# ENERGY AND HYDROGEN SYSTEMS REAL TIME OPTIMIZATION

Oscar Santollani, Jorge Mamprin, Carlos Ruiz
Soteica Visual MESA LLC, Houston, TX

## Abstract

Hydrogen management can have a significant effect on refinery utility supply through the integration with the energy system. Real-time optimization of hydrogen production in conjunction with the steam, power and fuels can yield significant savings opportunities for the refining industry.

Hydrogen is required in refining processes to produce low and ultra-low sulfur fuels. Hydrogen sources can be external or internal, of course. External sources are generally nearby third party industrial gas providers, who supply pure hydrogen streams, sometimes in exchange of fuel gas (FG), liquid petroleum gases (LPG) or natural gas (NG) for either or both feed and fuel. In some cases, impure hydrogen can also be provided by external sources, which can be purified in the refinery in the Pressure Swing Absorption (PSA) units, producing FG as a by-product.

Many refineries operate internal high purity hydrogen production units, generally based on gas reforming, using either NG or process off gas as feedstock. Gas reforming processes are endothermic, requiring FG for heating the reactors, and use steam as diluent of the feed and power to drive the feed charge and product compressors, which can be either electric or steam driven. The Steam Methane Reforming (SMRs) units usually produce steam and FG as byproducts.

When FG is used as a feedstock, critical decisions must be made about the best use of sources of the FG streams within the refinery units. When NG is used as a feedstock, many times it is considered a petrochemical feedstock rather than a fuel, having an incremental cost that could depend on its final use.

Any decision to import or internally produce hydrogen will affect not only the hydrogen system purity and availability, but also the FG system in addition; affecting the volumes of any externally purchased or internally supplied fuels (like NG or LPG).

Attempts to reduce the costs from the utilities side (i.e., to optimize the energy production and distribution system) should be based on accurate utility system models including steam, fuels, and power and calibrated with validated and consistent set of measurements. In order to consider the interaction of the hydrogen with the fuel system, a compositional model of the fuel must be included in the model. Solving and optimizing the energy and hydrogen balances at the same time is key to ensuring consistency with operations and constraints handling.

This paper describes, using a real time optimization model example, how an integrated model optimizing the energy and hydrogen systems altogether can be implemented in complex industrial environments.

## Hydrogen and Energy Systems Interaction

Hydrogen management can have a significant effect on refinery utility supply through the integration with the energy system. Real-time optimization of hydrogen production in conjunction with the steam, power and fuels can yield significant savings opportunities for the refining industry. A good discussion of the challenges and perspectives of the hydrogen in modern refineries can be found in refs. 1 and 2.

In ref. 1, it is mentioned that several proven options can be used to improve the thermal efficiency of both new and existing hydrogen facilities, including advanced hydrogen management, along with the integrated utilization of refinery off gas (ROG), enhanced energy efficiency, increased economies of scale, augmentation of existing H2 capacity, and strategic Over-the-fence (third party) hydrogen supply. Most of these options provides added benefits of improved availability and reduced environmental impact.

Ref. 2 states that modern hydrogen plants are designed with improved safety and reliability performance; these plants provide processing flexibility to handle a wide variety of ROG streams, along with captive propane + hydrocarbon (HC) liquids ranging from LPG to heavy naphtha. These plants can be operated in various modes to enhance feed flexibility, including supplemental mixed feeds and alternative feeds or backup feeds based on sites pecific issues. For example, a refiner may have an excess of butane during the summer months due to gasoline Reid vapor pressure (RVP) limits. The surplus butane, under favorable economics, can be used as part or full feed to produce required H2 rather than exported. In addition, LPG or naphtha, as alternative feedstocks, can provide protection from any anticipated natural gas (primary feedstock) curtailments or interruptions. Many hydrogen generation projects have been designed to process multiple feeds. ROG, coker gas, isomerization vent gas, hydrorefining purge gas and refinery liquids, including butane, propane and pentane, are some of the HC streams used to supplement natural gas feed.

As it was stated above, many refineries operate internal high purity hydrogen production units, generally based on steam reforming (SMRs), using either NG or ROG as feedstock. Gas reforming processes are endothermic, requiring FG for heating the reactors, and use steam as diluent of the feed and power to drive the feed charge and product compressors, either electric or steam driven. The SMRs produce steam and FG as byproducts.

