **Temperature ($^oC$)** | **Flow (m3/h @ STP)** | **Relative Humidity (%)** |
| **Ambient Air** | 30.0 | | 60.0 |
| **Fuel** | 30.0 | 6,320.1 | 0.0 |
| **Combustion Air** | 30.0 | 0.0 | 60.0 |
| **Flue Gas** | 195.0 | 0.0 | N/A |

| General Simulation Data | |
|---|---|
| **Analysis Method** | Fuel Flow And Stack Gas |
| **Flue Gas Type** | Dry |
| **Local Barometric Pressure (kPa)** | 95.8 |
| **Nominal Rated Power Output (kW)** | 0 |
| **Fuel Cost (USD/GJ)** | 3.66 |

| Stack Gas Analysis | |
|---|---|
| **Component** | **Concentration (On A Dry Volume Basis)** |
| **Oxygen (%)** | 2.20 |
| **Carbon Monoxide (ppm)** | 2.00 |
| **Total Combustible (ppm)** | 0.00 |
| **Unburnt Fuel (calculated) (ppm)** | 0.00 |
| **Nitric Oxide (ppm)** | 109.30 |
| **Nitrogen Dioxide (ppm)** | 1.40 |
| **Sulfur Dioxide (ppm)** | 58.80 |

| Fuel Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Ethane | 0.040830 | 0.040830 | 0.041435 |
| Hydrogen (normal) | 0.015585 | 0.015585 | 0.015816 |
| Isobutane | 0.002245 | 0.002245 | 0.002278 |
| Isopentane | 0.000680 | 0.000680 | 0.000690 |
| Methane | 0.906545 | 0.906545 | 0.919985 |
| n-Butane | 0.002460 | 0.002460 | 0.002496 |
| n-Heptane | 0.000360 | 0.000360 | 0.000365 |
| n-Hexane | 0.000260 | 0.000260 | 0.000264 |
| Nitrogen | 0.016140 | 0.016140 | 0.004689 |
| n-Pentane | 0.000585 | 0.000585 | 0.000594 |
| Oxygen | 0.003090 | 0.003090 | 0.000000 |
| Propane | 0.011220 | 0.011220 | 0.011386 |
| **Total** | **1.000000** | **1.000000** | **1.000000** |

## Combustion Analysis Output

| Fuel Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 17.1 |
| Quality (inlet condition) (%) | 1.0 |
| Gross Heating Value ($MJ/m^3$) | 39.8 |
| Net Heating Value ($MJ/m^3$) | 35.3 |
| Theoretic Combustion Air Requirement (kmol/kmol) | 10.3 |

| Material Balance | |
|---|---|
| Stream | Flow Rate ($10^3 m^3/d$) |
| Fuel | 151.68 |
| Air | 1720.40 |
| Stack Gas | 1877.50 |

| Excess Air | |
|---|---|
| Type | Amount (%) |
| Actual | 10.5 |
| Recommended Lower Limit | 5.0 |
| Recommended Upper Limit | 10.0 |

| Energy Balance | |
|---|---|
| Type | Amount (kW) |
| Gross Input Energy | 70,367.1 |
| Net Input Energy | 56,425.2 |

| Avoidable Energy Consumption (Losses) | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| High Excess Air | 0.0 | 20.0 |
| Unburnt Fuel | 0.0 | 0.4 |
| Recoverable Heat in Flue Gas[1] | 6.6 | 3733.2 |

| Unavoidable Energy Comsumption Losses | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| Unrecoverable Heat in Flue Gas[1] | 16.2 | 9,138.9 |

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C. The unrecoverable portion is the energy still left in the flue gas at that temperature.

| Efficiencies | |
|---|---|
| Efficiency Type | Amount (%) |
| Apparent Thermal Efficiency | 77.2 |
| Carbon Combustion Efficiency | 100.0 |

| Stack Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 27.55 |
| Dew Temperature (°C) | 58.1 |

| Determined Flue Gas Emission Factors[2] | |
|---|---|
| Component | Amount (ng/J) |
| Carbon Monoxide | 0.6 |
| Carbon Dioxide | 49,867.7 |
| Methane | 0.0 |
| Ethane | 0.0 |
| Total VOC | 0.0 |
| Total Hydrocarbons | 0.0 |
| Nitric Oxide | 34.9 |
| Nitrogen Dioxide | 0.7 |
| Total Oxides of Nitrogen | 35.6 |
| Hydrogen Sulfide | 0.0 |
| Sulfur Dioxide | 49.5 |
| Carbon Disulfide | 0.0 |
| Carbonyl Sulfide | 0.0 |
| Total TRS | 0.0 |

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The $SO_2$ emission factor is based on the concentration measured in the flue gas.

| Dry Flue Gas Analysis | |
|---|---|
| **Component** | **Mole Fraction** |
| nitrogen | 0.871375 |
| carbon_dioxide | 0.106513 |
| oxygen | 0.022000 |
| nitric_oxide | 0.000109 |
| carbon_monoxide | 0.000002 |
| nitrogen_dioxide | 0.000001 |
| **Total** | **1.000000** |

## Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Switch Fuel Source | Switching to field gas | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0.03 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | 0 | 0 | 0 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0 | 4,375 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Switch Fuel Source | Switching to field gas | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |
| Tuning | Upgrade Fuel Drum and Boilers | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

# Control Technology Input Streams

| Technology type | Application Description | Use | Temperature (°C) | Pressure (kPa) | Line Name | Cross Sectional Shape |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | 25 | 101 | | Circular |

| Stream Pipe/Duct Cross-sectional Flow Area Dimension | | | | | | |
|---|---|---|---|---|---|---|
| Technology type | Application Description | Use | Pipe Outside Diameter (mm) | Pipe Wall Thickness (mm) | Pipe Rectangular Length (mm) | Pipe Rectangular Width (mm) |
| Switch Fuel Source | Switching to field gas | Fuel Stream | | | | |

| Stream Flow Rate | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Technology type | Application Description | Use | Measurement Type | Reading Type | Measurement Date | Velocity (m/s) | Flow Rate ($m^3/h$) | Standard Flow Rate ($m^3/h$) |
| Switch Fuel Source | Switching to field gas | Fuel Stream | Back Calculated Based on Measured Unit Output | Flow Rate (Standard Conditions) | | | | 6194.52 |

| Stream Composition | | | | |
|---|---|---|---|---|
| Technology type | Application Description | Use | Composition Name | Sample ID |
| Switch Fuel Source | Switching to field gas | Fuel Stream | Gas de Campos | 47 |

## Simulation Results

| Source Name | Source Tag No. | Service Type | Value of Fuel/Loss Stream (USD/y) | Total Product Loss Flow ($m^3/h$) | Total Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3m^3/d$) | Ethane ($m^3/d$ liq) | LPG ($m^3/d$ liq) | NGL ($m^3/d$) | Hydrogen ($m^3/d$) |
| Balance Boiler 2 | B-2952 | Steam Generator | 10,258,354 | 6,320.0 | 139.54 | 22.33 | 9.39 | 1.52 | 2,398.98 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| 2.2 | 109,918 | 1.98 | 110,579 | 5.1 | 1.3 | 78.4 | 0.0 | 1.8 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Tuning | 0.03 | 149,063 | 0 | 4,375 | 3,396 | -156,277 | NA | NA |
| Switch Fuel Source | 100.00 | 0 | 0 | 0 | 194,829 | 1,435,063 | NA | 0.00 |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| Tuning | 0.00 | 36 | 0.00 | 37 | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 |
| Switch Fuel Source | -0.01 | -1,049 | -0.00 | -1,051 | -0.01 | -76.03 | -182.30 | 0.00 | -0.00 |

# Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Tuning | Upgrade Fuel Drum and Boilers |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Construction | Other Constuction Cost | Per Burner Installation. | 80,000.00 | 0.0 | 0 |
| | | Process GC installation (per drum) | 30,000.00 | 7.0 | 210,000 |
| Material | Instruments | CO Analyzer (per boiler) | 50,000.00 | 16.0 | 800,000 |
| | | Combustion Analyzer (per site) | 15,000.00 | 1.0 | 15,000 |
| | | Per Boiler Instrumentation | 50,000.00 | 16.0 | 800,000 |
| | | Process GC for Gas Anal. & A/F Control (per drum) | 80,000.00 | 7.0 | 560,000 |
| | Other Material Cost | High Efficiency Burners (4x per boiler) | 80,000.00 | 0.0 | 0 |
| | | | | **Total** | 2,385,000 |

# Combustion Analysis
# Report Summary

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Device | |
|---|---|
| **Name** | Balance Boiler 3 |
| **ID** | B-2953 |
| **On Site Location** | Barrancabermeja |
| **Category** | Heaters and Boilers |
| **Type** | Wall-fired (>29 MW)<br>Uncontrolled Pre-NSPS |
| **Service** | Steam Generator |
| **Manufacturer** | N/A |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |

| Report Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Alfonso Garcia |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 2013/09/08 |

| Applied Emission Factors (ng/J) | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor** | 1.00 | US EPA AP-42 |
| **$N_2O$ Emission Factor** | 0.90 | US EPA AP-42 |
| **VOC Emission Factor** | 2.30 | US EPA AP-42 |
| **CO Emission Factor** | 0.00 | User Entered |
| **PM Emission Factor** | 0.80 | US EPA AP-42 |
| **$NO_x$ Emission Factor** | 56.17 | User Entered |

| Device Comments and Assumptions |
|---|
| Boiler |

| Data Comments and Assumptions |
|---|
| N/A |

## Combustion Analysis Input

| Gas Stream Conditions | | | |
|---|---|---|---|
| **Stream** | **Temperature ($^oC$)** | **Flow (m3/h @ STP)** | **Relative Humidity (%)** |
| **Ambient Air** | 30.0 | | 60.0 |
| **Fuel** | 30.0 | 10,210.1 | 0.0 |
| **Combustion Air** | 30.0 | 0.0 | 60.0 |
| **Flue Gas** | 163.7 | 0.0 | N/A |

| General Simulation Data | |
|---|---|
| **Analysis Method** | Fuel Flow And Stack Gas |
| **Flue Gas Type** | Dry |
| **Local Barometric Pressure (kPa)** | 95.8 |
| **Nominal Rated Power Output (kW)** | 0 |
| **Fuel Cost (USD/GJ)** | 3.66 |

| Stack Gas Analysis | |
|---|---|
| **Component** | **Concentration (On A Dry Volume Basis)** |
| **Oxygen (%)** | 2.20 |
| **Carbon Monoxide (ppm)** | 0.00 |
| **Total Combustible (ppm)** | 23.30 |
| **Unburnt Fuel (calculated) (ppm)** | 23.30 |
| **Nitric Oxide (ppm)** | 176.00 |
| **Nitrogen Dioxide (ppm)** | 0.00 |
| **Sulfur Dioxide (ppm)** | 89.30 |

| Fuel Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Ethane | 0.040830 | 0.040830 | 0.041435 |
| Hydrogen (normal) | 0.015585 | 0.015585 | 0.015816 |
| Isobutane | 0.002245 | 0.002245 | 0.002278 |
| Isopentane | 0.000680 | 0.000680 | 0.000690 |
| Methane | 0.906545 | 0.906545 | 0.919985 |
| n-Butane | 0.002460 | 0.002460 | 0.002496 |
| n-Heptane | 0.000360 | 0.000360 | 0.000365 |
| n-Hexane | 0.000260 | 0.000260 | 0.000264 |
| Nitrogen | 0.016140 | 0.016140 | 0.004689 |
| n-Pentane | 0.000585 | 0.000585 | 0.000594 |
| Oxygen | 0.003090 | 0.003090 | 0.000000 |
| Propane | 0.011220 | 0.011220 | 0.011386 |
| **Total** | **1.000000** | **1.000000** | **1.000000** |

## Combustion Analysis Output

| Fuel Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 17.1 |
| Quality (inlet condition) (%) | 1.0 |
| Gross Heating Value ($MJ/m^3$) | 39.8 |
| Net Heating Value ($MJ/m^3$) | 35.3 |
| Theoretic Combustion Air Requirement (kmol/kmol) | 10.3 |

| Material Balance | |
|---|---|
| Stream | Flow Rate ($10^3 m^3/d$) |
| Fuel | 245.04 |
| Air | 2779.12 |
| Stack Gas | 3032.90 |

| Excess Air | |
|---|---|
| Type | Amount (%) |
| Actual | 10.5 |
| Recommended Lower Limit | 5.0 |
| Recommended Upper Limit | 10.0 |

| Energy Balance | |
|---|---|
| Type | Amount (kW) |
| Gross Input Energy | 113,678.5 |
| Net Input Energy | 91,160.4 |

| Avoidable Energy Consumption (Losses) | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| High Excess Air | 0.0 | 25.7 |
| Unburnt Fuel | 0.0 | 26.3 |
| Recoverable Heat in Flue Gas[1] | 5.0 | 4523.8 |

| Unavoidable Energy Comsumption Losses | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| Unrecoverable Heat in Flue Gas[1] | 16.2 | 14,760.9 |

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C. The unrecoverable portion is the energy still left in the flue gas at that temperature.

| Efficiencies | |
|---|---|
| Efficiency Type | Amount (%) |
| Apparent Thermal Efficiency | 78.8 |
| Carbon Combustion Efficiency | 100.0 |

| Stack Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 27.55 |
| Dew Temperature ($^oC$) | 58.1 |

| Determined Flue Gas Emission Factors[2] | |
|---|---|
| Component | Amount (ng/J) |
| Carbon Monoxide | 0.0 |
| Carbon Dioxide | 49,856.9 |
| Methane | 3.7 |
| Ethane | 0.3 |
| Total VOC | 0.2 |
| Total Hydrocarbons | 4.2 |
| Nitric Oxide | 56.2 |
| Nitrogen Dioxide | 0.0 |
| Total Oxides of Nitrogen | 56.2 |
| Hydrogen Sulfide | 0.0 |
| Sulfur Dioxide | 75.2 |
| Carbon Disulfide | 0.0 |
| Carbonyl Sulfide | 0.0 |
| Total TRS | 0.0 |

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The $SO_2$ emission factor is based on the concentration measured in the flue gas.

| Dry Flue Gas Analysis | |
|---|---|
| **Component** | **Mole Fraction** |
| nitrogen | 0.871307 |
| carbon_dioxide | 0.106493 |
| oxygen | 0.022000 |
| nitric_oxide | 0.000176 |
| methane | 0.000022 |
| ethane | 0.000001 |
| hydrogen_(normal) | 0.000000 |
| propane | 0.000000 |
| n-butane | 0.000000 |
| isobutane | 0.000000 |
| isopentane | 0.000000 |
| n-pentane | 0.000000 |
| n-heptane | 0.000000 |
| n-hexane | 0.000000 |
| **Total** | **1.000000** |

## Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Switch Fuel Source | Switching to field gas | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0.03 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | 0 | 0 | 0 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0 | 4,375 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Switch Fuel Source | Switching to field gas | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |
| Tuning | Upgrade Fuel Drum and Boilers | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

# Control Technology Input Streams

| Technology type | Application Description | Use | Temperature (°C) | Pressure (kPa) | Line Name | Cross Sectional Shape |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | 25 | 101 | | Circular |

**Stream Pipe/Duct Cross-sectional Flow Area Dimension**

| Technology type | Application Description | Use | Pipe Outside Diameter (mm) | Pipe Wall Thickness (mm) | Pipe Rectangular Length (mm) | Pipe Rectangular Width (mm) |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | | | | |

**Stream Flow Rate**

| Technology type | Application Description | Use | Measurement Type | Reading Type | Measurement Date | Velocity (m/s) | Flow Rate ($m^3/h$) | Standard Flow Rate ($m^3/h$) |
|---|---|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Back Calculated Based on Measured Unit Output | Flow Rate (Standard Conditions) | | | | 10007.29 |

**Stream Composition**

| Technology type | Application Description | Use | Composition Name | Sample ID |
|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Gas de Campos | 47 |

## Simulation Results

| Source Name | Source Tag No. | Service Type | Value of Fuel/Loss Stream (USD/y) | Total Product Loss Flow ($m^3/h$) | Total Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3 m^3/d$) | Ethane ($m^3/d$ liq) | LPG ($m^3/d$ liq) | NGL ($m^3/d$) | Hydrogen ($m^3/d$) |
| Balance Boiler 3 | B-2953 | Steam Generator | 16,572,435 | 10,210.0 | 225.43 | 36.07 | 15.17 | 2.45 | 3,875.57 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| 3.6 | 177,573 | 3.20 | 178,641 | 8.2 | 0.0 | 200.0 | 0.0 | 2.8 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Tuning | 0.03 | 149,063 | 0 | 4,375 | 4,309 | -149,550 | NA | NA |
| Switch Fuel Source | 100.00 | 0 | 0 | 0 | 314,741 | 2,318,309 | NA | 0.00 |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| Tuning | 0.00 | 46 | 0.00 | 46 | 0.00 | 0.00 | 0.05 | 0.00 | 0.00 |
| Switch Fuel Source | -0.01 | -1,695 | -0.01 | -1,698 | -0.02 | -124.92 | -221.16 | 0.00 | -0.01 |

## Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Tuning | Upgrade Fuel Drum and Boilers |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Construction | Other Constuction Cost | Per Burner Installation. | 80,000.00 | 0.0 | 0 |
| | | Process GC installation (per drum) | 30,000.00 | 7.0 | 210,000 |
| Material | Instruments | CO Analyzer (per boiler) | 50,000.00 | 16.0 | 800,000 |
| | | Combustion Analyzer (per site) | 15,000.00 | 1.0 | 15,000 |
| | | Per Boiler Instrumentation | 50,000.00 | 16.0 | 800,000 |
| | | Process GC for Gas Anal. & A/F Control (per drum) | 80,000.00 | 7.0 | 560,000 |
| | Other Material Cost | High Efficiency Burners (4x per boiler) | 80,000.00 | 0.0 | 0 |

| | |
|---|---|
| **Total** | 2,385,000 |

# Combustion Analysis
# Report Summary

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Device | |
|---|---|
| **Name** | Balance Boiler 4 |
| **ID** | B-2954 |
| **On Site Location** | Barrancabermeja |
| **Category** | Heaters and Boilers |
| **Type** | Wall-fired (>29 MW)<br>Uncontrolled Pre-NSPS |
| **Service** | Steam Generator |
| **Manufacturer** | N/A |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |

| Report Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Alfonso Garcia |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 2013/09/08 |

| Applied Emission Factors (ng/J) | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor** | 1.00 | US EPA AP-42 |
| **$N_2O$ Emission Factor** | 0.90 | US EPA AP-42 |
| **VOC Emission Factor** | 2.30 | US EPA AP-42 |
| **CO Emission Factor** | 12.57 | User Entered |
| **PM Emission Factor** | 0.80 | US EPA AP-42 |
| **$NO_x$ Emission Factor** | 50.29 | User Entered |

| Device Comments and Assumptions |
|---|
| Boiler |

| Data Comments and Assumptions |
|---|
| N/A |

## Combustion Analysis Input

| Gas Stream Conditions | | | |
|---|---|---|---|
| **Stream** | **Temperature ($^oC$)** | **Flow (m3/h @ STP)** | **Relative Humidity (%)** |
| **Ambient Air** | 30.0 | | 60.0 |
| **Fuel** | 30.0 | 9,040.1 | 0.0 |
| **Combustion Air** | 30.0 | 0.0 | 60.0 |
| **Flue Gas** | 228.0 | 0.0 | N/A |

| General Simulation Data | |
|---|---|
| **Analysis Method** | Fuel Flow And Stack Gas |
| **Flue Gas Type** | Dry |
| **Local Barometric Pressure (kPa)** | 95.8 |
| **Nominal Rated Power Output (kW)** | 0 |
| **Fuel Cost (USD/GJ)** | 3.66 |

| Stack Gas Analysis | |
|---|---|
| **Component** | **Concentration (On A Dry Volume Basis)** |
| **Oxygen (%)** | 1.40 |
| **Carbon Monoxide (ppm)** | 44.00 |
| **Total Combustible (ppm)** | 0.00 |
| **Unburnt Fuel (calculated) (ppm)** | 0.00 |
| **Nitric Oxide (ppm)** | 159.80 |
| **Nitrogen Dioxide (ppm)** | 2.90 |
| **Sulfur Dioxide (ppm)** | 22.50 |

| Fuel Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Ethane | 0.040830 | 0.040830 | 0.041435 |
| Hydrogen (normal) | 0.015585 | 0.015585 | 0.015816 |
| Isobutane | 0.002245 | 0.002245 | 0.002278 |
| Isopentane | 0.000680 | 0.000680 | 0.000690 |
| Methane | 0.906545 | 0.906545 | 0.919985 |
| n-Butane | 0.002460 | 0.002460 | 0.002496 |
| n-Heptane | 0.000360 | 0.000360 | 0.000365 |
| n-Hexane | 0.000260 | 0.000260 | 0.000264 |
| Nitrogen | 0.016140 | 0.016140 | 0.004689 |
| n-Pentane | 0.000585 | 0.000585 | 0.000594 |
| Oxygen | 0.003090 | 0.003090 | 0.000000 |
| Propane | 0.011220 | 0.011220 | 0.011386 |
| **Total** | **1.000000** | **1.000000** | **1.000000** |

## Combustion Analysis Output

| Fuel Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 17.1 |
| Quality (inlet condition) (%) | 1.0 |
| Gross Heating Value ($MJ/m^3$) | 39.8 |
| Net Heating Value ($MJ/m^3$) | 35.3 |
| Theoretic Combustion Air Requirement (kmol/kmol) | 10.3 |

| Material Balance | |
|---|---|
| Stream | Flow Rate ($10^3 m^3/d$) |
| Fuel | 216.96 |
| Air | 2369.76 |
| Stack Gas | 2594.51 |

| Excess Air | |
|---|---|
| Type | Amount (%) |
| Actual | 6.4 |
| Recommended Lower Limit | 5.0 |
| Recommended  Upper Limit | 10.0 |

| Energy Balance | |
|---|---|
| Type | Amount (kW) |
| Gross Input Energy | 100,605.5 |
| Net Input Energy | 80,688.3 |

| Avoidable Energy Consumption (Losses) | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| Unburnt Fuel | 0.0 | 12.7 |
| Recoverable Heat in Flue Gas[1] | 8.1 | 6518.8 |

| Unavoidable Energy Comsumption Losses | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| Unrecoverable Heat in Flue Gas[1] | 16.1 | 13,000.8 |

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C.  The unrecoverable portion is the energy still left in the flue gas at that temperature.

| Efficiencies | |
|---|---|
| Efficiency Type | Amount (%) |
| Apparent Thermal Efficiency | 75.8 |
| Carbon Combustion Efficiency | 100.0 |

| Stack Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 27.52 |
| Dew Temperature (°C) | 58.8 |

| Determined Flue Gas Emission Factors[2] | |
|---|---|
| Component | Amount (ng/J) |
| Carbon Monoxide | 12.6 |
| Carbon Dioxide | 49,848.8 |
| Methane | 0.0 |
| Ethane | 0.0 |
| Total VOC | 0.0 |
| Total Hydrocarbons | 0.0 |
| Nitric Oxide | 48.9 |
| Nitrogen Dioxide | 1.4 |
| Total Oxides of Nitrogen | 50.3 |
| Hydrogen Sulfide | 0.0 |
| Sulfur Dioxide | 18.3 |
| Carbon Disulfide | 0.0 |
| Carbonyl Sulfide | 0.0 |
| Total TRS | 0.0 |

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The $SO_2$ emission factor is based on the concentration measured in the flue gas.

| Dry Flue Gas Analysis | |
|---|---|
| **Component** | **Mole Fraction** |
| nitrogen | 0.874794 |
| carbon_dioxide | 0.110999 |
| oxygen | 0.014000 |
| nitric_oxide | 0.000160 |
| carbon_monoxide | 0.000044 |
| nitrogen_dioxide | 0.000003 |
| **Total** | **1.000000** |

## Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Switch Fuel Source | Switching to field gas | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0.01 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | 0 | 0 | 0 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0 | 4,375 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Switch Fuel Source | Switching to field gas | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |
| Tuning | Upgrade Fuel Drum and Boilers | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

# Control Technology Input Streams

| Technology type | Application Description | Use | Temperature ($^oC$) | Pressure (kPa) | Line Name | Cross Sectional Shape |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | 25 | 101 | | Circular |

**Stream Pipe/Duct Cross-sectional Flow Area Dimension**

| Technology type | Application Description | Use | Pipe Outside Diameter (mm) | Pipe Wall Thickness (mm) | Pipe Rectangular Length (mm) | Pipe Rectangular Width (mm) |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | | | | |

**Stream Flow Rate**

| Technology type | Application Description | Use | Measurement Type | Reading Type | Measurement Date | Velocity (m/s) | Flow Rate ($m^3/h$) | Standard Flow Rate ($m^3/h$) |
|---|---|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Back Calculated Based on Measured Unit Output | Flow Rate (Standard Conditions) | | | | 8909.53 |

**Stream Composition**

| Technology type | Application Description | Use | Composition Name | Sample ID |
|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Gas de Campos | 47 |

## Simulation Results

| Source Name | Source Tag No. | Service Type | Value of Fuel/Loss Stream (USD/y) | Total Product Loss Flow ($m^3$/h) | Total Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3m^3$/d) | Ethane ($m^3$/d liq) | LPG ($m^3$/d liq) | NGL ($m^3$/d) | Hydrogen ($m^3$/d) |
| Balance Boiler 4 | B-2954 | Steam Generator | 14,673,341 | 9,040.0 | 199.60 | 31.93 | 13.43 | 2.17 | 3,431.45 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| 3.2 | 157,224 | 2.84 | 158,170 | 7.3 | 39.6 | 158.6 | 0.0 | 2.5 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Tuning | 0.01 | 149,063 | 0 | 4,375 | 2,054 | -166,156 | NA | NA |
| Switch Fuel Source | 100.00 | 0 | 0 | 0 | 199,051 | 1,466,167 | NA | 0.00 |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| Tuning | 0.00 | 22 | 0.00 | 22 | 0.00 | 0.01 | 0.02 | 0.00 | 0.00 |
| Switch Fuel Source | -0.02 | -2,379 | -0.02 | -2,387 | -0.06 | -71.59 | -216.42 | 0.00 | -0.02 |

## Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Tuning | Upgrade Fuel Drum and Boilers |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Construction | Other Constuction Cost | Per Burner Installation. | 80,000.00 | 0.0 | 0 |
| | | Process GC installation (per drum) | 30,000.00 | 7.0 | 210,000 |
| Material | Instruments | CO Analyzer (per boiler) | 50,000.00 | 16.0 | 800,000 |
| | | Combustion Analyzer (per site) | 15,000.00 | 1.0 | 15,000 |
| | | Per Boiler Instrumentation | 50,000.00 | 16.0 | 800,000 |
| | | Process GC for Gas Anal. & A/F Control (per drum) | 80,000.00 | 7.0 | 560,000 |
| | Other Material Cost | High Efficiency Burners (4x per boiler) | 80,000.00 | 0.0 | 0 |

| | |
|---|---|
| **Total** | 2,385,000 |

# Combustion Analysis Report Summary

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Device | |
|---|---|
| **Name** | Balance Boiler 5 |
| **ID** | B-2955 |
| **On Site Location** | Barrancabermeja |
| **Category** | Heaters and Boilers |
| **Type** | Wall-fired (>29 MW)<br>Uncontrolled Pre-NSPS |
| **Service** | Steam Generator |
| **Manufacturer** | N/A |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |

| Report Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Alfonso Garcia |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 2013/09/08 |

| Applied Emission Factors (ng/J) | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor** | 1.00 | US EPA AP-42 |
| **$N_2O$ Emission Factor** | 0.90 | US EPA AP-42 |
| **VOC Emission Factor** | 2.30 | US EPA AP-42 |
| **CO Emission Factor** | 35.00 | User Entered |
| **PM Emission Factor** | 0.80 | US EPA AP-42 |
| **$NO_x$ Emission Factor** | 49.37 | User Entered |

| Device Comments and Assumptions |
|---|
| Boiler |

| Data Comments and Assumptions |
|---|
| N/A |

## Combustion Analysis Input

| Gas Stream Conditions | | | |
|---|---|---|---|
| **Stream** | **Temperature ($^oC$)** | **Flow (m3/h @ STP)** | **Relative Humidity (%)** |
| **Ambient Air** | 30.0 | | 60.0 |
| **Fuel** | 30.0 | 7,930.1 | 0.0 |
| **Combustion Air** | 30.0 | 0.0 | 60.0 |
| **Flue Gas** | 211.0 | 0.0 | N/A |

| General Simulation Data | |
|---|---|
| **Analysis Method** | Fuel Flow And Stack Gas |
| **Flue Gas Type** | Dry |
| **Local Barometric Pressure (kPa)** | 95.8 |
| **Nominal Rated Power Output (kW)** | 0 |
| **Fuel Cost (USD/GJ)** | 3.66 |

| Stack Gas Analysis | |
|---|---|
| **Component** | **Concentration (On A Dry Volume Basis)** |
| **Oxygen (%)** | 2.30 |
| **Carbon Monoxide (ppm)** | 0.00 |
| **Total Combustible (ppm)** | 0.00 |
| **Unburnt Fuel (calculated) (ppm)** | 0.00 |
| **Nitric Oxide (ppm)** | 150.00 |
| **Nitrogen Dioxide (ppm)** | 2.50 |
| **Sulfur Dioxide (ppm)** | 4.30 |

| Fuel Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Ethane | 0.040830 | 0.040830 | 0.041435 |
| Hydrogen (normal) | 0.015585 | 0.015585 | 0.015816 |
| Isobutane | 0.002245 | 0.002245 | 0.002278 |
| Isopentane | 0.000680 | 0.000680 | 0.000690 |
| Methane | 0.906545 | 0.906545 | 0.919985 |
| n-Butane | 0.002460 | 0.002460 | 0.002496 |
| n-Heptane | 0.000360 | 0.000360 | 0.000365 |
| n-Hexane | 0.000260 | 0.000260 | 0.000264 |
| Nitrogen | 0.016140 | 0.016140 | 0.004689 |
| n-Pentane | 0.000585 | 0.000585 | 0.000594 |
| Oxygen | 0.003090 | 0.003090 | 0.000000 |
| Propane | 0.011220 | 0.011220 | 0.011386 |
| **Total** | **1.000000** | **1.000000** | **1.000000** |

# Combustion Analysis Output

| Fuel Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 17.1 |
| Quality (inlet condition) (%) | 1.0 |
| Gross Heating Value ($MJ/m^3$) | 39.8 |
| Net Heating Value ($MJ/m^3$) | 35.3 |
| Theoretic Combustion Air Requirement (kmol/kmol) | 10.3 |

| Material Balance | |
|---|---|
| Stream | Flow Rate ($10^3m^3/d$) |
| Fuel | 190.32 |
| Air | 2169.38 |
| Stack Gas | 2366.49 |

| Excess Air | |
|---|---|
| Type | Amount (%) |
| Actual | 11.1 |
| Recommended Lower Limit | 5.0 |
| Recommended Upper Limit | 10.0 |

| Energy Balance | |
|---|---|
| Type | Amount (kW) |
| Gross Input Energy | 88,298.4 |
| Net Input Energy | 70,801.9 |

| Avoidable Energy Consumption (Losses) | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| High Excess Air | 0.1 | 56.1 |
| Recoverable Heat in Flue Gas[1] | 7.5 | 5312.3 |

| Unavoidable Energy Comsumption Losses | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| Unrecoverable Heat in Flue Gas[1] | 16.2 | 11,475.4 |

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C. The unrecoverable portion is the energy still left in the flue gas at that temperature.

| Efficiencies | |
|---|---|
| Efficiency Type | Amount (%) |
| Apparent Thermal Efficiency | 76.3 |
| Carbon Combustion Efficiency | 100.0 |

| Stack Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 27.56 |
| Dew Temperature (°C) | 58.1 |

| Determined Flue Gas Emission Factors[2] | |
|---|---|
| Component | Amount (ng/J) |
| Carbon Monoxide | 0.0 |
| Carbon Dioxide | 49,868.6 |
| Methane | 0.0 |
| Ethane | 0.0 |
| Total VOC | 0.0 |
| Total Hydrocarbons | 0.0 |
| Nitric Oxide | 48.1 |
| Nitrogen Dioxide | 1.2 |
| Total Oxides of Nitrogen | 49.4 |
| Hydrogen Sulfide | 0.0 |
| Sulfur Dioxide | 3.6 |
| Carbon Disulfide | 0.0 |
| Carbonyl Sulfide | 0.0 |
| Total TRS | 0.0 |

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The $SO_2$ emission factor is based on the concentration measured in the flue gas.

| Dry Flue Gas Analysis | |
|---|---|
| **Component** | **Mole Fraction** |
| nitrogen | 0.870912 |
| carbon_dioxide | 0.105935 |
| oxygen | 0.023000 |
| nitric_oxide | 0.000150 |
| nitrogen_dioxide | 0.000002 |
| **Total** | **1.000000** |

## Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Switch Fuel Source | Switching to field gas | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0.07 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | 0 | 0 | 0 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0 | 4,375 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Switch Fuel Source | Switching to field gas | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |
| Tuning | Upgrade Fuel Drum and Boilers | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

# Control Technology Input Streams

| Technology type | Application Description | Use | Temperature ($^oC$) | Pressure (kPa) | Line Name | Cross Sectional Shape |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | 25 | 101 | | Circular |

**Stream Pipe/Duct Cross-sectional Flow Area Dimension**

| Technology type | Application Description | Use | Pipe Outside Diameter (mm) | Pipe Wall Thickness (mm) | Pipe Rectangular Length (mm) | Pipe Rectangular Width (mm) |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | | | | |

**Stream Flow Rate**

| Technology type | Application Description | Use | Measurement Type | Reading Type | Measurement Date | Velocity (m/s) | Flow Rate ($m^3/h$) | Standard Flow Rate ($m^3/h$) |
|---|---|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Back Calculated Based on Measured Unit Output | Flow Rate (Standard Conditions) | | | | 7772.56 |

**Stream Composition**

| Technology type | Application Description | Use | Composition Name | Sample ID |
|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Gas de Campos | 47 |

## Simulation Results

| Source Name | Source Tag No. | Service Type | Value of Fuel/Loss Stream (USD/y) | Total Product Loss Flow ($m^3/h$) | Total Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3 m^3/d$) | Ethane ($m^3/d$ liq) | LPG ($m^3/d$ liq) | NGL ($m^3/d$) | Hydrogen ($m^3/d$) |
| Balance Boiler 5 | B-2955 | Steam Generator | 12,871,637 | 7,930.0 | 175.09 | 28.01 | 11.78 | 1.90 | 3,010.11 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| 2.8 | 137,919 | 2.49 | 138,749 | 6.4 | 96.8 | 136.5 | 0.0 | 2.2 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Tuning | 0.07 | 149,063 | 0 | 4,375 | 9,396 | -112,077 | 3.37 | 29.69 |
| Switch Fuel Source | 100.00 | 0 | 0 | 0 | 244,451 | 1,800,574 | NA | 0.00 |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| Tuning | 0.00 | 101 | 0.00 | 101 | 0.00 | 0.07 | 0.10 | 0.00 | 0.00 |
| Switch Fuel Source | -0.01 | -1,317 | -0.01 | -1,319 | -0.02 | -0.23 | -190.58 | 0.00 | -0.01 |

# Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Tuning | Upgrade Fuel Drum and Boilers |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Construction | Other Constuction Cost | Per Burner Installation. | 80,000.00 | 0.0 | 0 |
| | | Process GC installation (per drum) | 30,000.00 | 7.0 | 210,000 |
| Material | Instruments | CO Analyzer (per boiler) | 50,000.00 | 16.0 | 800,000 |
| | | Combustion Analyzer (per site) | 15,000.00 | 1.0 | 15,000 |
| | | Per Boiler Instrumentation | 50,000.00 | 16.0 | 800,000 |
| | | Process GC for Gas Anal. & A/F Control (per drum) | 80,000.00 | 7.0 | 560,000 |
| | Other Material Cost | High Efficiency Burners (4x per boiler) | 80,000.00 | 0.0 | 0 |
| | | | | **Total** | 2,385,000 |

# Combustion Analysis Report Summary

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Device | |
|---|---|
| **Name** | Foster Boiler B |
| **ID** | B-901 B |
| **On Site Location** | Barrancabermeja |
| **Category** | Heaters and Boilers |
| **Type** | Wall-fired (<=29 MW) Uncontrolled |
| **Service** | Steam Generator |
| **Manufacturer** | N/A |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |

| Report Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Alfonso Garcia |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 2013/09/08 |

| Applied Emission Factors (ng/J) | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor** | 1.00 | US EPA AP-42 |
| **$N_2O$ Emission Factor** | 0.90 | US EPA AP-42 |
| **VOC Emission Factor** | 2.30 | US EPA AP-42 |
| **CO Emission Factor** | 35.00 | US EPA AP-42 |
| **PM Emission Factor** | 0.80 | US EPA AP-42 |
| **$NO_x$ Emission Factor** | 42.00 | US EPA AP-42 |

| Device Comments and Assumptions |
|---|
| Boiler |

| Data Comments and Assumptions |
|---|
| In this case to run the simulation, all the pertinent data provided by Ecopetrol was used. |

# Combustion Analysis Input

| Gas Stream Conditions | | | |
|---|---|---|---|
| **Stream** | **Temperature ($^oC$)** | **Flow (m3/h @ STP)** | **Relative Humidity (%)** |
| **Ambient Air** | 30.0 | | 60.0 |
| **Fuel** | 30.0 | 3,140.0 | 0.0 |
| **Combustion Air** | 30.0 | 0.0 | 60.0 |
| **Flue Gas** | 197.4 | 0.0 | N/A |

| General Simulation Data | |
|---|---|
| **Analysis Method** | Fuel Flow And Stack Gas |
| **Flue Gas Type** | Dry |
| **Local Barometric Pressure (kPa)** | 95.8 |
| **Nominal Rated Power Output (kW)** | 0 |
| **Fuel Cost (USD/GJ)** | 3.66 |

| Stack Gas Analysis | |
|---|---|
| **Component** | **Concentration (On A Dry Volume Basis)** |
| **Oxygen (%)** | 2.50 |
| **Carbon Monoxide (ppm)** | 0.00 |
| **Total Combustible (ppm)** | 0.00 |
| **Unburnt Fuel (calculated) (ppm)** | 0.00 |
| **Nitric Oxide (ppm)** | 0.00 |
| **Nitrogen Dioxide (ppm)** | 0.00 |
| **Sulfur Dioxide (ppm)** | 0.00 |

| Fuel Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.003140 | 0.003140 | 0.003209 |
| Ethane | 0.055125 | 0.055125 | 0.056342 |
| Hydrogen (normal) | 0.355785 | 0.355785 | 0.363642 |
| Isobutane | 0.009620 | 0.009620 | 0.009832 |
| Isopentane | 0.001525 | 0.001525 | 0.001559 |
| Methane | 0.497710 | 0.497710 | 0.508701 |
| n-Butane | 0.010135 | 0.010135 | 0.010359 |
| n-Heptane | 0.000680 | 0.000680 | 0.000695 |
| n-Hexane | 0.000605 | 0.000605 | 0.000618 |
| Nitrogen | 0.025590 | 0.025590 | 0.008743 |
| n-Pentane | 0.001035 | 0.001035 | 0.001058 |
| Oxygen | 0.004570 | 0.004570 | 0.000000 |
| Propane | 0.034480 | 0.034480 | 0.035241 |
| **Total** | **1.000000** | **1.000000** | **1.000000** |

## Combustion Analysis Output

| Fuel Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 14.0 |
| Quality (inlet condition) (%) | 1.0 |
| Gross Heating Value ($MJ/m^3$) | 33.9 |
| Net Heating Value ($MJ/m^3$) | 29.9 |
| Theoretic Combustion Air Requirement (kmol/kmol) | 8.5 |

| Material Balance | |
|---|---|
| Stream | Flow Rate ($10^3 m^3/d$) |
| Fuel | 75.36 |
| Air | 718.73 |
| Stack Gas | 788.00 |

| Excess Air | |
|---|---|
| Type | Amount (%) |
| Actual | 12.0 |
| Recommended Lower Limit | 5.0 |
| Recommended Upper Limit | 10.0 |

| Energy Balance | |
|---|---|
| Type | Amount (kW) |
| Gross Input Energy | 30,152.2 |
| Net Input Energy | 24,056.0 |

| Avoidable Energy Consumption (Losses) | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| High Excess Air | 0.1 | 32.4 |
| Recoverable Heat in Flue Gas[1] | 6.6 | 1585.2 |

| Unavoidable Energy Comsumption Losses | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| Unrecoverable Heat in Flue Gas[1] | 16.5 | 3,973.1 |

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C. The unrecoverable portion is the energy still left in the flue gas at that temperature.

| Efficiencies | |
|---|---|
| Efficiency Type | Amount (%) |
| Apparent Thermal Efficiency | 76.9 |
| Carbon Combustion Efficiency | 100.0 |

| Stack Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 27.39 |
| Dew Temperature (°C) | 58.9 |

| Determined Flue Gas Emission Factors[2] | |
|---|---|
| Component | Amount (ng/J) |
| Carbon Monoxide | 0.0 |
| Carbon Dioxide | 45,660.9 |
| Methane | 0.0 |
| Ethane | 0.0 |
| Total VOC | 0.0 |
| Total Hydrocarbons | 0.0 |
| Nitric Oxide | 0.0 |
| Nitrogen Dioxide | 0.0 |
| Total Oxides of Nitrogen | 0.0 |
| Hydrogen Sulfide | 0.0 |
| Sulfur Dioxide | 0.0 |
| Carbon Disulfide | 0.0 |
| Carbonyl Sulfide | 0.0 |
| Total TRS | 0.0 |

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The $SO_2$ emission factor is based on the concentration measured in the flue gas.

| Dry Flue Gas Analysis | |
|---|---|
| **Component** | **Mole Fraction** |
| nitrogen | 0.875689 |
| carbon_dioxide | 0.099311 |
| oxygen | 0.025000 |
| **Total** | **1.000000** |

# Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Switch Fuel Source | Switching to field gas | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0.12 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | 0 | 0 | 0 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0 | 4,375 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Switch Fuel Source | Switching to field gas | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 42.00 | N/A |
| Tuning | Upgrade Fuel Drum and Boilers | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

## Control Technology Input Streams

| Technology type | Application Description | Use | Temperature (°C) | Pressure (kPa) | Line Name | Cross Sectional Shape |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | 25 | 101 | | Circular |

| Stream Pipe/Duct Cross-sectional Flow Area Dimension | | | | | | |
|---|---|---|---|---|---|---|
| **Technology type** | **Application Description** | **Use** | **Pipe Outside Diameter (mm)** | **Pipe Wall Thickness (mm)** | **Pipe Rectangular Length (mm)** | **Pipe Rectangular Width (mm)** |
| Switch Fuel Source | Switching to field gas | Fuel Stream | | | | |

| Stream Flow Rate | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Technology type** | **Application Description** | **Use** | **Measurement Type** | **Reading Type** | **Measurement Date** | **Velocity (m/s)** | **Flow Rate ($m^3$/h)** | **Standard Flow Rate ($m^3$/h)** |
| Switch Fuel Source | Switching to field gas | Fuel Stream | Back Calculated Based on Measured Unit Output | Flow Rate (Standard Conditions) | | | | 2605.56 |

| Stream Composition | | | | |
|---|---|---|---|---|
| **Technology type** | **Application Description** | **Use** | **Composition Name** | **Sample ID** |
| Switch Fuel Source | Switching to field gas | Fuel Stream | Gas de Campos | 47 |

## Simulation Results

| Source Name | Source Tag No. | Service Type | Value of Fuel/Loss Stream (USD/y) | Total Product Loss Flow ($m^3/h$) | Total Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3m^3/d$) | Ethane ($m^3$/d liq) | LPG ($m^3$/d liq) | NGL ($m^3/d$) | Hydrogen ($m^3/d$) |
| Foster Boiler B | B-901 B | Steam Generator | 5,387,204 | 3,140.0 | 38.34 | 15.08 | 16.16 | 1.55 | 27,404.06 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| 0.9 | 42,634 | 0.84 | 42,914 | 2.1 | 32.7 | 39.2 | 0.0 | 0.7 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Tuning | 0.12 | 149,063 | 0 | 4,375 | 6,465 | -133,671 | 1.40 | 71.33 |
| Switch Fuel Source | 100.00 | 0 | 0 | 0 | 1,154,250 | 8,501,945 | NA | 0.00 |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| Tuning | 0.00 | 51 | 0.00 | 51 | 0.00 | 0.04 | 0.05 | 0.00 | 0.00 |
| Switch Fuel Source | 0.00 | -4,041 | 0.00 | -4,040 | 0.01 | 0.15 | 0.18 | 0.00 | 0.00 |

# Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Tuning | Upgrade Fuel Drum and Boilers |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Construction | Other Constuction Cost | Per Burner Installation. | 80,000.00 | 0.0 | 0 |
| | | Process GC installation (per drum) | 30,000.00 | 7.0 | 210,000 |
| Material | Instruments | CO Analyzer (per boiler) | 50,000.00 | 16.0 | 800,000 |
| | | Combustion Analyzer (per site) | 15,000.00 | 1.0 | 15,000 |
| | | Per Boiler Instrumentation | 50,000.00 | 16.0 | 800,000 |
| | | Process GC for Gas Anal. & A/F Control (per drum) | 80,000.00 | 7.0 | 560,000 |
| | Other Material Cost | High Efficiency Burners (4x per boiler) | 80,000.00 | 0.0 | 0 |

| | |
|---|---|
| **Total** | 2,385,000 |

# Combustion Analysis Report Summary

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Device | |
|---|---|
| **Name** | Foster Boiler D |
| **ID** | B-901 D |
| **On Site Location** | Barrancabermeja |
| **Category** | Heaters and Boilers |
| **Type** | Wall-fired (<=29 MW) Uncontrolled |
| **Service** | Steam Generator |
| **Manufacturer** | N/A |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |

| Report Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Alfonso Garcia |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 2013/09/08 |

| Applied Emission Factors (ng/J) | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor** | 1.00 | US EPA AP-42 |
| **$N_2O$ Emission Factor** | 0.90 | US EPA AP-42 |
| **VOC Emission Factor** | 2.30 | US EPA AP-42 |
| **CO Emission Factor** | 35.00 | US EPA AP-42 |
| **PM Emission Factor** | 0.80 | US EPA AP-42 |
| **$NO_x$ Emission Factor** | 42.00 | US EPA AP-42 |

| Device Comments and Assumptions |
|---|
| Boiler |

| Data Comments and Assumptions |
|---|
| In this case to run the simulation, all the data provided by Ecopetrol was used |

# Combustion Analysis Input

| Gas Stream Conditions | | | |
|---|---|---|---|
| **Stream** | **Temperature ($^oC$)** | **Flow (m3/h @ STP)** | **Relative Humidity (%)** |
| **Ambient Air** | 30.0 | | 60.0 |
| **Fuel** | 30.0 | 3,540.0 | 0.0 |
| **Combustion Air** | 30.0 | 0.0 | 60.0 |
| **Flue Gas** | 189.4 | 0.0 | N/A |

| General Simulation Data | |
|---|---|
| **Analysis Method** | Fuel Flow And Stack Gas |
| **Flue Gas Type** | Dry |
| **Local Barometric Pressure (kPa)** | 95.8 |
| **Nominal Rated Power Output (kW)** | 0 |
| **Fuel Cost (USD/GJ)** | 3.66 |

| Stack Gas Analysis | |
|---|---|
| **Component** | **Concentration (On A Dry Volume Basis)** |
| **Oxygen (%)** | 2.50 |
| **Carbon Monoxide (ppm)** | 0.00 |
| **Total Combustible (ppm)** | 0.00 |
| **Unburnt Fuel (calculated) (ppm)** | 0.00 |
| **Nitric Oxide (ppm)** | 0.00 |
| **Nitrogen Dioxide (ppm)** | 0.00 |
| **Sulfur Dioxide (ppm)** | 0.00 |

| Fuel Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.003140 | 0.003140 | 0.003209 |
| Ethane | 0.055125 | 0.055125 | 0.056342 |
| Hydrogen (normal) | 0.355785 | 0.355785 | 0.363642 |
| Isobutane | 0.009620 | 0.009620 | 0.009832 |
| Isopentane | 0.001525 | 0.001525 | 0.001559 |
| Methane | 0.497710 | 0.497710 | 0.508701 |
| n-Butane | 0.010135 | 0.010135 | 0.010359 |
| n-Heptane | 0.000680 | 0.000680 | 0.000695 |
| n-Hexane | 0.000605 | 0.000605 | 0.000618 |
| Nitrogen | 0.025590 | 0.025590 | 0.008743 |
| n-Pentane | 0.001035 | 0.001035 | 0.001058 |
| Oxygen | 0.004570 | 0.004570 | 0.000000 |
| Propane | 0.034480 | 0.034480 | 0.035241 |
| **Total** | **1.000000** | **1.000000** | **1.000000** |

# Combustion Analysis Output

| Fuel Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 14.0 |
| Quality (inlet condition) (%) | 1.0 |
| Gross Heating Value ($MJ/m^3$) | 33.9 |
| Net Heating Value ($MJ/m^3$) | 29.9 |
| Theoretic Combustion Air Requirement (kmol/kmol) | 8.5 |

| Material Balance | |
|---|---|
| Stream | Flow Rate ($10^3m^3/d$) |
| Fuel | 84.96 |
| Air | 810.29 |
| Stack Gas | 888.38 |

| Excess Air | |
|---|---|
| Type | Amount (%) |
| Actual | 12.0 |
| Recommended Lower Limit | 5.0 |
| Recommended Upper Limit | 10.0 |

| Energy Balance | |
|---|---|
| Type | Amount (kW) |
| Gross Input Energy | 33,993.3 |
| Net Input Energy | 27,120.5 |

| Avoidable Energy Consumption (Losses) | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| High Excess Air | 0.1 | 34.7 |
| Recoverable Heat in Flue Gas[1] | 6.2 | 1673.1 |

| Unavoidable Energy Comsumption Losses | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| Unrecoverable Heat in Flue Gas[1] | 16.5 | 4,479.3 |

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C. The unrecoverable portion is the energy still left in the flue gas at that temperature.

| Efficiencies | |
|---|---|
| Efficiency Type | Amount (%) |
| Apparent Thermal Efficiency | 77.3 |
| Carbon Combustion Efficiency | 100.0 |

| Stack Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 27.39 |
| Dew Temperature (°C) | 58.9 |

| Determined Flue Gas Emission Factors[2] | |
|---|---|
| Component | Amount (ng/J) |
| Carbon Monoxide | 0.0 |
| Carbon Dioxide | 45,660.9 |
| Methane | 0.0 |
| Ethane | 0.0 |
| Total VOC | 0.0 |
| Total Hydrocarbons | 0.0 |
| Nitric Oxide | 0.0 |
| Nitrogen Dioxide | 0.0 |
| Total Oxides of Nitrogen | 0.0 |
| Hydrogen Sulfide | 0.0 |
| Sulfur Dioxide | 0.0 |
| Carbon Disulfide | 0.0 |
| Carbonyl Sulfide | 0.0 |
| Total TRS | 0.0 |

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The $SO_2$ emission factor is based on the concentration measured in the flue gas.

| Dry Flue Gas Analysis | |
|---|---|
| **Component** | **Mole Fraction** |
| nitrogen | 0.875689 |
| carbon_dioxide | 0.099311 |
| oxygen | 0.025000 |
| **Total** | **1.000000** |

## Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Switch Fuel Source | Switching to field gas | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0.11 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | 0 | 0 | 0 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0 | 4,375 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Switch Fuel Source | Switching to field gas | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 42.00 | N/A |
| Tuning | Upgrade Fuel Drum and Boilers | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

## Control Technology Input Streams

| Technology type | Application Description | Use | Temperature (°C) | Pressure (kPa) | Line Name | Cross Sectional Shape |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | 25 | 101 | | Circular |

**Stream Pipe/Duct Cross-sectional Flow Area Dimension**

| Technology type | Application Description | Use | Pipe Outside Diameter (mm) | Pipe Wall Thickness (mm) | Pipe Rectangular Length (mm) | Pipe Rectangular Width (mm) |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | | | | |

**Stream Flow Rate**

| Technology type | Application Description | Use | Measurement Type | Reading Type | Measurement Date | Velocity (m/s) | Flow Rate ($m^3$/h) | Standard Flow Rate ($m^3$/h) |
|---|---|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Back Calculated Based on Measured Unit Output | Flow Rate (Standard Conditions) | | | | 2937.69 |

**Stream Composition**

| Technology type | Application Description | Use | Composition Name | Sample ID |
|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Gas de Campos | 47 |

## Simulation Results

| Source Name | Source Tag No. | Service Type | Value of Fuel/Loss Stream (USD/y) | Total Product Loss Flow ($m^3/h$) | Total Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3 m^3/d$) | Ethane ($m^3/d$ liq) | LPG ($m^3/d$ liq) | NGL ($m^3/d$) | Hydrogen ($m^3/d$) |
| Foster Boiler D | B-901 D | Steam Generator | 6,073,472 | 3,540.0 | 43.22 | 17.00 | 18.22 | 1.74 | 30,895.02 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| 1.1 | 48,065 | 0.95 | 48,381 | 2.4 | 36.8 | 44.2 | 0.0 | 0.8 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Tuning | 0.11 | 149,063 | 0 | 4,375 | 6,681 | -132,078 | 1.55 | 64.65 |
| Switch Fuel Source | 100.00 | 0 | 0 | 0 | 1,300,944 | 9,582,464 | NA | 0.00 |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| Tuning | 0.00 | 53 | 0.00 | 53 | 0.00 | 0.04 | 0.05 | 0.00 | 0.00 |
| Switch Fuel Source | 0.00 | -4,560 | 0.00 | -4,558 | 0.01 | 0.17 | 0.20 | 0.00 | 0.00 |

## Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Tuning | Upgrade Fuel Drum and Boilers |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Construction | Other Constuction Cost | Per Burner Installation. | 80,000.00 | 0.0 | 0 |
| | | Process GC installation (per drum) | 30,000.00 | 7.0 | 210,000 |
| Material | Instruments | CO Analyzer (per boiler) | 50,000.00 | 16.0 | 800,000 |
| | | Combustion Analyzer (per site) | 15,000.00 | 1.0 | 15,000 |
| | | Per Boiler Instrumentation | 50,000.00 | 16.0 | 800,000 |
| | | Process GC for Gas Anal. & A/F Control (per drum) | 80,000.00 | 7.0 | 560,000 |
| | Other Material Cost | High Efficiency Burners (4x per boiler) | 80,000.00 | 0.0 | 0 |

| | |
|---|---|
| **Total** | 2,385,000 |

# Combustion Analysis Report Summary

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Device | |
|---|---|
| **Name** | Calderas Nuevas Boiler |
| **ID** | B-952 |
| **On Site Location** | Barrancabermeja |
| **Category** | Heaters and Boilers |
| **Type** | Wall-fired (>29 MW) Uncontrolled Pre-NSPS |
| **Service** | Steam Generator |
| **Manufacturer** | N/A |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |

| Report Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Alfonso Garcia |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 2013/09/08 |

| Applied Emission Factors (ng/J) | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor** | 1.00 | US EPA AP-42 |
| **$N_2O$ Emission Factor** | 0.90 | US EPA AP-42 |
| **VOC Emission Factor** | 2.30 | US EPA AP-42 |
| **CO Emission Factor** | 1,202 | User Entered |
| **PM Emission Factor** | 0.80 | US EPA AP-42 |
| **$NO_x$ Emission Factor** | 118.00 | US EPA AP-42 |

| Device Comments and Assumptions |
|---|
| N/A |

| Data Comments and Assumptions |
|---|
| N/A |

# Combustion Analysis Input

| Gas Stream Conditions | | | |
|---|---|---|---|
| **Stream** | **Temperature ($^oC$)** | **Flow (m3/h @ STP)** | **Relative Humidity (%)** |
| **Ambient Air** | 30.0 | | 60.0 |
| **Fuel** | 30.0 | 2,718.4 | 0.0 |
| **Combustion Air** | 30.0 | 0.0 | 60.0 |
| **Flue Gas** | 142.0 | 0.0 | N/A |

| General Simulation Data | |
|---|---|
| **Analysis Method** | Fuel Flow And Stack Gas |
| **Flue Gas Type** | Dry |
| **Local Barometric Pressure (kPa)** | 95.8 |
| **Nominal Rated Power Output (kW)** | 30,100 |
| **Assumed Efficiency (%)** | 80 |
| **Assumed Loading (%)** | 100 |
| **Fuel Cost (USD/GJ)** | 3.66 |

| Stack Gas Analysis | |
|---|---|
| **Component** | **Concentration (On A Dry Volume Basis)** |
| **Oxygen (%)** | 14.40 |
| **Carbon Monoxide (ppm)** | 1,465.40 |
| **Total Combustible (ppm)** | 0.00 |
| **Unburnt Fuel (calculated) (ppm)** | 0.00 |
| **Nitric Oxide (ppm)** | 0.00 |
| **Nitrogen Dioxide (ppm)** | 0.00 |
| **Sulfur Dioxide (ppm)** | 0.00 |

| Fuel Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.009065 | 0.009065 | 0.009272 |
| Ethane | 0.091295 | 0.091295 | 0.093383 |
| Hydrogen (normal) | 0.361855 | 0.361855 | 0.370132 |
| Isobutane | 0.017560 | 0.017560 | 0.017962 |
| Isopentane | 0.002765 | 0.002765 | 0.002828 |
| Methane | 0.393485 | 0.393485 | 0.402486 |
| n-Butane | 0.009735 | 0.009735 | 0.009958 |
| n-Heptane | 0.000625 | 0.000625 | 0.000639 |
| n-Hexane | 0.000555 | 0.000555 | 0.000568 |
| Nitrogen | 0.033885 | 0.033885 | 0.016624 |
| n-Pentane | 0.001620 | 0.001620 | 0.001657 |
| Oxygen | 0.004730 | 0.004730 | 0.000000 |
| Propane | 0.072825 | 0.072825 | 0.074491 |
| **Total** | **1.000000** | **1.000000** | **1.000000** |

## Combustion Analysis Output

| Fuel Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 16.1 |
| Quality (inlet condition) (%) | 1.0 |
| Gross Heating Value (MJ/m$^3$) | 37.4 |
| Net Heating Value (MJ/m$^3$) | 33.2 |
| Theoretic Combustion Air Requirement (kmol/kmol) | 9.4 |

| Material Balance | |
|---|---|
| Stream | Flow Rate ($10^3 m^3/d$) |
| Fuel | 65.24 |
| Air | 1799.14 |
| Stack Gas | 1864.68 |

| Excess Air | |
|---|---|
| Type | Amount (%) |
| Actual | 193.0 |
| Recommended Lower Limit | 5.0 |
| Recommended Upper Limit | 10.0 |

| Energy Balance | |
|---|---|
| Type | Amount (kW) |
| Gross Input Energy | 29,034.7 |
| Net Input Energy | 23,122.6 |

| Avoidable Energy Consumption (Losses) | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| High Excess Air | 8.0 | 1842.4 |
| Unburnt Fuel | 1.5 | 343.5 |
| Recoverable Heat in Flue Gas[1] | 10.7 | 2472.8 |

| Unavoidable Energy Comsumption Losses | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| Unrecoverable Heat in Flue Gas[1] | 19.2 | 4,448.5 |

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C. The unrecoverable portion is the energy still left in the flue gas at that temperature.

| Efficiencies | |
|---|---|
| Efficiency Type | Amount (%) |
| Apparent Thermal Efficiency | 68.6 |
| Carbon Combustion Efficiency | 96.1 |

| Stack Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 28.12 |
| Dew Temperature ($^oC$) | 43.6 |

| Determined Flue Gas Emission Factors[2] | |
|---|---|
| Component | Amount (ng/J) |
| Carbon Monoxide | 1,201.6 |
| Carbon Dioxide | 46,026.5 |
| Methane | 0.0 |
| Ethane | 0.0 |
| Total VOC | 0.0 |
| Total Hydrocarbons | 0.0 |
| Nitric Oxide | 0.0 |
| Nitrogen Dioxide | 0.0 |
| Total Oxides of Nitrogen | 0.0 |
| Hydrogen Sulfide | 0.0 |
| Sulfur Dioxide | 0.0 |
| Carbon Disulfide | 0.0 |
| Carbonyl Sulfide | 0.0 |
| Total TRS | 0.0 |

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The $SO_2$ emission factor is based on the concentration measured in the flue gas.

| Dry Flue Gas Analysis | |
|---|---|
| **Component** | **Mole Fraction** |
| nitrogen | 0.818809 |
| oxygen | 0.144000 |
| carbon_dioxide | 0.035726 |
| carbon_monoxide | 0.001465 |
| **Total** | **1.000000** |

## Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Switch Fuel Source | Switching to field gas | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 7.30 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | 0 | 0 | 0 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0 | 4,375 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Switch Fuel Source | Switching to field gas | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 42.00 | N/A |
| Tuning | Upgrade Fuel Drum and Boilers | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

# Control Technology Input Streams

| Technology type | Application Description | Use | Temperature (°C) | Pressure (kPa) | Line Name | Cross Sectional Shape |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | 25 | 101 | | Circular |

**Stream Pipe/Duct Cross-sectional Flow Area Dimension**

| Technology type | Application Description | Use | Pipe Outside Diameter (mm) | Pipe Wall Thickness (mm) | Pipe Rectangular Length (mm) | Pipe Rectangular Width (mm) |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | | | | |

**Stream Flow Rate**

| Technology type | Application Description | Use | Measurement Type | Reading Type | Measurement Date | Velocity (m/s) | Flow Rate ($m^3$/h) | Standard Flow Rate ($m^3$/h) |
|---|---|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Back Calculated Based on Measured Unit Output | Flow Rate (Standard Conditions) | | | | 2485.75 |

**Stream Composition**

| Technology type | Application Description | Use | Composition Name | Sample ID |
|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Gas de Campos | 47 |

## Simulation Results

| Source Name | Source Tag No. | Service Type | Value of Fuel/Loss Stream (USD/y) | Total Product Loss Flow ($m^3/h$) | Total Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3m^3/d$) | Ethane ($m^3/d$ liq) | LPG ($m^3/d$ liq) | NGL ($m^3/d$) | Hydrogen ($m^3/d$) |
| Calderas Nuevas Boiler | B-952 | Steam Generator | 5,681,591 | 2,718.3 | 26.26 | 21.64 | 25.52 | 1.89 | 24,147.43 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| 0.9 | 42,726 | 0.80 | 42,993 | 2.1 | 1071.4 | 105.2 | 0.0 | 0.7 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Tuning | 7.30 | 149,063 | 0 | 4,375 | 414,756 | 2,873,714 | 275.31 | 0.36 |
| Switch Fuel Source | 100.00 | 0 | 0 | 0 | 1,643,279 | 12,104,026 | NA | 0.00 |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| Tuning | 0.07 | 3,119 | 0.06 | 3,139 | 0.15 | 78.21 | 7.68 | 0.00 | 0.05 |
| Switch Fuel Source | 0.01 | -1,803 | 0.00 | -1,802 | 0.01 | 1,040.34 | 67.98 | 0.00 | 0.00 |

## Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Tuning | Upgrade Fuel Drum and Boilers |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Construction | Other Constuction Cost | Per Burner Installation. | 80,000.00 | 0.0 | 0 |
| | | Process GC installation (per drum) | 30,000.00 | 7.0 | 210,000 |
| Material | Instruments | CO Analyzer (per boiler) | 50,000.00 | 16.0 | 800,000 |
| | | Combustion Analyzer (per site) | 15,000.00 | 1.0 | 15,000 |
| | | Per Boiler Instrumentation | 50,000.00 | 16.0 | 800,000 |
| | | Process GC for Gas Anal. & A/F Control (per drum) | 80,000.00 | 7.0 | 560,000 |
| | Other Material Cost | High Efficiency Burners (4x per boiler) | 80,000.00 | 0.0 | 0 |

| | |
|---|---|
| **Total** | 2,385,000 |

# Combustion Analysis Report Summary

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Device | |
|---|---|
| **Name** | Distral Boiler 4 |
| **ID** | B-954 |
| **On Site Location** | Barrancabermeja |
| **Category** | Heaters and Boilers |
| **Type** | Wall-fired (<=29 MW) Uncontrolled |
| **Service** | Steam Generator |
| **Manufacturer** | N/A |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |

| Report Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Alfonso Garcia |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 2013/09/08 |

| Applied Emission Factors (ng/J) | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor** | 1.00 | US EPA AP-42 |
| **$N_2O$ Emission Factor** | 0.90 | US EPA AP-42 |
| **VOC Emission Factor** | 2.30 | US EPA AP-42 |
| **CO Emission Factor** | 1.73 | User Entered |
| **PM Emission Factor** | 0.80 | US EPA AP-42 |
| **$NO_x$ Emission Factor** | 42.00 | US EPA AP-42 |

| Device Comments and Assumptions |
|---|
| Boiler |

| Data Comments and Assumptions |
|---|
| N/A |

# Combustion Analysis Input

| Gas Stream Conditions | | | |
|---|---|---|---|
| **Stream** | **Temperature ($^oC$)** | **Flow (m3/h @ STP)** | **Relative Humidity (%)** |
| **Ambient Air** | 30.0 | | 60.0 |
| **Fuel** | 30.0 | 4,710.1 | 0.0 |
| **Combustion Air** | 30.0 | 0.0 | 60.0 |
| **Flue Gas** | 218.3 | 0.0 | N/A |

| General Simulation Data | |
|---|---|
| **Analysis Method** | Fuel Flow And Stack Gas |
| **Flue Gas Type** | Dry |
| **Local Barometric Pressure (kPa)** | 95.8 |
| **Nominal Rated Power Output (kW)** | 18,700 |
| **Assumed Efficiency (%)** | 80 |
| **Assumed Loading (%)** | 100 |
| **Fuel Cost (USD/GJ)** | 3.66 |

| Stack Gas Analysis | |
|---|---|
| **Component** | **Concentration (On A Dry Volume Basis)** |
| **Oxygen (%)** | 3.30 |
| **Carbon Monoxide (ppm)** | 5.50 |
| **Total Combustible (ppm)** | 0.00 |
| **Unburnt Fuel (calculated) (ppm)** | 0.00 |
| **Nitric Oxide (ppm)** | 0.00 |
| **Nitrogen Dioxide (ppm)** | 0.00 |
| **Sulfur Dioxide (ppm)** | 0.00 |

| Fuel Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.014950 | 0.014950 | 0.015243 |
| Ethane | 0.070990 | 0.070990 | 0.072383 |
| Hydrogen (normal) | 0.109650 | 0.109650 | 0.111801 |
| Isobutane | 0.003550 | 0.003550 | 0.003620 |
| Isopentane | 0.000930 | 0.000930 | 0.000948 |
| Methane | 0.684470 | 0.684470 | 0.697899 |
| n-Butane | 0.003100 | 0.003100 | 0.003161 |
| n-Heptane | 0.000700 | 0.000700 | 0.000714 |
| n-Hexane | 0.000440 | 0.000440 | 0.000449 |
| Nitrogen | 0.034770 | 0.034770 | 0.019982 |
| n-Pentane | 0.000565 | 0.000565 | 0.000576 |
| Oxygen | 0.004070 | 0.004070 | 0.000000 |
| Propane | 0.071815 | 0.071815 | 0.073224 |
| **Total** | **1.000000** | **1.000000** | **1.000000** |

# Combustion Analysis Output

| Fuel Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 18.4 |
| Quality (inlet condition) (%) | 1.0 |
| Gross Heating Value ($MJ/m^3$) | 41.0 |
| Net Heating Value ($MJ/m^3$) | 36.5 |
| Theoretic Combustion Air Requirement (kmol/kmol) | 10.5 |

| Material Balance | |
|---|---|
| Stream | Flow Rate ($10^3m^3/d$) |
| Fuel | 113.04 |
| Air | 1386.92 |
| Stack Gas | 1507.01 |

| Excess Air | |
|---|---|
| Type | Amount (%) |
| Actual | 16.8 |
| Recommended Lower Limit | 5.0 |
| Recommended Upper Limit | 10.0 |

| Energy Balance | |
|---|---|
| Type | Amount (kW) |
| Gross Input Energy | 54,083.0 |
| Net Input Energy | 43,628.0 |

| Avoidable Energy Consumption (Losses) | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| High Excess Air | 0.5 | 224.3 |
| Unburnt Fuel | 0.0 | 0.9 |
| Recoverable Heat in Flue Gas[1] | 8.2 | 3579.9 |

| Unavoidable Energy Comsumption Losses | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| Unrecoverable Heat in Flue Gas[1] | 15.8 | 6,914.8 |

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C. The unrecoverable portion is the energy still left in the flue gas at that temperature.

| Efficiencies | |
|---|---|
| Efficiency Type | Amount (%) |
| Apparent Thermal Efficiency | 75.9 |
| Carbon Combustion Efficiency | 100.0 |

| Stack Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 27.67 |
| Dew Temperature (°C) | 56.9 |

| Determined Flue Gas Emission Factors[2] | |
|---|---|
| Component | Amount (ng/J) |
| Carbon Monoxide | 1.7 |
| Carbon Dioxide | 50,804.3 |
| Methane | 0.0 |
| Ethane | 0.0 |
| Total VOC | 0.0 |
| Total Hydrocarbons | 0.0 |
| Nitric Oxide | 0.0 |
| Nitrogen Dioxide | 0.0 |
| Total Oxides of Nitrogen | 0.0 |
| Hydrogen Sulfide | 0.0 |
| Sulfur Dioxide | 0.0 |
| Carbon Disulfide | 0.0 |
| Carbonyl Sulfide | 0.0 |
| Total TRS | 0.0 |

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The $SO_2$ emission factor is based on the concentration measured in the flue gas.

| Dry Flue Gas Analysis | |
|---|---|
| **Component** | **Mole Fraction** |
| nitrogen | 0.864583 |
| carbon_dioxide | 0.102412 |
| oxygen | 0.033000 |
| carbon_monoxide | 0.000006 |
| **Total** | **1.000000** |

## Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Switch Fuel Source | Switching to field gas | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0.47 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | 0 | 0 | 0 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0 | 4,375 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Switch Fuel Source | Switching to field gas | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 42.00 | N/A |
| Tuning | Upgrade Fuel Drum and Boilers | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

# Control Technology Input Streams

| Technology type | Application Description | Use | Temperature (°C) | Pressure (kPa) | Line Name | Cross Sectional Shape |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | 25 | 101 | | Circular |

**Stream Pipe/Duct Cross-sectional Flow Area Dimension**

| Technology type | Application Description | Use | Pipe Outside Diameter (mm) | Pipe Wall Thickness (mm) | Pipe Rectangular Length (mm) | Pipe Rectangular Width (mm) |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | | | | |

**Stream Flow Rate**

| Technology type | Application Description | Use | Measurement Type | Reading Type | Measurement Date | Velocity (m/s) | Flow Rate ($m^3$/h) | Standard Flow Rate ($m^3$/h) |
|---|---|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Back Calculated Based on Measured Unit Output | Flow Rate (Standard Conditions) | | | | 4240.07 |

**Stream Composition**

| Technology type | Application Description | Use | Composition Name | Sample ID |
|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Gas de Campos | 47 |

## Simulation Results

| Source Name | Source Tag No. | Service Type | Value of Fuel/Loss Stream (USD/y) | Total Product Loss Flow ($m^3/h$) | Total Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3 m^3/d$) | Ethane ($m^3/d$ liq) | LPG ($m^3/d$ liq) | NGL ($m^3/d$) | Hydrogen ($m^3/d$) |
| Distral Boiler 4 | B-954 | Steam Generator | 9,378,690 | 4,710.0 | 78.89 | 29.07 | 33.63 | 1.63 | 12,638.02 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| 1.7 | 86,013 | 1.52 | 86,521 | 3.9 | 2.9 | 71.1 | 0.0 | 1.4 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Tuning | 0.47 | 149,063 | 0 | 4,375 | 44,080 | 143,395 | 26.64 | 3.75 |
| Switch Fuel Source | 100.00 | 0 | 0 | 0 | 2,490,335 | 18,343,255 | NA | 0.00 |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| Tuning | 0.01 | 404 | 0.01 | 407 | 0.02 | 0.01 | 0.33 | 0.00 | 0.01 |
| Switch Fuel Source | 0.18 | 10,057 | 0.16 | 10,111 | 0.42 | -50.00 | 7.58 | 0.00 | 0.14 |

# Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Tuning | Upgrade Fuel Drum and Boilers |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Construction | Other Constuction Cost | Per Burner Installation. | 80,000.00 | 0.0 | 0 |
| | | Process GC installation (per drum) | 30,000.00 | 7.0 | 210,000 |
| Material | Instruments | CO Analyzer (per boiler) | 50,000.00 | 16.0 | 800,000 |
| | | Combustion Analyzer (per site) | 15,000.00 | 1.0 | 15,000 |
| | | Per Boiler Instrumentation | 50,000.00 | 16.0 | 800,000 |
| | | Process GC for Gas Anal. & A/F Control (per drum) | 80,000.00 | 7.0 | 560,000 |
| | Other Material Cost | High Efficiency Burners (4x per boiler) | 80,000.00 | 0.0 | 0 |

| | |
|---|---|
| **Total** | 2,385,000 |

# Combustion Analysis
# Report Summary

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Device | |
|---|---|
| **Name** | Distral Boiler 5 |
| **ID** | B-955 |
| **On Site Location** | Barrancabermeja |
| **Category** | Heaters and Boilers |
| **Type** | Wall-fired (<=29 MW) Uncontrolled |
| **Service** | Steam Generator |
| **Manufacturer** | N/A |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |

| Report Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Alfonso Garcia |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 2013/09/08 |

| Applied Emission Factors (ng/J) | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor** | 1.00 | US EPA AP-42 |
| **$N_2O$ Emission Factor** | 0.90 | US EPA AP-42 |
| **VOC Emission Factor** | 2.30 | US EPA AP-42 |
| **CO Emission Factor** | 0.09 | User Entered |
| **PM Emission Factor** | 0.80 | US EPA AP-42 |
| **$NO_x$ Emission Factor** | 42.00 | US EPA AP-42 |

| Device Comments and Assumptions |
|---|
| Boiler |

| Data Comments and Assumptions |
|---|
| N/A |

## Combustion Analysis Input

| Gas Stream Conditions | | | |
|---|---|---|---|
| **Stream** | **Temperature ($^oC$)** | **Flow (m3/h @ STP)** | **Relative Humidity (%)** |
| **Ambient Air** | 30.0 | | 60.0 |
| **Fuel** | 30.0 | 4,570.1 | 0.0 |
| **Combustion Air** | 30.0 | 0.0 | 60.0 |
| **Flue Gas** | 189.4 | 0.0 | N/A |

| General Simulation Data | |
|---|---|
| **Analysis Method** | Fuel Flow And Stack Gas |
| **Flue Gas Type** | Dry |
| **Local Barometric Pressure (kPa)** | 95.8 |
| **Nominal Rated Power Output (kW)** | 18,700 |
| **Assumed Efficiency (%)** | 80 |
| **Assumed Loading (%)** | 100 |
| **Fuel Cost (USD/GJ)** | 3.66 |

| Stack Gas Analysis | |
|---|---|
| **Component** | **Concentration (On A Dry Volume Basis)** |
| **Oxygen (%)** | 3.10 |
| **Carbon Monoxide (ppm)** | 0.30 |
| **Total Combustible (ppm)** | 0.00 |
| **Unburnt Fuel (calculated) (ppm)** | 0.00 |
| **Nitric Oxide (ppm)** | 0.00 |
| **Nitrogen Dioxide (ppm)** | 0.00 |
| **Sulfur Dioxide (ppm)** | 0.00 |

| Fuel Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.014950 | 0.014950 | 0.015243 |
| Ethane | 0.070990 | 0.070990 | 0.072383 |
| Hydrogen (normal) | 0.109650 | 0.109650 | 0.111801 |
| Isobutane | 0.003550 | 0.003550 | 0.003620 |
| Isopentane | 0.000930 | 0.000930 | 0.000948 |
| Methane | 0.684470 | 0.684470 | 0.697899 |
| n-Butane | 0.003100 | 0.003100 | 0.003161 |
| n-Heptane | 0.000700 | 0.000700 | 0.000714 |
| n-Hexane | 0.000440 | 0.000440 | 0.000449 |
| Nitrogen | 0.034770 | 0.034770 | 0.019982 |
| n-Pentane | 0.000565 | 0.000565 | 0.000576 |
| Oxygen | 0.004070 | 0.004070 | 0.000000 |
| Propane | 0.071815 | 0.071815 | 0.073224 |
| **Total** | **1.000000** | **1.000000** | **1.000000** |

## Combustion Analysis Output

| Fuel Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 18.4 |
| Quality (inlet condition) (%) | 1.0 |
| Gross Heating Value ($MJ/m^3$) | 41.0 |
| Net Heating Value ($MJ/m^3$) | 36.5 |
| Theoretic Combustion Air Requirement (kmol/kmol) | 10.5 |

| Material Balance | |
|---|---|
| Stream | Flow Rate ($10^3 m^3/d$) |
| Fuel | 109.68 |
| Air | 1331.94 |
| Stack Gas | 1448.46 |

| Excess Air | |
|---|---|
| Type | Amount (%) |
| Actual | 15.6 |
| Recommended Lower Limit | 5.0 |
| Recommended Upper Limit | 10.0 |

| Energy Balance | |
|---|---|
| Type | Amount (kW) |
| Gross Input Energy | 52,468.5 |
| Net Input Energy | 42,328.0 |

| Avoidable Energy Consumption (Losses) | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| High Excess Air | 0.4 | 151.5 |
| Unburnt Fuel | 0.0 | 0.0 |
| Recoverable Heat in Flue Gas[1] | 6.5 | 2771.3 |

| Unavoidable Energy Comsumption Losses | | |
|---|---|---|
| Loss Type | Net Input Energy (%) | Loss Rate (kW) |
| Unrecoverable Heat in Flue Gas[1] | 15.8 | 6,698.8 |

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C. The unrecoverable portion is the energy still left in the flue gas at that temperature.

| Efficiencies | |
|---|---|
| Efficiency Type | Amount (%) |
| Apparent Thermal Efficiency | 77.6 |
| Carbon Combustion Efficiency | 100.0 |

| Stack Gas Characteristics | |
|---|---|
| Molecular Weight (kg/kmol) | 27.66 |
| Dew Temperature (°C) | 57.0 |

| Determined Flue Gas Emission Factors[2] | |
|---|---|
| Component | Amount (ng/J) |
| Carbon Monoxide | 0.1 |
| Carbon Dioxide | 50,806.9 |
| Methane | 0.0 |
| Ethane | 0.0 |
| Total VOC | 0.0 |
| Total Hydrocarbons | 0.0 |
| Nitric Oxide | 0.0 |
| Nitrogen Dioxide | 0.0 |
| Total Oxides of Nitrogen | 0.0 |
| Hydrogen Sulfide | 0.0 |
| Sulfur Dioxide | 0.0 |
| Carbon Disulfide | 0.0 |
| Carbonyl Sulfide | 0.0 |
| Total TRS | 0.0 |

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The $SO_2$ emission factor is based on the concentration measured in the flue gas.

| Dry Flue Gas Analysis | |
|---|---|
| **Component** | **Mole Fraction** |
| nitrogen | 0.865427 |
| carbon_dioxide | 0.103573 |
| oxygen | 0.031000 |
| carbon_monoxide | 0.000000 |
| **Total** | **1.000000** |

## Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Switch Fuel Source | Switching to field gas | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0.32 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | 0 | 0 | 0 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0 | 4,375 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Switch Fuel Source | Switching to field gas | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 42.00 | N/A |
| Tuning | Upgrade Fuel Drum and Boilers | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

# Control Technology Input Streams

| Technology type | Application Description | Use | Temperature ($^{o}C$) | Pressure (kPa) | Line Name | Cross Sectional Shape |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | 25 | 101 | | Circular |

**Stream Pipe/Duct Cross-sectional Flow Area Dimension**

| Technology type | Application Description | Use | Pipe Outside Diameter (mm) | Pipe Wall Thickness (mm) | Pipe Rectangular Length (mm) | Pipe Rectangular Width (mm) |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | | | | |

**Stream Flow Rate**

| Technology type | Application Description | Use | Measurement Type | Reading Type | Measurement Date | Velocity (m/s) | Flow Rate ($m^3/h$) | Standard Flow Rate ($m^3/h$) |
|---|---|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Back Calculated Based on Measured Unit Output | Flow Rate (Standard Conditions) | | | | 4114.03 |

**Stream Composition**

| Technology type | Application Description | Use | Composition Name | Sample ID |
|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Gas de Campos | 47 |

## Simulation Results

| Source Name | Source Tag No. | Service Type | Value of Fuel/Loss Stream (USD/y) | Total Product Loss Flow ($m^3/h$) | Total Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3 m^3/d$) | Ethane ($m^3/d$ liq) | LPG ($m^3/d$ liq) | NGL ($m^3/d$) | Hydrogen ($m^3/d$) |
| Distral Boiler 5 | B-955 | Steam Generator | 9,099,918 | 4,570.0 | 76.55 | 28.20 | 32.63 | 1.58 | 12,262.37 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| 1.6 | 83,456 | 1.48 | 83,949 | 3.8 | 0.1 | 69.0 | 0.0 | 1.3 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Tuning | 0.32 | 149,063 | 0 | 4,375 | 29,120 | 33,202 | 16.60 | 6.02 |
| Switch Fuel Source | 100.00 | 0 | 0 | 0 | 2,416,326 | 17,798,119 | NA | 0.00 |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| Tuning | 0.01 | 267 | 0.00 | 269 | 0.01 | 0.00 | 0.22 | 0.00 | 0.00 |
| Switch Fuel Source | 0.18 | 9,758 | 0.16 | 9,811 | 0.40 | -51.21 | 7.36 | 0.00 | 0.14 |

# Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Tuning | Upgrade Fuel Drum and Boilers |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Construction | Other Constuction Cost | Per Burner Installation. | 80,000.00 | 0.0 | 0 |
| | | Process GC installation (per drum) | 30,000.00 | 7.0 | 210,000 |
| Material | Instruments | CO Analyzer (per boiler) | 50,000.00 | 16.0 | 800,000 |
| | | Combustion Analyzer (per site) | 15,000.00 | 1.0 | 15,000 |
| | | Per Boiler Instrumentation | 50,000.00 | 16.0 | 800,000 |
| | | Process GC for Gas Anal. & A/F Control (per drum) | 80,000.00 | 7.0 | 560,000 |
| | Other Material Cost | High Efficiency Burners (4x per boiler) | 80,000.00 | 0.0 | 0 |

| | |
|---|---|
| **Total** | 2,385,000 |

# Combustion Analysis Report Summary

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Device | |
|---|---|
| **Name** | Distral Boiler 6 |
| **ID** | B-956 |
| **On Site Location** | Barrancabermeja |
| **Category** | Heaters and Boilers |
| **Type** | Wall-fired (<=29 MW) Uncontrolled |
| **Service** | Steam Generator |
| **Manufacturer** | N/A |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |

| Report Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Alfonso Garcia |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 2013/09/08 |

**Applied Emission Factors (ng/J)**

| Substance | Value | Source |
|---|---|---|
| **$CH_4$ Emission Factor** | 1.00 | US EPA AP-42 |
| **$N_2O$ Emission Factor** | 0.90 | US EPA AP-42 |
| **VOC Emission Factor** | 2.30 | US EPA AP-42 |
| **CO Emission Factor** | 6.91 | User Entered |
| **PM Emission Factor** | 0.80 | US EPA AP-42 |
| **$NO_x$ Emission Factor** | 42.00 | US EPA AP-42 |

| Device Comments and Assumptions |
|---|
| Boiler |

| Data Comments and Assumptions |
|---|
| N/A |

## Combustion Analysis Input

| Gas Stream Conditions | | | |
|---|---|---|---|
| **Stream** | **Temperature ($^oC$)** | **Flow (m3/h @ STP)** | **Relative Humidity (%)** |
| **Ambient Air** | 30.0 | | 60.0 |
| **Fuel** | 30.0 | 5,720.1 | 0.0 |
| **Combustion Air** | 30.0 | 0.0 | 60.0 |
| **Flue Gas** | 218.3 | 0.0 | N/A |

| General Simulation Data | |
|---|---|
| **Analysis Method** | Fuel Flow And Stack Gas |
| **Flue Gas Type** | Dry |
| **Local Barometric Pressure (kPa)** | 95.8 |
| **Nominal Rated Power Output (kW)** | 18,700 |
| **Assumed Efficiency (%)** | 80 |
| **Assumed Loading (%)** | 100 |
| **Fuel Cost (USD/GJ)** | 3.66 |

| Stack Gas Analysis | |
|---|---|
| **Component** | **Concentration (On A Dry Volume Basis)** |
| **Oxygen (%)** | 1.60 |
| **Carbon Monoxide (ppm)** | 24.00 |
| **Total Combustible (ppm)** | 0.00 |
| **Unburnt Fuel (calculated) (ppm)** | 0.00 |
| **Nitric Oxide (ppm)** | 0.00 |
| **Nitrogen Dioxide (ppm)** | 0.00 |
| **Sulfur Dioxide (ppm)** | 0.00 |

| Fuel Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.014950 | 0.014950 | 0.015243 |
| Ethane | 0.070990 | 0.070990 | 0.072383 |
| Hydrogen (normal) | 0.109650 | 0.109650 | 0.111801 |
| Isobutane | 0.003550 | 0.003550 | 0.003620 |
| Isopentane | 0.000930 | 0.000930 | 0.000948 |
| Methane | 0.684470 | 0.684470 | 0.697899 |
| n-Butane | 0.003100 | 0.003100 | 0.003161 |
| n-Heptane | 0.000700 | 0.000700 | 0.000714 |
| n-Hexane | 0.000440 | 0.000440 | 0.000449 |
| Nitrogen | 0.034770 | 0.034770 | 0.019982 |
| n-Pentane | 0.000565 | 0.000565 | 0.000576 |
| Oxygen | 0.004070 | 0.004070 | 0.000000 |
| Propane | 0.071815 | 0.071815 | 0.073224 |
| **Total** | **1.000000** | **1.000000** | **1.000000** |

# Combustion Analysis Output

| Fuel Gas Characteristics | |
|---|---|
| **Molecular Weight (kg/kmol)** | 18.4 |
| **Quality (inlet condition) (%)** | 1.0 |
| **Gross Heating Value (MJ/$m^3$)** | 41.0 |
| **Net Heating Value (MJ/$m^3$)** | 36.5 |
| **Theoretic Combustion Air Requirement (kmol/kmol)** | 10.5 |

| Material Balance | |
|---|---|
| **Stream** | **Flow Rate ($10^3 m^3$/d)** |
| **Fuel** | 137.28 |
| **Air** | 1549.11 |
| **Stack Gas** | 1694.97 |

| Excess Air | |
|---|---|
| **Type** | **Amount (%)** |
| **Actual** | 7.4 |
| **Recommended Lower Limit** | 5.0 |
| **Recommended Upper Limit** | 10.0 |

| Energy Balance | |
|---|---|
| **Type** | **Amount (kW)** |
| **Gross Input Energy** | 65,611.8 |
| **Net Input Energy** | 52,952.0 |

| Avoidable Energy Consumption (Losses) | | |
|---|---|---|
| **Loss Type** | **Net Input Energy (%)** | **Loss Rate (kW)** |
| **Unburnt Fuel** | 0.0 | 4.6 |
| **Recoverable Heat in Flue Gas[1]** | 7.6 | 4008.2 |

| Unavoidable Energy Comsumption Losses | | |
|---|---|---|
| **Loss Type** | **Net Input Energy (%)** | **Loss Rate (kW)** |
| **Unrecoverable Heat in Flue Gas[1]** | 15.7 | 8,293.0 |

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C. The unrecoverable portion is the energy still left in the flue gas at that temperature.

| Efficiencies | |
|---|---|
| **Efficiency Type** | **Amount (%)** |
| **Apparent Thermal Efficiency** | 76.8 |
| **Carbon Combustion Efficiency** | 100.0 |

| Stack Gas Characteristics | |
|---|---|
| **Molecular Weight (kg/kmol)** | 27.60 |
| **Dew Temperature ($^o$C)** | 58.3 |

| Determined Flue Gas Emission Factors[2] | |
|---|---|
| **Component** | **Amount (ng/J)** |
| **Carbon Monoxide** | 6.9 |
| **Carbon Dioxide** | 50,796.2 |
| **Methane** | 0.0 |
| **Ethane** | 0.0 |
| **Total VOC** | 0.0 |
| **Total Hydrocarbons** | 0.0 |
| **Nitric Oxide** | 0.0 |
| **Nitrogen Dioxide** | 0.0 |
| **Total Oxides of Nitrogen** | 0.0 |
| **Hydrogen Sulfide** | 0.0 |
| **Sulfur Dioxide** | 0.0 |
| **Carbon Disulfide** | 0.0 |
| **Carbonyl Sulfide** | 0.0 |
| **Total TRS** | 0.0 |

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The $SO_2$ emission factor is based on the concentration measured in the flue gas.

| Dry Flue Gas Analysis | |
|---|---|
| **Component** | **Mole Fraction** |
| nitrogen | 0.871742 |
| carbon_dioxide | 0.112234 |
| oxygen | 0.016000 |
| carbon_monoxide | 0.000024 |
| **Total** | **1.000000** |

## Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Switch Fuel Source | Switching to field gas | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0.01 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | 0 | 0 | 0 | 0 |
| Tuning | Upgrade Fuel Drum and Boilers | 0 | 4,375 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Switch Fuel Source | Switching to field gas | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 42.00 | N/A |
| Tuning | Upgrade Fuel Drum and Boilers | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

# Control Technology Input Streams

| Technology type | Application Description | Use | Temperature (°C) | Pressure (kPa) | Line Name | Cross Sectional Shape |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | 25 | 101 | | Circular |

**Stream Pipe/Duct Cross-sectional Flow Area Dimension**

| Technology type | Application Description | Use | Pipe Outside Diameter (mm) | Pipe Wall Thickness (mm) | Pipe Rectangular Length (mm) | Pipe Rectangular Width (mm) |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | | | | |

**Stream Flow Rate**

| Technology type | Application Description | Use | Measurement Type | Reading Type | Measurement Date | Velocity (m/s) | Flow Rate ($m^3$/h) | Standard Flow Rate ($m^3$/h) |
|---|---|---|---|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Back Calculated Based on Measured Unit Output | Flow Rate (Standard Conditions) | | | | 5149.03 |

**Stream Composition**

| Technology type | Application Description | Use | Composition Name | Sample ID |
|---|---|---|---|---|
| Switch Fuel Source | Switching to field gas | Fuel Stream | Gas de Campos | 47 |

## Simulation Results

| Source Name | Source Tag No. | Service Type | Value of Fuel/Loss Stream (USD/y) | Total Product Loss Flow ($m^3/h$) | Total Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3m^3/d$) | Ethane ($m^3/d$ liq) | LPG ($m^3/d$ liq) | NGL ($m^3/d$) | Hydrogen ($m^3/d$) |
| Distral Boiler 6 | B-956 | Steam Generator | 11,389,832 | 5,720.0 | 95.81 | 35.30 | 40.84 | 1.97 | 15,348.09 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| 2.1 | 104,457 | 1.85 | 105,074 | 4.7 | 14.2 | 86.3 | 0.0 | 1.6 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Tuning | 0.01 | 149,063 | 0 | 4,375 | 888 | -174,744 | NA | NA |
| Switch Fuel Source | 100.00 | 0 | 0 | 0 | 3,024,794 | 22,279,959 | NA | 0.00 |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| Tuning | 0.00 | 8 | 0.00 | 8 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 |
| Switch Fuel Source | 0.22 | 12,219 | 0.20 | 12,284 | 0.50 | -50.07 | 9.21 | 0.00 | 0.18 |

## Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Tuning | Upgrade Fuel Drum and Boilers |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Construction | Other Constuction Cost | Per Burner Installation. | 80,000.00 | 0.0 | 0 |
| | | Process GC installation (per drum) | 30,000.00 | 7.0 | 210,000 |
| Material | Instruments | CO Analyzer (per boiler) | 50,000.00 | 16.0 | 800,000 |
| | | Combustion Analyzer (per site) | 15,000.00 | 1.0 | 15,000 |
| | | Per Boiler Instrumentation | 50,000.00 | 16.0 | 800,000 |
| | | Process GC for Gas Anal. & A/F Control (per drum) | 80,000.00 | 7.0 | 560,000 |
| | Other Material Cost | High Efficiency Burners (4x per boiler) | 80,000.00 | 0.0 | 0 |
| | | | | **Total** | 2,385,000 |

# APPENDIX D STEAM SYSTEMS

## D.1 Introduction

This appendix focuses on opportunities to reduce avoidable steam and heat losses from steam systems as a means of reducing related energy consumption, operating costs and atmospheric emissions, while increasing system reliability and workplace safety.

## D.2 Background

Steam is either used as a medium to perform useful process work in a closed-loop system (such as provide process heat in heat exchangers or power turbines that drive fans, pumps and compressors), or it is consumed for purposes such as purge gas, flare assist gas or feedstock for steam-methane reformers. In closed-loop systems, after the useable energy content of the steam has been extracted, it is condensed, and returned to the boiler feedwater tank for re-use. However, the closed loop portion of a steam system is still subject to some losses, which need to be managed.

If the steam is consumed then makeup water is also need to replace the consumed steam.

The actual amount of steam being lost or consumed at a facility is normally well known since the amount of boiler feedwater makeup being provided is accurately recorded. What is more challenging to determine is the portion of this makeup water requirement that is practicable to avoid and the cost and emissions implications of these losses.

The following subsections describe the key components of a steam system and the related opportunities for energy efficiency improvement and GHG emissions reduction.

### D.2.1 Steam Generators

Steam is used as a heating medium in many process industries because of its high latent heat content and excellent thermal stability. The process industries that are utilizing steam as a heating medium have a set of steam generators or boilers to produce steam. In the steam generators, fuels such as natural gas, fuel oils, coke, coals, and combustible biomaterials (such as bagasse and woodchips), are burned to produce steam from liquid water. The chemical energy of the burned fuels is thus converted into the thermal energy content (latent heat) in steam.

All the thermal energy generated by combustion of fuel does not get transferred to the generated steam in a boiler. To reduce the cost of steam production, the boiler must operate to extract as much energy from the fuel as possible. In addition to reducing the fuel cost, using energy efficiently is an effective way of reducing greenhouse gas emissions. When less fuel is burned to produce a given amount of steam, the greenhouse gas emissions are reduced.

The boiler efficiency is improved by reducing heat loss in the system. Heat loss in the context of boilers is defined as the thermal energy that is not transferred to water to increase its thermal energy to produce steam. When assessing the boiler efficiency it is important that all forms of heat loss are considered. The efficiency of the boiler is not constant throughout the entire operating range. Peak efficiency usually occurs at a particular output (typically the design output) of steam. Operations that deviate from this output usually result in less than peak efficiency. Continuous operation at peak efficiency is not practical due to seasonal demands and load variations. Operation at steady load and the avoidance of cyclic or on/off operation can improve efficiency. Any cyclic or discontinuous operation will reduce overall energy usage.

While every boiler and burner arrangement will perform somewhat differently, it is possible to project variations in efficiency based on the boiler load. The boiler efficiency loss can be up to 10 percent when the operation changes from the maximum continuous rating (MCR) to reduced boiler output (30 to 40 percent of rated capacity) (Oland 2002). The key to increased efficiency involves minimizing all forms of combustion and boiler loss.

### D.2.2 Steam Distribution System

The hot steam produced in the steam generators is supplied to various units in an industrial facility that utilizes energy from steam for its operation. This is done via a piping network constituting a steam distribution system. The water used for generating steam is conserved by a water/condensate collection system that recycles the water formed by condensing steam in the process units and/or steam distribution system back to the steam generators.

The steam distribution system efficiency is improved by reducing heat loss in the pipes by maintaining adequate insulation to minimize heat loss to the ambient air. Efficiency is also improved by reducing steam and condensate leakage from valves, steam traps, etc. and by minimizing the infiltration of non-condensable gases (i.e. air) in steam and condensate lines (especially in low pressure sections of the system, such as steam jet ejectors and associated equipment).

### D.2.3 Boiler Blowdown

The periodic or continuous withdrawal of small amounts of condensate in a steam generation/distribution system is known as blowdown. It is performed to control the accumulation of dissolved chemicals in the circulating water by replacing a portion of the circulating water with make-up water containing lower amounts of dissolved chemicals. The sensible heat content in the condensate constitutes heat loss and it should be reduced by maximizing heat recovery and regular periodic optimization of the blowdown amount based on the water quality measurements (TDS or chloride) for circulating and make-up water.

The blowdown water from the boiler is typically cooled by flashing at a lower pressure and temperature. The vapour generated is either vented to the atmosphere or used to provide heating steam to the degasser. Venting to the atmosphere results in both energy and water loss.

### D.2.4 Boiler Feedwater Degasser/Deaerator

The water used in the boiler for generating steam is continuously degassed in a degasser or deaerator (i.e., the dissolved oxygen and nitrogen in the boiler feed water is reduced by passing the steam through the water to strip out these dissolved fractions in a gas-liquid separator). The water is degassed to prevent the excessive accumulation of non-condensable gases in the steam supply lines and heat exchangers that use the steam. Heat exchangers using steam are periodically purged of non-condensable gases by venting a small amount of the steam into the degasser unit. This reduces the live steam requirement in the degasser. The presence of non-condensable gases even in small amounts results in considerable deterioration of heat exchanger performance and an increase in steam consumption. The vapour from the gas-liquid separator is typically vented to the atmosphere. Steam is vented along with the non-condensable gases, resulting in water and energy loss. The water should be condensed and energy recovered from this stream if it is economically feasible.

### D.2.5 Boiler Feedwater Degasser/Deaerator

The water/condensate recovery system uses cooling towers to either directly or indirectly cool the condensed water and low pressure waste steam produced in the process. The cooling tower performance needs to be optimized so the total water loss due to evaporation, windage or drift (water droplet carryover by air), splashing losses and blowdown are minimal. It must be periodically inspected for air passage blockages and excessive salt and other solid deposition. The blowdown amount should be periodically optimized.

### D.2.6 Steam Condensate Tanks

The condensate tanks are provided with vent lines to vent the vapour generated due to flashing losses in the tank. Any steam entering the condensate lines will also vent to the atmosphere. Steam loss from the condensate tank vent lines result in both water and energy loss. Excess steam in the vents can potentially be condensed using a vent condenser to reduce water loss if it is economically feasible; however, the energy loss can be prevented only if the recovery of heat from the vent steam results in additional reduction in energy requirements in the process facility and not an increase in the cooling duty of the facility. The operational practices have to be first examined to determine if the vent loss can be minimized without additional investment in equipment.

Any increase in efficiency of the steam distribution system and water/condensate recovery system can potentially lead to the following benefits:

- Reduction in steam and fuel consumption
- Reduction in make-up water consumption and resulting savings in water treatment cost
- Minimizing the overall energy loss in the system

### D.3 Steam System Evaluation Methodology

The steam system, especially at larger facilities, can be very complex comprising an integrated network of boilers, waste-heat recovery units, co-generation units, inputs from higher-pressure circuits to lower-pressure circuits, energy removals, steam removals and condensers.

To accurately model all of the above system elements would require a very complex process simulation model which is simply not warranted. Instead, the basic approach taken here has been to assess the gross avoidable losses after considering all engineered steam removals. This was done by benchmarking the performance of the closed-loop portion of the system to relevant industry standards, and evaluating the cost and emissions implications of the avoidable losses based on the marginal costs and emissions intensity of the steam. The avoidable steam demand is assumed to be satisfied by the boilers, while the steam generated by waste heat recovery units and con-generation units is assumed to be applied to the base load. Where possible, the actual emissions factors and efficiency of the facility's boilers have been applied.

Total make-up water due to fugitive leaks and typical blowdown requirements amounts to about 4 to 8 percent of the total amount of water in circulation through the system (Hart and Jaber, 2001). *In plants that have well designed water-treatment facilities, the make-up water amount can be as low as 2 % of the circulating water amount. A benchmark value of 5% has been used here.*

The input process and equipment data needed to conduct the steam system evaluation were collected from facility staff in the form of overall material balance sheets for steam in the facility. The additional plant data required was collected during plant visit by observing instrument readings and enquiring from facility staff.

Where suitable access and time were available, measurements were performed to delineate losses from individual steam circuits, and the VPAC acoustical leak measurement device was used to quantify leakage rates from individual steam valves into vent systems. The measurements performed on individual circuits involved measuring all engineered inputs and outputs (steam and water), and then determining the total circuit steam losses based on a mass balance. The individual circuit measurements were performed using clamp-on transit-time gas flow meters and either clamp-on transit-time or Doppler liquid flow meters, as well as drawing of readings from any applicable flow meters permanently installed on the steam system.

Additionally, selected engineering withdrawals of steam were reviewed (especially, the use of steam as flare assist gas) to determine their cost effectiveness relative to other options.

### D.3.1 Boiler or Steam Generator Efficiency

The losses to be considered for improving the steam generator efficiency are as follows:

- Combustion losses.
- Boiler Losses.

Combustion efficiency is a measure of the chemical energy available in fuel that is liberated by the combustion process (Oland 2002). Quantifying combustion efficiency involves determining:

- Losses from unburned carbon in the flue gas (CO).
- Losses from unburned carbon in the solid residue (bottom ash and fly ash).
- Losses from unburned hydrocarbons in the flue gas.

The combustion losses occur mainly due to insufficient supply of air for combustion and poor mixing of fuel and air in the burner and combustion chamber. The air supply should be just sufficient to promote complete combustion of fuel as excess supply of air is also detrimental to boiler efficiency. The recommended excess air for boilers as well as the details and results on any tests performed on the boilers are provided in Appendix H.

The boiler losses are the thermal energy from the fuel that is not transferred to the steam that is produced in the boiler. The heat that is not transferred to the water includes:

- Flue gas losses.
- Radiant heat losses.
- Blowdown losses.
- Unaccounted for losses.

Flue gas losses are often the primary cause for reduced boiler efficiency. Energy is wasted whenever the hot flue gas is carried out of the boiler and up the stack. Air in excess of that required for complete combustion represents a major flue gas loss. The loss is a function of excess air supplied for combustion and the final temperature of air in the flue gas. The energy content of this air is wasted as it is not used for heating water.

Radiant heat loss from the boiler outer surface to atmosphere is independent of the boiler load and hence becomes worse at lower loads. The radiant losses can be reduced by adding extra insulation to the outer body of the boiler and by operating the boiler at the lowest temperature possible based on the system and manufacturer’s specification. A portion of the radiant losses can be recovered by using the boiler room air for combustion air if the room has sufficient ventilation.

The typical radiation loss as a percentage of total fuel energy input is shown in Figure 3.

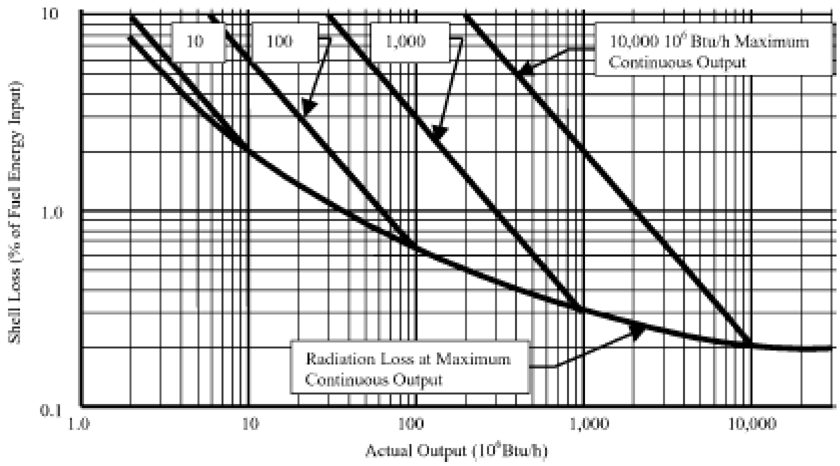


**Figure 3: Radiant losses for the boilers (Harrell, 2001).**

Blowdown losses can be minimized by maintaining the blowdown rate to the optimum value estimated using the following relationship:

$$M_{bd} = M_s / ( CC_s - 1 )$$

**Equation 13**

$$CC_s = TDS_{max} / TDS_{mup}$$

**Equation 14**

Where

| | | |
|---|---|---|
| $M_{bd}$ | = | the blowdown rate (kg/hr) |
| $M_s$ | = | the steam production rate (kg/hr) |
| $CC_s$ | = | the cycles of chemicals |
| $TDS_{mup}$ | = | the TDS (Total Dissolved Solids) content in make-up water (mg/L) |
| $TDS_{max}$ | = | the maximum permissible TDS in boiler feed water (mg/L) |

The quality of the make-up water must be periodically tested and the optimal blowdown rate maintained accordingly. Sensible heat from the blowdown stream must be recovered if economically feasible. The recommended maximum values for total dissolved solids (TDS) for boilers are provided in Figure 4.

Table 5. Boiler water chemical limits

| Parameters | Boiler pressure (psig) | | | | | |
|---|---|---|---|---|---|---|
| | 150 | 300 | 600 | 900 | 1,200 | 1,500 |
| | Chemical concentration (mg/L) | | | | | |
| TDS (maximum) | 4,000 | 3,500 | 3,000 | 2,000 | 500 | 300 |
| Phosphate (as $PO_4$) | 30–60 | 30–60 | 20–40 | 15–20 | 10–15 | 5–10 |
| Hydroxide (as $CaCO_3$) | 300–400 | 250–300 | 150–200 | 120–150 | 100–120 | 80–100 |
| Sulfite | 30–60 | 30–40 | 20–30 | 15–20 | 10–15 | 5–10 |
| Silica (as $SiO_2$) | 100 | 50 | 30 | 10 | 5 | 3 |
| Total iron (as Fe) | 10 | 5 | 3 | 2 | 2 | 1 |
| Organics | 70–100 | 70–100 | 70–100 | 50–70 | 50–70 | 50–70 |

**Figure 4: Maximum TDS specification for boiler water (Harrell, 2001).**

### D.3.2 Steam Distribution System Losses

The steam distribution system usually consists of steam supply headers and pipes which transport steam from the steam generators to the various process units requiring steam.

Most process industries have the steam supply headers providing steam at one or more of the four pressure levels:

- High Pressure (typically 9800 kPag or more ).
- Medium Pressure (typically 4000 to 5000 kPag ).
- Intermediate Pressure (typically 1000 to 2000 kPag).
- Low Pressure Steam (typically 50 to 500 kPag).

All the steam headers, pipes and fittings should be insulated to minimize the heat loss to the atmosphere, and they have steam traps to remove any liquid condensate formed in the steam pipes and prevent their accumulation in the steam pipes. Steam traps discharge the condensate and any leaking steam from steam pipes either into a drain or into a condensate line. The condensate and steam discharged into the drain or leaking from the steam traps contributes to reduced energy and efficiency.

The major factors in the steam distribution system that results in energy losses are:

- Heat loss to the atmosphere.
- Leakage of steam and condensate through the steam trap and other fittings.
- Condensate and steam lost to the drain.
- Heat exchanger purge gas venting.
- Flash gas venting losses.
- Excess fuel consumption resulting from high-pressure steam being used to generate low-pressure steam.

#### D.3.2.1 Fugitive Steam Losses

Any steam escaping with the condensate from a steam trap usually gets vented from the condensate collection tank or the degasser when the trap discharges into a condensate line. Excessive venting from condensate collection tanks and degasser may indicate steam leakage from some of the steam traps.

#### D.3.2.2 Energy Losses from Producing Low-Pressure Steam from High-Pressure Steam

The energy benefit of producing the steam at the required lower pressure instead of throttling a high pressure steam to produce a lower pressure steam is determined as follows:

$$x = ( h_{hp} - h_{lpl} ) / ( h_{lpv} - h_{lpl} )$$

**Equation 15**

Where

$x$ = the quality of steam after throttling (will be less than one only when the high pressure steam is at pressure greater than 500 psia).

$h_{hp}$ = the enthalpy of high-pressure steam (kJ/kg).

$h_{lpl}$ = the enthalpy of low-pressure liquid condensate (kJ/kg).

$h_{lpv}$ = the enthalpy of low-pressure steam (kJ/kg).

$$C_{pr} = M_{thr} \cdot ( h_{hp} - q \cdot h_{lpv} ) \cdot G_f \ / 1000000 \cdot 8760$$

**Equation 16**

Where,

$C_{pr}$ = the fuel cost savings ($/yr).

$M_{thr}$ = the amount of high-pressure steam undergoing throttling (kg/hr).

$G_f$ = the cost of fuel ($/GJ).

### D.3.3 Water/Condensate Collection System Losses

The water/condensate collection system is a network of pipes collecting the condensate discharged from steam traps, and the process equipment using steam. The collected condensate is cooled using either heat exchanger or cooling towers before being stored in a condensate storage tank. The collected condensate from the storage tank is mixed with make-up water and sent to a degasser before it is used as a boiler feed water to generate steam.

The major factors in the water/condensate collection system that results in energy losses are:

- Steam loss from the deaerators or degassers.

- Condensate collection tank venting.
- Evaporation, drift, blowdown and splashing losses from cooling tower.
- Heat loss to the atmosphere.

A simple visual inspection of excess loss of steam from deaerator recommended in the CIBO Energy Efficiency Handbook (CIBO, 1997) is the plume should form about six inches from the top of the vent and be visibly steam for only two feet. This is enough to remove all the dissolved gases; more than two feet is a waste of steam. This waste steam must be recovered by condensation to reduce the make-up water requirement.

The cooling tower schematic is typically as shown in Figure 5 below.

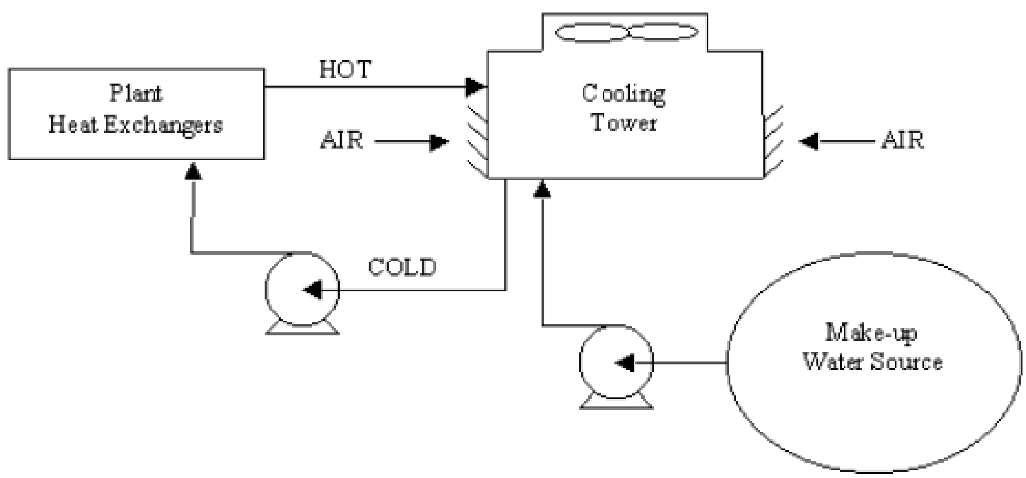


**Figure 5: Typical cooling tower arrangement.**

The evaporation losses for the cooling tower may be estimated using the following relation (Qureshi and Zubair, 2006):

$$E = -0.00849 + 0.154 \cdot \Delta t_w$$

**Equation 17**

Where

| | | |
|---|---|---|
| $E$ | = | $M_{evap} / M_{wc} \cdot 100$ |
| $M_{evap}$ | = | the water loss by evaporation (kg/hr). |
| $M_{wc}$ | = | the water circulation rate (kg/hr). |
| $\Delta t_w$ | = | $t_h - t_c$ |
| $t_h$ | = | the temperature of the hot water entering the cooling tower in °C. |
| $t_c$ | = | the temperature of the cold water leaving the cooling tower in °C. |

The drift loss from the cooling tower may be estimated as:

$$M_{drift} = 0.0005 \cdot M_{wc}$$

**Equation 18**

on the basis of typical design specification of less than 0.05 % drift loss for most cooling towers.

The blowdown losses for cooling tower are estimated as:

$$M_{bl} = M_{evap} / ( CC - 1 )$$

**Equation 19**

Where

| | | |
|---|---|---|
| $M_{drift}$ | = | the drift moisture loss (kg/hr). |
| $M_{bl}$ | = | the blow down rate (kg/hr). |
| CC | = | the cycle of chemicals which is the ratio of total dissolved solid (or total chloride) concentration in circulating water and the make-up water. |

The total make-up water amount is estimated as:

$$M_{tm} = M_{evap} + M_{drift} + M_{bl}$$

**Equation 20**

Where,

$M_{tm}$ = the total make-up water to the cooling tower (kg/hr).

When only the water circulation rate and range of the cooling tower ($\Delta t_w$) is known the total make-up water is estimated using the following relationship (Hamanaka et. al. 2009):

$$M_{tm} = ( 0.0039 \cdot \Delta t_w + 0.002 ) \cdot M_{wc}$$

**Equation 21**

The above relations include evaporation, drift and blowdown losses.

Any make-up water in excess of the above estimated value will result in an incremental cost in water treatment, chemical additives, and fuel consumption.

### D.3.4 Energy Management and Control Options

The various opportunities available for the system wide improvement in efficiency of steam generation and distribution system in most industries are summarized below (USDOE 2002):

- Minimize boiler combustion loss by optimizing the excess air supply.
- Improving boiler operation practices.
- Repairing or replacing poorly performing burners and parts.

- Install feed water economizers.
- Install combustion air preheaters.
- Improve water treatments.
- Clean boiler heat transfer surfaces.
- Improve blowdown practices.
- Install continuous blowdown heat recovery.
- Add/restore boiler refractories.
- Establish the correct vent rate for deaerators or degassers.
- Reduce steam system generating pressure.
- Improve quality of steam delivered.
- Implement an effective steam trap maintenance program.
- Ensure steam system piping, valves, fittings, and vessels are well insulated.
- Minimize vented steam.
- Repair steam leaks.
- Isolate steam from unused lines.
- Improve system balance.
- Improve plant wide testing and maintenance practices.
- Improve condensate recovery.
- Use high-pressure condensate to produce low-pressure steam.
- Implement a combined heat and power (cogeneration) project.
- Minimize throttling high-pressure steam (greater than 3500 kPa [500 psia]) to generate low pressure steam.

U.S. Department of Energy, on their website for combustion energy at http://www1.eere.energy.gov/industry/combustion/about.html, provide links to useful case studies, reports, guidance material and some useful free software the process industries can use to study and make preliminary assessment of the economic benefits of any system wide changes that result in reduction of energy consumption.

## D.4 References

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Oland C.B. 2002. Guide to Low Emissions Boilers and Combustion Equipment Selection, Oak Ridge National Laboratory Report No. ORNL/TM-2002/19. Oak Ridge, Tennessee, U.S.A.

Qureshi B.A. and Zubair S.M. 2006. Prediction of Evaporation Losses in Wet Cooling Tower. Heat Transfer Engineering. Vol. 27(9), pp. 86-92.

U.S. Department of Energy (USDOE). 2002. Steam System Opportunity Assessment for the Pulp and Paper, Chemical Manufacturing, and Petroleum Refining Industries Main Report. Report No. DOE/GO-102002-1639. U.S. Department of Energy (DOE). Washington U.S.A.

## D.5 <u>Results</u>

Results of calculations performed for the analysis of the steam system at the surveyed facility are presented below.

# Steam System Index

| Facility Name | Device Category | Tag Number | Name | Device Type | Service |
|---|---|---|---|---|---|
| Barancabermeja Refinery | Steam | Avoidable Steam | Steam Generation System (Avoidable Refinery Steam) | Medium-pressure Steam | None |
| Barancabermeja Refinery | Steam | Purge Gas | Steam Flare Assist | Medium-pressure Steam | None |
| Barancabermeja Refinery | Steam | UOP I | Flue Gas Economic Analysis | Low-pressure Steam | None |

# Steam Simulation Input

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Site Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Report Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Alfonso Garcia |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 8-Sep-2013 |

| Device | |
|---|---|
| **Name** | Steam Generation System (Avoidable Refinery Steam) |
| **ID** | Avoidable Steam |
| **On Site Location** | N/A |
| **Category** | Steam System |
| **Type** | Medium-pressure Steam |
| **Manufacturer** | N/A |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |
| **Boiler Type** | Wall-fired (<=29 MW) Uncontrolled |
| **Generator Thermal Efficiency (%)** | 80 |
| **Service** | None |

| General Simulation Data | |
|---|---|
| **Operating Factor (%)**[1] | 1.00 |
| **Flow Adjustment (std $m^3$/h)**[1] | 0 |
| **Adjustment Comment** | No comments |
| **Maximum Reduction Potential (%)** | 0.00 |
| **Activity Level**[2] | 1 |
| **Extrapolated Activity Level**[2] | 0 |
| **Inlet Temperature (°C)** | 20 |
| **Ambient Temperature (°C)** | 30 |
| **Ambient Pressure (kPa)** | 95.8 |

| Device Description and Comments |
|---|
| Steam Generation System of the Refinery. The steam production from the Balance Area is not considered. |

| Applied Emission Factors (ng/J) | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor** | 1.00 | US EPA AP-42 |
| **$N_2O$ Emission Factor** | 0.90 | US EPA AP-42 |
| **VOC Emission Factor** | 2.30 | US EPA AP-42 |
| **CO Emission Factor** | 71.21 | User Entered |
| **PM Emission Factor** | 0.80 | US EPA AP-42 |
| **$NO_x$ Emission Factor** | 37.86 | User Entered |

| Data Comments and Assumptions |
|---|
| N/A |

[1] Operating Factors is a multiplicative adjustment to the measured/reported flow rate applied during simulation, with 100% being no adjustment. Flow Adjustment is additional flow at standard conditions applied after all other corrections and adjustments.

[2] Activity Level and Extrapolated Activity Level are used when extrapolating from this steam system. The unit(s) not tested are assumed to have losses of Extrapolated Activity Level/Activity Level times this Source.

| Property | Steam Stream |
| --- | --- |
| Temperature ($^oC$) | 402.6 |
| Pressure (kPa gage) | 2,757.9 |
| Line Name | N/A |
| Cross Sectional Shape | Circular |
| Pipe Outside Diameter (mm) | N/A |
| Pipe Wall Thickness (mm) | N/A |
| Pipe Rectangular Length (mm) | N/A |
| Pipe Rectangular Width (mm) | N/A |
| Measurement Type | Reported Steam Flow Rate |
| Reading Type | Flow Rate (Actual Conditions) |
| Measurement Date | N/A |
| Velocity (m/s) | --- |
| Flow Rate ($m^3$/h) | 21,587.0 |
| Standard Flow Rate (std $m^3$/h) | --- |
| Composition Name | Vapor |
| Composition ID | 37 |

# Fuel Composition Source Data

CLEARSTONE ENGINEERING

| Anaylsis Adminstration Data | |
|---|---|
| **Name** | Refinary Fuel Composition |
| **Description** | N/A |
| **Creation Date** | 3/27/2013 |
| **Sample Date** | N/A |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 38 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.005005 | 0.005005 | 0.005077 |
| Ethane | 0.058058 | 0.058058 | 0.058894 |
| Hydrogen (normal) | 0.083083 | 0.083083 | 0.084280 |
| Isobutane | 0.003003 | 0.003003 | 0.003046 |
| Isopentane | 0.001001 | 0.001001 | 0.001015 |
| Methane | 0.787788 | 0.787788 | 0.799134 |
| n-Butane | 0.003003 | 0.003003 | 0.003046 |
| n-Heptane | 0.001001 | 0.001001 | 0.001015 |
| Nitrogen | 0.025025 | 0.025025 | 0.014029 |
| Oxygen | 0.003003 | 0.003003 | 0.000000 |
| Propane | 0.030030 | 0.030030 | 0.030463 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

## Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Directed Inspection and Repair | Maintenance Program | 75.00 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Directed Inspection and Repair | Maintenance Program | 0 | 1,680,000 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Directed Inspection and Repair | Maintenance Program | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

## Simulation Results

| Source Tag No. | Value of Fuel Stream (USD/y) | Total Fuel Loss Flow ($m^3/h$) | Steam Energy Value (MJ/kg) | Steam Money Value (USD/kg) | Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3m^3/d$) | Ethane ($m^3/d$ liq) | LPG ($m^3/d$ liq) | NGL ($m^3/d$) | Hydrogen ($m^3/d$) |
| Avoidable Steam | 35,373,300 | 20,607.7 | 3.16 | 0.02 | 395.2 | 103.5 | 68.0 | 5.6 | 41,683.5 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | $NO_x$ | $SO_2$ | PM |
| 7.1 | 352,789 | 6.4 | 354,917 | 16.3 | 505.1 | 268.6 | 0.0 | 5.7 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Directed Inspection and Repair | 75.00 | 195,000 | 0 | 1,680,000 | 26,529,975 | 182,844,368 | 12,743.58 | 0.01 |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | $NO_x$ | $SO_2$ | PM |
| Directed Inspection and Repair | 5.32 | 264,592 | 4.79 | 266,188 | 12.24 | 378.84 | 201.42 | 0.00 | 4.26 |

## Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Directed Inspection and Repair | Maintenance Program |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Engineering and Drafting | Other Engineering Cost | Software | 50,000.00 | 1.0 | 50,000 |
| | Process | Procedures Development | 25,000.00 | 1.0 | 25,000 |
| Material | Instruments | Clamp-on Flow Meter | 30,000.00 | 2.0 | 60,000 |
| | | VPAC Unit | 30,000.00 | 2.0 | 60,000 |

| | |
|---|---|
| **Total** | 195,000 |

# Steam Simulation Input

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Site Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Report Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Alfonso Garcia |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 8-Sep-2013 |

| Device | |
|---|---|
| **Name** | Steam Flare Assist |
| **ID** | Purge Gas |
| **On Site Location** | N/A |
| **Category** | Steam System |
| **Type** | Medium-pressure Steam |
| **Manufacturer** | N/A |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |
| **Boiler Type** | Wall-fired (<=29 MW) Uncontrolled |
| **Generator Thermal Efficiency (%)** | 80 |
| **Service** | None |

| General Simulation Data | |
|---|---|
| **Operating Factor (%)[1]** | 1.00 |
| **Flow Adjustment (std $m^3$/h)[1]** | 0 |
| **Adjustment Comment** | No comments |
| **Maximum Reduction Potential (%)** | 0.00 |
| **Activity Level[2]** | 1 |
| **Extrapolated Activity Level[2]** | 0 |
| **Inlet Temperature (°C)** | 20 |
| **Ambient Temperature (°C)** | 30 |
| **Ambient Pressure (kPa)** | 95.8 |

| Applied Emission Factors (ng/J) | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor** | 1.00 | US EPA AP-42 |
| **$N_2O$ Emission Factor** | 0.90 | US EPA AP-42 |
| **VOC Emission Factor** | 2.30 | US EPA AP-42 |
| **CO Emission Factor** | 71.21 | User Entered |
| **PM Emission Factor** | 0.80 | US EPA AP-42 |
| **$NO_x$ Emission Factor** | 37.86 | User Entered |

**Device Description and Comments**

Steam that is used in the Tea 2,3,4 and 7.

**Data Comments and Assumptions**

N/A

[1] Operating Factors is a multiplicative adjustment to the measured/reported flow rate applied during simulation, with 100% being no adjustment. Flow Adjustment is additional flow at standard conditions applied after all other corrections and adjustments.

[2] Activity Level and Extrapolated Activity Level are used when extrapolating from this steam system. The unit(s) not tested are assumed to have losses of Extrapolated Activity Level/Activity Level times this Source.

| Property | Steam Stream |
|---|---|
| Temperature ($^oC$) | 402.6 |
| Pressure (kPa gage) | 2,757.9 |
| Line Name | N/A |
| Cross Sectional Shape | Circular |
| Pipe Outside Diameter (mm) | N/A |
| Pipe Wall Thickness (mm) | N/A |
| Pipe Rectangular Length (mm) | N/A |
| Pipe Rectangular Width (mm) | N/A |
| Measurement Type | Reported Steam Flow Rate |
| Reading Type | Flow Rate (Actual Conditions) |
| Measurement Date | N/A |
| Velocity (m/s) | --- |
| Flow Rate ($m^3/h$) | 207.0 |
| Standard Flow Rate (std $m^3/h$) | --- |
| Composition Name | Vapor |
| Composition ID | 37 |

# Fuel Composition Source Data

| Anaylsis Adminstration Data | |
|---|---|
| **Name** | Refinary Fuel Composition |
| **Description** | N/A |
| **Creation Date** | 3/27/2013 |
| **Sample Date** | N/A |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 38 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.005005 | 0.005005 | 0.005077 |
| Ethane | 0.058058 | 0.058058 | 0.058894 |
| Hydrogen (normal) | 0.083083 | 0.083083 | 0.084280 |
| Isobutane | 0.003003 | 0.003003 | 0.003046 |
| Isopentane | 0.001001 | 0.001001 | 0.001015 |
| Methane | 0.787788 | 0.787788 | 0.799134 |
| n-Butane | 0.003003 | 0.003003 | 0.003046 |
| n-Heptane | 0.001001 | 0.001001 | 0.001015 |
| Nitrogen | 0.025025 | 0.025025 | 0.014029 |
| Oxygen | 0.003003 | 0.003003 | 0.000000 |
| Propane | 0.030030 | 0.030030 | 0.030463 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

## Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Conversion to Air Assist | Air assisted flare | 100.00 | 0.00 | 0.00 | 20 | 20 | 683,679 |
| Conversion to Air Assist | Blower (LP Air Supply) | 100.00 | 0.00 | 0.00 | 20 | 20 | 134,488 |
| Conversion to Air Assist | Ecopetrol Air Conversion (Six Flares) | 100.00 | 0.00 | 0.00 | 20 | 20 | 205,667 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Conversion to Air Assist | Air assisted flare | 0 | 0 | 0 | 0 |
| Conversion to Air Assist | Blower (LP Air Supply) | 0 | 0 | 0 | 0 |
| Conversion to Air Assist | Ecopetrol Air Conversion (Six Flares) | 0 | 0 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Conversion to Air Assist | Air assisted flare | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Conversion to Air Assist | Blower (LP Air Supply) | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Conversion to Air Assist | Ecopetrol Air Conversion (Six Flares) | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

## Simulation Results

| Source Tag No. | Value of Fuel Stream (USD/y) | Total Fuel Loss Flow ($m^3/h$) | Steam Energy Value (MJ/kg) | Steam Money Value (USD/kg) | Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3m^3/d$) | Ethane ($m^3/d$ liq) | LPG ($m^3/d$ liq) | NGL ($m^3/d$) | Hydrogen ($m^3/d$) |
| Purge Gas | 339,133 | 197.6 | 3.16 | 0.02 | 3.8 | 1.0 | 0.7 | 0.1 | 399.6 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | $NO_x$ | $SO_2$ | PM |
| 0.1 | 3,382 | 0.1 | 3,403 | 0.2 | 4.8 | 2.6 | 0.0 | 0.1 |

### Potential Control Options

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Conversion to Air Assist | 100.00 | 6,413,505 | 0 | 0 | 270,765 | -4,419,112 | 4.22 | 23.69 |
| Conversion to Air Assist | 100.00 | 32,400 | 0 | 0 | 325,684 | 2,366,515 | 1,005.20 | 0.10 |
| Conversion to Air Assist | 100.00 | 1,025,283 | 0 | 0 | 318,566 | 1,321,203 | 31.07 | 3.22 |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | $NO_x$ | $SO_2$ | PM |
| Conversion to Air Assist | 0.07 | 3,275 | 0.06 | 3,295 | 0.16 | 4.84 | 2.57 | 0.00 | 0.05 |
| Conversion to Air Assist | 0.07 | 3,361 | 0.06 | 3,381 | 0.16 | 4.84 | 2.57 | 0.00 | 0.05 |
| Conversion to Air Assist | 0.07 | 3,350 | 0.06 | 3,370 | 0.16 | 4.84 | 2.57 | 0.00 | 0.05 |

# Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Conversion to Air Assist | Blower (LP Air Supply) |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Construction | Other Constuction Cost | Construction/Installation | 12,960.00 | 1.0 | 12,960 |
| Engineering and Drafting | Other Engineering Cost | Engineering | 3,240.00 | 1.0 | 3,240 |
| Material | Other Material Cost | Blower | 2,700.00 | 6.0 | 16,200 |
| | | | | **Total** | 32,400 |

CLEARSTONE ENGINEERING

# Steam Simulation Input

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Site Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Report Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Alfonso Garcia |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 8-Sep-2013 |

| General Simulation Data | |
|---|---|
| **Operating Factor (%)**[1] | 1.00 |
| **Flow Adjustment (std $m^3$/h)**[1] | 0 |
| **Adjustment Comment** | No comments |
| **Maximum Reduction Potential (%)** | 0.00 |
| **Activity Level**[2] | 1 |
| **Extrapolated Activity Level**[2] | 0 |
| **Inlet Temperature (°C)** | 20 |
| **Ambient Temperature (°C)** | 30 |
| **Ambient Pressure (kPa)** | 95.8 |

| Device | |
|---|---|
| **Name** | Flue Gas Economic Analysis |
| **ID** | UOP I |
| **On Site Location** | N/A |
| **Category** | Steam System |
| **Type** | Low-pressure Steam |
| **Manufacturer** | N/A |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |
| **Boiler Type** | Wall-fired (<=29 MW) Uncontrolled |
| **Generator Thermal Efficiency (%)** | 80 |
| **Service** | None |

| Applied Emission Factors (ng/J) | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor** | 1.00 | US EPA AP-42 |
| **$N_2O$ Emission Factor** | 0.90 | US EPA AP-42 |
| **VOC Emission Factor** | 2.30 | US EPA AP-42 |
| **CO Emission Factor** | 35.00 | US EPA AP-42 |
| **PM Emission Factor** | 0.80 | US EPA AP-42 |
| **$NO_x$ Emission Factor** | 42.00 | US EPA AP-42 |

| Device Description and Comments |
|---|
| Economic analysis of low pressure steam production. |

| Data Comments and Assumptions |
|---|
| N/A |

[1] Operating Factors is a multiplicative adjustment to the measured/reported flow rate applied during simulation, with 100% being no adjustment. Flow Adjustment is additional flow at standard conditions applied after all other corrections and adjustments.

[2] Activity Level and Extrapolated Activity Level are used when extrapolating from this steam system. The unit(s) not tested are assumed to have losses of Extrapolated Activity Level/Activity Level times this Source.

| Property | Steam Stream |
|---|---|
| Temperature ($^{o}C$) | 185.6 |
| Pressure (kPa gage) | 1,137.6 |
| Line Name | N/A |
| Cross Sectional Shape | Circular |
| Pipe Outside Diameter (mm) | N/A |
| Pipe Wall Thickness (mm) | N/A |
| Pipe Rectangular Length (mm) | N/A |
| Pipe Rectangular Width (mm) | N/A |
| Measurement Type | Reported Steam Flow Rate |
| Reading Type | Flow Rate (Actual Conditions) |
| Measurement Date | N/A |
| Velocity (m/s) | --- |
| Flow Rate ($m^3$/h) | 1,832.0 |
| Standard Flow Rate (std $m^3$/h) | --- |
| Composition Name | Vapor |
| Composition ID | 37 |

# Fuel Composition Source Data

| Anaylsis Adminstration Data | |
|---|---|
| **Name** | Gas de Campos |
| **Description** | Purchase Gas. "Gas de Campos" is "Field Gas" is Spanish. Automatically entered raw data. |
| **Creation Date** | 3/28/2013 |
| **Sample Date** | 2/6/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Field Gas |
| **Clearstone ID** | 47 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Ethane | 0.066727 | 0.066727 | 0.067874 |
| Isobutane | 0.000409 | 0.000409 | 0.000416 |
| Isopentane | 0.000194 | 0.000194 | 0.000198 |
| Methane | 0.901302 | 0.901302 | 0.916801 |
| n-Butane | 0.000713 | 0.000713 | 0.000725 |
| n-Heptane | 0.000564 | 0.000564 | 0.000573 |
| n-Hexane | 0.000229 | 0.000229 | 0.000233 |
| Nitrogen | 0.014936 | 0.014936 | 0.001634 |
| n-Pentane | 0.000254 | 0.000254 | 0.000259 |
| Oxygen | 0.003576 | 0.003576 | 0.000000 |
| Propane | 0.011096 | 0.011096 | 0.011287 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

## Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Waste Heat Recovery | Heat Exchanger | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Waste Heat Recovery | Heat Exchanger | 0 | 0 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Waste Heat Recovery | Heat Exchanger | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

## Simulation Results

| Source Tag No. | Value of Fuel Stream (USD/y) | Total Fuel Loss Flow ($m^3/h$) | Steam Energy Value (MJ/kg) | Steam Money Value (USD/kg) | Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3 m^3/d$) | Ethane ($m^3/d$ liq) | LPG ($m^3/d$ liq) | NGL ($m^3/d$) | Hydrogen ($m^3/d$) |
| UOP I | 1,551,914 | 955.3 | 2.70 | 0.02 | 21.0 | 5.5 | 1.1 | 0.2 | 0.0 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | $NO_x$ | $SO_2$ | PM |
| 0.3 | 17,112 | 0.3 | 17,215 | 0.8 | 11.9 | 14.3 | 0.0 | 0.3 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Waste Heat Recovery | 100.00 | 1,002,500 | 0 | 0 | 1,551,914 | 10,428,549 | 154.80 | 0.65 |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | $NO_x$ | $SO_2$ | PM |
| Waste Heat Recovery | 0.34 | 17,112 | 0.31 | 17,215 | 0.78 | 11.92 | 14.31 | 0.00 | 0.27 |

## Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Waste Heat Recovery | Heat Exchanger |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Construction | Crane Operation | Crane | 5,000.00 | 1.0 | 5,000 |
| | Electrical | Electrical Contractor (Day) | 1,600.00 | 10.0 | 16,000 |
| | Freight | | 15,000.00 | 1.0 | 15,000 |
| | Instrumentation | Instrumentation Contractor (Day) | 1,600.00 | 10.0 | 16,000 |
| | Labourers | Structural Labour | 50,000.00 | 1.0 | 50,000 |
| | Other Constuction Cost | 10% Contingency Fund | 84,200.00 | 1.0 | 84,200 |
| | | Mechanical Contractor (day) | 6,400.00 | 50.0 | 320,000 |
| Engineering and Drafting | Civil/Geotechnical | Civil Engineering | 30,000.00 | 1.0 | 30,000 |
| | Drafting | 5% Overhead | 42,100.00 | 1.0 | 42,100 |
| | Mechanical/Structural | Building | 10,000.00 | 1.0 | 10,000 |
| | Other Engineering Cost | 10% Overhead | 84,200.00 | 1.0 | 84,200 |
| Material | Instruments | Electrial | 20,000.00 | 1.0 | 20,000 |
| | | Instrumentation | 20,000.00 | 1.0 | 20,000 |
| | Miscellaneous Material Cost | Structural | 20,000.00 | 1.0 | 20,000 |
| | Other Material Cost | Condensing System | 50,000.00 | 1.0 | 50,000 |
| | | Insulation | 30,000.00 | 1.0 | 30,000 |
| | | Kettle type reboiler | 110,000.00 | 1.0 | 110,000 |
| | | Surge Drum | 20,000.00 | 1.0 | 20,000 |
| | Pipes and Fittings | Values and Piping. | 40,000.00 | 1.0 | 40,000 |
| | Pumps | | 10,000.00 | 2.0 | 20,000 |

| | |
|---|---|
| **Total** | 1,002,500 |

## APPENDIX E FLARE SYSTEMS

### E.1 Introduction

Flare and vent systems exist in essentially all segments of the oil and gas industry and are used for two basic types of waste gas disposal: intermittent and continuous. Intermittent applications may include the disposal of waste volumes from emergency pressure relief episodes, operator initiated or instrumented depressurization events (e.g., depressurization of process equipment for inspection or maintenance purposes, or depressurization of piping for tie-ins), plant or system upsets, well servicing and testing, pigging events, and routine blowdown of instruments, drip pots and scrubbers. Continuous applications may include disposal of associated gas and/or tank vapours at oil production facilities where gas conservation is uneconomical or until such economics can be evaluated, casing gas at heavy oil wells, process waste or byproduct streams that either have little or no value or are uneconomical to recover (e.g., vent gas from glycol dehydrators, acid gas from gas sweetening units, and sometimes stabilizer overheads), and vent gas from gas-operated devices where natural gas is used as the supply medium (e.g., instrument control loops, chemical injection pumps, samplers, etc.). Typically, waste gas volumes are flared if they pose an odour, health or safety concern, and otherwise are vented.