When FG is used as a feedstock, a critical decision must be made about the best use of sources of the process off-gas and FG streams within the refinery units. When NG is used as a feedstock for the Hydrogen Manufacturing Units, many times it is considered a petrochemical feedstock rather than a fuel, having an incremental cost that could depend on its final use. For example, a site may operate a cogeneration unit, including gas turbines, and the NG could have a tax credit resulting in a lower incremental cost that NG purchased for other uses. In the case of a cogeneration unit, the electric power production becomes an integral part of the economics affecting operational decisions. Frequently, refineries will also have sources of low purity hydrogen that can be either purified at PSAs or used directly in the process, being mixed with high purity hydrogen streams.

The processing units that use hydrogen need to maintain a certain Hydrogen-to-Oil Ratio (HOR) in order to provide the proper amount of hydrogen to drive the process (i.e., hydrotreaters and hydrocrackers). These units produce low purity but relatively rich hydrogen streams that need to be purged into the FG system, but their purge rates need to be carefully calculated in order to avoid excess purging. If the high purity hydrogen streams sent to the FG system are at a relatively higher rate than typical, the impact on the FG heating value could be very noticeable, impacting boiler and fired heater burner capacity (i.e., they will need to burn a higher volume of gas in order to provide the process the required duty, possibly reaching a constraint due to capacity limits).

As it was also said before, many refineries both external and internal hydrogen sources, either pure or impure, are available and can be used together. As explained previously, any decision to import or internally produce hydrogen will affect not only the hydrogen system purity and availability, but also the FG system, affecting the volumes of any externally purchased or internally supplied reposition fuels (like NG or LPG).

Any attempt to reduce the costs from the utilities side (i.e., to optimize the energy system) should be based on accurate utility system models including steam, fuels, and power and calibrated with validated and consistent set of measurements. In order to consider the interaction of the hydrogen with the fuel system, a compositional model of the fuel must be included in the model. Solving and optimizing the energy and hydrogen balances at the same time is key to ensuring consistency with operations and constraints handling.

The optimization's goal should be to reduce the overall utilities cost. In order to do this accurately, the model must take into account constraints associated with the existing equipment combined with the pricing for steam, fuels, power, hydrogen. Detailed models for contracts for the purchase and/or supply of utilities are essential to calculating accurate incremental pricing in the optimization. To add even more complexity, the economic optimization should be also consider the emission limits as constraints or as part of the objective function (i.e. cost or credit of the $CO_2$ emission if above or below a certain quota). The energy management system models needs to be executed and optimized at a scheduled frequency with online, real time data in order to provide operations personnel with continuously updated recommendations.

Besides the optimization role, Key Performance Indicators (KPIs) should also be calculated and stored in the Site Plant Information System or DCSs for Operations and Management use. Validation of the meters used by the energy management system to calculate KPIs ensures the accuracy of KPI history.

The following describes how an integrated model optimizing the utilities and their interaction hydrogen system has been implemented in a real industrial environment. The main project steps are explained and critical details to be taken into account to assure successful use and proper technology transfer to the client are discussed. It also presents real industrial examples are presented in which the cost of the site-wide utilities of a production site (i.e., steam, fuels, boiler feed water, hydrogen and electricity) is optimized with a real-time, online software system that is well established in the refining and petrochemical industry.

## Real Time Energy and Utilities Management Systems

Refineries and petrochemical plants usually operate large and complex utilities and energy systems. They typically burn multiple fuels, operate cogeneration units to supplement the electric power purchases or export electricity, need to provide steam at several pressure levels to serve different types of consumers, have several sources and consumers of hydrogen and need to observe emission limits.

In almost all of the cases, these complex utilities and energy systems have a number of degrees of freedom. Proper manipulation of the degrees of freedom with the aid of cost-based optimization software can result in significant operating cost savings. Power industry deregulation provides new challenges to operations in the minimization of cost, as the price for electricity can change several times each hour. Electricity price represents one of the main economic trade-offs with the hydrogen, steam, and site emissions limits.

Other important aspects to consider are that utilities systems continuously evolve (changes are frequent) and that sometimes, there is a lack of sensors and no chance to reconcile data because redundancy is almost nonexistent. Therefore, measurement errors need to be addressed properly.