### E.2 Background

The design of a flare must consider the maximum flow rate or release volume, the waste gas composition, temperature and pressure, heat release rates, the minimum required destruction efficiency, the impact of the emissions at ground level and at downwind receptors, and the potential for liquids to be contained or formed in the waste gas being sent to the flare.

Specific design features that affect flare performance include the discharge nozzle (or burner tip) design, the ignition system, the purge gas system and, if applicable, the enriching gas and assist gas systems. A review of the flare design and features is conducted to determine if there is a potential to reduce energy consumption, recovery the flare gas and emissions.

### E.3 Performance Evaluation Methodology

#### E.3.1 Flared Gas Flow Rate Determination

When evaluating opportunities for reducing fuel consumption and flared volumes, actual site measurements are preferred for assessing the flare performance and for completing economic evaluations.

If existing flare gas flow meters are in place, then the available flow readings from these are used if they are of adequate quality. Otherwise, independent measurements or assessments are performed during the site survey.

#### E.3.1.1 Installed Flow Meters

Flare meters are excellent diagnostic tools which can be used to identify excessive purge rates and/or leakage into the flare system that might otherwise go unnoticed, as well as quantify total intermittent and continuous flared volumes Pilot, purge, enriching and assist gas should be metered independently wherever possible.

Alberta ERCB recommends the use of flare meters at larger oil and natural gas batteries, pipeline facilities and gas processing plants where there are multiple connections to the flare system, even when the aforementioned average flaring rate is not exceeded (ERCB 2006). Similar requirements exist in many other jurisdictions. At a minimum, sufficient fittings should be installed to facilitate periodic checking of the residual flare rate if continuous flare metering is not required or deemed necessary. Flare streams are particularly challenging to meter because of the high variability in flow and composition.

Generally, flare meters should be gas-composition independent and exhibit accuracy over a high turndown range (i.e. 1:100 or better). Ultrasonic flow meters are the preferred choice in most permanent vent or flare applications involving wet and dirty gas, provided the liquid content does not exceed about 0.5 percent by volume. Ultrasonic flow meters offer excellent rangeability (2000:1), low uncertainties (±2 to 5 percent of value), do not require frequent calibration, are not composition dependent (i.e., corrections for the composition of the gas are not required) and they do not pose any significant flow restriction (i.e., the transducers are only wetted to the flow and are not extended into the flow as depicted in Figure 6). If greater amounts of liquids are anticipated then a liquids knockout system should be installed immediately upstream of the flow meter. Orifice and venturi meters may be considered instead of ultrasonic flow meters in applications involving stable wet or dirty flows; they can tolerate the presence of more liquids but have the disadvantages of greatly reduced rangeability (5:1) and the need for frequent calibrations, especially if the gas composition is variable. If properly maintained and calibrated, they provide uncertainties of ±2 to 4 percent of full scale readings.

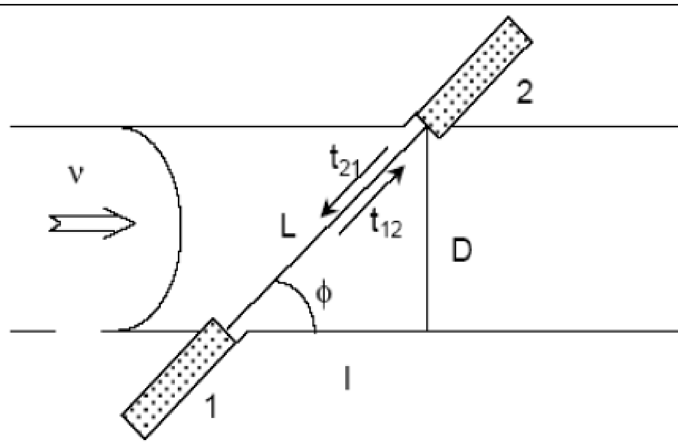


**Figure 6: Schematic diagram depicting a pair of ultrasonic flow transducers wetted to the flow in a pipe.**

Optical flow meters may also be considered. They are a more recent flare gas measurement technology and there is little published experience on the use of these flow meters. The optical flow meter measures flow velocity based on the transit time of naturally occurring particles in the flow stream over a short known path length. The rangeability of optical flow meters is 2000:1 and the uncertainty of the measurements is ±2.5 to 7 percent of value. The optical flow meter is reportedly suitable for moderately wet or dirty fluids. A particular advantage of the technology is that it comprises a single measurement probe that is easy to install (see Figure 7).

**Figure 7: Photograph of an optical flow meter probe.**

The use of thermal anemometers in flare gas flow measurement applications is generally not practical as they are highly composition dependent and are susceptible to fouling and cannot tolerate the presence of any liquids of condensation.

#### E.3.1.2 Independent Flow Measurements

If no flare metering is in place or the results available from those meters are of questionable accuracy, then the flare rate is measured using one of two basic techniques: a portable velocity probe or by conducting an inline tracer test. In either case, it is necessary that suitable ports be available; otherwise, the flaring rate is estimated using a flame-length technique (see the next section).

Most portable velocity probes can be inserted into the flare piping through a NPS ¾ full port valve. Typically, an optical flow meter manufactured by Photon Control. The instrument readings are continuously data logged at 1 Hz for sufficient time to characterize the flow variations. The velocity measurements are taken downstream of all tie-ins in a straight section of pipe. Where possible, the measurement point is selected to be 15 pipe-diameters downstream and 5 pipe-diameters upstream of any flow disturbances.

To conduct an inline tracer test it is necessary to have fittings on the flare line for injecting tracer gas and for withdrawing a sample. The injection point must be located somewhere on the flare line where there is flow and the sampling point needs to be sufficiently far downstream of the injection point and all tie-ins to allow for good mixing of the entire flare stream and the tracer gas. The basic approach involves injecting the tracer gas at a known rate and, based on the concentration of the tracer gas at the sample location, calculating the gas flow rate needed to produce the observed amount of tracer dilution. The selected tracer gas is a substance that is inert, easy to detect in low concentrations and not naturally occurring in the flare gas. Either $SF_6$ or $N_2O$ is normally used. The tracer gas analyses are performed onsite using a micro-gas chromatograph or a cavity ringdown spectrometer, respectively.

### E.3.1.3 Flow Estimation based on Flare Flame Length

If direct flow measurements cannot be performed then the flare rate is estimated using an empirical flame-length correlation derived by Gas Processors Suppliers Association (GPSA) from data provided in the flame-length versus heat-release-rate graphs presented in the American Petroleum Institute's (API's) Recommended Practice (RP) 521. The correlation applies to flare with simple tip designs and can be expected, where the gas composition is well known, to provide accuracies in the range of ±10 to 60% (i.e., based in the scatter in the available data). The better accuracies tend to occur at the higher flow rates. The correlation is applicable to turbulent diffusion flames for simple flare tip designs up to the point where flame lift-off from the flare tip starts to occur, and for greater flows, underestimates the actual flare rate.

The primary advantage of the method is that it is easy and safe to apply, and it provides a reasonable initial estimate of the flaring rate which makes it useful as a screening technique.

GPSA correlates the flame length $L_f$ and the energy (equivalent) flare flow rate $Q$ (W) of the flare gas stream using the following relation:

$$L_f = 2.14(Q \times 10^{-6})^{0.474}$$

**Equation 22**

The flame length is determined by photographing the flare tip (see Figure 8), and then scaling up the stack diameter $D_p$ and flame length, $L_p$, dimensions measured from the photograph to match the actual stack diameter, $D_f$. This is done using the following relation:

$$L_f = \frac{L_p}{D_p} D_f$$

**Equation 23**

The flame from each flare is photographed using a Canon EOS 60D SLR digital camera equipped with a 200 mm zoom lens. Multiple images are taken of each flame to fully characterize the range of natural fluctuations in the flame size. The fluctuations in the flame length can be appreciable, even when the flow rate is constant. The flare rate correlates best with the average determined flame length.

The stack outside diameter is determined by back-calculation from the measured stack circumference and confirmed against standard pipe sizes.

The calorific value of the flare gas is determined based on typical gas analyses provided by the facility operators or based on flare gas samples collected and analyzed during the site survey.

With the flame length $L_f$ known, the GPSA correlation is applied to back-calculate the flow rate of the flare gas.

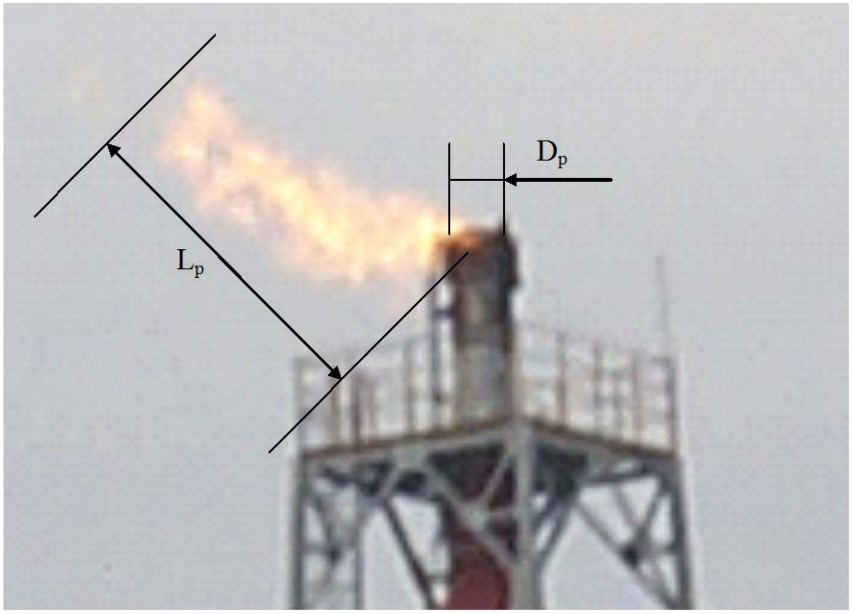


**Figure 8: A photograph of one flare flame showing the related dimensions for the flame length approach.**

## E.3.2 Purge Gas Flow Rate

### E.3.2.1 Minimum Purge Rate based on BMP

For plain end flares, the purge gas required to avoid unsafe air infiltration can be estimated using the Husa purge model. (CAPP 2008) Equation 24 is an adaptation of the Husa purge model that can be used to estimate minimum purge gas requirements for flare systems:

$$Q = -\ln\left(\frac{O_2\%}{21}\right)\frac{KD^{3.46}}{Ls}\left[1 - 0.75\left(\frac{MW}{28.96}\right)^{1.5}\right]$$

**Equation 24**

Where:

- $Q$ is the purge gas consumption in $m^3/h$;
- $K$ is $5.26\times10^{-8}$ ;
- $D$ is the internal diameter of the stack in mm;
- $O_2\%$ is the acceptable oxygen concentration at $Ls$ in % (note: 6% is usually acceptable);

- *Ls* is the distance into the stack where the safe condition is met in m (note: the lesser of 7.62 m or 10 stack diameters is usually acceptable);
- *MW* is the molecular weight of the purge gas (19.5 is typical for raw natural gas).

Larger flares are often equipped with seals, which reduce the continuous purge rate required to avoid unsafe air infiltration into the stack. Purge reduction seals do not physically isolate the stack from the surrounding atmosphere. Instead, they utilize proprietary internals, either baffle-type or labyrinth-type, to reduce the ability for buoyant movement of air into the stack. Equation 25 can be used to estimate typical purge requirements for flare systems outfitted with baffle-type seals and Equation 26 can be used to estimate the typical purge gas consumption associated with labyrinth-type seals. Actual purge rates will depend on the seal design and should be obtained from the manufacturer. For baffle-type purge reduction tips (assuming an average purge velocity of 0.0122 m/s), the following relation may be applied to estimate purge gas requirements:

$$Q = 3.447 \times 10^{-5} D^2$$

**Equation 25**

Where:

- Q is the purge gas consumption in $m^3/h$;
- D is the internal diameter of the stack in mm;

For labyrinth-type purge reduction tips (assuming an average purge velocity of 0.0030 m/s), the following relations may be applied:

$$Q = 8.618 \times 10^{-6} D^2$$

**Equation 26**

Where:

- Q is the purge gas consumption in $m^3/h$;
- D is the internal diameter of the stack in mm;
  Assuming: the average required purge velocity for flares equipped with labyrinth-type purge reduction tips is 0.0030 m/s.

Table 18 presents typical minimum required purge gas rates for different sizes of flares equipped with different types of seals (CAPP 2008).

| Table 18: Typical minimum purge rates to avoid unsafe air infiltration. | | | |
|---|---|---|---|
| Flare Diameter (NPS)[1] | Purge Gas Consumption Rate ($m^3/h$) | | |
| | Plain End[2] | Baffle Type Seal | Labyrinth Type Seal |
| 2 | 0.07 | 0.09 | 0.02 |
| 3 | 0.17 | 0.21 | 0.05 |
| 4 | 0.34 | 0.36 | 0.09 |
| 6 | 0.93 | 0.82 | 0.20 |
| 8 | 1.83 | 1.42 | 0.35 |
| 10 | 3.19 | 2.23 | 0.56 |
| 12 | 4.98 | 3.20 | 0.80 |
| 14 | 6.35 | 3.90 | 0.98 |
| 16 | 8.98 | 5.17 | 1.29 |
| 18 | 12.16 | 6.62 | 1.65 |
| 20 | 15.92 | 8.24 | 2.06 |
| 24 | 25.34 | 12.02 | 3.01 |
| 26 | 31.04 | 14.18 | 3.54 |
| 30 | 44.57 | 19.03 | 4.76 |
| 36 | 82.87 | 27.63 | 6.91 |
| 42 | 142.76 | 37.84 | 9.46 |
| 48 | 228.39 | 49.65 | 12.41 |
| 54 | 345.39 | 63.06 | 15.77 |
| 60 | 499.74 | 78.07 | 19.52 |

[1] Standard wall pipe

### E.3.3 Minimum Energy Content of Combined Flare Volume

The minimum energy content of flared gas is an important performance consideration; the minimum requirements are typically specified by regulatory agencies.

ERCB (2006) Directive 060 requires the combined net heating value (i.e. lower heating value) of flared gases and make-up fuel to meet or exceed 20 MJ/$m^3$ except for existing flares with a history of stable operation and emergency flare systems in sour gas plants where the heating value may be as low as 12 MJ/$m^3$.

### E.3.4 Fuel Consumption Rate Reduction Options

#### E.3.4.1 Purge Gas Rate

Metered or estimated purge gas flow rates are compared to best management practice (BMP) values. The purge rate can be estimated from the flame length where residual flows include purge gas and leakage into the flare header, and do not include any contributions due to emergency or planned depressurization events.

The minimum required pure rate will depend on the type of seal used, stack diameter, properties of the purge gas and ambient and system conditions.

An opportunity may exist to reduce fuel consumed by continuously purged flare systems by installing purge reduction seals, using instrumentation to control purge rates, switching to an inert gas purge and/or reducing purge rates in response to leakage into the flare system. When evaluating purge gas reductions the purge rate required to maintain a safe stack condition (i.e. prevent air ingress) should be considered in conjunction with purge requirements to prevent burn back and provide adequate header sweep.

Purge reduction seals reduce the purge velocity required to avoid air infiltration into the flare stack and can lead to a significant reductions in the amount of purge gas consumption, especially on larger diameter stacks. These devices should be considered in most situations where flare systems are continuously purged.

The minimum purge rate required to avoid unsafe air ingress into the stack is not only a function of the stack diameter and purge gas composition, but is dependent on changes in ambient temperature, pressure, wind speed and temperature of products in the flare header. To compensate for the dynamic nature of these dependencies, continuous purge rates are often set above the minimum value required for the conditions under which the flare usually operates. An alternative to specifying an excessive purge rate is to use instrumentation to monitor critical parameters in the flare system (e.g. oxygen concentration, temperature, etc.) and automatically adjust the purge rate to maintain a safe stack condition. The reliability, regular calibration and preventive maintenance of instrumented purge gas control systems is critical to their success.

Leakage into the flare system can be difficult to identify and sometimes necessitates a plant shutdown to correct. During the time it takes to find and repair a leaking component, all or part of the losses can be mitigated by using the leak as a purge source and reducing the supply of purge gas up to the volume of the leak rate.

Some sources of leakage into a flare system are easy to detect because they are audible or cause condensation or ice formation on the outside of the leaking valve. However, many leakage sources are difficult to detect, even with thermal imaging cameras. A technology that has proven to be very effective in detecting leak flare gas valves is the VPAC, an acoustical leak detector manufactured by Mistras Group, which provides both leak detect and quantification capabilities. The amount of leakage is quantified by inputting the numeric acoustical reading from the VPAC into an empirical correlation along with information concerning the fluid, valve type and size and the pressure difference across the valve. This technology was originally developed in cooperation with BP and is most widely used at petroleum refineries, but it is also suitable for detecting leaking flare valves at upstream oil and natural gas facilities as well.

#### E.3.4.2 Pilot Gas Rate

Many flares are outfitted with continuously burning gas pilots to ensure ignition of the flared gases or liquids. The number and type of pilots required depends on the flare size, stream composition and wind conditions. Typical pilot requirements and fuel consumption rates are summarized in Table 19. These rates assume an average pilot fuel consumption rate of 1.98 $m^3$/h/pilot which is reasonable for energy-efficient pilots fueled by sales-quality natural gas (U.S. EPA 2000); however, the actual consumption rate will depend on the burner design and fuel properties. The average fuel requirement of the pilot in Table 2 is multiplied by a safety factor of 2 to estimate the reasonable pilot fuel consumption rate for the flare.

**Table 19: Average fuel gas consumption for energy-efficient flare pilots[1].**

| Flare Tip Diameter | | Number of Pilot Burners | Average Pilot Gas Consumption | |
|---|---|---|---|---|
| Inches | Mm | | $m^3$/h | $m^3$/d |
| 1-10 | 25.4-254 | 1 | 1.98 | 47.52 |
| 12-24 | 304.8-609.6 | 2 | 3.96[1] | 95.04[1] |
| 30-60 | 762-1524 | 3 | 5.95 | 142.80 |
| >60 | >1524 | 4 | 7.93 | 190.32 |

1 Adapted from CAPP (2008). The value of average pilot gas consumption for 12 to 24 NPS flares is reported as 3.63 $m^3$/h in the original CAPP document. The correct value is 3.96 $m^3$/h based on the fuel consumption rate of 70 scf/h/pilot in the original source reference of USEPA (2000).

#### E.3.4.3 Make-Up Gas Rate

Make-up fuel is sometimes required to raise the calorific value of flared waste gas to levels that will support stable and efficient combustion.

Equation 27 can be used to estimate minimum make-up gas requirements (CAPP 2008).

$$Q_m = Q_w \frac{LHV_r - LHV_w}{LHV_m - LHV_r}$$

**Equation 27**

Where:

- $Q_m$ is the make-up fuel gas flow rate ($m^3$/h),
- $Q_w$ is the waste gas flow rate ($m^3$/h),
- $LHV_r$ is the required combined net heating value (i.e. 20 MJ/$m^3$),
- $LHV_m$ is the lower heating value of the make-up gas (MJ/$m^3$),
- $LHV_w$ is the net heating value of the waste gas (MJ/$m^3$).

The quantity of fuel gas used to raise the calorific value of waste gas streams can be reduced by using incinerators in place of flares or by installing instrumentation to automatically adjust the delivery of make-up gas.

### E.3.5 Heating Value Requirement

According to ERCB (2006) Directive 060, the combined net or lower heating value of waste gas, including make-up fuel gas, directed to a flare must not be less than 20 MJ/$m^3$.

If the flare has a history of flame failure, odour complaints, and/or exceedances of the *Ambient Air Quality Objectives*, operators must operate with a combined flare gas heating value of not less than 20 MJ/m$^3$.

### E.3.6 Flare Efficiency

For a typical flare, the efficiency improves as the exit velocity and heating value of the gas increase, and then decrease when soot formation (black smoke) and/or lift-off of the flame from the flare tip start to occur. A quantitative estimate of the flaring efficiency, where no flame lift-off is occurring, may be evaluated based on the following approach:

- Any aerosols that form in the flare gas between the flare knock-out drum and the flare tip is assumed to either pass through the flame zone unburned or to form soot. The amount of aerosol formation is estimated by determining the temperature of the flare knockout drum and assuming the gas at the flare tip is at ambient temperature. The formation of aerosols tends to reduce the heating value and exit velocity of the remaining gas phase since the aerosols are comprised mainly of the higher-molecular weight hydrocarbons.
- The combustion efficiency of the gas phase is assumed to be characterized by the flaring efficiency model published by Johnson *et al.* (1999). That model presents the flaring efficiency as a function of the stack diameter, exit velocity, flare gas heating value and the local wind speed, and was developed based on extensive wind tunnel tests on bench scale and full-scale flares.

The approach taken in Johnson's research project was to experimentally study scaled-down, generic pipe flares under well-controlled conditions to understand the performance of flares in general. To provide control over the wind, research was conducted in a closed-loop wind tunnel where the wind speed from a known direction could be set and the level of turbulence could be prescribed.

A methodology was developed to accurately determine the efficiencies of flares where the combustion products are predominantly gaseous. For a flare burning a mixture of hydrocarbon fuels, the efficiency is described by the "carbon conversion efficiency," which is the effectiveness of the flare in converting the carbon in the fuel to carbon in $CO_2$.

For a stream with a lower heating value (LHV < 30 MJ/m$^3$), the following relation applies:

$$(1-\eta)(LHV_{mass})^3 = 146.5\exp\{0.1745 \cdot U_\infty / [(gV_j)^{1/3}(d_0{}^{1/2})]\}$$

**Equation 28**

Where:

| | | |
|---|---|---|
| $\eta$ | = | flare efficiency (dimensionless); |
| LHV | = | lower heating value of the flare gas (MJ/kg); |
| $U_\infty$ | = | wind speed (m/s); |

g = gravitational constant (m/s$^2$);
$V_j$ = flare gas exit velocity (m/s);
$d_0$ = stack outside diameter (m).

Equation 28 presents the influence of crosswind speed, flare gas exit velocity, flare diameter, and fuel type to flare efficiency. Results show the crosswind has a strong effect on the destruction efficiency. At relatively low values of $U_\infty$ the efficiencies are extremely high, but as $U_\infty$ is increased the efficiency decreases dramatically. The destruction efficiency also depends on the mean fuel jet exit velocity ($V_j$). Higher velocity fuel jets are less sensitive to the effects of crosswind. The larger diameter flare stacks are more resistant to the effects of increased crosswind speed.

For a stream with greater a heating value (LHV > 30 MJ/m$^3$), Equation 28 overestimates the importance of energy density and gives unreasonably high efficiencies. The following correlation should be use in this case:

$$\begin{cases} \dfrac{U_\infty}{(gV_j)^{1/3} d_0^{1/2}} < 25 & 100 \cdot (1-\eta) = 0.12375 \cdot \exp\{0.16357 \cdot U_\infty / [(gV_j)^{1/3} (d_0{}^{1/2})]\} \\ \dfrac{U_\infty}{(gV_j)^{1/3} d_0^{1/2}} \geq 25 & 100 \cdot (1-\eta) = 14.75 \cdot \ln\{U_\infty / [(gV_j)^{1/3} (d_0{}^{1/2})]\} - 40.3695 \end{cases}$$

**Equation 29**

### E.3.7 Wind Speed Correction

The flare destruction efficiency is calculated as a function of the wind speed at the stack top. To relate the wind speed back to wind speed at the standard monitoring height at meteorological monitoring stations, Equation 30 is used:

$$U_{\infty,Z} = U_{\infty,0} \left( \frac{H_Z}{H_0} \right)^n$$

**Equation 30**

Where:

$U_\infty$ = wind speed (m/s);
H = height (m);
Z = subscript representing stack top;
0 = subscript representing meteorological monitoring station (the height is usually 10 m);
n = exponential constant (n = 0.3 is used for worst case scenario).

### E.3.8 Steam Assisted Flare Analysis

The steam assisted flares are often used to promote smoke free operation. High pressure steam is injected into the combustion zone to promote better mixing and to promote complete combustion of the waste gas. The steam amount injected should be optimal to get the desired results. The steam requirement for an industrial flare ranges from 0.01 to 0.6 kg of steam per kg of flare gas (U.S. EPA 2000, 2012). The amount of steam used in the flare should be within this range to achieve high combustion efficiencies. Using excess steam leads to rapid reduction in combustion efficiency of the flare and also results in avoidable loss of steam and its energy. When the steam injection rate for the flare is known the losses associated with the excess steam requirement can be determined as follows:

$$S_{ex} = S_m - 0.6\, F_m \qquad \text{When } S_m \text{ is greater than } 0.6\, F_m$$

**Equation 31**

Where

| | | |
|---|---|---|
| $S_{ex}$ | = | Excess steam being used (kg/h) |
| $S_m$ | = | Measured steam injection rate (kg/h) |
| $F_m$ | = | Mass Flow Rate of the Flare Gas (kg/h) |

When the steam flow rate to the flare is not known or the measured steam mass flow rate is less than 1% of flare gas mass flow rate, the steam requirement for steam assisted flares is determined based on the following U.S. EPA (2000) recommendation:

$$S_{rq} = 0.4\, F_m \qquad \text{When } S_m \text{ is less than } 0.01\, F_m \text{ or } 0$$

**Equation 32**

Where

| | | |
|---|---|---|
| $S_{rq}$ | = | Steam Requirement (kg/h) |

The energy loss in excess steam is determined using the following equation:

$$E_{ex} = S_{ex}\,(H_{sb} - H_{wb})\, g_c$$

**Equation 33**

Where

| | | |
|---|---|---|
| $E_{ex}$ | = | Energy loss in excess steam (kW) |
| $H_{sb}$ | = | Enthalpy of steam used at the boiler pressure of the steam source (kJ/kg) |
| $H_{wb}$ | = | Enthalpy of inlet water at the boiler inlet temperature and pressure Conditions (kJ/kg) |
| $g_c$ | = | A constant of proportionality |
| | = | $2.778 \times 10^{-4}$ (h/s) |

The enthalpy of steam at appropriate boiler pressure and water at boiler inlet temperature and pressure is determined using steam tables.

Similarly the steam energy requirement to provide the necessary steam flow for a steam assisted flare is determined using the following equation:

$$E_{rq} = (S_{rq} - S_m)(H_{sb} - H_{wb})\, g_c \qquad \text{When } S_m \text{ is less than } 0.01\, F_m \text{ or } 0$$

**Equation 34**

Where

$E_{rq}$ = Energy requirement for extra steam to be provided to the flare (kW).

The fuel energy required for the generation of steam lost or extra steam requirement in a flare is computed as follows:

$$E_{engy\ loss} = \frac{E_{ex}}{\varphi_b}\,.100$$

**Equation 35**

And

$$E_{engy\ req} = \frac{E_{rq}}{\varphi_b}\,.100$$

**Equation 36**

Where

$E_{engy\ loss}$ = Fuel energy required for steam lost in the flare, (kW)

$E_{engy\ req}$ = Fuel energy required for extra steam requirement for the flare, (kW)

$\varphi_b$ = Boiler efficiency (%)

= 80 % by default or the actual measured or estimated value when available.

The fuel energy value from Equation 35 or Equation 36 is used to estimate the value of the fuel saved or extra fuel required as follows:

$$V_{fuel} = E_{fuel}\,.C_{fuel}\,.g_c$$

**Equation 37**

Where

$V_{fuel}$ = Value of fuel saved or cost of extra fuel required ($/y)above

$E_{fuel}$ = Energy of fuel saved ($E_{engy\ loss}$) or extra fuel required ($E_{engy\ req}$) (kW)

$C_{fuel}$ = Price of the fuel ($/GJ)
$g_c$ = A constant of proportionality
= 31.536 (GJ/kJ.s/y)

The emission rates for various combustion products and GHG are computed using the following equation:

$$ER_i = E_{fuel} \cdot EF_{i,b} \cdot g_c$$

**Equation 38**

Where
$ER_i$ = Emission rate of substance ‘i’, (t/y)
$EF_{i,b}$ = Emission factor for substance ‘i’ for the boiler, (ng/J)
$g_c$ = A constant of proportionality
= $3.1536 \times 10^{-5}$ (t/ng.J/kJ.s/y)

The emission factors can be estimated either based on combustion analysis of the boiler or the default values of emission factors for industrial boilers provided in US EPA’s AP-42 compilation of air pollutant emission factors.

### E.3.9 Air Assisted Flare Analysis

Air assisted flares are being used in industry for smokeless operation of flares. Recently US EPA (2012) has published extensive measurement data on the combustion efficiency of air assisted flare operations. The results showed that the mass flow rate for air in air assisted flares should be less than 7 times the stoichiometric air mass flow rate required for the flare gas. The maximum air requirement for an air assisted flare is estimated using the following equation:

$$m_{a,max} = 7\, m_{a,stoich}$$

**Equation 39**

Where
$m_{a,max}$ = maximum mass flow rate of air (kg/h).
$m_{a,stoich}$ = Stoichiometric air requirement for flare gas combustion (kg/h).

The stoichiometric air requirement for flare gas is determined based on the composition of flare gas. Stoichiometric (or theoretical) combustion is a process which burns all the carbon (C) to $CO_2$, all hydrogen (H) to $H_2O$ and all sulphur (S) to $SO_2$.

The excess air used in an air-assisted flare is determined using the following equation:

$$A_{ex} = A_m - m_{a,max}$$

**Equation 40**

Where

| | | |
|---|---|---|
| $A_{ex}$ | = | Excess air being used (kg/h). |
| $A_m$ | = | Measured air injection rate (kg/h). |

The savings in energy consumption of blower or the energy requirement for the air blower for air assisted flare is determined as follows:

$$E_{sav} = \frac{A_{ex} \cdot g_c}{\beta_b \beta_m} . \Delta H_{ad}$$

**Equation 41**

Where

| | | |
|---|---|---|
| $E_{sav}$ | = | Energy saving potential in air blower (kW) |
| $\beta_b$ | = | Blower Efficiency (0.70 for typical blower). |
| $\beta_m$ | = | Blower motor efficiency (0.9 for typical motor). |
| $A_{ex}$ | = | Excess air flow rate (kg/h) |
| $g_c$ | = | A proportionality constant |
| | = | $2.778 \times 10^{-4}$ (h/s). |

And

$$\Delta H_{ad} = \frac{RT_a}{8.41}\left[\left(\frac{P_d}{P_a}\right)^{0.283} - 1\right]$$

**Equation 42**

Where

| | | |
|---|---|---|
| $\Delta H_{ad}$ | = | Adiabatic head generated by blower (kJ/kg). |
| R | = | Universal Gas Constant |
| | = | 8.31451 (J/mol/K). |
| $T_a$ | = | Ambient Temperature in absolute (°K). |
| $P_d$ | = | Discharge Pressure in absolute for the blower (kPa). |
| $P_a$ | = | Ambient Pressure in absolute (kPa). |

Similarly the maximum power requirement for the blower is determined as follows:

$$E_{b,max} = \frac{m_{a,max} \cdot g_c}{\beta_b \beta_m} . \Delta H_{ad}$$

**Equation 43**

Where

$E_{b,max}$ = Maximum energy requirement for air blower (kW).

## E.4 Control Options

Where waste gas can support combustion, it is preferable to flare it than to vent it since this reduces greenhouse gas emissions as well as emissions of volatile organic compounds, air toxics and malodours. Where flares are used they need to be designed and operated to provide good destruction efficiencies, smokeless operation and to be fuel efficient.

There are various measures that may be considered for managing the fuel requirements of fares and for improving their destruction efficiencies. These options include switching to the use of incinerators, installing auto-ignition systems, optimizing purge gas consumption and providing assist gas to ensure smokeless combustion.

For intermittent flares, leakage of process gas into the flare header past the seats of pressure relieve valves and blowdown or drain valves can be a significant source of emissions and economic loss. Monitoring flare systems to detect excessive amounts of leakage and implementing a formal program to detect and repair individual leaks can offer attractive economic benefits. Flare gas recovery systems are an option for achieving nearly zero flaring except during process upsets.

For continuous flares, consideration should be given to conserving the gas by compressing it back into the process or a gas gathering system, utilizing the gas for onsite fuel needs or generate electric power (especially where it is possible to wheel the power across the electrical grid for use at other locations). Another option, for streams rich in condensable hydrocarbons, is to install a condenser system to recover the condensable fraction and use the residue gas to power the process and for onsite fuel or to produce electric power.

Further details on each of these opportunities is provided in the subsections below.

### E.4.1 Incinerators

Incinerators are an alternative to flares that can be considered for disposing of steady continuous waste gas streams with low heating values. These devices maintain waste gases in the presence of oxygen at higher temperatures for longer residence times than flares. Destruction efficiencies are greater and gases with low calorific values can be more efficiently combusted. In many cases waste gas streams that do not meet the calorific requirements to maintain reliable and stable combustion in a flare can be disposed of using an incinerator without adding any fuel gas. Even in situations where incinerators do require fuel gas to treat a waste stream, the amount of fuel consumed is minimal compared to the make-up gas that would be required to sufficiently enrich the stream for disposal using a flare.

Although incinerators offer a number of benefits, they are not viable alternative to flares in all situations. Incinerators have lower turndown ratios (i.e., typically only 10:1) and higher capital cost than flares.

Instrumentation, including online calorimeters and flow meters, may be used to regulate the delivery of make-up gas to ensure calorific requirements of the combined stream are satisfied while minimizing the amount of fuel gas consumed. This may be particularly beneficial in situations where the composition and flow of the waste gas are variable.

### E.4.2 Auto-Ignition System

The use of electronic ignition devices and/or energy efficient flare pilots can minimize the amount of fuel gas used to sustain flare pilots, while minimizing the potential for flame failure. Often operators will increase purge gas flows to reduce the likelihood of a flame failure which is much less energy efficient or cost effective than investing in a reliable auto-ignition system.

**Electronic Ignition Devices-** Electronic ignition devices that ensure continuous flare ignition by systematically producing high voltage electric sparks can often be used in place of gas operated pilots. Electric energy consumption is low and is typically supplied by solar recharged batteries.

**Energy Efficient Pilots-** In situations where pilots cannot be replaced by electronic ignition devices, the fuel efficiency of the gas pilot should be evaluated and consideration given to installing a better design. Efficiency of pilots can be maintained by ensuring that wind shielding and pilot nozzles are in good condition. Some vendors offer designs that consume as little as $0.57m^3$/h/burner of fuel gas.

### E.4.3 Smokeless Flares

Air and steam assisted systems are available that can be used to eliminate flare smoke formation and help improve flare efficiencies. These systems can be retrofit to existing flares but may require some modifications to the flare tip.

A rough order-of-magnitude cost for retrofitting a medium sized flare (e.g., 30 NPS) for smoke free operation is $150,000 to $300,000. This does not include installation.

The information needed to evaluate and design a system includes: stack diameter, stack height, flare rate, and flare gas composition. Air assist is preferable for smaller to medium sized applications and steam assist is normally used on larger flares; although, many facilities have converted from steam-assist to air-assist due to the lower operating costs and reduced emissions (i.e., direct and indirect).

An air-assist retrofit installation would include a blower, an air line to the top of the stack and a new flare tip and pilot assembly. The size of the air line would depend on the amount of air required to ensure smokeless operation. There are some basic rules of thumb regarding the mass of assist-air to waste-gas ratios. The existing structure would need to be checked to verify that it could support the additional weight. The size of the air line could be reduced by using higher-pressure air. This may require the use of air from the instrument air system or separate compressor, depending on pressure requirements. One vendor said they have used the derrick legs to transport assist air to the flare tip, assuming the legs are of tubular construction.

The air flow to the stack tip would be controlled by measuring the waste gas flow to the stack (e.g., by linking the blower controls into a flare gas flow meter output signal).

A two-stage flare may also be a good solution, assuming the smoking problems occur at lower relief rates. For example, a second line could be run up the existing stack, with a separate tip and pilot assembly. This option would only be applicable if the waste gas stream has sufficient pressure.

Typical vendors of smokeless flare systems include John Zinc, NAO Inc., Tornado Tech and Flare Industries.

### E.4.4 Management of Leaking Flare Valves

It is reported that 5 to 10 percent of flare valves leak and 1 to 2 percent of those account for 70 percent of the leakage into flare headers. For flare systems that are sized for large relief events, significant amounts of leakage can easily go undetected (i.e., because the incremental flow is not visibly discernible and because the flow meters that are present are generally sized to only record much larger flows during relief or blowdown events).

The use of permanent monitoring systems or facilities should be considered to facilitate easy screening for excessive leakage into flare systems and where leakage occurs, this should leakage should be used to allow reduction of the flare purge gas requirements until the leaks can be isolated and repaired. Additionally, consideration should be given to implementing formal programs to detect and quantify individual flare valve leaks (for example, using a VPAC or similar technology).

Monitoring ports should be provided on all emergency vent and flare lines and blowdown systems to allow convenient periodic detection and quantification of residual flows in these systems where continuous flow meters are not provided or where such meters are only sized to quantify large flow rates (e.g., during relief or blowdown episodes).

Predictive maintenance techniques are preferable to reactive measures and should be considered for applications involving chronic or frequent leakers (e.g., compressor seal vents and leakage into vent and flare systems). This requires the implementation of continuous, frequent or early warning monitoring systems to provide advance notice of developing leaks and to facilitate pre-planning of repair or replacement activities.

Devices such as flow switches, flow meters, vapour sensors or transducers for other parameters that provide a good indication of leakage may be installed to allow continuous or frequent detection of leaks from component vent ports and in vent or flare systems.

An effective method of reducing fugitive emissions from pressure relief devices is to install a relief valve with a rupture disk immediately upstream of it, at each relief point. A pressure gauge or suitable telltale indicator is needed between the disk and the relief valve to indicate when the disk has failed (ASME, 1989). The rupture disk will shield the relief valve from corrosive process fluids during normal operation. If an overpressure condition occurs, replacement of the disk may be delayed until the next scheduled shutdown period. In the interim, protection against over-pressuring is provided by the relief valve. Sometimes a block valve is installed upstream of the relief system to facilitate early replacement or repair of the components. This use of an upstream block valve is allowed under most Boiler and Pressure Vessel Acts, provided the valve is normally car-sealed open.

The rupture disk should have a set pressure that is slightly higher than that of the relief valve to help avoid simmering problems.

An additional control method is to use resilient valve seats (elastomeric o-rings), as they have superior re-sealing characteristics.

These same strategies may be used to prevent leakage from pressure relief valves that release into closed-vent systems (for example, a flare system). In this case, leakage is difficult to detect and, as a result, may lead to a significant level of waste and cause unnecessary emissions from the combustion device.

The basic rupture disk assembly needed for use upstream of a pressure relief valve comprises a prebulged disk, disk holder, telltale indicator, and vent valve. Additionally, a spool piece may be required between the disk and the valve to provide adequate room for the disk to open during a rupture event. There are two basic types of rupture disks that may be used: forward acting and reverse acting. The forward acting disks are the least expensive and most commonly used type. The latter type is used in applications where significant vacuums or pressures may occur on the downstream side of the rupture disk. A forward acting disk would tend to break prematurely in these situations. A standard reason for using a reverse acting rupture disk is to allow the space between the disk and the pressure relief valve to be pressurized to test the set point of the valve in situ and to check for leaks.

For manual blowdown valves, one option to reduce leakage potential is to install as second valve to provide double shutoff protection.

### E.4.5 Flare Gas Recovery Systems

While is preferable to control leakage into flare systems at the source, this may not always be practicable. Installing a flare gas recovery system can result in nearly 100 percent reduction of normal flaring, limiting flare operation to emergency releases and scheduled maintenance. Captured flare gas can then be reused as valuable fuel or feedstock.

Flare Gas Recovery systems perform the following processes:

- Isolating the flare header with a proprietary-design liquid seal or staging valve.
- Recovering the normally flared gases.
- Removing liquids.
- Compressing gases up to a defined pressure level.
- Cooling recovered gases (if required).
- Delivering the recovered gases into the facility, so they can be processed and re-used as fuel gas.

Typical flare gas recovery unit are sized for the following conditions:

- Flowrate Ranges: 0 to 11,100 $m^3/h$ (0 to 10 MMSCFD).
- Pressure Ranges: 240 to 2070 kPa (35 to 300 psig)

Flare gas recovery systems may be used to recovery either continuous waste gas flows or residual flows to a flare or vent system and either put the recovery gas back into the facility inlet or, if the gas is sweet, put it into the fuel gas system. During a flaring event, the portion of the gas flow that is in excess of the capacity of the flare/vent gas recovery unit simply continues on to the flare/vent outlet. Given the challenge in trying to manage leakage into flare and vent headers and avoid facility shutdowns to repair such leaks, the economics for a flare gas recovery system can often be very attractive, especially at larger facilities.

### E.4.6 Recovery of Condensable Hydrocarbons from Flare Gas

When a condensation approach is adopted to recover heavy hydrocarbon components, there are three different design technologies that may be considered: refrigeration, refrigerated lean oil absorption and Joule-Thomson expansion cooling.

Flare gas streams may contain both high-molecular-weight hydrocarbons, primarily propane, butane, pentane and heptane, as well as lighter components, methane and ethane. At petroleum refineries, the gas may also contain appreciable amounts of valuable hydrogen. When effectively processed, the higher-molecular-weight components of the flare gas can be separated from the lighter components to produce two valuable commodities: a hydrocarbon liquid product (composed of condensed natural gas liquids (NGL) and liquefied petroleum gas (LPG)) and a high-quality compressed residue gas available for conservation or use as fuel.

At production facilities, the producer can truck the recovered hydrocarbon liquids can be transported to marked by truck as a high vapour pressure product, dissolved in weathered crude oil and shipped by tank truck, or be injected into the crude oil pipeline (if one exists), which reduces evaporation losses, decreases the oil viscosity and thereby the specific pipeline energy requirements. The latter approach avoids the need for any onsite pressurized storage facilities for the produced hydrocarbon liquids. When processed downstream, the crude oil enriched with the condensate yields higher fractions of saleable liquid products such as ethane, propane, butane, isobutene and natural gasoline. In either case, these liquid fractions have a variety of different uses in the marketplace including enhancing oil recovery in oil wells, feedstock for oil refineries and petrochemical plants, and as sources of energy.

## E.5 References


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## E.6 Results

The detailed flare analysis results are presented below:

# Flare Index

| Facility Name | Device Category | Tag Number | Name | Device Type | Service |
|---|---|---|---|---|---|
| Barancabermeja Refinery | Flares | TEA-1 | Flare TEA-1 | Flare Stack (Unassisted) | Emergency or Intermittent Waste Gas Disposal |
| Barancabermeja Refinery | Flares | TEA-2 | Flare TEA-2 | Flare Stack (Steam Assist) | Emergency or Intermittent Waste Gas Disposal |
| Barancabermeja Refinery | Flares | TEA-3 | Flare TEA-3 | Flare Stack (Steam Assist) | Emergency or Intermittent Waste Gas Disposal |
| Barancabermeja Refinery | Flares | TEA-4 | Flare TEA-4 | Flare Stack (Steam Assist) | Emergency or Intermittent Waste Gas Disposal |
| Barancabermeja Refinery | Flares | TEA-6 | Flare TEA-6 | Flare Stack (Steam Assist) | Emergency or Intermittent Waste Gas Disposal |
| Barancabermeja Refinery | Flares | TEA-7 | Flare TEA-7 | Flare Stack (Steam Assist) | Emergency or Intermittent Waste Gas Disposal |

# Point Source Information

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Device | |
|---|---|
| **Name** | Flare TEA-1 |
| **ID** | TEA-1 |
| **On Site Location** | Barrancabermeja |
| **Category** | Flares |
| **Type** | Stack (Unassisted) |
| **Service** | |
| **Manufacturer** | |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |
| | N/A |

| Data Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Mojgan Karimi |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 2013/09/08 |

| Device Comments and Assumptions |
|---|
| Flare Stack |

| General Simulation Data | |
|---|---|
| **Operating Factor (%)**[1] | 100.00 |
| **Load Factor (%)**[1] | 100.00 |
| **Flow Adjustment ($m^3$/h)**[1] | 0.00 |
| **Adjustment Comment** | no adjustment required |
| **Activity Level**[2] | 1.0 |
| **Extrapolated Activity Level**[2] | 0.0 |
| **Ambient Temperature ($^oC$)** | 30.0 |
| **Ambient Pressure (kPa)** | 95.9 |

[1] Operating and Load Factors are multiplicative adjustments to the measured/reported flow rate applied during simulation, with 100% being no adjustment. Flow Adjustment is additional flow at standard conditions applied after all other corrections and adjustments.

[2] Activity Level and Extrapolated Activity Level are used when extrapolating from this Emission Point Source. The Unit(s)/Source(s) not tested are assumed to have losses and emissions of Extrapolated Activity Level/Activity Level times this Source.

| Data Comments and Assumptions |
|---|
| N/A |

| Applied Emission Factors | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor (ng/J)** | 18.21 | User Entered |
| **$N_2O$ Emission Factor (ng/J)** | 0.10 | US EPA AP-42 |
| **VOC Emission Factor (ng/J)** | 22.30 | US EPA AP-42 |
| **CO Emission Factor (ng/J)** | 159.10 | US EPA AP-42 |
| **PM Emission Factor (ng/J)** | 57.00 | US EPA AP-42 |
| **$NO_x$ Emission Factor (ng/J)** | 29.20 | US EPA AP-42 |
| **HC Destruction Efficiency (%)** | 98.00 | US EPA AP-42 |

# Simulation Input Stream

| Input Stream | |
|---|---|
| **Temperature ($^{o}C$)** | 30 |
| **Pressure (kPa gage)** | 95.9 |
| **Line Name** | N/A |
| **Cross Sectional Shape** | Circular |
| **Pipe Outside Diameter (mm)** | N/A |
| **Pipe Wall Thickness (mm)** | N/A |
| **Pipe Rectangular Length (mm)** | N/A |
| **Pipe Rectangular Width (mm)** | N/A |
| **Measurement Type** | Reported Flare Volumes |
| **Reading Type** | Flow Rate (Standard Conditions) |
| **Measurement Date** | N/A |
| **Velocity (m/s)** | --- |
| **Flow Rate ($m^3/h$)** | --- |
| **Standard Flow Rate ($m^3/h$)** | 17.7 |
| **Composition Name** | TEA-1 |
| **Composition ID** | 39 |

# Input Stream Composition Source Data

| Anaylsis Adminstration Data | |
|---|---|
| **Name** | TEA-1 |
| **Description** | gas to flare 1 From Ecopetrol\2012 - NAMA Development\2013 - Refinery Audit |
| **Creation Date** | 3/28/2013 |
| **Sample Date** | N/A |
| **Sample Type** | As Sampled |
| **Substance Type** | Waste Gas |
| **Clearstone ID** | 39 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| 1-3-Butadiene | 0.000502 | 0.000502 | 0.000507 |
| 1-Butene | 0.139358 | 0.139358 | 0.140776 |
| 1-Pentene | 0.001710 | 0.001710 | 0.001727 |
| 2-Butene-cis | 0.028854 | 0.028854 | 0.029148 |
| 2-Methyl-1-butene | 0.007191 | 0.007191 | 0.007264 |
| 2-Methyl-2-butene | 0.004171 | 0.004171 | 0.004213 |
| 2-Pentene-cis | 0.002440 | 0.002440 | 0.002465 |
| 2-Pentene-trans | 0.004151 | 0.004151 | 0.004193 |
| 3-Methyl-1-butene | 0.000940 | 0.000940 | 0.000950 |
| Carbon dioxide | 0.003410 | 0.003410 | 0.003445 |
| Carbon monoxide | 0.000920 | 0.000920 | 0.000929 |
| Ethane | 0.030024 | 0.030024 | 0.030329 |
| Ethylene | 0.018402 | 0.018402 | 0.018589 |
| Hydrogen (normal) | 0.045076 | 0.045076 | 0.045535 |
| Hydrogen sulfide | 0.000600 | 0.000600 | 0.000606 |
| Isobutane | 0.148529 | 0.148529 | 0.150040 |
| Isopentane | 0.040735 | 0.040735 | 0.041149 |
| Methane | 0.043696 | 0.043696 | 0.044141 |
| n-Butane | 0.107344 | 0.107344 | 0.108436 |
| n-Hexane | 0.035655 | 0.035655 | 0.036018 |
| Nitrogen | 0.010311 | 0.010311 | 0.002395 |
| n-Pentane | 0.017372 | 0.017372 | 0.017549 |
| Oxygen | 0.002130 | 0.002130 | 0.000000 |
| Propane | 0.126276 | 0.126276 | 0.127561 |

| | | | | |
|---|---|---|---|---|
| Propylene | | 0.180203 | 0.180203 | 0.182036 |
| **Total** | | 1.000000 | 1.000000 | 1.000000 |

## Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Flare Valve Management | Ongoing valve managment. | 70.00 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Flare Valve Management | Ongoing valve managment. | 0 | 36,000 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Flare Valve Management | Ongoing valve managment. | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

## Simulation Results

| Source Name | Source Tag No. | Service Type | Value of Fuel/Loss Stream (USD/y) | Total Product Loss Flow ($m^3/h$) | Total Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3 m^3/d$) | Ethane ($m^3$/d liq) | LPG ($m^3$/d liq) | NGL ($m^3/d$) | Hydrogen ($m^3/d$) |
| Flare TEA-1 | TEA-1 | Emergency or Intermittent Waste Gas Disposal | 167,445 | 17.7 | 0.02 | 0.07 | 1.23 | 0.25 | 19.38 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| 0.1 | 984 | 0.00 | 987 | 0.4 | 2.5 | 0.5 | 0.3 | 0.9 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Flare Valve Management | 70.00 | 17,500 | 0 | 36,000 | 117,211 | 580,684 | 464.06 | 0.22 |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| Flare Valve Management | 0.07 | 689 | 0.00 | 691 | 0.25 | 1.78 | 0.33 | 0.18 | 0.64 |

# Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Flare Valve Management | Ongoing valve managment. |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Engineering and Drafting | Other Engineering Cost | Software | 50,000.00 | 1.0 | 50,000 |
| | Process | Process Development | 1.00 | 25,000.0 | 25,000 |
| Material | Instruments | VPAC unit (per site) | 30,000.00 | 1.0 | 30,000 |

| | |
|---|---|
| **Total** | 105,000 |

# Point Source Information

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Device | |
|---|---|
| **Name** | Flare TEA-2 |
| **ID** | TEA-2 |
| **On Site Location** | Barrancabermeja |
| **Category** | Flares |
| **Type** | Stack (Assisted) |
| **Service** | |
| **Manufacturer** | |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |
| | N/A |

| Data Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Mojgan Karimi |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 2013/09/08 |

| Device Comments and Assumptions |
|---|
| Flare Stack |

| General Simulation Data | |
|---|---|
| **Operating Factor (%)**[1] | 100.00 |
| **Load Factor (%)**[1] | 100.00 |
| **Flow Adjustment ($m^3$/h)**[1] | 0.00 |
| **Adjustment Comment** | not required |
| **Activity Level**[2] | 1.0 |
| **Extrapolated Activity Level**[2] | 0.0 |
| **Ambient Temperature ($^{o}$C)** | 30.0 |
| **Ambient Pressure (kPa)** | 95.9 |

[1] Operating and Load Factors are multiplicative adjustments to the measured/reported flow rate applied during simulation, with 100% being no adjustment. Flow Adjustment is additional flow at standard conditions applied after all other corrections and adjustments.

[2] Activity Level and Extrapolated Activity Level are used when extrapolating from this Emission Point Source. The Unit(s)/Source(s) not tested are assumed to have losses and emissions of Extrapolated Activity Level/Activity Level times this Source.

| Data Comments and Assumptions |
|---|
| N/A |

| Applied Emission Factors | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor (ng/J)** | 65.36 | User Entered |
| **$N_2O$ Emission Factor (ng/J)** | 0.10 | US EPA AP-42 |
| **VOC Emission Factor (ng/J)** | 22.30 | US EPA AP-42 |
| **CO Emission Factor (ng/J)** | 159.10 | US EPA AP-42 |
| **PM Emission Factor (ng/J)** | 57.00 | US EPA AP-42 |
| **$NO_x$ Emission Factor (ng/J)** | 29.20 | US EPA AP-42 |
| **HC Destruction Efficiency (%)** | 99.50 | US EPA AP-42 |

## Simulation Input Stream

| Input Stream | |
|---|---|
| **Temperature ($^oC$)** | 30 |
| **Pressure (kPa gage)** | 95.9 |
| **Line Name** | N/A |
| **Cross Sectional Shape** | Circular |
| **Pipe Outside Diameter (mm)** | N/A |
| **Pipe Wall Thickness (mm)** | N/A |
| **Pipe Rectangular Length (mm)** | N/A |
| **Pipe Rectangular Width (mm)** | N/A |
| **Measurement Type** | Reported Flare Volumes |
| **Reading Type** | Flow Rate (Standard Conditions) |
| **Measurement Date** | N/A |
| **Velocity (m/s)** | --- |
| **Flow Rate ($m^3/h$)** | --- |
| **Standard Flow Rate ($m^3/h$)** | 55.5 |
| **Composition Name** | TEA-2 |
| **Composition ID** | 40 |

# Input Stream Composition Source Data

| Anaylsis Adminstration Data | |
|---|---|
| **Name** | TEA-2 |
| **Description** | gas to flare2. From Ecopetrol\2012 - NAMA Development\2013 - Refinery Audit |
| **Creation Date** | 3/28/2013 |
| **Sample Date** | N/A |
| **Sample Type** | As Sampled |
| **Substance Type** | Waste Gas |
| **Clearstone ID** | 40 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| 1-3-Butadiene | 0.000812 | 0.000812 | 0.000823 |
| 1-Butene | 0.077239 | 0.077239 | 0.078257 |
| 1-Pentene | 0.003562 | 0.003562 | 0.003609 |
| 2-Butene-cis | 0.018892 | 0.018892 | 0.019141 |
| 2-Methyl-1-butene | 0.009996 | 0.009996 | 0.010128 |
| 2-Methyl-2-butene | 0.006834 | 0.006834 | 0.006924 |
| 2-Pentene-cis | 0.004143 | 0.004143 | 0.004198 |
| 2-Pentene-trans | 0.006974 | 0.006974 | 0.007066 |
| 3-Methyl-1-butene | 0.001911 | 0.001911 | 0.001936 |
| Carbon dioxide | 0.007785 | 0.007785 | 0.007888 |
| Carbon monoxide | 0.004683 | 0.004683 | 0.004745 |
| Ethane | 0.052073 | 0.052073 | 0.052760 |
| Ethylene | 0.044358 | 0.044358 | 0.044943 |
| Hydrogen (normal) | 0.155910 | 0.155910 | 0.157965 |
| Isobutane | 0.042937 | 0.042937 | 0.043503 |
| Isopentane | 0.029309 | 0.029309 | 0.029695 |
| Methane | 0.134236 | 0.134236 | 0.136006 |
| n-Butane | 0.036323 | 0.036323 | 0.036802 |
| n-Hexane | 0.039996 | 0.039996 | 0.040523 |
| Nitrogen | 0.153818 | 0.153818 | 0.145452 |
| n-Pentane | 0.011687 | 0.011687 | 0.011841 |
| Oxygen | 0.002752 | 0.002752 | 0.000000 |
| Propane | 0.052654 | 0.052654 | 0.053348 |
| Propylene | 0.101115 | 0.101115 | 0.102448 |

| | | | |
|---|---|---|---|
| **Total** | 0.999999 | 1.000000 | 1.000000 |

## Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Flare Valve Management | Ongoing valve managment. | 70.00 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Flare Valve Management | Ongoing valve managment. | 0 | 36,000 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Flare Valve Management | Ongoing valve managment. | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

## Simulation Results

| Source Name | Source Tag No. | Service Type | Value of Fuel/Loss Stream (USD/y) | Total Product Loss Flow ($m^3/h$) | Total Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3 m^3/d$) | Ethane ($m^3/d$ liq) | LPG ($m^3/d$ liq) | NGL ($m^3/d$) | Hydrogen ($m^3/d$) |
| Flare TEA-2 | TEA-2 | Emergency or Intermittent Waste Gas Disposal | 349,338 | 55.5 | 0.18 | 0.45 | 1.72 | 0.78 | 210.25 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| 0.2 | 1,940 | 0.00 | 1,946 | 0.7 | 5.2 | 0.9 | 0.0 | 1.9 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Flare Valve Management | 70.00 | 17,500 | 0 | 36,000 | 244,537 | 1,518,533 | 1191.64 | 0.08 |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| Flare Valve Management | 0.16 | 1,358 | 0.00 | 1,362 | 0.51 | 3.62 | 0.66 | 0.00 | 1.30 |

# Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Flare Valve Management | Ongoing valve managment. |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Engineering and Drafting | Other Engineering Cost | Software | 50,000.00 | 1.0 | 50,000 |
| | Process | Process Development | 1.00 | 25,000.0 | 25,000 |
| Material | Instruments | VPAC unit (per site) | 30,000.00 | 1.0 | 30,000 |

| | |
|---|---|
| **Total** | 105,000 |

# Point Source Information

CLEARSTONE ENGINEERING

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Device | |
|---|---|
| **Name** | Flare TEA-3 |
| **ID** | TEA-3 |
| **On Site Location** | Barrancabermeja |
| **Category** | Flares |
| **Type** | Stack (Assisted) |
| **Service** | |
| **Manufacturer** | |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |
| | N/A |

| Data Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Mojgan Karimi |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 2013/09/08 |

| Device Comments and Assumptions |
|---|
| Flare Stack |

| General Simulation Data | |
|---|---|
| **Operating Factor (%)**[1] | 100.00 |
| **Load Factor (%)**[1] | 100.00 |
| **Flow Adjustment ($m^3$/h)**[1] | 0.00 |
| **Adjustment Comment** | not required |
| **Activity Level**[2] | 1.0 |
| **Extrapolated Activity Level**[2] | 0.0 |
| **Ambient Temperature ($^o$C)** | 30.0 |
| **Ambient Pressure (kPa)** | 95.8 |

[1] Operating and Load Factors are multiplicative adjustments to the measured/reported flow rate applied during simulation, with 100% being no adjustment. Flow Adjustment is additional flow at standard conditions applied after all other corrections and adjustments.

[2] Activity Level and Extrapolated Activity Level are used when extrapolating from this Emission Point Source. The Unit(s)/Source(s) not tested are assumed to have losses and emissions of Extrapolated Activity Level/Activity Level times this Source.

| Data Comments and Assumptions |
|---|
| N/A |

| Applied Emission Factors | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor (ng/J)** | 100.92 | User Entered |
| **$N_2O$ Emission Factor (ng/J)** | 0.10 | US EPA AP-42 |
| **VOC Emission Factor (ng/J)** | 22.30 | US EPA AP-42 |
| **CO Emission Factor (ng/J)** | 159.10 | US EPA AP-42 |
| **PM Emission Factor (ng/J)** | 57.00 | US EPA AP-42 |
| **$NO_x$ Emission Factor (ng/J)** | 29.20 | US EPA AP-42 |
| **HC Destruction Efficiency (%)** | 99.50 | US EPA AP-42 |

## Simulation Input Stream

| Input Stream | |
|---|---|
| **Temperature ($^oC$)** | 30 |
| **Pressure (kPa gage)** | 95.8 |
| **Line Name** | N/A |
| **Cross Sectional Shape** | Circular |
| **Pipe Outside Diameter (mm)** | N/A |
| **Pipe Wall Thickness (mm)** | N/A |
| **Pipe Rectangular Length (mm)** | N/A |
| **Pipe Rectangular Width (mm)** | N/A |
| **Measurement Type** | Reported Flare Volumes |
| **Reading Type** | Flow Rate (Standard Conditions) |
| **Measurement Date** | N/A |
| **Velocity (m/s)** | --- |
| **Flow Rate ($m^3$/h)** | --- |
| **Standard Flow Rate ($m^3$/h)** | 31.0 |
| **Composition Name** | TEA-3 |
| **Composition ID** | 41 |

# Input Stream Composition Source Data

| Anaylsis Adminstration Data | |
|---|---|
| **Name** | TEA-3 |
| **Description** | gas to flare 3. From Ecopetrol\2012 - NAMA Development\2013 - Refinery Audit |
| **Creation Date** | 3/28/2013 |
| **Sample Date** | N/A |
| **Sample Type** | As Sampled |
| **Substance Type** | Waste Gas |
| **Clearstone ID** | 41 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| 1-Butene | 0.001052 | 0.001052 | 0.001482 |
| Carbon dioxide | 0.000750 | 0.000750 | 0.001057 |
| Ethane | 0.140958 | 0.140958 | 0.198617 |
| Hydrogen (normal) | 0.258212 | 0.258212 | 0.363833 |
| Isobutane | 0.009422 | 0.009422 | 0.013276 |
| Isopentane | 0.001550 | 0.001550 | 0.002184 |
| Methane | 0.157351 | 0.157351 | 0.221715 |
| n-Butane | 0.006001 | 0.006001 | 0.008456 |
| n-Hexane | 0.011812 | 0.011812 | 0.016644 |
| Nitrogen | 0.279416 | 0.279416 | 0.071181 |
| n-Pentane | 0.001990 | 0.001990 | 0.002804 |
| Oxygen | 0.061402 | 0.061402 | 0.000000 |
| Propane | 0.070084 | 0.070084 | 0.098752 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

## Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Flare Valve Management | Ongoing valve managment. | 70.00 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Flare Valve Management | Ongoing valve managment. | 0 | 36,000 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Flare Valve Management | Ongoing valve managment. | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

## Simulation Results

| Source Name | Source Tag No. | Service Type | Value of Fuel/Loss Stream (USD/y) | Total Product Loss Flow ($m^3/h$) | Total Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3 m^3/d$) | Ethane ($m^3$/d liq) | LPG ($m^3$/d liq) | NGL ($m^3/d$) | Hydrogen ($m^3/d$) |
| Flare TEA-3 | TEA-3 | Emergency or Intermittent Waste Gas Disposal | 82,918 | 31.0 | 0.16 | 0.52 | 0.34 | 0.09 | 270.39 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| 0.2 | 572 | 0.00 | 577 | 0.3 | 1.8 | 0.3 | 0.0 | 0.6 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Flare Valve Management | 70.00 | 17,500 | 0 | 36,000 | 58,043 | 144,863 | 125.96 | 0.79 |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| Flare Valve Management | 0.14 | 401 | 0.00 | 404 | 0.18 | 1.27 | 0.23 | 0.00 | 0.45 |

# Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Flare Valve Management | Ongoing valve managment. |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Engineering and Drafting | Other Engineering Cost | Software | 50,000.00 | 1.0 | 50,000 |
| | Process | Process Development | 1.00 | 25,000.0 | 25,000 |
| Material | Instruments | VPAC unit (per site) | 30,000.00 | 1.0 | 30,000 |
| | | | | **Total** | 105,000 |

# Point Source Information

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Device | |
|---|---|
| **Name** | Flare TEA-4 |
| **ID** | TEA-4 |
| **On Site Location** | Barrancabermeja |
| **Category** | Flares |
| **Type** | Stack (Assisted) |
| **Service** | |
| **Manufacturer** | |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |

N/A

| Data Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Mojgan Karimi |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 2013/09/08 |

| Device Comments and Assumptions |
|---|
| Flare Stack |

| General Simulation Data | |
|---|---|
| **Operating Factor (%)**[1] | 100.00 |
| **Load Factor (%)**[1] | 100.00 |
| **Flow Adjustment ($m^3$/h)**[1] | 0.00 |
| **Adjustment Comment** | not required |
| **Activity Level**[2] | 1.0 |
| **Extrapolated Activity Level**[2] | 0.0 |
| **Ambient Temperature ($^{o}$C)** | 30.0 |
| **Ambient Pressure (kPa)** | 95.8 |

[1] Operating and Load Factors are multiplicative adjustments to the measured/reported flow rate applied during simulation, with 100% being no adjustment. Flow Adjustment is additional flow at standard conditions applied after all other corrections and adjustments.

[2] Activity Level and Extrapolated Activity Level are used when extrapolating from this Emission Point Source. The Unit(s)/Source(s) not tested are assumed to have losses and emissions of Extrapolated Activity Level/Activity Level times this Source.

| Data Comments and Assumptions |
|---|
| N/A |

| Applied Emission Factors | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor (ng/J)** | 6.96 | User Entered |
| **$N_2O$ Emission Factor (ng/J)** | 0.10 | US EPA AP-42 |
| **VOC Emission Factor (ng/J)** | 22.30 | US EPA AP-42 |
| **CO Emission Factor (ng/J)** | 159.10 | US EPA AP-42 |
| **PM Emission Factor (ng/J)** | 57.00 | US EPA AP-42 |
| **$NO_x$ Emission Factor (ng/J)** | 29.20 | US EPA AP-42 |
| **HC Destruction Efficiency (%)** | 99.50 | US EPA AP-42 |

## Simulation Input Stream

| Input Stream | |
|---|---|
| **Temperature ($^oC$)** | 30 |
| **Pressure (kPa gage)** | 95.8 |
| **Line Name** | N/A |
| **Cross Sectional Shape** | Circular |
| **Pipe Outside Diameter (mm)** | N/A |
| **Pipe Wall Thickness (mm)** | N/A |
| **Pipe Rectangular Length (mm)** | N/A |
| **Pipe Rectangular Width (mm)** | N/A |
| **Measurement Type** | Reported Flare Volumes |
| **Reading Type** | Flow Rate (Standard Conditions) |
| **Measurement Date** | N/A |
| **Velocity (m/s)** | --- |
| **Flow Rate ($m^3$/h)** | --- |
| **Standard Flow Rate ($m^3$/h)** | 40.7 |
| **Composition Name** | TEA-4 |
| **Composition ID** | 42 |

# Input Stream Composition Source Data

| Anaylsis Adminstration Data | |
|---|---|
| **Name** | TEA-4 |
| **Description** | Gas to flare 4. From Ecopetrol\2012 - NAMA Development\2013 - Refinery Audit |
| **Creation Date** | 3/28/2013 |
| **Sample Date** | N/A |
| **Sample Type** | As Sampled |
| **Substance Type** | Waste Gas |
| **Clearstone ID** | 42 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Ethane | 0.637298 | 0.637298 | 0.661836 |
| Ethylene | 0.273594 | 0.273594 | 0.284128 |
| Hydrogen (normal) | 0.026151 | 0.026151 | 0.027158 |
| Methane | 0.017277 | 0.017277 | 0.017942 |
| Nitrogen | 0.034754 | 0.034754 | 0.005733 |
| Oxygen | 0.007842 | 0.007842 | 0.000000 |
| Propane | 0.000811 | 0.000811 | 0.000842 |
| Propylene | 0.002273 | 0.002273 | 0.002361 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

## Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Flare Valve Management | Ongoing valve managment. | 70.00 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Flare Valve Management | Ongoing valve managment. | 0 | 36,000 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Flare Valve Management | Ongoing valve managment. | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

## Simulation Results

| Source Name | Source Tag No. | Service Type | Value of Fuel/Loss Stream (USD/y) | Total Product Loss Flow ($m^3/h$) | Total Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3 m^3/d$) | Ethane ($m^3$/d liq) | LPG ($m^3$/d liq) | NGL ($m^3/d$) | Hydrogen ($m^3/d$) |
| Flare TEA-4 | TEA-4 | Emergency or Intermittent Waste Gas Disposal | 97,740 | 40.7 | 0.02 | 3.21 | 0.01 | 0.00 | 26.51 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| 0.0 | 1,273 | 0.00 | 1,274 | 0.5 | 3.5 | 0.6 | 0.0 | 1.3 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Flare Valve Management | 70.00 | 17,500 | 0 | 36,000 | 68,418 | 221,285 | 185.25 | 0.54 |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| Flare Valve Management | 0.02 | 891 | 0.00 | 892 | 0.35 | 2.47 | 0.45 | 0.00 | 0.89 |

## Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Flare Valve Management | Ongoing valve managment. |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Engineering and Drafting | Other Engineering Cost | Software | 50,000.00 | 1.0 | 50,000 |
| | Process | Process Development | 1.00 | 25,000.0 | 25,000 |
| Material | Instruments | VPAC unit (per site) | 30,000.00 | 1.0 | 30,000 |

| | |
|---|---|
| **Total** | 105,000 |

# Point Source Information

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Device | |
|---|---|
| **Name** | Flare TEA-6 |
| **ID** | TEA-6 |
| **On Site Location** | Barrancabermeja |
| **Category** | Flares |
| **Type** | Stack (Assisted) |
| **Service** | |
| **Manufacturer** | |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |

N/A

| Data Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Mojgan Karimi |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 2013/09/08 |

| Device Comments and Assumptions |
|---|
| Flare Stack |

| General Simulation Data | |
|---|---|
| **Operating Factor (%)**[1] | 100.00 |
| **Load Factor (%)**[1] | 100.00 |
| **Flow Adjustment ($m^3$/h)**[1] | 0.00 |
| **Adjustment Comment** | not required |
| **Activity Level**[2] | 1.0 |
| **Extrapolated Activity Level**[2] | 0.0 |
| **Ambient Temperature ($^o$C)** | 30.0 |
| **Ambient Pressure (kPa)** | 95.8 |

[1] Operating and Load Factors are multiplicative adjustments to the measured/reported flow rate applied during simulation, with 100% being no adjustment. Flow Adjustment is additional flow at standard conditions applied after all other corrections and adjustments.

[2] Activity Level and Extrapolated Activity Level are used when extrapolating from this Emission Point Source. The Unit(s)/Source(s) not tested are assumed to have losses and emissions of Extrapolated Activity Level/Activity Level times this Source.

| Data Comments and Assumptions |
|---|
| N/A |

| Applied Emission Factors | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor (ng/J)** | 146.82 | User Entered |
| **$N_2O$ Emission Factor (ng/J)** | 0.10 | US EPA AP-42 |
| **VOC Emission Factor (ng/J)** | 22.30 | US EPA AP-42 |
| **CO Emission Factor (ng/J)** | 159.10 | US EPA AP-42 |
| **PM Emission Factor (ng/J)** | 57.00 | US EPA AP-42 |
| **$NO_x$ Emission Factor (ng/J)** | 29.20 | US EPA AP-42 |
| **HC Destruction Efficiency (%)** | 99.50 | US EPA AP-42 |

## Simulation Input Stream

| Input Stream | |
|---|---|
| **Temperature ($^oC$)** | 30 |
| **Pressure (kPa gage)** | 95.8 |
| **Line Name** | N/A |
| **Cross Sectional Shape** | Circular |
| **Pipe Outside Diameter (mm)** | N/A |
| **Pipe Wall Thickness (mm)** | N/A |
| **Pipe Rectangular Length (mm)** | N/A |
| **Pipe Rectangular Width (mm)** | N/A |
| **Measurement Type** | Reported Flare Volumes |
| **Reading Type** | Flow Rate (Standard Conditions) |
| **Measurement Date** | N/A |
| **Velocity (m/s)** | --- |
| **Flow Rate ($m^3$/h)** | --- |
| **Standard Flow Rate ($m^3$/h)** | 64.0 |
| **Composition Name** | TEA-6 |
| **Composition ID** | 43 |

# Input Stream Composition Source Data

| Anaylsis Adminstration Data | |
|---|---|
| **Name** | TEA-6 |
| **Description** | gas to flare 6. From Ecopetrol\2012 - NAMA Development\2013 - Refinery Audit |
| **Creation Date** | 3/28/2013 |
| **Sample Date** | N/A |
| **Sample Type** | As Sampled |
| **Substance Type** | Waste Gas |
| **Clearstone ID** | 43 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| 1-Butene | 0.012178 | 0.012178 | 0.012715 |
| 2-Butene-cis | 0.001342 | 0.001342 | 0.001401 |
| Carbon dioxide | 0.001492 | 0.001492 | 0.001558 |
| Carbon monoxide | 0.002524 | 0.002524 | 0.002635 |
| Ethane | 0.071067 | 0.071067 | 0.074201 |
| Ethylene | 0.074902 | 0.074902 | 0.078205 |
| Hydrogen (normal) | 0.205669 | 0.205669 | 0.214738 |
| Isobutane | 0.013341 | 0.013341 | 0.013929 |
| Isopentane | 0.002213 | 0.002213 | 0.002311 |
| Methane | 0.354151 | 0.354151 | 0.369768 |
| n-Butane | 0.022063 | 0.022063 | 0.023036 |
| n-Hexane | 0.001552 | 0.001552 | 0.001620 |
| Nitrogen | 0.061723 | 0.061723 | 0.029675 |
| n-Pentane | 0.000591 | 0.000591 | 0.000617 |
| Oxygen | 0.008933 | 0.008933 | 0.000000 |
| Propane | 0.037997 | 0.037997 | 0.039673 |
| Propylene | 0.128262 | 0.128262 | 0.133918 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

## Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Flare Valve Management | Ongoing valve managment. | 70.00 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Flare Valve Management | Ongoing valve managment. | 0 | 36,000 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Flare Valve Management | Ongoing valve managment. | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

## Simulation Results

| Source Name | Source Tag No. | Service Type | Value of Fuel/Loss Stream (USD/y) | Total Product Loss Flow ($m^3$/h) | Total Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3 m^3$/d) | Ethane ($m^3$/d liq) | LPG ($m^3$/d liq) | NGL ($m^3$/d) | Hydrogen ($m^3$/d) |
| Flare TEA-6 | TEA-6 | Emergency or Intermittent Waste Gas Disposal | 191,429 | 64.0 | 0.57 | 0.80 | 1.27 | 0.04 | 329.85 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| 0.7 | 1,490 | 0.00 | 1,506 | 0.6 | 4.3 | 0.8 | 0.0 | 1.6 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Flare Valve Management | 70.00 | 17,500 | 0 | 36,000 | 134,000 | 704,346 | 560.00 | 0.18 |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| Flare Valve Management | 0.49 | 1,043 | 0.00 | 1,054 | 0.43 | 3.04 | 0.56 | 0.00 | 1.09 |

## Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Flare Valve Management | Ongoing valve managment. |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Engineering and Drafting | Other Engineering Cost | Software | 50,000.00 | 1.0 | 50,000 |
| | Process | Process Development | 1.00 | 25,000.0 | 25,000 |
| Material | Instruments | VPAC unit (per site) | 30,000.00 | 1.0 | 30,000 |
| | | | | **Total** | 105,000 |

# Point Source Information

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Device | |
|---|---|
| **Name** | Flare TEA-7 |
| **ID** | TEA-7 |
| **On Site Location** | Barrancabermeja |
| **Category** | Flares |
| **Type** | Stack (Assisted) |
| **Service** | |
| **Manufacturer** | |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |
| | N/A |

| Data Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Mojgan Karimi |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 2013/09/08 |

| Device Comments and Assumptions |
|---|
| Flare Stack |

| General Simulation Data | |
|---|---|
| **Operating Factor (%)**[1] | 100.00 |
| **Load Factor (%)**[1] | 100.00 |
| **Flow Adjustment ($m^3$/h)**[1] | 0.00 |
| **Adjustment Comment** | not required |
| **Activity Level**[2] | 1.0 |
| **Extrapolated Activity Level**[2] | 0.0 |
| **Ambient Temperature ($^o$C)** | 30.0 |
| **Ambient Pressure (kPa)** | 95.8 |

[1] Operating and Load Factors are multiplicative adjustments to the measured/reported flow rate applied during simulation, with 100% being no adjustment. Flow Adjustment is additional flow at standard conditions applied after all other corrections and adjustments.

[2] Activity Level and Extrapolated Activity Level are used when extrapolating from this Emission Point Source. The Unit(s)/Source(s) not tested are assumed to have losses and emissions of Extrapolated Activity Level/Activity Level times this Source.

| Data Comments and Assumptions |
|---|
| N/A |

| Applied Emission Factors | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor (ng/J)** | 49.37 | User Entered |
| **$N_2O$ Emission Factor (ng/J)** | 0.10 | US EPA AP-42 |
| **VOC Emission Factor (ng/J)** | 22.30 | US EPA AP-42 |
| **CO Emission Factor (ng/J)** | 159.10 | US EPA AP-42 |
| **PM Emission Factor (ng/J)** | 57.00 | US EPA AP-42 |
| **$NO_x$ Emission Factor (ng/J)** | 29.20 | US EPA AP-42 |
| **HC Destruction Efficiency (%)** | 99.50 | US EPA AP-42 |

## Simulation Input Stream

| Input Stream | |
|---|---|
| **Temperature ($^oC$)** | 30 |
| **Pressure (kPa gage)** | 95.8 |
| **Line Name** | N/A |
| **Cross Sectional Shape** | Circular |
| **Pipe Outside Diameter (mm)** | N/A |
| **Pipe Wall Thickness (mm)** | N/A |
| **Pipe Rectangular Length (mm)** | N/A |
| **Pipe Rectangular Width (mm)** | N/A |
| **Measurement Type** | Reported Flare Volumes |
| **Reading Type** | Flow Rate (Standard Conditions) |
| **Measurement Date** | N/A |
| **Velocity (m/s)** | --- |
| **Flow Rate ($m^3$/h)** | --- |
| **Standard Flow Rate ($m^3$/h)** | 6.6 |
| **Composition Name** | TEA-7 |
| **Composition ID** | 44 |

# Input Stream Composition Source Data

| Anaylsis Adminstration Data | |
|---|---|
| **Name** | TEA-7 |
| **Description** | gas to flare 7. From Ecopetrol\2012 - NAMA Development\2013 - Refinery Audit |
| **Creation Date** | 3/28/2013 |
| **Sample Date** | N/A |
| **Sample Type** | As Sampled |
| **Substance Type** | Waste Gas |
| **Clearstone ID** | 44 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| 1-Butene | 0.009798 | 0.009798 | 0.009836 |
| 1-Pentene | 0.001141 | 0.001141 | 0.001145 |
| 2-Butene-cis | 0.002442 | 0.002442 | 0.002451 |
| 2-Methyl-1-butene | 0.003563 | 0.003563 | 0.003577 |
| 2-Methyl-2-butene | 0.002162 | 0.002162 | 0.002170 |
| 2-Pentene-cis | 0.001581 | 0.001581 | 0.001587 |
| 2-Pentene-trans | 0.002632 | 0.002632 | 0.002642 |
| Carbon dioxide | 0.005514 | 0.005514 | 0.005535 |
| Carbon monoxide | 0.005214 | 0.005214 | 0.005234 |
| Ethane | 0.058487 | 0.058487 | 0.058712 |
| Ethylene | 0.055185 | 0.055185 | 0.055397 |
| Hydrogen (normal) | 0.125271 | 0.125271 | 0.125753 |
| Hydrogen sulfide | 0.051822 | 0.051822 | 0.052021 |
| Isobutane | 0.185601 | 0.185601 | 0.186315 |
| Isopentane | 0.007326 | 0.007326 | 0.007354 |
| Methane | 0.116995 | 0.116995 | 0.117445 |
| n-Butane | 0.006025 | 0.006025 | 0.006048 |
| n-Hexane | 0.018855 | 0.018855 | 0.018928 |
| Nitrogen | 0.019306 | 0.019306 | 0.016345 |
| n-Pentane | 0.001401 | 0.001401 | 0.001406 |
| Oxygen | 0.000811 | 0.000811 | 0.000000 |
| Propane | 0.258209 | 0.258209 | 0.259203 |
| Propylene | 0.060659 | 0.060659 | 0.060892 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

## Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Flare Valve Management | Ongoing valve managment. | 70.00 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Flare Valve Management | Ongoing valve managment. | 0 | 36,000 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Flare Valve Management | Ongoing valve managment. | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

## Simulation Results

| Source Name | Source Tag No. | Service Type | Value of Fuel/Loss Stream (USD/y) | Total Product Loss Flow ($m^3/h$) | Total Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3 m^3/d$) | Ethane ($m^3$/d liq) | LPG ($m^3$/d liq) | NGL ($m^3/d$) | Hydrogen ($m^3/d$) |
| Flare TEA-7 | TEA-7 | Emergency or Intermittent Waste Gas Disposal | 39,651 | 6.6 | 0.02 | 0.06 | 0.32 | 0.03 | 20.04 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| 0.0 | 254 | 0.00 | 255 | 0.1 | 0.7 | 0.1 | 8.2 | 0.3 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Flare Valve Management | 70.00 | 17,500 | 0 | 36,000 | 27,756 | -78,227 | NA | NA |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| Flare Valve Management | 0.02 | 178 | 0.00 | 178 | 0.07 | 0.49 | 0.09 | 5.74 | 0.18 |

## Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Flare Valve Management | Ongoing valve managment. |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Engineering and Drafting | Other Engineering Cost | Software | 50,000.00 | 1.0 | 50,000 |
| | Process | Process Development | 1.00 | 25,000.0 | 25,000 |
| Material | Instruments | VPAC unit (per site) | 30,000.00 | 1.0 | 30,000 |
| | | | | **Total** | 105,000 |

## APPENDIX F WASTE HEAT RECOVERY

The section presents the detailed analysis results for the waste heat recovery opportunity considered in UOP 1.

# Steam Simulation Input

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Site Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Report Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Alfonso Garcia |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 8-Sep-2013 |

| General Simulation Data | |
|---|---|
| **Operating Factor (%)**[1] | 1.00 |
| **Flow Adjustment (std $m^3$/h)**[1] | 0 |
| **Adjustment Comment** | No comments |
| **Maximum Reduction Potential (%)** | 0.00 |
| **Activity Level**[2] | 1 |
| **Extrapolated Activity Level**[2] | 0 |
| **Inlet Temperature ($^oC$)** | 20 |
| **Ambient Temperature ($^oC$)** | 30 |
| **Ambient Pressure (kPa)** | 95.8 |

| Device | |
|---|---|
| **Name** | Flue Gas Economic Analysis |
| **ID** | UOP I |
| **On Site Location** | N/A |
| **Category** | Steam System |
| **Type** | Low-pressure Steam |
| **Manufacturer** | N/A |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |
| **Boiler Type** | Wall-fired (<=29 MW) Uncontrolled |
| **Generator Thermal Efficiency (%)** | 80 |
| **Service** | None |

| Applied Emission Factors (ng/J) | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor** | 1.00 | US EPA AP-42 |
| **$N_2O$ Emission Factor** | 0.90 | US EPA AP-42 |
| **VOC Emission Factor** | 2.30 | US EPA AP-42 |
| **CO Emission Factor** | 35.00 | US EPA AP-42 |
| **PM Emission Factor** | 0.80 | US EPA AP-42 |
| **$NO_x$ Emission Factor** | 42.00 | US EPA AP-42 |

| Device Description and Comments |
|---|
| Economic analysis of low pressure steam production. |

| Data Comments and Assumptions |
|---|
| N/A |

[1] Operating Factors is a multiplicative adjustment to the measured/reported flow rate applied during simulation, with 100% being no adjustment. Flow Adjustment is additional flow at standard conditions applied after all other corrections and adjustments.

[2] Activity Level and Extrapolated Activity Level are used when extrapolating from this steam system. The unit(s) not tested are assumed to have losses of Extrapolated Activity Level/Activity Level times this Source.

| Property | Steam Stream |
| --- | --- |
| **Temperature ($^oC$)** | 185.6 |
| **Pressure (kPa gage)** | 1,137.6 |
| **Line Name** | N/A |
| **Cross Sectional Shape** | Circular |
| **Pipe Outside Diameter (mm)** | N/A |
| **Pipe Wall Thickness (mm)** | N/A |
| **Pipe Rectangular Length (mm)** | N/A |
| **Pipe Rectangular Width (mm)** | N/A |
| **Measurement Type** | Reported Steam Flow Rate |
| **Reading Type** | Flow Rate (Actual Conditions) |
| **Measurement Date** | N/A |
| **Velocity (m/s)** | --- |
| **Flow Rate ($m^3$/h)** | 1,832.0 |
| **Standard Flow Rate (std $m^3$/h)** | --- |
| **Composition Name** | Vapor |
| **Composition ID** | 37 |

# Fuel Composition Source Data

| Anaylsis Adminstration Data | |
|---|---|
| **Name** | Gas de Campos |
| **Description** | Purchase Gas. "Gas de Campos" is "Field Gas" is Spanish. Automatically entered raw data. |
| **Creation Date** | 3/28/2013 |
| **Sample Date** | 2/6/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Field Gas |
| **Clearstone ID** | 47 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Ethane | 0.066727 | 0.066727 | 0.067874 |
| Isobutane | 0.000409 | 0.000409 | 0.000416 |
| Isopentane | 0.000194 | 0.000194 | 0.000198 |
| Methane | 0.901302 | 0.901302 | 0.916801 |
| n-Butane | 0.000713 | 0.000713 | 0.000725 |
| n-Heptane | 0.000564 | 0.000564 | 0.000573 |
| n-Hexane | 0.000229 | 0.000229 | 0.000233 |
| Nitrogen | 0.014936 | 0.014936 | 0.001634 |
| n-Pentane | 0.000254 | 0.000254 | 0.000259 |
| Oxygen | 0.003576 | 0.003576 | 0.000000 |
| Propane | 0.011096 | 0.011096 | 0.011287 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Waste Heat Recovery | Heat Exchanger | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Waste Heat Recovery | Heat Exchanger | 0 | 0 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Waste Heat Recovery | Heat Exchanger | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

## Simulation Results

| Source Tag No. | Value of Fuel Stream (USD/y) | Total Fuel Loss Flow ($m^3/h$) | Steam Energy Value (MJ/kg) | Steam Money Value (USD/kg) | Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3 m^3/d$) | Ethane ($m^3/d$ liq) | LPG ($m^3/d$ liq) | NGL ($m^3/d$) | Hydrogen ($m^3/d$) |
| UOP I | 1,551,914 | 955.3 | 2.70 | 0.02 | 21.0 | 5.5 | 1.1 | 0.2 | 0.0 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | $NO_x$ | $SO_2$ | PM |
| 0.3 | 17,112 | 0.3 | 17,215 | 0.8 | 11.9 | 14.3 | 0.0 | 0.3 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Waste Heat Recovery | 100.00 | 1,002,500 | 0 | 0 | 1,551,914 | 10,428,549 | 154.80 | 0.65 |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | $NO_x$ | $SO_2$ | PM |
| Waste Heat Recovery | 0.34 | 17,112 | 0.31 | 17,215 | 0.78 | 11.92 | 14.31 | 0.00 | 0.27 |

## Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Waste Heat Recovery | Heat Exchanger |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Construction | Crane Operation | Crane | 5,000.00 | 1.0 | 5,000 |
| | Electrical | Electrical Contractor (Day) | 1,600.00 | 10.0 | 16,000 |
| | Freight | | 15,000.00 | 1.0 | 15,000 |
| | Instrumentation | Instrumentation Contractor (Day) | 1,600.00 | 10.0 | 16,000 |
| | Labourers | Structural Labour | 50,000.00 | 1.0 | 50,000 |
| | Other Constuction Cost | 10% Contingency Fund | 84,200.00 | 1.0 | 84,200 |
| | | Mechanical Contractor (day) | 6,400.00 | 50.0 | 320,000 |
| Engineering and Drafting | Civil/Geotechnical | Civil Engineering | 30,000.00 | 1.0 | 30,000 |
| | Drafting | 5% Overhead | 42,100.00 | 1.0 | 42,100 |
| | Mechanical/Structural | Building | 10,000.00 | 1.0 | 10,000 |
| | Other Engineering Cost | 10% Overhead | 84,200.00 | 1.0 | 84,200 |
| Material | Instruments | Electrial | 20,000.00 | 1.0 | 20,000 |
| | | Instrumentation | 20,000.00 | 1.0 | 20,000 |
| | Miscellaneous Material Cost | Structural | 20,000.00 | 1.0 | 20,000 |
| | Other Material Cost | Condensing System | 50,000.00 | 1.0 | 50,000 |
| | | Insulation | 30,000.00 | 1.0 | 30,000 |
| | | Kettle type reboiler | 110,000.00 | 1.0 | 110,000 |
| | | Surge Drum | 20,000.00 | 1.0 | 20,000 |
| | Pipes and Fittings | Values and Piping. | 40,000.00 | 1.0 | 40,000 |
| | Pumps | | 10,000.00 | 2.0 | 20,000 |

| | |
|---|---|
| **Total** | 1,002,500 |

## APPENDIX G FUEL SYSTEM

This section presents the detailed information used to evaluate the benefits of recovering valuable non-methane commodities present in the refinery fuel and using purchased natural gas to replace the recovered commodities.

# Heater and Boiler Index

| Facility Name | Device Category | Tag Number | Name | Device Type | Service |
|---|---|---|---|---|---|
| Barancabermeja Refinery | Boilers and Heaters | D 968 | Distral Mix Drum | Wall-fired (>29 MW) Uncontrolled Pre-NSPS | Steam Generator |
| Barancabermeja Refinery | Boilers and Heaters | D-2421 | Central Norte Mix Drum | Wall-fired (>29 MW) Uncontrolled Pre-NSPS | Steam Generator |
| Barancabermeja Refinery | Boilers and Heaters | D-2953 | Balance Mix Drum | Wall-fired (>29 MW) Uncontrolled Pre-NSPS | Steam Generator |
| Barancabermeja Refinery | Boilers and Heaters | D-940 | Caldaers Nuevas Mix Drum | Wall-fired (>29 MW) Uncontrolled Pre-NSPS | Steam Generator |
| Barancabermeja Refinery | Boilers and Heaters | D-942 | Foster Mix Drum | Wall-fired (>29 MW) Uncontrolled Pre-NSPS | Steam Generator |

# Point Source Information

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Device | |
|---|---|
| **Name** | Distral Mix Drum |
| **ID** | D 968 |
| **On Site Location** | N/A |
| **Category** | Boilers and Heaters |
| **Type** | Wall-fired (>29 MW) Uncontrolled Pre-NSPS |
| **Service** | |
| **Manufacturer** | |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |

N/A

| Data Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Alfonso Garcia |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 2013/09/08 |

| Device Comments and Assumptions |
|---|
| Mix drum feeding fuel gas to the Distral Boilers. |

| General Simulation Data | |
|---|---|
| **Operating Factor (%)[1]** | 100.00 |
| **Load Factor (%)[1]** | 100.00 |
| **Flow Adjustment ($m^3$/h)[1]** | 0.00 |
| **Adjustment Comment** | None |
| **Activity Level[2]** | 1.0 |
| **Extrapolated Activity Level[2]** | 0.0 |
| **Ambient Temperature ($^oC$)** | 25.0 |
| **Ambient Pressure (kPa)** | 101.3 |

[1] Operating and Load Factors are multiplicative adjustments to the measured/reported flow rate applied during simulation, with 100% being no adjustment. Flow Adjustment is additional flow at standard conditions applied after all other corrections and adjustments.