Moreover, utilities systems typically have several constraints that come from the operational and contractual sides and are highly interrelated; therefore, decisions to optimize or alleviate constraints on one sub-system will affect the rest. Examples of these constraints are:

- minimum and maximum high purity hydrogen purchase from the external providers,
- operational limits in the SMRs (like reformer tube temperature and feed rate),
- steam production capacity in the boilers,
- $NO_x$ / $CO_2$ emission constraints,
- the need to maintain a steam production cushion due to reliability reasons,
- fuels and electric power quotas and penalties,
- and many other

In addition, it is important to mention that traditionally, depicting the high economical potential and perhaps because of the complexity of the integrated systems, the optimization of the utilities was traditionally managed at the level of each individual sub-system, Plant or Area. However, the optimization of each individual Area does not necessarily give the true overall site optimum. Moreover, an attempt to optimize a whole site based on an isolated view of each Plant or sub-system at a time could be worse than not attempting any optimization.

In the dynamic operational and economic environment of a Plant, implementing the proper actions necessary to reach the optimum overall utilities system management can only be done with the aid of an on-line tool. Such a system should execute in an unattended, automated way, providing the correct recommendations at all times to the different users, whether they be operators or engineers, with the man-machine interface appropriate for each one of them.

To add more complexity to the problem, the environmental constraints are becoming more and more complex and stringent. With all the regulations already on place and those coming on the horizon, emissions will become a significant factor in operations and planning, adding new operational constraints, increasing the operating cost, involving potential needs of capital investment and adding an opportunity to generate value from trading. In the path to compliance, organizations are facing several challenges in establishing an effective procedure to deal with the emissions on a consistent, optimum cost basis.

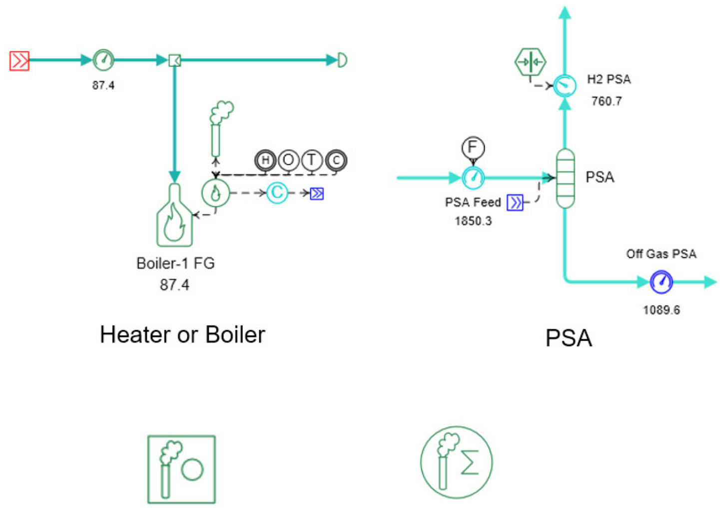
Moreover, to add even more burden to the problem, control rooms worldwide are facing a shortage of people. Operators are concentrating more and more on the Units under his or her responsibility. DCS screens have flourished, with hundreds or even thousands of tags being available for each Unit and with a multitude of process diagrams and trends being projected on walls and even ceilings. With only a few employees available to take care of the interaction between energy system operations and economics, having a rigorous model to optimize the energy system is becoming important. Industrial energy systems are becoming increasingly complex and inter-related, not only connecting Units of the same Site but also with the hydrogen, power and utilities systems of neighboring facilities.

The evolution from decentralized plant information scattered throughout many islands of automation to a unified and centralized Plant Information System was a clear enabling layer for site-wide energy system models. DCSs (Distributed Control Systems (DCS) and Plant information (PI) systems are the most widely available data sources in the current industrial context. PI systems usually acquire data from the DCSs and store it in a unique repository. The long term, facility-wide PI system-based historians constitute what is known as an *enabling technology*, because they are the cornerstone on top of which decision support systems, such as energy management systems, can be built. Centralized real-time databases provide access to massive current and historical process, laboratory and financial data.

## Energy and Utilities Management System Software Description and Functionality

A software tool called Visual MESA has been used extensively that properly address all the issues mentioned above. The original MESA program was developed in the early 1980's. Since the first Visual MESA version was released in 1997 with a graphical user interface, it has been continuously improved and adapted to be able to cope with all these changing scenarios.