[2] Activity Level and Extrapolated Activity Level are used when extrapolating from this Emission Point Source. The Unit(s)/Source(s) not tested are assumed to have losses and emissions of Extrapolated Activity Level/Activity Level times this Source.

| Data Comments and Assumptions |
|---|
| N/A |

| Applied Emission Factors | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor (ng/J)** | 1.00 | US EPA AP-42 |
| **$N_2O$ Emission Factor (ng/J)** | 0.90 | US EPA AP-42 |
| **VOC Emission Factor (ng/J)** | 2.30 | US EPA AP-42 |
| **CO Emission Factor (ng/J)** | 35.00 | US EPA AP-42 |
| **PM Emission Factor (ng/J)** | 0.80 | US EPA AP-42 |
| **$NO_x$ Emission Factor (ng/J)** | 118.00 | US EPA AP-42 |
| **HC Destruction Efficiency (%)** | N/A | |

## Simulation Input Stream

| Input Stream | |
|---|---|
| **Temperature ($^oC$)** | 15 |
| **Pressure (kPa gage)** | 101.325 |
| **Line Name** | N/A |
| **Cross Sectional Shape** | Circular |
| **Pipe Outside Diameter (mm)** | N/A |
| **Pipe Wall Thickness (mm)** | N/A |
| **Pipe Rectangular Length (mm)** | N/A |
| **Pipe Rectangular Width (mm)** | N/A |
| **Measurement Type** | Proration of Reported Fuel Consumption |
| **Reading Type** | Flow Rate (Standard Conditions) |
| **Measurement Date** | N/A |
| **Velocity (m/s)** | --- |
| **Flow Rate ($m^3$/h)** | --- |
| **Standard Flow Rate ($m^3$/h)** | 15,000.0 |
| **Composition Name** | D-958 |
| **Composition ID** | 29 |

# Input Stream Composition Source Data

| Anaylsis Adminstration Data | |
|---|---|
| **Name** | D-958 |
| **Description** | Distral boilers' feed stream composition. Equivalent to Mix Drum - Inlet and outlet D958 (Feb 01) |
| **Creation Date** | 2/25/2013 |
| **Sample Date** | 2/1/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 29 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.014950 | 0.014950 | 0.015243 |
| Ethane | 0.070990 | 0.070990 | 0.072383 |
| Hydrogen (normal) | 0.109650 | 0.109650 | 0.111801 |
| Isobutane | 0.003550 | 0.003550 | 0.003620 |
| Isopentane | 0.000930 | 0.000930 | 0.000948 |
| Methane | 0.684470 | 0.684470 | 0.697899 |
| n-Butane | 0.003100 | 0.003100 | 0.003161 |
| n-Heptane | 0.000700 | 0.000700 | 0.000714 |
| n-Hexane | 0.000440 | 0.000440 | 0.000449 |
| Nitrogen | 0.034770 | 0.034770 | 0.019982 |
| n-Pentane | 0.000565 | 0.000565 | 0.000576 |
| Oxygen | 0.004070 | 0.004070 | 0.000000 |
| Propane | 0.071815 | 0.071815 | 0.073224 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

## Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Switch Fuel Source | Switch To: Mix Drum - Inlet and outlet ... ID 153 | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | 0 | 0 | 0 | 0 |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | 0 | 0 | 0 | 0 |
| Switch Fuel Source | Switch To: Mix Drum - Inlet and outlet ... ID 153 | 0 | 0 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |
| Switch Fuel Source | Switch To: Mix Drum - Inlet and outlet ... ID 153 | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

## Control Technology Input Streams

| Technology type | Application Description | Use | Temperature (°C) | Pressure (kPa) | Line Name | Cross Sectional Shape |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | Fuel Stream | 15 | 101.325 | | Circular |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | Fuel Stream | 15 | 101.325 | | Circular |
| Switch Fuel Source | Switch To: Mix Drum - Inlet and outlet ... ID 153 | Fuel Stream | 15 | 101.325 | | Circular |

| Stream Pipe/Duct Cross-sectional Flow Area Dimension | | | | | | |
|---|---|---|---|---|---|---|
| **Technology type** | **Application Description** | **Use** | **Pipe Outside Diameter (mm)** | **Pipe Wall Thickness (mm)** | **Pipe Rectangular Length (mm)** | **Pipe Rectangular Width (mm)** |
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | Fuel Stream | | | | |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | Fuel Stream | | | | |
| Switch Fuel Source | Switch To: Mix Drum - Inlet and outlet ... ID 153 | Fuel Stream | | | | |

| Stream Flow Rate | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Technology type** | **Application Description** | **Use** | **Measurement Type** | **Reading Type** | **Measurement Date** | **Velocity (m/s)** | **Flow Rate ($m^3$/h)** | **Standard Flow Rate ($m^3$/h)** |
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | Fuel Stream | Mass and Energy Balance | Flow Rate (Standard Conditions) | | | | 16320.3668 |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | Fuel Stream | Mass and Energy Balance | Flow Rate (Standard Conditions) | | | | 15149.93984 |
| Switch Fuel Source | Switch To: Mix Drum - Inlet and outlet ... ID 153 | Fuel Stream | Mass and Energy Balance | Flow Rate (Standard Conditions) | | | | 16803.61725 |

| Stream Composition | | | | |
|---|---|---|---|---|
| **Technology type** | **Application Description** | **Use** | **Composition Name** | **Sample ID** |
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | Fuel Stream | Dry Natural Gas | 301 |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | Fuel Stream | Gas de Campos | 47 |
| Switch Fuel Source | Switch To: Mix Drum - Inlet and outlet ... ID 153 | Fuel Stream | Mix Drum - Inlet and outlet D958 (Feb 04) | 153 |

## Simulation Results

| Source Name | Source Tag No. | Service Type | Value of Fuel/Loss Stream (USD/y) | Total Product Loss Flow ($m^3/h$) | Total Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3m^3/d$) | Ethane ($m^3/d$ liq) | LPG ($m^3/d$ liq) | NGL ($m^3/d$) | Hydrogen ($m^3/d$) |
| Distral Mix Drum | D 968 | Steam Generator | 29,868,440 | 15,000.0 | 251.24 | 92.57 | 107.10 | 5.18 | 40,248.48 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| 5.4 | 273,926 | 4.85 | 275,543 | 12.4 | 188.7 | 636.2 | 0.0 | 4.3 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Switch Fuel Source | 100.00 | 0 | 0 | 0 | 2,318,228 | 17,075,547 | NA | 0.00 |
| Switch Fuel Source | 100.00 | 33,410,000 | 0 | 0 | 5,256,073 | 5,305,061 | 15.73 | 6.36 |
| Switch Fuel Source | 100.00 | 33,410,000 | 0 | 0 | 6,418,310 | 13,865,837 | 19.21 | 5.21 |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| Switch Fuel Source | -0.02 | 7,978 | -0.02 | 7,971 | -0.05 | -0.81 | -2.71 | 0.00 | -0.02 |
| Switch Fuel Source | -0.01 | 2,534 | -0.01 | 2,530 | -0.03 | -0.43 | -1.44 | 0.00 | -0.01 |
| Switch Fuel Source | -0.03 | 7,823 | -0.03 | 7,814 | -0.07 | -1.07 | -3.62 | 0.00 | -0.02 |

## Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Lump sum | Lump sum | Improved Hydrogen Plant Controls | 250,000.00 | 0.2 | 50,000 |
| | | Refinery Gas Processing ($/m3/h) | 2,400.00 | 13,900.0 | 33,360,000 |
| | | | | **Total** | 33,410,000 |

# Point Source Information

CLEARSTONE ENGINEERING

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Device | |
|---|---|
| **Name** | Central Norte Mix Drum |
| **ID** | D-2421 |
| **On Site Location** | N/A |
| **Category** | Boilers and Heaters |
| **Type** | Wall-fired (>29 MW)<br>Uncontrolled Pre-NSPS |
| **Service** | |
| **Manufacturer** | |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |
| | N/A |

| Data Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Alfonso Garcia |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 2013/09/08 |

| Device Comments and Assumptions |
|---|
| The mix drum feeding the Central Norte boilers. |

| General Simulation Data | |
|---|---|
| **Operating Factor (%)[1]** | 100.00 |
| **Load Factor (%)[1]** | 100.00 |
| **Flow Adjustment ($m^3$/h)[1]** | 0.00 |
| **Adjustment Comment** | none |
| **Activity Level[2]** | 1.0 |
| **Extrapolated Activity Level[2]** | 0.0 |
| **Ambient Temperature ($^o$C)** | 25.0 |
| **Ambient Pressure (kPa)** | 101.3 |

[1] Operating and Load Factors are multiplicative adjustments to the measured/reported flow rate applied during simulation, with 100% being no adjustment. Flow Adjustment is additional flow at standard conditions applied after all other corrections and adjustments.

[2] Activity Level and Extrapolated Activity Level are used when extrapolating from this Emission Point Source. The Unit(s)/Source(s) not tested are assumed to have losses and emissions of Extrapolated Activity Level/Activity Level times this Source.

| Data Comments and Assumptions |
|---|
| N/A |

| Applied Emission Factors | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor (ng/J)** | 1.00 | US EPA AP-42 |
| **$N_2O$ Emission Factor (ng/J)** | 0.90 | US EPA AP-42 |
| **VOC Emission Factor (ng/J)** | 2.30 | US EPA AP-42 |
| **CO Emission Factor (ng/J)** | 35.00 | US EPA AP-42 |
| **PM Emission Factor (ng/J)** | 0.80 | US EPA AP-42 |
| **$NO_x$ Emission Factor (ng/J)** | 118.00 | US EPA AP-42 |
| **HC Destruction Efficiency (%)** | N/A | |

## Simulation Input Stream

| Input Stream | |
|---|---|
| **Temperature ($^oC$)** | 15 |
| **Pressure (kPa gage)** | 101.325 |
| **Line Name** | N/A |
| **Cross Sectional Shape** | Circular |
| **Pipe Outside Diameter (mm)** | N/A |
| **Pipe Wall Thickness (mm)** | N/A |
| **Pipe Rectangular Length (mm)** | N/A |
| **Pipe Rectangular Width (mm)** | N/A |
| **Measurement Type** | Proration of Reported Fuel Consumption |
| **Reading Type** | Flow Rate (Standard Conditions) |
| **Measurement Date** | N/A |
| **Velocity (m/s)** | --- |
| **Flow Rate ($m^3$/h)** | --- |
| **Standard Flow Rate ($m^3$/h)** | 35,615.3 |
| **Composition Name** | D-2421 |
| **Composition ID** | 28 |

CLEARSTONE ENGINEERING

# Input Stream Composition Source Data

| Anaylsis Adminstration Data | |
|---|---|
| **Name** | D-2421 |
| **Description** | Central Norte boilers' feed stream composition. Equivalent to Mix Drum - Outlet D-2421 (Feb 01) |
| **Creation Date** | 2/25/2013 |
| **Sample Date** | 2/1/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 28 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.001190 | 0.001180 | 0.001193 |
| Ethane | 0.051599 | 0.051157 | 0.051731 |
| Isobutane | 0.000822 | 0.000815 | 0.000824 |
| Isopentane | 0.000292 | 0.000290 | 0.000293 |
| Methane | 0.921223 | 0.913340 | 0.923574 |
| n-Butane | 0.000988 | 0.000980 | 0.000991 |
| n-Heptane | 0.000464 | 0.000460 | 0.000465 |
| n-Hexane | 0.000187 | 0.000185 | 0.000187 |
| Nitrogen | 0.020589 | 0.020413 | 0.011806 |
| n-Pentane | 0.000282 | 0.000280 | 0.000283 |
| Oxygen | 0.002364 | 0.002344 | 0.000000 |
| Propane | 0.008631 | 0.008557 | 0.008653 |
| **Total** | 1.008631 | 1.000000 | 1.000000 |

## Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Switch Fuel Source | Switch To: Mix Drum - Outlet D-2421 ID 137 | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Switch Fuel Source | Switch To: Mix Drum - Outlet D-2421 (Fe... ID 155 | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | 0 | 0 | 0 | 0 |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | 0 | 0 | 0 | 0 |
| Switch Fuel Source | Switch To: Mix Drum - Outlet D-2421 ID 137 | 0 | 0 | 0 | 0 |
| Switch Fuel Source | Switch To: Mix Drum - Outlet D-2421 (Fe... ID 155 | 0 | 0 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |
| Switch Fuel Source | Switch To: Mix Drum - Outlet D-2421 ID 137 | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |
| Switch Fuel Source | Switch To: Mix Drum - Outlet D-2421 (Fe... ID 155 | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

## Control Technology Input Streams

| Technology type | Application Description | Use | Temperature ($^oC$) | Pressure (kPa) | Line Name | Cross Sectional Shape |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | Fuel Stream | 15 | 101.325 | | Circular |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | Fuel Stream | 15 | 101.325 | | Circular |
| Switch Fuel Source | Switch To: Mix Drum - Outlet D-2421 ID 137 | Fuel Stream | 15 | 101.325 | | Circular |
| Switch Fuel Source | Switch To: Mix Drum - Outlet D-2421 (Fe... ID 155 | Fuel Stream | 15 | 101.325 | | Circular |

| Stream Pipe/Duct Cross-sectional Flow Area Dimension | | | | | | |
|---|---|---|---|---|---|---|
| **Technology type** | **Application Description** | **Use** | **Pipe Outside Diameter (mm)** | **Pipe Wall Thickness (mm)** | **Pipe Rectangular Length (mm)** | **Pipe Rectangular Width (mm)** |
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | Fuel Stream | | | | |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | Fuel Stream | | | | |
| Switch Fuel Source | Switch To: Mix Drum - Outlet D-2421 ID 137 | Fuel Stream | | | | |
| Switch Fuel Source | Switch To: Mix Drum - Outlet D-2421 (Fe... ID 155 | Fuel Stream | | | | |

| Stream Flow Rate | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Technology type** | **Application Description** | **Use** | **Measurement Type** | **Reading Type** | **Measurement Date** | **Velocity (m/s)** | **Flow Rate ($m^3/h$)** | **Standard Flow Rate ($m^3/h$)** |
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | Fuel Stream | Mass and Energy Balance | Flow Rate (Standard Conditions) | | | | 37421.37467 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | Fuel Stream | Mass and Energy Balance | Flow Rate (Standard Conditions) | | | | 34737.6736 |
| Switch Fuel Source | Switch To: Mix Drum - Outlet D-2421 ID 137 | Fuel Stream | Mass and Energy Balance | Flow Rate (Standard Conditions) | | | | 45700.61182 |
| Switch Fuel Source | Switch To: Mix Drum - Outlet D-2421 (Fe... ID 155 | Fuel Stream | Mass and Energy Balance | Flow Rate (Standard Conditions) | | | | 35547.94382 |

**Stream Composition**

| Technology type | Application Description | Use | Composition Name | Sample ID |
|---|---|---|---|---|
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | Fuel Stream | Dry Natural Gas | 301 |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | Fuel Stream | Gas de Campos | 47 |
| Switch Fuel Source | Switch To: Mix Drum - Outlet D-2421 ID 137 | Fuel Stream | Mix Drum - Outlet D-2421 | 137 |
| Switch Fuel Source | Switch To: Mix Drum - Outlet D-2421 (Fe... ID 155 | Fuel Stream | Mix Drum - Outlet D-2421 (Feb04) | 155 |

## Simulation Results

| Source Name | Source Tag No. | Service Type | Value of Fuel/Loss Stream (USD/y) | Total Product Loss Flow ($m^3/h$) | Total Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3m^3/d$) | Ethane ($m^3/d$ liq) | LPG ($m^3/d$ liq) | NGL ($m^3/d$) | Hydrogen ($m^3/d$) |
| Central Norte Mix Drum | D-2421 | Steam Generator | 56,164,894 | 35,615.3 | 789.44 | 157.08 | 33.70 | 5.77 | 0.00 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| 12.4 | 620,602 | 11.16 | 624,321 | 28.5 | 433.9 | 1462.8 | 0.0 | 9.9 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Switch Fuel Source | 100.00 | 0 | 0 | 0 | -4,770,063 | -35,135,221 | NA | NA |
| Switch Fuel Source | 100.00 | 0 | 0 | 0 | -2,382,945 | -17,552,242 | NA | NA |
| Switch Fuel Source | 100.00 | 78,530,000 | 0 | 0 | -269,414 | -80,514,446 | NA | NA |
| Switch Fuel Source | 100.00 | 78,530,000 | 0 | 0 | 2,395,507 | -60,885,230 | 3.05 | 32.78 |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| Switch Fuel Source | -0.09 | 37,899 | -0.08 | 37,872 | -0.21 | -3.20 | -10.79 | 0.00 | -0.07 |
| Switch Fuel Source | 0.01 | -1,655 | 0.00 | -1,654 | 0.01 | 0.19 | 0.64 | 0.00 | 0.00 |
| Switch Fuel Source | 0.01 | -1,681 | 0.01 | -1,678 | 0.02 | 0.24 | 0.82 | 0.00 | 0.01 |
| Switch Fuel Source | -0.04 | 10,448 | -0.03 | 10,438 | -0.08 | -1.24 | -4.18 | 0.00 | -0.03 |

## Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Lump sum | Lump sum | gas processing plant | 2,400.00 | 32,700.0 | 78,480,000 |
| | | of Improved Hydrogen Plant Controls | 250,000.00 | 0.2 | 50,000 |

| | |
|---|---|
| **Total** | 78,530,000 |

# Point Source Information

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barrancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Device | |
|---|---|
| **Name** | Balance Mix Drum |
| **ID** | D-2953 |
| **On Site Location** | N/A |
| **Category** | Boilers and Heaters |
| **Type** | Wall-fired (>29 MW) Uncontrolled Pre-NSPS |
| **Service** | |
| **Manufacturer** | |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |
| | N/A |

| Data Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Alfonso Garcia |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 2013/09/08 |

| Device Comments and Assumptions |
|---|
| The Mix drum that supplies the fuel gas for the Balance boilers. |

| General Simulation Data | |
|---|---|
| **Operating Factor (%)**[1] | 100.00 |
| **Load Factor (%)**[1] | 100.00 |
| **Flow Adjustment ($m^3$/h)**[1] | 0.00 |
| **Adjustment Comment** | None |
| **Activity Level**[2] | 1.0 |
| **Extrapolated Activity Level**[2] | 0.0 |
| **Ambient Temperature ($^o$C)** | 25.0 |
| **Ambient Pressure (kPa)** | 101.3 |

[1] Operating and Load Factors are multiplicative adjustments to the measured/reported flow rate applied during simulation, with 100% being no adjustment. Flow Adjustment is additional flow at standard conditions applied after all other corrections and adjustments.

[2] Activity Level and Extrapolated Activity Level are used when extrapolating from this Emission Point Source. The Unit(s)/Source(s) not tested are assumed to have losses and emissions of Extrapolated Activity Level/Activity Level times this Source.

| Data Comments and Assumptions |
|---|
| N/A |

| Applied Emission Factors | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor (ng/J)** | 1.00 | US EPA AP-42 |
| **$N_2O$ Emission Factor (ng/J)** | 0.90 | US EPA AP-42 |
| **VOC Emission Factor (ng/J)** | 2.30 | US EPA AP-42 |
| **CO Emission Factor (ng/J)** | 35.00 | US EPA AP-42 |
| **PM Emission Factor (ng/J)** | 0.80 | US EPA AP-42 |
| **$NO_x$ Emission Factor (ng/J)** | 118.00 | US EPA AP-42 |
| **HC Destruction Efficiency (%)** | N/A | |

## Simulation Input Stream

| Input Stream | |
|---|---|
| **Temperature ($^oC$)** | 15 |
| **Pressure (kPa gage)** | 101.325 |
| **Line Name** | N/A |
| **Cross Sectional Shape** | Circular |
| **Pipe Outside Diameter (mm)** | N/A |
| **Pipe Wall Thickness (mm)** | N/A |
| **Pipe Rectangular Length (mm)** | N/A |
| **Pipe Rectangular Width (mm)** | N/A |
| **Measurement Type** | Proration of Reported Fuel Consumption |
| **Reading Type** | Flow Rate (Standard Conditions) |
| **Measurement Date** | N/A |
| **Velocity (m/s)** | --- |
| **Flow Rate ($m^3$/h)** | --- |
| **Standard Flow Rate ($m^3$/h)** | 40,961.7 |
| **Composition Name** | D-2953 |
| **Composition ID** | 32 |

# Input Stream Composition Source Data

| Anaylsis Adminstration Data | |
|---|---|
| **Name** | D-2953 |
| **Description** | Balance boilers' feed stream composition. Equivalent to Mix Drum - Inlet D-2953 |
| **Creation Date** | 2/25/2013 |
| **Sample Date** | 2/2/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Refinery Gas |
| **Clearstone ID** | 32 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Ethane | 0.040830 | 0.040830 | 0.041435 |
| Hydrogen (normal) | 0.015585 | 0.015585 | 0.015816 |
| Isobutane | 0.002245 | 0.002245 | 0.002278 |
| Isopentane | 0.000680 | 0.000680 | 0.000690 |
| Methane | 0.906545 | 0.906545 | 0.919985 |
| n-Butane | 0.002460 | 0.002460 | 0.002496 |
| n-Heptane | 0.000360 | 0.000360 | 0.000365 |
| n-Hexane | 0.000260 | 0.000260 | 0.000264 |
| Nitrogen | 0.016140 | 0.016140 | 0.004689 |
| n-Pentane | 0.000585 | 0.000585 | 0.000594 |
| Oxygen | 0.003090 | 0.003090 | 0.000000 |
| Propane | 0.011220 | 0.011220 | 0.011386 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Switch Fuel Source | Switch To: Mix Drum - Outlet D-2953 ID 148 | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | 0 | 0 | 0 | 0 |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | 0 | 0 | 0 | 0 |
| Switch Fuel Source | Switch To: Mix Drum - Outlet D-2953 ID 148 | 0 | 0 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |
| Switch Fuel Source | Switch To: Mix Drum - Outlet D-2953 ID 148 | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

# Control Technology Input Streams

| Technology type | Application Description | Use | Temperature (°C) | Pressure (kPa) | Line Name | Cross Sectional Shape |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | Fuel Stream | 15 | 101.325 | | Circular |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | Fuel Stream | 15 | 101.325 | | Circular |
| Switch Fuel Source | Switch To: Mix Drum - Outlet D-2953 ID 148 | Fuel Stream | 15 | 101.325 | | Circular |

| Stream Pipe/Duct Cross-sectional Flow Area Dimension | | | | | | |
|---|---|---|---|---|---|---|
| **Technology type** | **Application Description** | **Use** | **Pipe Outside Diameter (mm)** | **Pipe Wall Thickness (mm)** | **Pipe Rectangular Length (mm)** | **Pipe Rectangular Width (mm)** |
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | Fuel Stream | | | | |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | Fuel Stream | | | | |
| Switch Fuel Source | Switch To: Mix Drum - Outlet D-2953 ID 148 | Fuel Stream | | | | |

| Stream Flow Rate | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Technology type** | **Application Description** | **Use** | **Measurement Type** | **Reading Type** | **Measurement Date** | **Velocity (m/s)** | **Flow Rate ($m^3/h$)** | **Standard Flow Rate ($m^3/h$)** |
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | Fuel Stream | Mass and Energy Balance | Flow Rate (Standard Conditions) | | | | 43109.44749 |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | Fuel Stream | Mass and Energy Balance | Flow Rate (Standard Conditions) | | 1 | | 40017.82215 |
| Switch Fuel Source | Switch To: Mix Drum - Outlet D-2953 ID 148 | Fuel Stream | Mass and Energy Balance | Flow Rate (Standard Conditions) | | | | 41300.7706 |

| Stream Composition | | | | |
|---|---|---|---|---|
| **Technology type** | **Application Description** | **Use** | **Composition Name** | **Sample ID** |
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | Fuel Stream | Dry Natural Gas | 301 |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | Fuel Stream | Gas de Campos | 47 |
| Switch Fuel Source | Switch To: Mix Drum - Outlet D-2953 ID 148 | Fuel Stream | Mix Drum - Outlet D-2953 | 148 |

## Simulation Results

| Source Name | Source Tag No. | Service Type | Value of Fuel/Loss Stream (USD/y) | Total Product Loss Flow ($m^3/h$) | Total Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3 m^3/d$) | Ethane ($m^3/d$ liq) | LPG ($m^3/d$ liq) | NGL ($m^3/d$) | Hydrogen ($m^3/d$) |
| Balance Mix Drum | D-2953 | Steam Generator | 66,487,230 | 40,961.7 | 904.42 | 144.70 | 60.87 | 9.84 | 15,548.45 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| 14.3 | 712,407 | 12.86 | 716,693 | 32.9 | 500.0 | 1685.7 | 0.0 | 11.4 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Switch Fuel Source | 100.00 | 0 | 0 | 0 | -5,359,701 | -39,478,359 | NA | NA |
| Switch Fuel Source | 100.00 | 91,250,000 | 0 | 0 | 1,474,871 | -80,386,427 | 1.62 | 61.87 |
| Switch Fuel Source | 100.00 | 91,250,000 | 0 | 0 | 4,544,863 | -57,773,557 | 4.98 | 20.08 |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| Switch Fuel Source | 0.00 | 2,679 | 0.00 | 2,680 | 0.01 | 0.08 | 0.28 | 0.00 | 0.00 |
| Switch Fuel Source | 0.01 | -4,462 | 0.01 | -4,458 | 0.03 | 0.44 | 1.50 | 0.00 | 0.01 |
| Switch Fuel Source | -0.04 | 9,510 | -0.03 | 9,499 | -0.08 | -1.27 | -4.27 | 0.00 | -0.03 |

## Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Lump sum | Lump sum | Improved Hydrogen Plant Controls | 250,000.00 | 0.2 | 50,000 |
| | | Refinery Gas Processing ($/m3/h) | 2,400.00 | 38,000.0 | 91,200,000 |

| | |
|---|---|
| **Total** | 91,250,000 |

# Point Source Information

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barrancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Device | |
|---|---|
| **Name** | Caldaers Nuevas Mix Drum |
| **ID** | D-940 |
| **On Site Location** | N/A |
| **Category** | Boilers and Heaters |
| **Type** | Wall-fired (>29 MW) Uncontrolled Pre-NSPS |
| **Service** | |
| **Manufacturer** | |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |
| | N/A |

| Data Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Alfonso Garcia |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 2013/09/08 |

| Device Comments and Assumptions |
|---|
| The Mix Drum feeding Fuel gas to the Caldaers Nuevas boilers. |

| General Simulation Data | |
|---|---|
| **Operating Factor (%)**[1] | 100.00 |
| **Load Factor (%)**[1] | 100.00 |
| **Flow Adjustment ($m^3$/h)**[1] | 0.00 |
| **Adjustment Comment** | None |
| **Activity Level**[2] | 1.0 |
| **Extrapolated Activity Level**[2] | 0.0 |
| **Ambient Temperature ($^{o}$C)** | 25.0 |
| **Ambient Pressure (kPa)** | 101.3 |

[1] Operating and Load Factors are multiplicative adjustments to the measured/reported flow rate applied during simulation, with 100% being no adjustment. Flow Adjustment is additional flow at standard conditions applied after all other corrections and adjustments.

[2] Activity Level and Extrapolated Activity Level are used when extrapolating from this Emission Point Source. The Unit(s)/Source(s) not tested are assumed to have losses and emissions of Extrapolated Activity Level/Activity Level times this Source.

| Data Comments and Assumptions |
|---|
| N/A |

| Applied Emission Factors | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor (ng/J)** | 1.00 | US EPA AP-42 |
| **$N_2O$ Emission Factor (ng/J)** | 0.90 | US EPA AP-42 |
| **VOC Emission Factor (ng/J)** | 2.30 | US EPA AP-42 |
| **CO Emission Factor (ng/J)** | 35.00 | US EPA AP-42 |
| **PM Emission Factor (ng/J)** | 0.80 | US EPA AP-42 |
| **$NO_x$ Emission Factor (ng/J)** | 118.00 | US EPA AP-42 |
| **HC Destruction Efficiency (%)** | N/A | |

## Simulation Input Stream

| Input Stream | |
|---|---|
| **Temperature ($^oC$)** | 15 |
| **Pressure (kPa gage)** | 101.325 |
| **Line Name** | N/A |
| **Cross Sectional Shape** | Circular |
| **Pipe Outside Diameter (mm)** | N/A |
| **Pipe Wall Thickness (mm)** | N/A |
| **Pipe Rectangular Length (mm)** | N/A |
| **Pipe Rectangular Width (mm)** | N/A |
| **Measurement Type** | Proration of Reported Fuel Consumption |
| **Reading Type** | Flow Rate (Standard Conditions) |
| **Measurement Date** | N/A |
| **Velocity (m/s)** | --- |
| **Flow Rate ($m^3/h$)** | --- |
| **Standard Flow Rate ($m^3/h$)** | 2,718.3 |
| **Composition Name** | D-940 |
| **Composition ID** | 30 |

# Input Stream Composition Source Data

| Anaylsis Adminstration Data | |
|---|---|
| **Name** | D-940 |
| **Description** | Calderas Nuevas boilers' feed stream composition. Equivent to Mix Drum - D940 final outlet (refinery |
| **Creation Date** | 2/25/2013 |
| **Sample Date** | 2/1/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 30 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.009065 | 0.009065 | 0.009272 |
| Ethane | 0.091295 | 0.091295 | 0.093383 |
| Hydrogen (normal) | 0.361855 | 0.361855 | 0.370132 |
| Isobutane | 0.017560 | 0.017560 | 0.017962 |
| Isopentane | 0.002765 | 0.002765 | 0.002828 |
| Methane | 0.393485 | 0.393485 | 0.402486 |
| n-Butane | 0.009735 | 0.009735 | 0.009958 |
| n-Heptane | 0.000625 | 0.000625 | 0.000639 |
| n-Hexane | 0.000555 | 0.000555 | 0.000568 |
| Nitrogen | 0.033885 | 0.033885 | 0.016624 |
| n-Pentane | 0.001620 | 0.001620 | 0.001657 |
| Oxygen | 0.004730 | 0.004730 | 0.000000 |
| Propane | 0.072825 | 0.072825 | 0.074491 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

## Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Switch Fuel Source | Switch To: Mix Drum - D940 final outlet... ID 135 | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Switch Fuel Source | Switch To: Mix Drum - D940 final outlet... ID 143 | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Switch Fuel Source | Switch To: Mix Drum - D940 final outlet... ID 156 | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Switch Fuel Source | Switch To: Mix Drum - D940 outlet (HDT,... ID 134 | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Switch Fuel Source | Switch To: Mix Drum - D940 outlet (top ... ID 152 | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Switch Fuel Source | Switch To: Mix Drum - D940 outlet ID 145 | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | 0 | 0 | 0 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | 0 | 0 | 0 | 0 |
| Switch Fuel Source | Switch To: Mix Drum - D940 final outlet... ID 135 | 0 | 0 | 0 | 0 |
| Switch Fuel Source | Switch To: Mix Drum - D940 final outlet... ID 143 | 0 | 0 | 0 | 0 |
| Switch Fuel Source | Switch To: Mix Drum - D940 final outlet... ID 156 | 0 | 0 | 0 | 0 |
| Switch Fuel Source | Switch To: Mix Drum - D940 outlet (HDT,... ID 134 | 0 | 0 | 0 | 0 |
| Switch Fuel Source | Switch To: Mix Drum - D940 outlet (top ... ID 152 | 0 | 0 | 0 | 0 |
| Switch Fuel Source | Switch To: Mix Drum - D940 outlet ID 145 | 0 | 0 | 0 | 0 |

| **Control Technology Type** | **Application Description** | **Applied Emission Factors[1] (ng/J)** | | | | | | **Hydrocarbon Destruction Efficiency (%)** |
|---|---|---|---|---|---|---|---|---|
| | | **$CH_4$** | **$N_2O$** | **VOC** | **CO** | **PM** | **$NO_x$** | |
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |
| Switch Fuel Source | Switch To: Mix Drum - D940 final outlet... ID 135 | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |
| Switch Fuel Source | Switch To: Mix Drum - D940 final outlet... ID 143 | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |
| Switch Fuel Source | Switch To: Mix Drum - D940 final outlet... ID 156 | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |
| Switch Fuel Source | Switch To: Mix Drum - D940 outlet (HDT,... ID 134 | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |
| Switch Fuel Source | Switch To: Mix Drum - D940 outlet (top ... ID 152 | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Switch Fuel Source | Switch To: Mix Drum - D940 outlet ID 145 | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

## Control Technology Input Streams

| Technology type | Application Description | Use | Temperature (°C) | Pressure (kPa) | Line Name | Cross Sectional Shape |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | Fuel Stream | 15 | 101.325 | | Circular |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | Fuel Stream | 15 | 101.325 | | Circular |
| Switch Fuel Source | Switch To: Mix Drum - D940 final outlet... ID 135 | Fuel Stream | 15 | 101.325 | | Circular |
| Switch Fuel Source | Switch To: Mix Drum - D940 final outlet... ID 143 | Fuel Stream | 15 | 101.325 | | Circular |
| Switch Fuel Source | Switch To: Mix Drum - D940 final outlet... ID 156 | Fuel Stream | 15 | 101.325 | | Circular |
| Switch Fuel Source | Switch To: Mix Drum - D940 outlet (HDT,... ID 134 | Fuel Stream | 15 | 101.325 | | Circular |
| Switch Fuel Source | Switch To: Mix Drum - D940 outlet (top ... ID 152 | Fuel Stream | 15 | 101.325 | | Circular |
| Switch Fuel Source | Switch To: Mix Drum - D940 outlet ID 145 | Fuel Stream | 15 | 101.325 | | Circular |

| Stream Pipe/Duct Cross-sectional Flow Area Dimension | | | | | | |
|---|---|---|---|---|---|---|
| **Technology type** | **Application Description** | **Use** | **Pipe Outside Diameter (mm)** | **Pipe Wall Thickness (mm)** | **Pipe Rectangular Length (mm)** | **Pipe Rectangular Width (mm)** |
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | Fuel Stream | | | | |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | Fuel Stream | | | | |
| Switch Fuel Source | Switch To: Mix Drum - D940 final outlet... ID 135 | Fuel Stream | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switch To: Mix Drum - D940 final outlet... ID 143 | Fuel Stream | | | | |
| Switch Fuel Source | Switch To: Mix Drum - D940 final outlet... ID 156 | Fuel Stream | | | | |
| Switch Fuel Source | Switch To: Mix Drum - D940 outlet (HDT,... ID 134 | Fuel Stream | | | | |
| Switch Fuel Source | Switch To: Mix Drum - D940 outlet (top ... ID 152 | Fuel Stream | | | | |
| Switch Fuel Source | Switch To: Mix Drum - D940 outlet ID 145 | Fuel Stream | | | | |

**Stream Flow Rate**

| Technology type | Application Description | Use | Measurement Type | Reading Type | Measurement Date | Velocity (m/s) | Flow Rate ($m^3$/h) | Standard Flow Rate ($m^3$/h) |
|---|---|---|---|---|---|---|---|---|
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | Fuel Stream | Mass and Energy Balance | Flow Rate (Standard Conditions) | | | | 2687.064795 |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | Fuel Stream | Mass and Energy Balance | Flow Rate (Standard Conditions) | | | | 2494.359991 |
| Switch Fuel Source | Switch To: Mix Drum - D940 final outlet... ID 135 | Fuel Stream | Mass and Energy Balance | Flow Rate (Standard Conditions) | | | | 2538.694753 |
| Switch Fuel Source | Switch To: Mix Drum - D940 final outlet... ID 143 | Fuel Stream | Mass and Energy Balance | Flow Rate (Standard Conditions) | | | | 2718.333333 |
| Switch Fuel Source | Switch To: Mix Drum - D940 final outlet... ID 156 | Fuel Stream | Mass and Energy Balance | Flow Rate (Standard Conditions) | | | | 2673.263183 |
| Switch Fuel Source | Switch To: Mix Drum - D940 outlet (HDT,... ID 134 | Fuel Stream | Mass and Energy Balance | Flow Rate (Standard Conditions) | | | | 2506.520003 |
| Switch Fuel Source | Switch To: Mix Drum - D940 outlet (top ... ID 152 | Fuel Stream | Mass and Energy Balance | Flow Rate (Standard Conditions) | | | | 2695.587227 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Switch Fuel Source | Switch To: Mix Drum - D940 outlet ID 145 | Fuel Stream | Mass and Energy Balance | Flow Rate (Standard Conditions) | | | | 2697.420439 |

**Stream Composition**

| Technology type | Application Description | Use | Composition Name | Sample ID |
|---|---|---|---|---|
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | Fuel Stream | Dry Natural Gas | 301 |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | Fuel Stream | Gas de Campos | 47 |
| Switch Fuel Source | Switch To: Mix Drum - D940 final outlet... ID 135 | Fuel Stream | Mix Drum - D940 final outlet (refinery gas @50%) | 135 |
| Switch Fuel Source | Switch To: Mix Drum - D940 final outlet... ID 143 | Fuel Stream | Mix Drum - D940 final outlet (refinery gas @ 100%) | 143 |
| Switch Fuel Source | Switch To: Mix Drum - D940 final outlet... ID 156 | Fuel Stream | Mix Drum - D940 final outlet (refinery gas 85%) | 156 |
| Switch Fuel Source | Switch To: Mix Drum - D940 outlet (HDT,... ID 134 | Fuel Stream | Mix Drum - D940 outlet (HDT, Orthoflow and mod IV) | 134 |
| Switch Fuel Source | Switch To: Mix Drum - D940 outlet (top ... ID 152 | Fuel Stream | Mix Drum - D940 outlet (top of the drum) | 152 |
| Switch Fuel Source | Switch To: Mix Drum - D940 outlet ID 145 | Fuel Stream | Mix Drum - D940 outlet | 145 |

## Simulation Results

| Source Name | Source Tag No. | Service Type | Value of Fuel/Loss Stream (USD/y) | Total Product Loss Flow ($m^3/h$) | Total Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3 m^3/d$) | Ethane ($m^3/d$ liq) | LPG ($m^3/d$ liq) | NGL ($m^3/d$) | Hydrogen ($m^3/d$) |
| Caldaers Nuevas Mix Drum | D-940 | Steam Generator | 5,681,591 | 2,718.3 | 26.26 | 21.64 | 25.52 | 1.89 | 24,147.43 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| 0.9 | 42,726 | 0.80 | 42,993 | 2.1 | 31.2 | 105.2 | 0.0 | 0.7 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Switch Fuel Source | 100.00 | 0 | 0 | 0 | 0 | 0 | NA | NA |
| Switch Fuel Source | 100.00 | 0 | 0 | 0 | -239,285 | -1,762,520 | NA | NA |
| Switch Fuel Source | 100.00 | 0 | 0 | 0 | -16,014 | -117,954 | NA | NA |
| Switch Fuel Source | 100.00 | 0 | 0 | 0 | -99,343 | -731,741 | NA | NA |
| Switch Fuel Source | 100.00 | 0 | 0 | 0 | -248,851 | -1,832,984 | NA | NA |
| Switch Fuel Source | 100.00 | 0 | 0 | 0 | -159,894 | -1,177,742 | NA | NA |
| Switch Fuel Source | 100.00 | 3,938,000 | 0 | 0 | 1,629,291 | 8,062,996 | 41.37 | 2.42 |
| Switch Fuel Source | 100.00 | 3,938,000 | 0 | 0 | 1,820,648 | 9,472,484 | 46.23 | 2.16 |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| Switch Fuel Source | 0.00 | 0 | 0.00 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Switch Fuel Source | 0.00 | -1,559 | 0.00 | -1,558 | 0.01 | 0.15 | 0.50 | 0.00 | 0.00 |
| Switch Fuel Source | 0.00 | -173 | 0.00 | -173 | 0.00 | 0.02 | 0.06 | 0.00 | 0.00 |
| Switch Fuel Source | 0.00 | -125 | 0.00 | -125 | 0.00 | 0.02 | 0.06 | 0.00 | 0.00 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Switch Fuel Source | 0.00 | -1,413 | 0.00 | -1,412 | 0.01 | 0.14 | 0.46 | 0.00 | 0.00 |
| Switch Fuel Source | 0.00 | -23 | 0.00 | -23 | 0.00 | 0.01 | 0.04 | 0.00 | 0.00 |
| Switch Fuel Source | 0.00 | -1,957 | 0.00 | -1,957 | 0.00 | 0.07 | 0.24 | 0.00 | 0.00 |
| Switch Fuel Source | -0.00 | -1,087 | -0.00 | -1,087 | -0.00 | -0.04 | -0.12 | 0.00 | -0.00 |

# Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Lump sum | Lump sum | Improved Hydrogen Plant Controls | 250,000.00 | 0.2 | 50,000 |
| | | Refinery Gas Processing ($/m3/h) | 2,400.00 | 1,620.0 | 3,888,000 |

| | |
|---|---|
| **Total** | 3,938,000 |

# Point Source Information

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Device | |
|---|---|
| **Name** | Foster Mix Drum |
| **ID** | D-942 |
| **On Site Location** | N/A |
| **Category** | Boilers and Heaters |
| **Type** | Wall-fired (>29 MW) Uncontrolled Pre-NSPS |
| **Service** | |
| **Manufacturer** | |
| **Model** | N/A |
| **Model Year** | N/A |
| **Installation Date** | N/A |
| | N/A |

| Data Administration Details | |
|---|---|
| **Period Start** | 2013/06/07 |
| **Period End** | 2013/06/07 |
| **Data Contact** | Alfonso Garcia |
| **Prepared By** | Ecopetrol |
| **Report Generated** | 2013/09/08 |

| Device Comments and Assumptions |
|---|
| The Mix drum that supplies fuel gas to the Foster Boilers. |

| General Simulation Data | |
|---|---|
| **Operating Factor (%)**[1] | 100.00 |
| **Load Factor (%)**[1] | 100.00 |
| **Flow Adjustment ($m^3$/h)**[1] | 0.00 |
| **Adjustment Comment** | None |
| **Activity Level**[2] | 1.0 |
| **Extrapolated Activity Level**[2] | 0.0 |
| **Ambient Temperature ($^oC$)** | 25.0 |
| **Ambient Pressure (kPa)** | 101.3 |

[1] Operating and Load Factors are multiplicative adjustments to the measured/reported flow rate applied during simulation, with 100% being no adjustment. Flow Adjustment is additional flow at standard conditions applied after all other corrections and adjustments.

[2] Activity Level and Extrapolated Activity Level are used when extrapolating from this Emission Point Source. The Unit(s)/Source(s) not tested are assumed to have losses and emissions of Extrapolated Activity Level/Activity Level times this Source.

| Data Comments and Assumptions |
|---|
| N/A |

| Applied Emission Factors | | |
|---|---|---|
| **Substance** | **Value** | **Source** |
| **$CH_4$ Emission Factor (ng/J)** | 1.00 | US EPA AP-42 |
| **$N_2O$ Emission Factor (ng/J)** | 0.90 | US EPA AP-42 |
| **VOC Emission Factor (ng/J)** | 2.30 | US EPA AP-42 |
| **CO Emission Factor (ng/J)** | 35.00 | US EPA AP-42 |
| **PM Emission Factor (ng/J)** | 0.80 | US EPA AP-42 |
| **$NO_x$ Emission Factor (ng/J)** | 118.00 | US EPA AP-42 |
| **HC Destruction Efficiency (%)** | N/A | |

## Simulation Input Stream

| Input Stream | |
|---|---|
| **Temperature ($^oC$)** | 15 |
| **Pressure (kPa gage)** | 101.325 |
| **Line Name** | N/A |
| **Cross Sectional Shape** | Circular |
| **Pipe Outside Diameter (mm)** | N/A |
| **Pipe Wall Thickness (mm)** | N/A |
| **Pipe Rectangular Length (mm)** | N/A |
| **Pipe Rectangular Width (mm)** | N/A |
| **Measurement Type** | Proration of Reported Fuel Consumption |
| **Reading Type** | Flow Rate (Standard Conditions) |
| **Measurement Date** | N/A |
| **Velocity (m/s)** | --- |
| **Flow Rate ($m^3$/h)** | --- |
| **Standard Flow Rate ($m^3$/h)** | 6,680.0 |
| **Composition Name** | D-942 |
| **Composition ID** | 31 |

# Input Stream Composition Source Data

| Anaylsis Adminstration Data | |
|---|---|
| **Name** | D-942 |
| **Description** | Foster boilers' feed stream composition. Equivalent to Mix Drum - Inlet and outlet D-942 (Feb 04) |
| **Creation Date** | 2/25/2013 |
| **Sample Date** | 2/4/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 31 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.003140 | 0.003140 | 0.003209 |
| Ethane | 0.055125 | 0.055125 | 0.056342 |
| Hydrogen (normal) | 0.355785 | 0.355785 | 0.363642 |
| Isobutane | 0.009620 | 0.009620 | 0.009832 |
| Isopentane | 0.001525 | 0.001525 | 0.001559 |
| Methane | 0.497710 | 0.497710 | 0.508701 |
| n-Butane | 0.010135 | 0.010135 | 0.010359 |
| n-Heptane | 0.000680 | 0.000680 | 0.000695 |
| n-Hexane | 0.000605 | 0.000605 | 0.000618 |
| Nitrogen | 0.025590 | 0.025590 | 0.008743 |
| n-Pentane | 0.001035 | 0.001035 | 0.001058 |
| Oxygen | 0.004570 | 0.004570 | 0.000000 |
| Propane | 0.034480 | 0.034480 | 0.035241 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Control Technology Input

| Control Technology Type | Application Description | Reduction Efficiencies (%) | | | Current System Life (y) | Control Technology Life (y) | Electric Power Requirements (kWh/y) |
|---|---|---|---|---|---|---|---|
| | | Energy | Hydro-carbon | Sulphur | | | |
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |
| Switch Fuel Source | Switch To: Mix Drum - Inlet and outlet ... ID 147 | 100.00 | 0.00 | 0.00 | 20 | 20 | 0 |

| Control Technology Type | Application Description | Year-0 Equip. Removal Salvage Value (USD) | Operating Costs (USD) | Operating Costs Avoided (USD) | Technology EOL Salvage Value (USD) |
|---|---|---|---|---|---|
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | 0 | 0 | 0 | 0 |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | 0 | 0 | 0 | 0 |
| Switch Fuel Source | Switch To: Mix Drum - Inlet and outlet ... ID 147 | 0 | 0 | 0 | 0 |

| Control Technology Type | Application Description | Applied Emission Factors[1] (ng/J) | | | | | | Hydrocarbon Destruction Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | VOC | CO | PM | $NO_x$ | |
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |
| Switch Fuel Source | Switch To: Mix Drum - Inlet and outlet ... ID 147 | 1.00 | 0.90 | 2.30 | 35.00 | 0.80 | 118.00 | N/A |

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

# Control Technology Input Streams

| Technology type | Application Description | Use | Temperature ($^oC$) | Pressure (kPa) | Line Name | Cross Sectional Shape |
|---|---|---|---|---|---|---|
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | Fuel Stream | 15 | 101.325 | | Circular |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | Fuel Stream | 15 | 101.325 | | Circular |
| Switch Fuel Source | Switch To: Mix Drum - Inlet and outlet ... ID 147 | Fuel Stream | 15 | 101.325 | | Circular |

| Stream Pipe/Duct Cross-sectional Flow Area Dimension | | | | | | |
|---|---|---|---|---|---|---|
| **Technology type** | **Application Description** | **Use** | **Pipe Outside Diameter (mm)** | **Pipe Wall Thickness (mm)** | **Pipe Rectangular Length (mm)** | **Pipe Rectangular Width (mm)** |
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | Fuel Stream | | | | |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | Fuel Stream | | | | |
| Switch Fuel Source | Switch To: Mix Drum - Inlet and outlet ... ID 147 | Fuel Stream | | | | |

| Stream Flow Rate | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Technology type** | **Application Description** | **Use** | **Measurement Type** | **Reading Type** | **Measurement Date** | **Velocity (m/s)** | **Flow Rate ($m^3/h$)** | **Standard Flow Rate ($m^3/h$)** |
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | Fuel Stream | Mass and Energy Balance | Flow Rate (Standard Conditions) | | | | 5951.104612 |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | Fuel Stream | Mass and Energy Balance | Flow Rate (Standard Conditions) | | | | 5524.316821 |
| Switch Fuel Source | Switch To: Mix Drum - Inlet and outlet ... ID 147 | Fuel Stream | Mass and Energy Balance | Flow Rate (Standard Conditions) | | | | 6640.859724 |

| Stream Composition | | | | |
|---|---|---|---|---|
| **Technology type** | **Application Description** | **Use** | **Composition Name** | **Sample ID** |
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 | Fuel Stream | Dry Natural Gas | 301 |
| Switch Fuel Source | Switch To: Gas de Campos ID 47 | Fuel Stream | Gas de Campos | 47 |
| Switch Fuel Source | Switch To: Mix Drum - Inlet and outlet ... ID 147 | Fuel Stream | Mix Drum - Inlet and outlet D-942 | 147 |

## Simulation Results

| Source Name | Source Tag No. | Service Type | Value of Fuel/Loss Stream (USD/y) | Total Product Loss Flow ($m^3/h$) | Total Product Losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Residue Gas ($10^3 m^3/d$) | Ethane ($m^3/d$ liq) | LPG ($m^3/d$ liq) | NGL ($m^3/d$) | Hydrogen ($m^3/d$) |
| Foster Mix Drum | D-942 | Steam Generator | 11,460,675 | 6,680.0 | 81.55 | 32.09 | 34.38 | 3.29 | 58,299.08 |

| Total (Direct and Indirect) Emissions (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| 2.0 | 90,700 | 1.79 | 91,296 | 4.6 | 69.5 | 234.4 | 0.0 | 1.6 |

**Potential Control Options**

| Control Technology Type | Energy Recovery Efficiency (%) | Capital Cost (USD) | Net Present Salvage Value (USD) | Net Operating Cost (USD/y) | Value of Conserved Energy (USD/y) | NPV (USD) | ROI (%) | Payback Period (y) |
|---|---|---|---|---|---|---|---|---|
| Switch Fuel Source | 100.00 | 0 | 0 | 0 | 242,081 | 1,783,118 | NA | 0.00 |
| Switch Fuel Source | 100.00 | 10,586,000 | 0 | 0 | 2,485,952 | 7,724,970 | 23.48 | 4.26 |
| Switch Fuel Source | 100.00 | 10,586,000 | 0 | 0 | 2,909,754 | 10,846,596 | 27.49 | 3.64 |

| Control Technology Type | Estimated Emission Reduction Potential (t/y) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $N_2O$ | $CO_2E$ | VOC | CO | NOx | $SO_2$ | PM |
| Switch Fuel Source | 0.00 | -429 | 0.00 | -428 | 0.00 | 0.02 | 0.07 | 0.00 | 0.00 |
| Switch Fuel Source | 0.02 | -8,261 | 0.01 | -8,257 | 0.04 | 0.56 | 1.89 | 0.00 | 0.01 |
| Switch Fuel Source | 0.01 | -6,333 | 0.01 | -6,330 | 0.02 | 0.32 | 1.09 | 0.00 | 0.01 |

## Capital Cost Details

| Control Technology Type | Application description |
|---|---|
| Switch Fuel Source | Switch To: Dry Natural Gas ID 301 |

| Cost Category | Cost Item Type | Item Description | Rate (USD/Unit) | Quantity (Unit) | Line Total (USD) |
|---|---|---|---|---|---|
| Lump sum | Lump sum | Improved Hydrogen Plant Controls | 250,000.00 | 0.2 | 50,000 |
| | | Refinery Gas Processing ($/m3/h) | 2,400.00 | 4,390.0 | 10,536,000 |

| | |
|---|---|
| **Total** | 10,586,000 |

## APPENDIX H GAS ANALYSES

This section presents a copy of all the gas analyses performed during the refinery study and any gas analyses provided by Ecopetrol.

| Listing of Gas and Vapour Analyses Performed | | | | |
|---|---|---|---|---|
| Facility | Substance | Composition Name | Clearstone ID # | Sample Date |
| Barancabermeja Refinery | Field Gas | Gas de Campos | 47 | 2/6/2013 |
| Barancabermeja Refinery | Field Gas | Mix Drum - Inlet D-2953 | 149 | 2/2/2013 |
| Barancabermeja Refinery | Fuel Gas | 2013-01-31 FID D562 fgd 10.30 | 247 | 1/31/2013 |
| Barancabermeja Refinery | Fuel Gas | 2013-01-31 FID D562 fgd 11.10 | 246 | 1/31/2013 |
| Barancabermeja Refinery | Fuel Gas | 2013-01-31 FID D940 final outlet 16.05 | 250 | 1/31/2013 |
| Barancabermeja Refinery | Fuel Gas | 2013-01-31 FID D940 H65019 FG 14.17 | 251 | 1/31/2013 |
| Barancabermeja Refinery | Fuel Gas | 2013-01-31 FID D940 outlet 15.55 | 249 | 1/31/2013 |
| Barancabermeja Refinery | Fuel Gas | 2013-02-01 FID D2421 outlet 09.21 | 253 | 2/1/2013 |
| Barancabermeja Refinery | Fuel Gas | 2013-02-01 FID D940 mod 4 2.15 | 258 | 2/1/2013 |
| Barancabermeja Refinery | Fuel Gas | 2013-02-01 FID D940 out B951.2 2.55 | 257 | 2/1/2013 |
| Barancabermeja Refinery | Fuel Gas | 2013-02-01 FID D940 outlet 2.40 | 256 | 2/1/2013 |
| Barancabermeja Refinery | Fuel Gas | 2013-02-01 FID D942 aro boil 3.15 | 259 | 2/1/2013 |
| Barancabermeja Refinery | Fuel Gas | 2013-02-01 FID FGM D958 15.20 | 255 | 2/1/2013 |
| Barancabermeja Refinery | Fuel Gas | 2013-02-02 FID D2453 outlet 13.35 | 260 | 2/2/2013 |
| Barancabermeja Refinery | Fuel Gas | 2013-02-02 FID D2953 balace 13.20 | 262 | 2/2/2013 |
| Barancabermeja Refinery | Fuel Gas | 2013-02-02 FID feed VBK2 15.25 | 261 | 2/2/2013 |
| Barancabermeja Refinery | Fuel Gas | 2013-02-04 FID D2421 out 09.30 | 268 | 2/4/2013 |
| Barancabermeja Refinery | Fuel Gas | 2013-02-04 FID D940 mod 4 08.25 | 270 | 2/4/2013 |
| Barancabermeja Refinery | Fuel Gas | 2013-02-04 FID D940 out 08.40 | 269 | 2/4/2013 |
| Barancabermeja Refinery | Fuel Gas | 2013-02-04 FID D940 outlet 08.55 | 265 | 2/4/2013 |
| Barancabermeja Refinery | Fuel Gas | 2013-02-04 FID D942 09.00 | 267 | 2/4/2013 |
| Barancabermeja Refinery | Fuel Gas | 2013-02-04 FID D958 09.05 | 266 | 2/4/2013 |
| Barancabermeja Refinery | Fuel Gas | 2013-02-06 FID Guajira 10.17 | 273 | 2/6/2013 |

| | | | | |
|---|---|---|---|---|
| Barancabermeja Refinery | Fuel Gas | D-2421 | 28 | 2/1/2013 |
| Barancabermeja Refinery | Fuel Gas | D-940 | 30 | 2/1/2013 |
| Barancabermeja Refinery | Fuel Gas | D-942 | 31 | 2/4/2013 |
| Barancabermeja Refinery | Fuel Gas | D-958 | 29 | 2/1/2013 |
| Barancabermeja Refinery | Fuel Gas | Mix Drum - D940 final outlet (refinery gas @ 100%) | 143 | 2/1/2013 |
| Barancabermeja Refinery | Fuel Gas | Mix Drum - D940 final outlet (refinery gas @50%) | 135 | 1/31/2013 |
| Barancabermeja Refinery | Fuel Gas | Mix Drum - D940 final outlet (refinery gas 85%) | 156 | 2/4/2013 |
| Barancabermeja Refinery | Fuel Gas | Mix Drum - D940 outlet | 145 | 2/1/2013 |
| Barancabermeja Refinery | Fuel Gas | Mix Drum - D940 outlet (HDT, Orthoflow and mod IV) | 134 | 1/31/2013 |
| Barancabermeja Refinery | Fuel Gas | Mix Drum - D940 outlet (top of the drum) | 152 | 2/4/2013 |
| Barancabermeja Refinery | Fuel Gas | Mix Drum - Inlet and outlet D-942 | 147 | 2/1/2013 |
| Barancabermeja Refinery | Fuel Gas | Mix Drum - Inlet and outlet D-942 (Feb 04) | 154 | 2/4/2013 |
| Barancabermeja Refinery | Fuel Gas | Mix Drum - Inlet and outlet D958 (Feb 01) | 140 | 2/1/2013 |
| Barancabermeja Refinery | Fuel Gas | Mix Drum - Inlet and outlet D958 (Feb 04) | 153 | 2/4/2013 |
| Barancabermeja Refinery | Fuel Gas | Mix Drum - Inlet and outlet of D-4322 | 139 | 2/1/2013 |
| Barancabermeja Refinery | Fuel Gas | Mix Drum - Outlet D-2421 | 137 | 2/1/2013 |
| Barancabermeja Refinery | Fuel Gas | Mix Drum - Outlet D-2421 (Feb01) | 138 | 2/1/2013 |
| Barancabermeja Refinery | Fuel Gas | Mix Drum - Outlet D-2421 (Feb04) | 155 | 2/4/2013 |
| Barancabermeja Refinery | Fuel Gas | Mix Drum - Outlet D-2953 | 148 | 2/2/2013 |
| Barancabermeja Refinery | Refinery Gas | 2013-01-31 FID 940 inlet mod 4 15.40 | 248 | 1/31/2013 |
| Barancabermeja Refinery | Refinery Gas | 2013-02-01 FID UOP2 D4322 10.20 | 254 | 2/1/2013 |
| Barancabermeja Refinery | Refinery Gas | 2013-02-01 FID UOP2 Inlet 09.05 | 252 | 2/1/2013 |
| Barancabermeja Refinery | Refinery Gas | 2013-02-02 FID D2953 inlet UOPI 13.50 | 263 | 2/2/2013 |
| Barancabermeja Refinery | Refinery Gas | 2013-02-02 FID D2991 inlet A27590 15.05 | 264 | 2/2/2013 |
| Barancabermeja Refinery | Refinery Gas | 2013-02-04 FID D2421 UOP2 09.25 | 271 | 2/4/2013 |
| Barancabermeja Refinery | Refinery Gas | 2013-02-04 FID RefineryStd | 272 | 2/4/2013 |
| Barancabermeja Refinery | Refinery Gas | D-2953 | 32 | 2/2/2013 |
| Barancabermeja Refinery | Refinery Gas | Mix Drum - D940 inlet HDT | 136 | 1/31/2013 |
| Barancabermeja Refinery | Refinery Gas | Mix Drum - D940 inlet mod 4 (D313 & D308) | 133 | 1/31/2013 |
| Barancabermeja Refinery | Refinery Gas | Mix Drum - D940 inlet mod 4 (FCC) | 157 | 2/4/2013 |
| Barancabermeja Refinery | Refinery Gas | Mix Drum - D940 mod 4 | 146 | 2/1/2013 |
| Barancabermeja Refinery | Refinery Gas | Mix Drum - Inlet D-2421 | 158 | 2/4/2013 |
| Barancabermeja Refinery | Refinery Gas | Mix Drum - Inlet D-2953-UOP1 | 150 | 2/2/2013 |
| Barancabermeja Refinery | Refinery Gas | Mix Drum - Inlet D-2991 | 151 | 2/2/2013 |

| Calculated or Reported Compositions | | | | |
|---|---|---|---|---|
| **Facility** | **Substance** | **Composition Name** | **Clearstone ID #** | **Data Entry Date** |
| Barancabermeja Refinery | Fuel Gas | Dry Natural Gas | 301 | 9/8/2013 |
| Barancabermeja Refinery | Fuel Gas | Refinary Fuel Composition | 38 | 3/27/2013 |
| Barancabermeja Refinery | Process Gas | Vapor | 37 | 3/20/2013 |
| Barancabermeja Refinery | Waste Gas | TEA-1 | 39 | 3/28/2013 |
| Barancabermeja Refinery | Waste Gas | TEA-2 | 40 | 3/28/2013 |
| Barancabermeja Refinery | Waste Gas | TEA-3 | 41 | 3/28/2013 |
| Barancabermeja Refinery | Waste Gas | TEA-4 | 42 | 3/28/2013 |
| Barancabermeja Refinery | Waste Gas | TEA-6 | 43 | 3/28/2013 |
| Barancabermeja Refinery | Waste Gas | TEA-7 | 44 | 3/28/2013 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | Gas de Campos |
| **Description and Comments** | Purchase Gas. "Gas de Campos" is "Field Gas" is Spanish. Automatically entered raw data. |
| **Data Entry Date** | 2013/03/28 |
| **Sample Date** | 2/6/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Field Gas |
| **Clearstone ID** | 47 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Ethane | 0.066727 | 0.066727 | 0.067874 |
| Isobutane | 0.000409 | 0.000409 | 0.000416 |
| Isopentane | 0.000194 | 0.000194 | 0.000198 |
| Methane | 0.901302 | 0.901302 | 0.916801 |
| n-Butane | 0.000713 | 0.000713 | 0.000725 |
| n-Heptane | 0.000564 | 0.000564 | 0.000573 |
| n-Hexane | 0.000229 | 0.000229 | 0.000233 |
| Nitrogen | 0.014936 | 0.014936 | 0.001634 |
| n-Pentane | 0.000254 | 0.000254 | 0.000259 |
| Oxygen | 0.003576 | 0.003576 | 0.000000 |
| Propane | 0.011096 | 0.011096 | 0.011287 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | Mix Drum - Inlet D-2953 |
| **Description and Comments** | Nat gas line |
| **Data Entry Date** | 2013/07/18 |
| **Sample Date** | 2/2/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Field Gas |
| **Clearstone ID** | 149 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Ethane | 0.040830 | 0.040830 | 0.041435 |
| Hydrogen (normal) | 0.015585 | 0.015585 | 0.015816 |
| Isobutane | 0.002245 | 0.002245 | 0.002278 |
| Isopentane | 0.000680 | 0.000680 | 0.000690 |
| Methane | 0.906545 | 0.906545 | 0.919985 |
| n-Butane | 0.002460 | 0.002460 | 0.002496 |
| n-Heptane | 0.000360 | 0.000360 | 0.000365 |
| n-Hexane | 0.000260 | 0.000260 | 0.000264 |
| Nitrogen | 0.016140 | 0.016140 | 0.004689 |
| n-Pentane | 0.000585 | 0.000585 | 0.000594 |
| Oxygen | 0.003090 | 0.003090 | 0.000000 |
| Propane | 0.011220 | 0.011220 | 0.011386 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-01-31 FID D562 fgd 10.30 |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 1/31/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 247 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.020415 | 0.020415 | 0.020850 |
| Ethane | 0.152380 | 0.152380 | 0.155629 |
| Hydrogen (normal) | 0.317860 | 0.317860 | 0.324636 |
| Isobutane | 0.010550 | 0.010550 | 0.010775 |
| Isopentane | 0.001695 | 0.001695 | 0.001731 |
| Methane | 0.319630 | 0.319630 | 0.326444 |
| n-Butane | 0.011400 | 0.011400 | 0.011643 |
| n-Heptane | 0.000165 | 0.000165 | 0.000169 |
| n-Hexane | 0.000140 | 0.000140 | 0.000143 |
| Nitrogen | 0.060455 | 0.060455 | 0.044934 |
| n-Pentane | 0.001000 | 0.001000 | 0.001021 |
| Oxygen | 0.004415 | 0.004415 | 0.000000 |
| Propane | 0.099895 | 0.099895 | 0.102025 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-01-31 FID D562 fgd 11.10 |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 1/31/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 246 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.024235 | 0.024235 | 0.024971 |
| Ethane | 0.150605 | 0.150605 | 0.155179 |
| Hydrogen (normal) | 0.313950 | 0.313950 | 0.323486 |
| Isobutane | 0.010445 | 0.010445 | 0.010762 |
| Isopentane | 0.001740 | 0.001740 | 0.001793 |
| Methane | 0.317805 | 0.317805 | 0.327458 |
| n-Butane | 0.011425 | 0.011425 | 0.011772 |
| n-Heptane | 0.000195 | 0.000195 | 0.000201 |
| n-Hexane | 0.000195 | 0.000195 | 0.000201 |
| Nitrogen | 0.062400 | 0.062400 | 0.040346 |
| n-Pentane | 0.001080 | 0.001080 | 0.001113 |
| Oxygen | 0.006235 | 0.006235 | 0.000000 |
| Propane | 0.099690 | 0.099690 | 0.102718 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-01-31 FID D940 final outlet 16.05 |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 1/31/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 250 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.015190 | 0.015190 | 0.015537 |
| Ethane | 0.117375 | 0.117375 | 0.120060 |
| Hydrogen (normal) | 0.333865 | 0.333865 | 0.341502 |
| Isobutane | 0.019040 | 0.019040 | 0.019476 |
| Isopentane | 0.002740 | 0.002740 | 0.002803 |
| Methane | 0.339655 | 0.339655 | 0.347424 |
| n-Butane | 0.010285 | 0.010285 | 0.010520 |
| n-Heptane | 0.000450 | 0.000450 | 0.000460 |
| n-Hexane | 0.000385 | 0.000385 | 0.000394 |
| Nitrogen | 0.042715 | 0.042715 | 0.025656 |
| n-Pentane | 0.001545 | 0.001545 | 0.001580 |
| Oxygen | 0.004730 | 0.004730 | 0.000000 |
| Propane | 0.112025 | 0.112025 | 0.114588 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

CLEARSTONE ENGINEERING

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-01-31 FID D940 H65019 FG 14.17 |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 1/31/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 251 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.000000 | 0.000000 | 0.000000 |
| Ethane | 0.074085 | 0.074085 | 0.075904 |
| Hydrogen (normal) | 0.468795 | 0.468795 | 0.480308 |
| Isobutane | 0.009055 | 0.009055 | 0.009277 |
| Isopentane | 0.007115 | 0.007115 | 0.007290 |
| Methane | 0.364880 | 0.364880 | 0.373841 |
| n-Butane | 0.011380 | 0.011380 | 0.011659 |
| n-Heptane | 0.000785 | 0.000785 | 0.000804 |
| n-Hexane | 0.001515 | 0.001515 | 0.001552 |
| Nitrogen | 0.021445 | 0.021445 | 0.002607 |
| n-Pentane | 0.005040 | 0.005040 | 0.005164 |
| Oxygen | 0.005070 | 0.005070 | 0.000000 |
| Propane | 0.030835 | 0.030835 | 0.031592 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-01-31 FID D940 outlet 15.55 |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 1/31/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 249 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.015310 | 0.015310 | 0.015601 |
| Ethane | 0.118240 | 0.118240 | 0.120487 |
| Hydrogen (normal) | 0.343650 | 0.343650 | 0.350181 |
| Isobutane | 0.016190 | 0.016190 | 0.016498 |
| Isopentane | 0.002825 | 0.002825 | 0.002879 |
| Methane | 0.333120 | 0.333120 | 0.339451 |
| n-Butane | 0.010705 | 0.010705 | 0.010908 |
| n-Heptane | 0.000320 | 0.000320 | 0.000326 |
| n-Hexane | 0.000365 | 0.000365 | 0.000372 |
| Nitrogen | 0.040145 | 0.040145 | 0.025922 |
| n-Pentane | 0.001635 | 0.001635 | 0.001666 |
| Oxygen | 0.003945 | 0.003945 | 0.000000 |
| Propane | 0.113550 | 0.113550 | 0.115708 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-02-01 FID D2421 outlet 09.21 |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 2/1/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 253 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.001180 | 0.001180 | 0.001193 |
| Ethane | 0.051157 | 0.051157 | 0.051730 |
| Hydrogen (normal) | 0.000000 | 0.000000 | 0.000000 |
| Isobutane | 0.000815 | 0.000815 | 0.000824 |
| Isopentane | 0.000290 | 0.000290 | 0.000293 |
| Methane | 0.913340 | 0.913340 | 0.923576 |
| n-Butane | 0.000980 | 0.000980 | 0.000991 |
| n-Heptane | 0.000460 | 0.000460 | 0.000465 |
| n-Hexane | 0.000185 | 0.000185 | 0.000187 |
| Nitrogen | 0.020413 | 0.020413 | 0.011805 |
| n-Pentane | 0.000280 | 0.000280 | 0.000283 |
| Oxygen | 0.002344 | 0.002344 | 0.000000 |
| Propane | 0.008557 | 0.008557 | 0.008653 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-02-01 FID D940 mod 4 2.15 |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 2/1/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 258 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.014400 | 0.014400 | 0.014695 |
| Ethane | 0.104955 | 0.104955 | 0.107102 |
| Hydrogen (normal) | 0.344610 | 0.344610 | 0.351659 |
| Isobutane | 0.026585 | 0.026585 | 0.027129 |
| Isopentane | 0.001335 | 0.001335 | 0.001362 |
| Methane | 0.347555 | 0.347555 | 0.354665 |
| n-Butane | 0.011095 | 0.011095 | 0.011322 |
| n-Heptane | 0.000155 | 0.000155 | 0.000158 |
| n-Hexane | 0.000045 | 0.000045 | 0.000046 |
| Nitrogen | 0.040755 | 0.040755 | 0.025459 |
| n-Pentane | 0.000595 | 0.000595 | 0.000607 |
| Oxygen | 0.004240 | 0.004240 | 0.000000 |
| Propane | 0.103675 | 0.103675 | 0.105796 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-02-01 FID D940 out B951.2 2.55 |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 2/1/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 257 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.009065 | 0.009065 | 0.009272 |
| Ethane | 0.091295 | 0.091295 | 0.093383 |
| Hydrogen (normal) | 0.361855 | 0.361855 | 0.370132 |
| Isobutane | 0.017560 | 0.017560 | 0.017962 |
| Isopentane | 0.002765 | 0.002765 | 0.002828 |
| Methane | 0.393485 | 0.393485 | 0.402486 |
| n-Butane | 0.009735 | 0.009735 | 0.009958 |
| n-Heptane | 0.000625 | 0.000625 | 0.000639 |
| n-Hexane | 0.000555 | 0.000555 | 0.000568 |
| Nitrogen | 0.033885 | 0.033885 | 0.016624 |
| n-Pentane | 0.001620 | 0.001620 | 0.001657 |
| Oxygen | 0.004730 | 0.004730 | 0.000000 |
| Propane | 0.072825 | 0.072825 | 0.074491 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-02-01 FID D940 outlet 2.40 |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 2/1/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 256 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.010000 | 0.010000 | 0.010203 |
| Ethane | 0.095895 | 0.095895 | 0.097838 |
| Hydrogen (normal) | 0.373330 | 0.373330 | 0.380893 |
| Isobutane | 0.019025 | 0.019025 | 0.019410 |
| Isopentane | 0.002905 | 0.002905 | 0.002964 |
| Methane | 0.367680 | 0.367680 | 0.375129 |
| n-Butane | 0.010275 | 0.010275 | 0.010483 |
| n-Heptane | 0.000580 | 0.000580 | 0.000592 |
| n-Hexane | 0.000550 | 0.000550 | 0.000561 |
| Nitrogen | 0.034545 | 0.034545 | 0.019271 |
| n-Pentane | 0.001680 | 0.001680 | 0.001714 |
| Oxygen | 0.004200 | 0.004200 | 0.000000 |
| Propane | 0.079335 | 0.079335 | 0.080942 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-02-01 FID D942 aro boil 3.15 |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 2/1/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 259 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.003110 | 0.003110 | 0.003157 |
| Ethane | 0.055175 | 0.055175 | 0.056012 |
| Hydrogen (normal) | 0.333735 | 0.333735 | 0.338797 |
| Isobutane | 0.008140 | 0.008140 | 0.008263 |
| Isopentane | 0.001575 | 0.001575 | 0.001599 |
| Methane | 0.530570 | 0.530570 | 0.538617 |
| n-Butane | 0.006875 | 0.006875 | 0.006979 |
| n-Heptane | 0.000485 | 0.000485 | 0.000492 |
| n-Hexane | 0.000590 | 0.000590 | 0.000599 |
| Nitrogen | 0.020530 | 0.020530 | 0.008883 |
| n-Pentane | 0.000985 | 0.000985 | 0.001000 |
| Oxygen | 0.003160 | 0.003160 | 0.000000 |
| Propane | 0.035070 | 0.035070 | 0.035602 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-02-01 FID FGM D958 15.20 |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 2/1/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 255 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.014950 | 0.014950 | 0.015243 |
| Ethane | 0.070990 | 0.070990 | 0.072383 |
| Hydrogen (normal) | 0.109650 | 0.109650 | 0.111801 |
| Isobutane | 0.003550 | 0.003550 | 0.003620 |
| Isopentane | 0.000930 | 0.000930 | 0.000948 |
| Methane | 0.684470 | 0.684470 | 0.697899 |
| n-Butane | 0.003100 | 0.003100 | 0.003161 |
| n-Heptane | 0.000700 | 0.000700 | 0.000714 |
| n-Hexane | 0.000440 | 0.000440 | 0.000449 |
| Nitrogen | 0.034770 | 0.034770 | 0.019982 |
| n-Pentane | 0.000565 | 0.000565 | 0.000576 |
| Oxygen | 0.004070 | 0.004070 | 0.000000 |
| Propane | 0.071815 | 0.071815 | 0.073224 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-02-02 FID D2453 outlet 13.35 |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 2/2/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 260 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.002353 | 0.002353 | 0.002393 |
| Ethane | 0.043867 | 0.043867 | 0.044608 |
| Hydrogen (normal) | 0.078320 | 0.078320 | 0.079644 |
| Isobutane | 0.003047 | 0.003047 | 0.003098 |
| Isopentane | 0.000650 | 0.000650 | 0.000661 |
| Methane | 0.804520 | 0.804520 | 0.818122 |
| n-Butane | 0.006963 | 0.006963 | 0.007081 |
| n-Heptane | 0.000400 | 0.000400 | 0.000407 |
| n-Hexane | 0.000260 | 0.000260 | 0.000264 |
| Nitrogen | 0.025080 | 0.025080 | 0.012173 |
| n-Pentane | 0.000543 | 0.000543 | 0.000553 |
| Oxygen | 0.003517 | 0.003517 | 0.000000 |
| Propane | 0.030480 | 0.030480 | 0.030995 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-02-02 FID D2953 balace 13.20 |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 2/2/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 262 |

**Analysis Results**

| Component Name | Mole Fraction | | |
|---|---|---|---|
| | Entered | Normalized | Air Free |
| Carbon monoxide | 0.000000 | 0.000000 | 0.000000 |
| Ethane | 0.040830 | 0.040830 | 0.041435 |
| Hydrogen (normal) | 0.015585 | 0.015585 | 0.015816 |
| Isobutane | 0.002245 | 0.002245 | 0.002278 |
| Isopentane | 0.000680 | 0.000680 | 0.000690 |
| Methane | 0.906545 | 0.906545 | 0.919985 |
| n-Butane | 0.002460 | 0.002460 | 0.002496 |
| n-Heptane | 0.000360 | 0.000360 | 0.000365 |
| n-Hexane | 0.000260 | 0.000260 | 0.000264 |
| Nitrogen | 0.016140 | 0.016140 | 0.004689 |
| n-Pentane | 0.000585 | 0.000585 | 0.000594 |
| Oxygen | 0.003090 | 0.003090 | 0.000000 |
| Propane | 0.011220 | 0.011220 | 0.011386 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-02-02 FID feed VBK2 15.25 |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 2/2/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 261 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.003575 | 0.003575 | 0.003642 |
| Ethane | 0.025585 | 0.025585 | 0.026062 |
| Hydrogen (normal) | 0.765940 | 0.765940 | 0.780234 |
| Isobutane | 0.001795 | 0.001795 | 0.001828 |
| Isopentane | 0.000070 | 0.000070 | 0.000071 |
| Methane | 0.117750 | 0.117750 | 0.119947 |
| n-Butane | 0.006315 | 0.006315 | 0.006433 |
| n-Heptane | 0.000080 | 0.000080 | 0.000081 |
| n-Hexane | 0.000065 | 0.000065 | 0.000066 |
| Nitrogen | 0.015000 | 0.015000 | 0.000565 |
| n-Pentane | 0.000110 | 0.000110 | 0.000112 |
| Oxygen | 0.003875 | 0.003875 | 0.000000 |
| Propane | 0.059840 | 0.059840 | 0.060957 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-02-04 FID D2421 out 09.30 |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 2/4/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 268 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.006020 | 0.006020 | 0.006138 |
| Ethane | 0.050100 | 0.050100 | 0.051084 |
| Hydrogen (normal) | 0.020960 | 0.020960 | 0.021372 |
| Isobutane | 0.002360 | 0.002360 | 0.002406 |
| Isopentane | 0.000775 | 0.000775 | 0.000790 |
| Methane | 0.869815 | 0.869815 | 0.886902 |
| n-Butane | 0.002930 | 0.002930 | 0.002988 |
| n-Heptane | 0.000500 | 0.000500 | 0.000510 |
| n-Hexane | 0.000345 | 0.000345 | 0.000352 |
| Nitrogen | 0.027150 | 0.027150 | 0.012194 |
| n-Pentane | 0.000675 | 0.000675 | 0.000688 |
| Oxygen | 0.004075 | 0.004075 | 0.000000 |
| Propane | 0.014295 | 0.014295 | 0.014576 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-02-04 FID D940 mod 4 08.25 |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 2/4/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 270 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.015110 | 0.015110 | 0.015381 |
| Ethane | 0.104915 | 0.104915 | 0.106793 |
| Hydrogen (normal) | 0.339985 | 0.339985 | 0.346072 |
| Isobutane | 0.033200 | 0.033200 | 0.033794 |
| Isopentane | 0.000350 | 0.000350 | 0.000356 |
| Methane | 0.342530 | 0.342530 | 0.348662 |
| n-Butane | 0.021190 | 0.021190 | 0.021569 |
| n-Heptane | 0.000135 | 0.000135 | 0.000137 |
| n-Hexane | 0.000055 | 0.000055 | 0.000056 |
| Nitrogen | 0.042355 | 0.042355 | 0.028997 |
| n-Pentane | 0.000050 | 0.000050 | 0.000051 |
| Oxygen | 0.003720 | 0.003720 | 0.000000 |
| Propane | 0.096405 | 0.096405 | 0.098131 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-02-04 FID D940 out 08.40 |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 2/4/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 269 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.008125 | 0.008125 | 0.008314 |
| Ethane | 0.089475 | 0.089475 | 0.091557 |
| Hydrogen (normal) | 0.358865 | 0.358865 | 0.367216 |
| Isobutane | 0.020990 | 0.020990 | 0.021478 |
| Isopentane | 0.002790 | 0.002790 | 0.002855 |
| Methane | 0.398735 | 0.398735 | 0.408014 |
| n-Butane | 0.016165 | 0.016165 | 0.016541 |
| n-Heptane | 0.000595 | 0.000595 | 0.000609 |
| n-Hexane | 0.000595 | 0.000595 | 0.000609 |
| Nitrogen | 0.031555 | 0.031555 | 0.013941 |
| n-Pentane | 0.001905 | 0.001905 | 0.001949 |
| Oxygen | 0.004810 | 0.004810 | 0.000000 |
| Propane | 0.065395 | 0.065395 | 0.066917 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

CLEARSTONE ENGINEERING

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-02-04 FID D940 outlet 08.55 |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 2/4/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 265 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.009335 | 0.009335 | 0.009483 |
| Ethane | 0.092650 | 0.092650 | 0.094121 |
| Hydrogen (normal) | 0.392525 | 0.392525 | 0.398756 |
| Isobutane | 0.023315 | 0.023315 | 0.023685 |
| Isopentane | 0.002775 | 0.002775 | 0.002819 |
| Methane | 0.355050 | 0.355050 | 0.360686 |
| n-Butane | 0.017350 | 0.017350 | 0.017625 |
| n-Heptane | 0.000630 | 0.000630 | 0.000640 |
| n-Hexane | 0.000585 | 0.000585 | 0.000594 |
| Nitrogen | 0.029315 | 0.029315 | 0.017264 |
| n-Pentane | 0.001905 | 0.001905 | 0.001935 |
| Oxygen | 0.003305 | 0.003305 | 0.000000 |
| Propane | 0.071260 | 0.071260 | 0.072391 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-02-04 FID D942 09.00 |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 2/4/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 267 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.003140 | 0.003140 | 0.003209 |
| Ethane | 0.055125 | 0.055125 | 0.056342 |
| Hydrogen (normal) | 0.355785 | 0.355785 | 0.363642 |
| Isobutane | 0.009620 | 0.009620 | 0.009832 |
| Isopentane | 0.001525 | 0.001525 | 0.001559 |
| Methane | 0.497710 | 0.497710 | 0.508701 |
| n-Butane | 0.010135 | 0.010135 | 0.010359 |
| n-Heptane | 0.000680 | 0.000680 | 0.000695 |
| n-Hexane | 0.000605 | 0.000605 | 0.000618 |
| Nitrogen | 0.025590 | 0.025590 | 0.008743 |
| n-Pentane | 0.001035 | 0.001035 | 0.001058 |
| Oxygen | 0.004570 | 0.004570 | 0.000000 |
| Propane | 0.034480 | 0.034480 | 0.035241 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-02-04 FID D958 09.05 |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 2/4/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 266 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.019345 | 0.019345 | 0.019749 |
| Ethane | 0.078695 | 0.078695 | 0.080340 |
| Hydrogen (normal) | 0.167115 | 0.167115 | 0.170608 |
| Isobutane | 0.004520 | 0.004520 | 0.004614 |
| Isopentane | 0.001135 | 0.001135 | 0.001159 |
| Methane | 0.656000 | 0.656000 | 0.669710 |
| n-Butane | 0.003995 | 0.003995 | 0.004078 |
| n-Heptane | 0.000850 | 0.000850 | 0.000868 |
| n-Hexane | 0.000565 | 0.000565 | 0.000577 |
| Nitrogen | 0.040935 | 0.040935 | 0.025311 |
| n-Pentane | 0.000725 | 0.000725 | 0.000740 |
| Oxygen | 0.004330 | 0.004330 | 0.000000 |
| Propane | 0.021790 | 0.021790 | 0.022245 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-02-06 FID Guajira 10.17 |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 2/6/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 273 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.000000 | 0.000000 | 0.000000 |
| Ethane | 0.003187 | 0.003187 | 0.003259 |
| Hydrogen (normal) | 0.000000 | 0.000000 | 0.000000 |
| Isobutane | 0.000151 | 0.000151 | 0.000154 |
| Isopentane | 0.000028 | 0.000028 | 0.000029 |
| Methane | 0.963962 | 0.963962 | 0.985589 |
| n-Butane | 0.000066 | 0.000066 | 0.000067 |
| n-Heptane | 0.000050 | 0.000050 | 0.000051 |
| n-Hexane | 0.000013 | 0.000013 | 0.000013 |
| Nitrogen | 0.027393 | 0.027393 | 0.010317 |
| n-Pentane | 0.000019 | 0.000019 | 0.000019 |
| Oxygen | 0.004641 | 0.004641 | 0.000000 |
| Propane | 0.000490 | 0.000490 | 0.000501 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

CLEARSTONE ENGINEERING

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | D-2421 |
| **Description and Comments** | Central Norte boilers' feed stream composition. Equivalent to Mix Drum - Outlet D-2421 (Feb 01) |
| **Data Entry Date** | 2013/02/25 |
| **Sample Date** | 2/1/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 28 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.001190 | 0.001180 | 0.001193 |
| Ethane | 0.051599 | 0.051157 | 0.051731 |
| Isobutane | 0.000822 | 0.000815 | 0.000824 |
| Isopentane | 0.000292 | 0.000290 | 0.000293 |
| Methane | 0.921223 | 0.913340 | 0.923574 |
| n-Butane | 0.000988 | 0.000980 | 0.000991 |
| n-Heptane | 0.000464 | 0.000460 | 0.000465 |
| n-Hexane | 0.000187 | 0.000185 | 0.000187 |
| Nitrogen | 0.020589 | 0.020413 | 0.011806 |
| n-Pentane | 0.000282 | 0.000280 | 0.000283 |
| Oxygen | 0.002364 | 0.002344 | 0.000000 |
| Propane | 0.008631 | 0.008557 | 0.008653 |
| **Total** | 1.008631 | 1.000000 | 1.000000 |

CLEARSTONE ENGINEERING

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | D-940 |
| **Description and Comments** | Calderas Nuevas boilers' feed stream composition. Equivent to Mix Drum - D940 final outlet (refinery gas @ 100%) |
| **Data Entry Date** | 2013/02/25 |
| **Sample Date** | 2/1/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 30 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.009065 | 0.009065 | 0.009272 |
| Ethane | 0.091295 | 0.091295 | 0.093383 |
| Hydrogen (normal) | 0.361855 | 0.361855 | 0.370132 |
| Isobutane | 0.017560 | 0.017560 | 0.017962 |
| Isopentane | 0.002765 | 0.002765 | 0.002828 |
| Methane | 0.393485 | 0.393485 | 0.402486 |
| n-Butane | 0.009735 | 0.009735 | 0.009958 |
| n-Heptane | 0.000625 | 0.000625 | 0.000639 |
| n-Hexane | 0.000555 | 0.000555 | 0.000568 |
| Nitrogen | 0.033885 | 0.033885 | 0.016624 |
| n-Pentane | 0.001620 | 0.001620 | 0.001657 |
| Oxygen | 0.004730 | 0.004730 | 0.000000 |
| Propane | 0.072825 | 0.072825 | 0.074491 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | D-942 |
| **Description and Comments** | Foster boilers' feed stream composition. Equivalent to Mix Drum - Inlet and outlet D-942 (Feb 04) |
| **Data Entry Date** | 2013/02/25 |
| **Sample Date** | 2/4/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 31 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.003140 | 0.003140 | 0.003209 |
| Ethane | 0.055125 | 0.055125 | 0.056342 |
| Hydrogen (normal) | 0.355785 | 0.355785 | 0.363642 |
| Isobutane | 0.009620 | 0.009620 | 0.009832 |
| Isopentane | 0.001525 | 0.001525 | 0.001559 |
| Methane | 0.497710 | 0.497710 | 0.508701 |
| n-Butane | 0.010135 | 0.010135 | 0.010359 |
| n-Heptane | 0.000680 | 0.000680 | 0.000695 |
| n-Hexane | 0.000605 | 0.000605 | 0.000618 |
| Nitrogen | 0.025590 | 0.025590 | 0.008743 |
| n-Pentane | 0.001035 | 0.001035 | 0.001058 |
| Oxygen | 0.004570 | 0.004570 | 0.000000 |
| Propane | 0.034480 | 0.034480 | 0.035241 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

CLEARSTONE ENGINEERING

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | D-958 |
| **Description and Comments** | Distral boilers' feed stream composition. Equivalent to Mix Drum - Inlet and outlet D958 (Feb 01) |
| **Data Entry Date** | 2013/02/25 |
| **Sample Date** | 2/1/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 29 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.014950 | 0.014950 | 0.015243 |
| Ethane | 0.070990 | 0.070990 | 0.072383 |
| Hydrogen (normal) | 0.109650 | 0.109650 | 0.111801 |
| Isobutane | 0.003550 | 0.003550 | 0.003620 |
| Isopentane | 0.000930 | 0.000930 | 0.000948 |
| Methane | 0.684470 | 0.684470 | 0.697899 |
| n-Butane | 0.003100 | 0.003100 | 0.003161 |
| n-Heptane | 0.000700 | 0.000700 | 0.000714 |
| n-Hexane | 0.000440 | 0.000440 | 0.000449 |
| Nitrogen | 0.034770 | 0.034770 | 0.019982 |
| n-Pentane | 0.000565 | 0.000565 | 0.000576 |
| Oxygen | 0.004070 | 0.004070 | 0.000000 |
| Propane | 0.071815 | 0.071815 | 0.073224 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | Mix Drum - D940 final outlet (refinery gas @ 100%) |
| **Description and Comments** | outlet of D-940, mixed with refinery gas control valve 100% open |
| **Data Entry Date** | 2013/07/18 |
| **Sample Date** | 2/1/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 143 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.009065 | 0.009065 | 0.009272 |
| Ethane | 0.091295 | 0.091295 | 0.093383 |
| Hydrogen (normal) | 0.361855 | 0.361855 | 0.370132 |
| Isobutane | 0.017560 | 0.017560 | 0.017962 |
| Isopentane | 0.002765 | 0.002765 | 0.002828 |
| Methane | 0.393485 | 0.393485 | 0.402486 |
| n-Butane | 0.009735 | 0.009735 | 0.009958 |
| n-Heptane | 0.000625 | 0.000625 | 0.000639 |
| n-Hexane | 0.000555 | 0.000555 | 0.000568 |
| Nitrogen | 0.033885 | 0.033885 | 0.016624 |
| n-Pentane | 0.001620 | 0.001620 | 0.001657 |
| Oxygen | 0.004730 | 0.004730 | 0.000000 |
| Propane | 0.072825 | 0.072825 | 0.074491 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | Mix Drum - D940 final outlet (refinery gas @50%) |
| **Description and Comments** | outlet of D-940, mixed with refinery gas control valve 50% open |
| **Data Entry Date** | 2013/07/18 |
| **Sample Date** | 1/31/2013 |
| **Sample Type** | Air Free |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 135 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.015190 | 0.015190 | 0.015537 |
| Ethane | 0.117375 | 0.117375 | 0.120060 |
| Hydrogen (normal) | 0.333865 | 0.333865 | 0.341502 |
| Isobutane | 0.019040 | 0.019040 | 0.019476 |
| Isopentane | 0.002740 | 0.002740 | 0.002803 |
| Methane | 0.339655 | 0.339655 | 0.347424 |
| n-Butane | 0.010285 | 0.010285 | 0.010520 |
| n-Heptane | 0.000450 | 0.000450 | 0.000460 |
| n-Hexane | 0.000385 | 0.000385 | 0.000394 |
| Nitrogen | 0.042715 | 0.042715 | 0.025656 |
| n-Pentane | 0.001545 | 0.001545 | 0.001580 |
| Oxygen | 0.004730 | 0.004730 | 0.000000 |
| Propane | 0.112025 | 0.112025 | 0.114588 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | Mix Drum - D940 final outlet (refinery gas 85%) |
| **Description and Comments** | outlet of D-940, mixed with refinery gas and gas from aromatic plant control valve 85% open |
| **Data Entry Date** | 2013/07/18 |
| **Sample Date** | 2/4/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 156 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.008125 | 0.008125 | 0.008314 |
| Ethane | 0.089475 | 0.089475 | 0.091557 |
| Hydrogen (normal) | 0.358865 | 0.358865 | 0.367216 |
| Isobutane | 0.020990 | 0.020990 | 0.021478 |
| Isopentane | 0.002790 | 0.002790 | 0.002855 |
| Methane | 0.398735 | 0.398735 | 0.408014 |
| n-Butane | 0.016165 | 0.016165 | 0.016541 |
| n-Heptane | 0.000595 | 0.000595 | 0.000609 |
| n-Hexane | 0.000595 | 0.000595 | 0.000609 |
| Nitrogen | 0.031555 | 0.031555 | 0.013941 |
| n-Pentane | 0.001905 | 0.001905 | 0.001949 |
| Oxygen | 0.004810 | 0.004810 | 0.000000 |
| Propane | 0.065395 | 0.065395 | 0.066917 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | Mix Drum - D940 outlet |
| **Description and Comments** | from the top of the drum- mix of: HDT and mod IV (no Orthoflow) |
| **Data Entry Date** | 2013/07/18 |
| **Sample Date** | 2/1/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 145 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.010000 | 0.010000 | 0.010203 |
| Ethane | 0.095895 | 0.095895 | 0.097838 |
| Hydrogen (normal) | 0.373330 | 0.373330 | 0.380893 |
| Isobutane | 0.019025 | 0.019025 | 0.019410 |
| Isopentane | 0.002905 | 0.002905 | 0.002964 |
| Methane | 0.367680 | 0.367680 | 0.375129 |
| n-Butane | 0.010275 | 0.010275 | 0.010483 |
| n-Heptane | 0.000580 | 0.000580 | 0.000592 |
| n-Hexane | 0.000550 | 0.000550 | 0.000561 |
| Nitrogen | 0.034545 | 0.034545 | 0.019271 |
| n-Pentane | 0.001680 | 0.001680 | 0.001714 |
| Oxygen | 0.004200 | 0.004200 | 0.000000 |
| Propane | 0.079335 | 0.079335 | 0.080942 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | Mix Drum - D940 outlet (HDT, Orthoflow and mod IV) |
| **Description and Comments** | from the top of the drum- mix of: HDT, Orthoflow and mod IV |
| **Data Entry Date** | 2013/07/18 |
| **Sample Date** | 1/31/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 134 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.015310 | 0.015310 | 0.015601 |
| Ethane | 0.118240 | 0.118240 | 0.120487 |
| Hydrogen (normal) | 0.343650 | 0.343650 | 0.350181 |
| Isobutane | 0.016190 | 0.016190 | 0.016498 |
| Isopentane | 0.002825 | 0.002825 | 0.002879 |
| Methane | 0.333120 | 0.333120 | 0.339451 |
| n-Butane | 0.010705 | 0.010705 | 0.010908 |
| n-Heptane | 0.000320 | 0.000320 | 0.000326 |
| n-Hexane | 0.000365 | 0.000365 | 0.000372 |
| Nitrogen | 0.040145 | 0.040145 | 0.025922 |
| n-Pentane | 0.001635 | 0.001635 | 0.001666 |
| Oxygen | 0.003945 | 0.003945 | 0.000000 |
| Propane | 0.113550 | 0.113550 | 0.115708 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | Mix Drum - D940 outlet (top of the drum) |
| **Description and Comments** | from the top of the drum |
| **Data Entry Date** | 2013/07/18 |
| **Sample Date** | 2/4/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 152 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.009335 | 0.009335 | 0.009483 |
| Ethane | 0.092650 | 0.092650 | 0.094121 |
| Hydrogen (normal) | 0.392525 | 0.392525 | 0.398756 |
| Isobutane | 0.023315 | 0.023315 | 0.023685 |
| Isopentane | 0.002775 | 0.002775 | 0.002819 |
| Methane | 0.355050 | 0.355050 | 0.360686 |
| n-Butane | 0.017350 | 0.017350 | 0.017625 |
| n-Heptane | 0.000630 | 0.000630 | 0.000640 |
| n-Hexane | 0.000585 | 0.000585 | 0.000594 |
| Nitrogen | 0.029315 | 0.029315 | 0.017264 |
| n-Pentane | 0.001905 | 0.001905 | 0.001935 |
| Oxygen | 0.003305 | 0.003305 | 0.000000 |
| Propane | 0.071260 | 0.071260 | 0.072391 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

CLEARSTONE ENGINEERING

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | Mix Drum - Inlet and outlet D-942 |
| **Description and Comments** | From Aromatic plant to Foster Boilers (B-901B and B-901D). Only one input stream at time of sample. |
| **Data Entry Date** | 2013/07/18 |
| **Sample Date** | 2/1/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 147 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.003110 | 0.003110 | 0.003157 |
| Ethane | 0.055175 | 0.055175 | 0.056012 |
| Hydrogen (normal) | 0.333735 | 0.333735 | 0.338797 |
| Isobutane | 0.008140 | 0.008140 | 0.008263 |
| Isopentane | 0.001575 | 0.001575 | 0.001599 |
| Methane | 0.530570 | 0.530570 | 0.538617 |
| n-Butane | 0.006875 | 0.006875 | 0.006979 |
| n-Heptane | 0.000485 | 0.000485 | 0.000492 |
| n-Hexane | 0.000590 | 0.000590 | 0.000599 |
| Nitrogen | 0.020530 | 0.020530 | 0.008883 |
| n-Pentane | 0.000985 | 0.000985 | 0.001000 |
| Oxygen | 0.003160 | 0.003160 | 0.000000 |
| Propane | 0.035070 | 0.035070 | 0.035602 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | Mix Drum - Inlet and outlet D-942 (Feb 04) |
| **Description and Comments** | From Aromatic plant to Foster Boilers (B-901B and B-901D). Only one input stream at time of sample. |
| **Data Entry Date** | 2013/07/18 |
| **Sample Date** | 2/4/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 154 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.003140 | 0.003140 | 0.003209 |
| Ethane | 0.055125 | 0.055125 | 0.056342 |
| Hydrogen (normal) | 0.355785 | 0.355785 | 0.363642 |
| Isobutane | 0.009620 | 0.009620 | 0.009832 |
| Isopentane | 0.001525 | 0.001525 | 0.001559 |
| Methane | 0.497710 | 0.497710 | 0.508701 |
| n-Butane | 0.010135 | 0.010135 | 0.010359 |
| n-Heptane | 0.000680 | 0.000680 | 0.000695 |
| n-Hexane | 0.000605 | 0.000605 | 0.000618 |
| Nitrogen | 0.025590 | 0.025590 | 0.008743 |
| n-Pentane | 0.001035 | 0.001035 | 0.001058 |
| Oxygen | 0.004570 | 0.004570 | 0.000000 |
| Propane | 0.034480 | 0.034480 | 0.035241 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | Mix Drum - Inlet and outlet D958 (Feb 01) |
| **Description and Comments** | From Aromatic plant to Distal Boilers. Only one input stream at time of sample. |
| **Data Entry Date** | 2013/07/18 |
| **Sample Date** | 2/1/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 140 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.014950 | 0.014950 | 0.015243 |
| Ethane | 0.070990 | 0.070990 | 0.072383 |
| Hydrogen (normal) | 0.109650 | 0.109650 | 0.111801 |
| Isobutane | 0.003550 | 0.003550 | 0.003620 |
| Isopentane | 0.000930 | 0.000930 | 0.000948 |
| Methane | 0.684470 | 0.684470 | 0.697899 |
| n-Butane | 0.003100 | 0.003100 | 0.003161 |
| n-Heptane | 0.000700 | 0.000700 | 0.000714 |
| n-Hexane | 0.000440 | 0.000440 | 0.000449 |
| Nitrogen | 0.034770 | 0.034770 | 0.019982 |
| n-Pentane | 0.000565 | 0.000565 | 0.000576 |
| Oxygen | 0.004070 | 0.004070 | 0.000000 |
| Propane | 0.071815 | 0.071815 | 0.073224 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | Mix Drum - Inlet and outlet D958 (Feb 04) |
| **Description and Comments** | From Aromatic plant to Distal Boilers. Only one input stream at time of sample. |
| **Data Entry Date** | 2013/07/18 |
| **Sample Date** | 2/4/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 153 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.019345 | 0.019345 | 0.019749 |
| Ethane | 0.078695 | 0.078695 | 0.080340 |
| Hydrogen (normal) | 0.167115 | 0.167115 | 0.170608 |
| Isobutane | 0.004520 | 0.004520 | 0.004614 |
| Isopentane | 0.001135 | 0.001135 | 0.001159 |
| Methane | 0.656000 | 0.656000 | 0.669710 |
| n-Butane | 0.003995 | 0.003995 | 0.004078 |
| n-Heptane | 0.000850 | 0.000850 | 0.000868 |
| n-Hexane | 0.000565 | 0.000565 | 0.000577 |
| Nitrogen | 0.040935 | 0.040935 | 0.025311 |
| n-Pentane | 0.000725 | 0.000725 | 0.000740 |
| Oxygen | 0.004330 | 0.004330 | 0.000000 |
| Propane | 0.021790 | 0.021790 | 0.022245 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | Mix Drum - Inlet and outlet of D-4322 |
| **Description and Comments** | Only one input stream at time of sample. |
| **Data Entry Date** | 2013/07/18 |
| **Sample Date** | 2/1/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 139 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.031370 | 0.031370 | 0.032621 |
| Ethane | 0.063695 | 0.063695 | 0.066235 |
| Hydrogen (normal) | 0.272110 | 0.272110 | 0.282960 |
| Isobutane | 0.000105 | 0.000105 | 0.000109 |
| Isopentane | 0.000140 | 0.000140 | 0.000146 |
| Methane | 0.553510 | 0.553510 | 0.575579 |
| n-Butane | 0.000170 | 0.000170 | 0.000177 |
| n-Heptane | 0.000315 | 0.000315 | 0.000328 |
| n-Hexane | 0.000030 | 0.000030 | 0.000031 |
| Nitrogen | 0.064315 | 0.064315 | 0.035441 |
| n-Pentane | 0.000070 | 0.000070 | 0.000073 |
| Oxygen | 0.008110 | 0.008110 | 0.000000 |
| Propane | 0.006060 | 0.006060 | 0.006302 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | Mix Drum - Outlet D-2421 |
| **Description and Comments** | N/A |
| **Data Entry Date** | 2013/07/18 |
| **Sample Date** | 2/1/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 137 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.031950 | 0.031950 | 0.032846 |
| Ethane | 0.076515 | 0.076515 | 0.078661 |
| Hydrogen (normal) | 0.276060 | 0.276060 | 0.283802 |
| Isobutane | 0.000690 | 0.000690 | 0.000709 |
| Isopentane | 0.000455 | 0.000455 | 0.000468 |
| Methane | 0.530540 | 0.530540 | 0.545419 |
| n-Butane | 0.001015 | 0.001015 | 0.001043 |
| n-Heptane | 0.000590 | 0.000590 | 0.000607 |
| n-Hexane | 0.000150 | 0.000150 | 0.000154 |
| Nitrogen | 0.066155 | 0.066155 | 0.045897 |
| n-Pentane | 0.000345 | 0.000345 | 0.000355 |
| Oxygen | 0.005770 | 0.005770 | 0.000000 |
| Propane | 0.009765 | 0.009765 | 0.010039 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | Mix Drum - Outlet D-2421 (Feb01) |
| **Description and Comments** | To boilers |
| **Data Entry Date** | 2013/07/18 |
| **Sample Date** | 2/1/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 138 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.001180 | 0.001180 | 0.001193 |
| Ethane | 0.051175 | 0.051157 | 0.051730 |
| Isobutane | 0.000815 | 0.000815 | 0.000824 |
| Isopentane | 0.000290 | 0.000290 | 0.000293 |
| Methane | 0.913660 | 0.913340 | 0.923576 |
| n-Butane | 0.000980 | 0.000980 | 0.000991 |
| n-Heptane | 0.000460 | 0.000460 | 0.000465 |
| n-Hexane | 0.000185 | 0.000185 | 0.000187 |
| Nitrogen | 0.020420 | 0.020413 | 0.011805 |
| n-Pentane | 0.000280 | 0.000280 | 0.000283 |
| Oxygen | 0.002345 | 0.002344 | 0.000000 |
| Propane | 0.008560 | 0.008557 | 0.008653 |
| **Total** | 1.000350 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | Mix Drum - Outlet D-2421 (Feb04) |
| **Description and Comments** | To Boilers |
| **Data Entry Date** | 2013/07/18 |
| **Sample Date** | 2/4/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 155 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.006020 | 0.006020 | 0.006138 |
| Ethane | 0.050100 | 0.050100 | 0.051084 |
| Hydrogen (normal) | 0.020960 | 0.020960 | 0.021372 |
| Isobutane | 0.002360 | 0.002360 | 0.002406 |
| Isopentane | 0.000775 | 0.000775 | 0.000790 |
| Methane | 0.869815 | 0.869815 | 0.886902 |
| n-Butane | 0.002930 | 0.002930 | 0.002988 |
| n-Heptane | 0.000500 | 0.000500 | 0.000510 |
| n-Hexane | 0.000345 | 0.000345 | 0.000352 |
| Nitrogen | 0.027150 | 0.027150 | 0.012194 |
| n-Pentane | 0.000675 | 0.000675 | 0.000688 |
| Oxygen | 0.004075 | 0.004075 | 0.000000 |
| Propane | 0.014295 | 0.014295 | 0.014576 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | Mix Drum - Outlet D-2953 |
| **Description and Comments** | mix of: Nat gas (hi-pressure) and gas from UOP1 (lo-pressure) |
| **Data Entry Date** | 2013/07/18 |
| **Sample Date** | 2/2/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 148 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.002353 | 0.002353 | 0.002393 |
| Ethane | 0.043867 | 0.043867 | 0.044608 |
| Hydrogen (normal) | 0.078320 | 0.078320 | 0.079644 |
| Isobutane | 0.003047 | 0.003047 | 0.003098 |
| Isopentane | 0.000650 | 0.000650 | 0.000661 |
| Methane | 0.804520 | 0.804520 | 0.818122 |
| n-Butane | 0.006963 | 0.006963 | 0.007081 |
| n-Heptane | 0.000400 | 0.000400 | 0.000407 |
| n-Hexane | 0.000260 | 0.000260 | 0.000264 |
| Nitrogen | 0.025080 | 0.025080 | 0.012173 |
| n-Pentane | 0.000543 | 0.000543 | 0.000553 |
| Oxygen | 0.003517 | 0.003517 | 0.000000 |
| Propane | 0.030480 | 0.030480 | 0.030995 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

CLEARSTONE ENGINEERING

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-01-31 FID 940 inlet mod 4 15.40 |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 1/31/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Refinery Gas |
| **Clearstone ID** | 248 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.014395 | 0.014395 | 0.014712 |
| Ethane | 0.110825 | 0.110825 | 0.113264 |
| Hydrogen (normal) | 0.375835 | 0.375835 | 0.384107 |
| Isobutane | 0.033525 | 0.033525 | 0.034263 |
| Isopentane | 0.001615 | 0.001615 | 0.001651 |
| Methane | 0.325280 | 0.325280 | 0.332439 |
| n-Butane | 0.010690 | 0.010690 | 0.010925 |
| n-Heptane | 0.000080 | 0.000080 | 0.000082 |
| n-Hexane | 0.000040 | 0.000040 | 0.000041 |
| Nitrogen | 0.038155 | 0.038155 | 0.021641 |
| n-Pentane | 0.000660 | 0.000660 | 0.000675 |
| Oxygen | 0.004555 | 0.004555 | 0.000000 |
| Propane | 0.084345 | 0.084345 | 0.086201 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-02-01 FID UOP2 D4322 10.20 |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 2/1/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Refinery Gas |
| **Clearstone ID** | 254 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.031370 | 0.031370 | 0.032621 |
| Ethane | 0.063695 | 0.063695 | 0.066235 |
| Hydrogen (normal) | 0.272110 | 0.272110 | 0.282960 |
| Isobutane | 0.000105 | 0.000105 | 0.000109 |
| Isopentane | 0.000140 | 0.000140 | 0.000146 |
| Methane | 0.553510 | 0.553510 | 0.575579 |
| n-Butane | 0.000170 | 0.000170 | 0.000177 |
| n-Heptane | 0.000315 | 0.000315 | 0.000328 |
| n-Hexane | 0.000030 | 0.000030 | 0.000031 |
| Nitrogen | 0.064315 | 0.064315 | 0.035441 |
| n-Pentane | 0.000070 | 0.000070 | 0.000073 |
| Oxygen | 0.008110 | 0.008110 | 0.000000 |
| Propane | 0.006060 | 0.006060 | 0.006302 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-02-01 FID UOP2 Inlet 09.05 |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 2/1/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Refinery Gas |
| **Clearstone ID** | 252 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.031950 | 0.031950 | 0.032846 |
| Ethane | 0.076515 | 0.076515 | 0.078661 |
| Hydrogen (normal) | 0.276060 | 0.276060 | 0.283802 |
| Isobutane | 0.000690 | 0.000690 | 0.000709 |
| Isopentane | 0.000455 | 0.000455 | 0.000468 |
| Methane | 0.530540 | 0.530540 | 0.545419 |
| n-Butane | 0.001015 | 0.001015 | 0.001043 |
| n-Heptane | 0.000590 | 0.000590 | 0.000607 |
| n-Hexane | 0.000150 | 0.000150 | 0.000154 |
| Nitrogen | 0.066155 | 0.066155 | 0.045897 |
| n-Pentane | 0.000345 | 0.000345 | 0.000355 |
| Oxygen | 0.005770 | 0.005770 | 0.000000 |
| Propane | 0.009765 | 0.009765 | 0.010039 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-02-02 FID D2953 inlet UOPI 13.50 |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 2/2/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Refinery Gas |
| **Clearstone ID** | 263 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.010535 | 0.010535 | 0.010752 |
| Ethane | 0.051010 | 0.051010 | 0.052060 |
| Hydrogen (normal) | 0.108930 | 0.108930 | 0.111172 |
| Isobutane | 0.003475 | 0.003475 | 0.003547 |
| Isopentane | 0.000680 | 0.000680 | 0.000694 |
| Methane | 0.743320 | 0.743320 | 0.758617 |
| n-Butane | 0.008455 | 0.008455 | 0.008629 |
| n-Heptane | 0.000650 | 0.000650 | 0.000663 |
| n-Hexane | 0.000300 | 0.000300 | 0.000306 |
| Nitrogen | 0.031455 | 0.031455 | 0.015876 |
| n-Pentane | 0.000555 | 0.000555 | 0.000566 |
| Oxygen | 0.004265 | 0.004265 | 0.000000 |
| Propane | 0.036370 | 0.036370 | 0.037118 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-02-02 FID D2991 inlet A27590 15.05 |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 2/2/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Refinery Gas |
| **Clearstone ID** | 264 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.038220 | 0.038220 | 0.039091 |
| Ethane | 0.025365 | 0.025365 | 0.025943 |
| Hydrogen (normal) | 0.279875 | 0.279875 | 0.286256 |
| Isobutane | 0.004190 | 0.004190 | 0.004286 |
| Isopentane | 0.000005 | 0.000005 | 0.000005 |
| Methane | 0.538990 | 0.538990 | 0.551279 |
| n-Butane | 0.003715 | 0.003715 | 0.003800 |
| n-Heptane | 0.000060 | 0.000060 | 0.000061 |
| n-Hexane | 0.000030 | 0.000030 | 0.000031 |
| Nitrogen | 0.070460 | 0.070460 | 0.054089 |
| n-Pentane | 0.000015 | 0.000015 | 0.000015 |
| Oxygen | 0.004715 | 0.004715 | 0.000000 |
| Propane | 0.034360 | 0.034360 | 0.035143 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-02-04 FID D2421 UOP2 09.25 |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 2/4/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Refinery Gas |
| **Clearstone ID** | 271 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.032575 | 0.032575 | 0.033326 |
| Ethane | 0.075095 | 0.075095 | 0.076826 |
| Hydrogen (normal) | 0.280165 | 0.280165 | 0.286622 |
| Isobutane | 0.000390 | 0.000390 | 0.000399 |
| Isopentane | 0.000155 | 0.000155 | 0.000159 |
| Methane | 0.530865 | 0.530865 | 0.543100 |
| n-Butane | 0.000880 | 0.000880 | 0.000900 |
| n-Heptane | 0.000185 | 0.000185 | 0.000189 |
| n-Hexane | 0.000075 | 0.000075 | 0.000077 |
| Nitrogen | 0.063905 | 0.063905 | 0.047205 |
| n-Pentane | 0.000085 | 0.000085 | 0.000087 |
| Oxygen | 0.004765 | 0.004765 | 0.000000 |
| Propane | 0.010860 | 0.010860 | 0.011110 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | 2013-02-04 FID RefineryStd |
| **Description and Comments** | Automatically entered raw data. |
| **Data Entry Date** | 2013/08/31 |
| **Sample Date** | 2/4/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Refinery Gas |
| **Clearstone ID** | 272 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.000000 | 0.000000 | 0.000000 |
| Ethane | 0.008555 | 0.008555 | 0.008916 |
| Hydrogen (normal) | 0.367525 | 0.367525 | 0.383045 |
| Isobutane | 0.039850 | 0.039850 | 0.041533 |
| Isopentane | 0.000235 | 0.000235 | 0.000245 |
| Methane | 0.000385 | 0.000385 | 0.000401 |
| n-Butane | 0.030200 | 0.030200 | 0.031475 |
| n-Heptane | 0.000105 | 0.000105 | 0.000109 |
| n-Hexane | 0.000060 | 0.000060 | 0.000063 |
| Nitrogen | 0.405015 | 0.405015 | 0.388821 |
| n-Pentane | 0.000305 | 0.000305 | 0.000318 |
| Oxygen | 0.008570 | 0.008570 | 0.000000 |
| Propane | 0.139195 | 0.139195 | 0.145073 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | D-2953 |
| **Description and Comments** | Balance boilers' feed stream composition.<br>Equivalent to Mix Drum - Inlet D-2953 |
| **Data Entry Date** | 2013/02/25 |
| **Sample Date** | 2/2/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Refinery Gas |
| **Clearstone ID** | 32 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Ethane | 0.040830 | 0.040830 | 0.041435 |
| Hydrogen (normal) | 0.015585 | 0.015585 | 0.015816 |
| Isobutane | 0.002245 | 0.002245 | 0.002278 |
| Isopentane | 0.000680 | 0.000680 | 0.000690 |
| Methane | 0.906545 | 0.906545 | 0.919985 |
| n-Butane | 0.002460 | 0.002460 | 0.002496 |
| n-Heptane | 0.000360 | 0.000360 | 0.000365 |
| n-Hexane | 0.000260 | 0.000260 | 0.000264 |
| Nitrogen | 0.016140 | 0.016140 | 0.004689 |
| n-Pentane | 0.000585 | 0.000585 | 0.000594 |
| Oxygen | 0.003090 | 0.003090 | 0.000000 |
| Propane | 0.011220 | 0.011220 | 0.011386 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | Mix Drum - D940 inlet HDT |
| **Description and Comments** | HDT |
| **Data Entry Date** | 2013/07/18 |
| **Sample Date** | 1/31/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Refinery Gas |
| **Clearstone ID** | 136 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Ethane | 0.074085 | 0.074085 | 0.075904 |
| Hydrogen (normal) | 0.468795 | 0.468795 | 0.480308 |
| Isobutane | 0.009055 | 0.009055 | 0.009277 |
| Isopentane | 0.007115 | 0.007115 | 0.007290 |
| Methane | 0.364880 | 0.364880 | 0.373841 |
| n-Butane | 0.011380 | 0.011380 | 0.011659 |
| n-Heptane | 0.000785 | 0.000785 | 0.000804 |
| n-Hexane | 0.001515 | 0.001515 | 0.001552 |
| Nitrogen | 0.021445 | 0.021445 | 0.002607 |
| n-Pentane | 0.005040 | 0.005040 | 0.005164 |
| Oxygen | 0.005070 | 0.005070 | 0.000000 |
| Propane | 0.030835 | 0.030835 | 0.031592 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

CLEARSTONE ENGINEERING

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | Mix Drum - D940 inlet mod 4 (D313 & D308) |
| **Description and Comments** | mod IV (from D313 &D308) |
| **Data Entry Date** | 2013/07/18 |
| **Sample Date** | 1/31/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Refinery Gas |
| **Clearstone ID** | 133 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.014395 | 0.014395 | 0.014712 |
| Ethane | 0.110825 | 0.110825 | 0.113264 |
| Hydrogen (normal) | 0.375835 | 0.375835 | 0.384107 |
| Isobutane | 0.033525 | 0.033525 | 0.034263 |
| Isopentane | 0.001615 | 0.001615 | 0.001651 |
| Methane | 0.325280 | 0.325280 | 0.332439 |
| n-Butane | 0.010690 | 0.010690 | 0.010925 |
| n-Heptane | 0.000080 | 0.000080 | 0.000082 |
| n-Hexane | 0.000040 | 0.000040 | 0.000041 |
| Nitrogen | 0.038155 | 0.038155 | 0.021641 |
| n-Pentane | 0.000660 | 0.000660 | 0.000675 |
| Oxygen | 0.004555 | 0.004555 | 0.000000 |
| Propane | 0.084345 | 0.084345 | 0.086201 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | Mix Drum - D940 inlet mod 4 (FCC) |
| **Description and Comments** | mod IV (from FCC) |
| **Data Entry Date** | 2013/07/18 |
| **Sample Date** | 2/4/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Refinery Gas |
| **Clearstone ID** | 157 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.015110 | 0.015110 | 0.015381 |
| Ethane | 0.104915 | 0.104915 | 0.106793 |
| Hydrogen (normal) | 0.339985 | 0.339985 | 0.346072 |
| Isobutane | 0.033200 | 0.033200 | 0.033794 |
| Isopentane | 0.000350 | 0.000350 | 0.000356 |
| Methane | 0.342530 | 0.342530 | 0.348662 |
| n-Butane | 0.021190 | 0.021190 | 0.021569 |
| n-Heptane | 0.000135 | 0.000135 | 0.000137 |
| n-Hexane | 0.000055 | 0.000055 | 0.000056 |
| Nitrogen | 0.042355 | 0.042355 | 0.028997 |
| n-Pentane | 0.000050 | 0.000050 | 0.000051 |
| Oxygen | 0.003720 | 0.003720 | 0.000000 |
| Propane | 0.096405 | 0.096405 | 0.098131 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

CLEARSTONE ENGINEERING

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | Mix Drum - D940 mod 4 |
| **Description and Comments** | mod IV (from D313) |
| **Data Entry Date** | 2013/07/18 |
| **Sample Date** | 2/1/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Refinery Gas |
| **Clearstone ID** | 146 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.014400 | 0.014400 | 0.014695 |
| Ethane | 0.104955 | 0.104955 | 0.107102 |
| Hydrogen (normal) | 0.344610 | 0.344610 | 0.351659 |
| Isobutane | 0.026585 | 0.026585 | 0.027129 |
| Isopentane | 0.001335 | 0.001335 | 0.001362 |
| Methane | 0.347555 | 0.347555 | 0.354665 |
| n-Butane | 0.011095 | 0.011095 | 0.011322 |
| n-Heptane | 0.000155 | 0.000155 | 0.000158 |
| n-Hexane | 0.000045 | 0.000045 | 0.000046 |
| Nitrogen | 0.040755 | 0.040755 | 0.025459 |
| n-Pentane | 0.000595 | 0.000595 | 0.000607 |
| Oxygen | 0.004240 | 0.004240 | 0.000000 |
| Propane | 0.103675 | 0.103675 | 0.105796 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | Mix Drum - Inlet D-2421 |
| **Description and Comments** | From UOP 2 |
| **Data Entry Date** | 2013/07/18 |
| **Sample Date** | 2/4/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Refinery Gas |
| **Clearstone ID** | 158 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.032575 | 0.032575 | 0.033326 |
| Ethane | 0.075095 | 0.075095 | 0.076826 |
| Hydrogen (normal) | 0.280165 | 0.280165 | 0.286622 |
| Isobutane | 0.000390 | 0.000390 | 0.000399 |
| Isopentane | 0.000155 | 0.000155 | 0.000159 |
| Methane | 0.530865 | 0.530865 | 0.543100 |
| n-Butane | 0.000880 | 0.000880 | 0.000900 |
| n-Heptane | 0.000185 | 0.000185 | 0.000189 |
| n-Hexane | 0.000075 | 0.000075 | 0.000077 |
| Nitrogen | 0.063905 | 0.063905 | 0.047205 |
| n-Pentane | 0.000085 | 0.000085 | 0.000087 |
| Oxygen | 0.004765 | 0.004765 | 0.000000 |
| Propane | 0.010860 | 0.010860 | 0.011110 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

CLEARSTONE ENGINEERING

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | Mix Drum - Inlet D-2953-UOP1 |
| **Description and Comments** | Gas line from UOP1 |
| **Data Entry Date** | 2013/07/18 |
| **Sample Date** | 2/2/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Refinery Gas |
| **Clearstone ID** | 150 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.010535 | 0.010535 | 0.010752 |
| Ethane | 0.051010 | 0.051010 | 0.052060 |
| Hydrogen (normal) | 0.108930 | 0.108930 | 0.111172 |
| Isobutane | 0.003475 | 0.003475 | 0.003547 |
| Isopentane | 0.000680 | 0.000680 | 0.000694 |
| Methane | 0.743320 | 0.743320 | 0.758617 |
| n-Butane | 0.008455 | 0.008455 | 0.008629 |
| n-Heptane | 0.000650 | 0.000650 | 0.000663 |
| n-Hexane | 0.000300 | 0.000300 | 0.000306 |
| Nitrogen | 0.031455 | 0.031455 | 0.015876 |
| n-Pentane | 0.000555 | 0.000555 | 0.000566 |
| Oxygen | 0.004265 | 0.004265 | 0.000000 |
| Propane | 0.036370 | 0.036370 | 0.037118 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | Mix Drum - Inlet D-2991 |
| **Description and Comments** | From T2758 (A27590 RX II) |
| **Data Entry Date** | 2013/07/18 |
| **Sample Date** | 2/2/2013 |
| **Sample Type** | As Sampled |
| **Substance Type** | Refinery Gas |
| **Clearstone ID** | 151 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.038220 | 0.038220 | 0.039091 |
| Ethane | 0.025365 | 0.025365 | 0.025943 |
| Hydrogen (normal) | 0.279875 | 0.279875 | 0.286256 |
| Isobutane | 0.004190 | 0.004190 | 0.004286 |
| Isopentane | 0.000005 | 0.000005 | 0.000005 |
| Methane | 0.538990 | 0.538990 | 0.551279 |
| n-Butane | 0.003715 | 0.003715 | 0.003800 |
| n-Heptane | 0.000060 | 0.000060 | 0.000061 |
| n-Hexane | 0.000030 | 0.000030 | 0.000031 |
| Nitrogen | 0.070460 | 0.070460 | 0.054089 |
| n-Pentane | 0.000015 | 0.000015 | 0.000015 |
| Oxygen | 0.004715 | 0.004715 | 0.000000 |
| Propane | 0.034360 | 0.034360 | 0.035143 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | Dry Natural Gas |
| **Description and Comments** | pure methane to represent a fuel source of produce with out market value. |
| **Data Entry Date** | 2013/09/08 |
| **Sample Date** | N/A |
| **Sample Type** | Computed |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 301 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Methane | 1.000000 | 1.000000 | 1.000000 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | Refinary Fuel Composition |
| **Description and Comments** | N/A |
| **Data Entry Date** | 2013/03/27 |
| **Sample Date** | N/A |
| **Sample Type** | As Sampled |
| **Substance Type** | Fuel Gas |
| **Clearstone ID** | 38 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Carbon monoxide | 0.005005 | 0.005005 | 0.005077 |
| Ethane | 0.058058 | 0.058058 | 0.058894 |
| Hydrogen (normal) | 0.083083 | 0.083083 | 0.084280 |
| Isobutane | 0.003003 | 0.003003 | 0.003046 |
| Isopentane | 0.001001 | 0.001001 | 0.001015 |
| Methane | 0.787788 | 0.787788 | 0.799134 |
| n-Butane | 0.003003 | 0.003003 | 0.003046 |
| n-Heptane | 0.001001 | 0.001001 | 0.001015 |
| Nitrogen | 0.025025 | 0.025025 | 0.014029 |
| Oxygen | 0.003003 | 0.003003 | 0.000000 |
| Propane | 0.030030 | 0.030030 | 0.030463 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | Vapor |
| **Description and Comments** | Water vapor for steam flows. |
| **Data Entry Date** | 2013/03/20 |
| **Sample Date** | N/A |
| **Sample Type** | Computed |
| **Substance Type** | Process Gas |
| **Clearstone ID** | 37 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Water | 1.000000 | 1.000000 | 1.000000 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | TEA-1 |
| **Description and Comments** | gas to flare 1 From Ecopetrol\2012 - NAMA Development\2013 - Refinery Audit (January)\Data\flare\flare data.xlsx |
| **Data Entry Date** | 2013/03/28 |
| **Sample Date** | N/A |
| **Sample Type** | As Sampled |
| **Substance Type** | Waste Gas |
| **Clearstone ID** | 39 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| 1-3-Butadiene | 0.000502 | 0.000502 | 0.000507 |
| 1-Butene | 0.139358 | 0.139358 | 0.140776 |
| 1-Pentene | 0.001710 | 0.001710 | 0.001727 |
| 2-Butene-cis | 0.028854 | 0.028854 | 0.029148 |
| 2-Methyl-1-butene | 0.007191 | 0.007191 | 0.007264 |
| 2-Methyl-2-butene | 0.004171 | 0.004171 | 0.004213 |
| 2-Pentene-cis | 0.002440 | 0.002440 | 0.002465 |
| 2-Pentene-trans | 0.004151 | 0.004151 | 0.004193 |
| 3-Methyl-1-butene | 0.000940 | 0.000940 | 0.000950 |
| Carbon dioxide | 0.003410 | 0.003410 | 0.003445 |
| Carbon monoxide | 0.000920 | 0.000920 | 0.000929 |
| Ethane | 0.030024 | 0.030024 | 0.030329 |
| Ethylene | 0.018402 | 0.018402 | 0.018589 |
| Hydrogen (normal) | 0.045076 | 0.045076 | 0.045535 |
| Hydrogen sulfide | 0.000600 | 0.000600 | 0.000606 |
| Isobutane | 0.148529 | 0.148529 | 0.150040 |
| Isopentane | 0.040735 | 0.040735 | 0.041149 |
| Methane | 0.043696 | 0.043696 | 0.044141 |
| n-Butane | 0.107344 | 0.107344 | 0.108436 |
| n-Hexane | 0.035655 | 0.035655 | 0.036018 |
| Nitrogen | 0.010311 | 0.010311 | 0.002395 |
| n-Pentane | 0.017372 | 0.017372 | 0.017549 |

| | | | |
|---|---|---|---|
| Oxygen | 0.002130 | 0.002130 | 0.000000 |
| Propane | 0.126276 | 0.126276 | 0.127561 |
| Propylene | 0.180203 | 0.180203 | 0.182036 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

CLEARSTONE ENGINEERING

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | TEA-2 |
| **Description and Comments** | gas to flare2. From Ecopetrol\2012 - NAMA Development\2013 - Refinery Audit (January)\Data\flare\flare data.xlsx |
| **Data Entry Date** | 2013/03/28 |
| **Sample Date** | N/A |
| **Sample Type** | As Sampled |
| **Substance Type** | Waste Gas |
| **Clearstone ID** | 40 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| 1-3-Butadiene | 0.000812 | 0.000812 | 0.000823 |
| 1-Butene | 0.077239 | 0.077239 | 0.078257 |
| 1-Pentene | 0.003562 | 0.003562 | 0.003609 |
| 2-Butene-cis | 0.018892 | 0.018892 | 0.019141 |
| 2-Methyl-1-butene | 0.009996 | 0.009996 | 0.010128 |
| 2-Methyl-2-butene | 0.006834 | 0.006834 | 0.006924 |
| 2-Pentene-cis | 0.004143 | 0.004143 | 0.004198 |
| 2-Pentene-trans | 0.006974 | 0.006974 | 0.007066 |
| 3-Methyl-1-butene | 0.001911 | 0.001911 | 0.001936 |
| Carbon dioxide | 0.007785 | 0.007785 | 0.007888 |
| Carbon monoxide | 0.004683 | 0.004683 | 0.004745 |
| Ethane | 0.052073 | 0.052073 | 0.052760 |
| Ethylene | 0.044358 | 0.044358 | 0.044943 |
| Hydrogen (normal) | 0.155910 | 0.155910 | 0.157965 |
| Isobutane | 0.042937 | 0.042937 | 0.043503 |
| Isopentane | 0.029309 | 0.029309 | 0.029695 |
| Methane | 0.134236 | 0.134236 | 0.136006 |
| n-Butane | 0.036323 | 0.036323 | 0.036802 |
| n-Hexane | 0.039996 | 0.039996 | 0.040523 |
| Nitrogen | 0.153818 | 0.153818 | 0.145452 |
| n-Pentane | 0.011687 | 0.011687 | 0.011841 |
| Oxygen | 0.002752 | 0.002752 | 0.000000 |

| | | | | |
|---|---|---|---|---|
| Propane | | 0.052654 | 0.052654 | 0.053348 |
| Propylene | | 0.101115 | 0.101115 | 0.102448 |
| **Total** | | 0.999999 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | TEA-3 |
| **Description and Comments** | gas to flare 3. From Ecopetrol\2012 - NAMA Development\2013 - Refinery Audit (January)\Data\flare\flare data.xlsx |
| **Data Entry Date** | 2013/03/28 |
| **Sample Date** | N/A |
| **Sample Type** | As Sampled |
| **Substance Type** | Waste Gas |
| **Clearstone ID** | 41 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| 1-Butene | 0.001052 | 0.001052 | 0.001482 |
| Carbon dioxide | 0.000750 | 0.000750 | 0.001057 |
| Ethane | 0.140958 | 0.140958 | 0.198617 |
| Hydrogen (normal) | 0.258212 | 0.258212 | 0.363833 |
| Isobutane | 0.009422 | 0.009422 | 0.013276 |
| Isopentane | 0.001550 | 0.001550 | 0.002184 |
| Methane | 0.157351 | 0.157351 | 0.221715 |
| n-Butane | 0.006001 | 0.006001 | 0.008456 |
| n-Hexane | 0.011812 | 0.011812 | 0.016644 |
| Nitrogen | 0.279416 | 0.279416 | 0.071181 |
| n-Pentane | 0.001990 | 0.001990 | 0.002804 |
| Oxygen | 0.061402 | 0.061402 | 0.000000 |
| Propane | 0.070084 | 0.070084 | 0.098752 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | TEA-4 |
| **Description and Comments** | Gas to flare 4. From Ecopetrol\2012 - NAMA Development\2013 - Refinery Audit (January)\Data\flare\flare data.xlsx |
| **Data Entry Date** | 2013/03/28 |
| **Sample Date** | N/A |
| **Sample Type** | As Sampled |
| **Substance Type** | Waste Gas |
| **Clearstone ID** | 42 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| Ethane | 0.637298 | 0.637298 | 0.661836 |
| Ethylene | 0.273594 | 0.273594 | 0.284128 |
| Hydrogen (normal) | 0.026151 | 0.026151 | 0.027158 |
| Methane | 0.017277 | 0.017277 | 0.017942 |
| Nitrogen | 0.034754 | 0.034754 | 0.005733 |
| Oxygen | 0.007842 | 0.007842 | 0.000000 |
| Propane | 0.000811 | 0.000811 | 0.000842 |
| Propylene | 0.002273 | 0.002273 | 0.002361 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | TEA-6 |
| **Description and Comments** | gas to flare 6. From Ecopetrol\2012 - NAMA Development\2013 - Refinery Audit (January)\Data\flare\flare data.xlsx |
| **Data Entry Date** | 2013/03/28 |
| **Sample Date** | N/A |
| **Sample Type** | As Sampled |
| **Substance Type** | Waste Gas |
| **Clearstone ID** | 43 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| 1-Butene | 0.012178 | 0.012178 | 0.012715 |
| 2-Butene-cis | 0.001342 | 0.001342 | 0.001401 |
| Carbon dioxide | 0.001492 | 0.001492 | 0.001558 |
| Carbon monoxide | 0.002524 | 0.002524 | 0.002635 |
| Ethane | 0.071067 | 0.071067 | 0.074201 |
| Ethylene | 0.074902 | 0.074902 | 0.078205 |
| Hydrogen (normal) | 0.205669 | 0.205669 | 0.214738 |
| Isobutane | 0.013341 | 0.013341 | 0.013929 |
| Isopentane | 0.002213 | 0.002213 | 0.002311 |
| Methane | 0.354151 | 0.354151 | 0.369768 |
| n-Butane | 0.022063 | 0.022063 | 0.023036 |
| n-Hexane | 0.001552 | 0.001552 | 0.001620 |
| Nitrogen | 0.061723 | 0.061723 | 0.029675 |
| n-Pentane | 0.000591 | 0.000591 | 0.000617 |
| Oxygen | 0.008933 | 0.008933 | 0.000000 |
| Propane | 0.037997 | 0.037997 | 0.039673 |
| Propylene | 0.128262 | 0.128262 | 0.133918 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |

# Composition Source Data

| Facility | |
|---|---|
| **Clearstone Client** | PTAC |
| **Data Client** | Ecopetrol |
| **Operator** | Ecopetrol |
| **Name** | Barancabermeja Refinery |
| **Location** | Barrancabermeja, Colombia |
| **ID** | Refinery-Barranca |
| **Category** | Refinery |
| **Type** | Oil Refinery |
| **Government ID** | N/A |
| **Operator BA Code** | N/A |
| **Licensee BA Code** | N/A |
| **Licensee Name** | N/A |

| Sample Data | |
|---|---|
| **Name** | TEA-7 |
| **Description and Comments** | gas to flare 7. From Ecopetrol\2012 - NAMA Development\2013 - Refinery Audit (January)\Data\flare\flare data.xlsx |
| **Data Entry Date** | 2013/03/28 |
| **Sample Date** | N/A |
| **Sample Type** | As Sampled |
| **Substance Type** | Waste Gas |
| **Clearstone ID** | 44 |

| Analysis Results | | | |
|---|---|---|---|
| **Component Name** | **Mole Fraction** | | |
| | **Entered** | **Normalized** | **Air Free** |
| 1-Butene | 0.009798 | 0.009798 | 0.009836 |
| 1-Pentene | 0.001141 | 0.001141 | 0.001145 |
| 2-Butene-cis | 0.002442 | 0.002442 | 0.002451 |
| 2-Methyl-1-butene | 0.003563 | 0.003563 | 0.003577 |
| 2-Methyl-2-butene | 0.002162 | 0.002162 | 0.002170 |
| 2-Pentene-cis | 0.001581 | 0.001581 | 0.001587 |
| 2-Pentene-trans | 0.002632 | 0.002632 | 0.002642 |
| Carbon dioxide | 0.005514 | 0.005514 | 0.005535 |
| Carbon monoxide | 0.005214 | 0.005214 | 0.005234 |
| Ethane | 0.058487 | 0.058487 | 0.058712 |
| Ethylene | 0.055185 | 0.055185 | 0.055397 |
| Hydrogen (normal) | 0.125271 | 0.125271 | 0.125753 |
| Hydrogen sulfide | 0.051822 | 0.051822 | 0.052021 |
| Isobutane | 0.185601 | 0.185601 | 0.186315 |
| Isopentane | 0.007326 | 0.007326 | 0.007354 |
| Methane | 0.116995 | 0.116995 | 0.117445 |
| n-Butane | 0.006025 | 0.006025 | 0.006048 |
| n-Hexane | 0.018855 | 0.018855 | 0.018928 |
| Nitrogen | 0.019306 | 0.019306 | 0.016345 |
| n-Pentane | 0.001401 | 0.001401 | 0.001406 |
| Oxygen | 0.000811 | 0.000811 | 0.000000 |
| Propane | 0.258209 | 0.258209 | 0.259203 |

| | | | |
|---|---|---|---|
| Propylene | 0.060659 | 0.060659 | 0.060892 |
| **Total** | 1.000000 | 1.000000 | 1.000000 |