Visual MESA is a computer program designed to model steam, boiler feed water (BFW), condensate, fuel, emissions, hydrogen and electrical systems. It is an on-line program that receives live plant data from the steam, fuel, condensate, BFW, and electrical system metering devices via a standard link to real-time data from the plant information system.

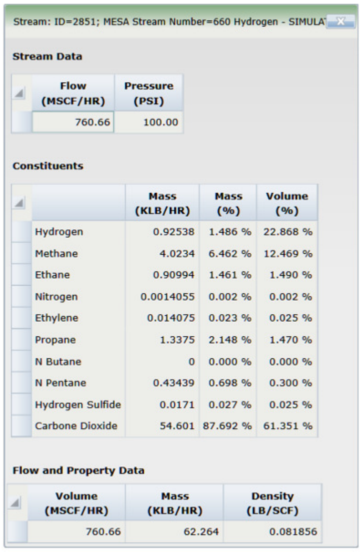


Heater or Boiler

PSA

Emissions Point Source

Emissions Collector



Stream: ID=2851; MESA Stream Number=660 Hydrogen - SIMULA

Stream Data

| Flow (MSCF/HR) | Pressure (PSI) |
|---|---|
| 760.66 | 100.00 |

Constituents

| | Mass (KLB/HR) | Mass (%) | Volume (%) |
|---|---|---|---|
| Hydrogen | 0.92538 | 1.486 % | 22.868 % |
| Methane | 4.0234 | 6.462 % | 12.469 % |
| Ethane | 0.90994 | 1.461 % | 1.490 % |
| Nitrogen | 0.0014055 | 0.002 % | 0.002 % |
| Ethylene | 0.014075 | 0.023 % | 0.025 % |
| Propane | 1.3375 | 2.148 % | 1.470 % |
| N Butane | 0 | 0.000 % | 0.000 % |
| N Pentane | 0.43439 | 0.698 % | 0.300 % |
| Hydrogen Sulfide | 0.0171 | 0.027 % | 0.025 % |
| Carbone Dioxide | 54.601 | 87.692 % | 61.351 % |

Flow and Property Data

| Volume (MSCF/HR) | Mass (KLB/HR) | Density (LB/SCF) |
|---|---|---|
| 760.66 | 62.264 | 0.081856 |

Compositionally Defined H2 Streams

**Figure 1** – Several standard Visual MESA Modeling blocks used for the Hydrogen systems simulation and optimization

It typically works automatically retrieving on-line data from the process using the OPC standard connectivity (ref. 3), continuously evaluating the utility and energy system optimization alternatives and writing key performance indicators back to the plant information system.

The software includes the necessary features to calculate and properly handle the hydrogen sub-system and its interaction with the rest of the utilities and including emissions. This is accomplished through a compositional representation of the hydrogen and fuels streams, combustion properties to calculate boilers and heaters efficiencies, open calculation blocks to accommodate ad-hoc equations and correlations, and emission source stoichiometric calculations or estimations based on correlations for individual process point sources (i.e., FCC catalyst Carbon emitted from the regenerator).

Main benefit sources from where high savings can usually be obtained are:

***Optimization:*** Direct recommendations for the most economically efficient mode of operation for the utilities and energy systems, while maintaining all operating constraints. It enables plant personnel to:

- Understand how to operate at the optimum steam/fuels/electrical/hydrogen system operation, including emission constraints and costs.
- Quick reaction to minimize the economic impact of an operational change affecting the energy system.
- Optimize the overall cost of fuel for steam generation and electricity, including the choice of the most cost effective combination of turbines and motors.
- Make good use of the utilities network data availability and improve the data quality.

***Monitoring:*** Features that help access data, control data quality, and alert to changes in the system, such as:

- Overall cost and potential savings calculated on a real-time basis
- Plant, equipment and stream information
- Trending data and calculation results
- Big changes on utilities streams and emissions regulations compliance alerts
- Data quality (balloons, graphically representing header mass balance imbalances)

***Case Studies ("What If?" Planning):*** Functionality enabling the performance and evaluation of "What If?" cases, which demonstrate to plant personnel how they can operate more efficiently and at less cost for a given operational scenario. Some examples are:

- Front-end loading on projects
- True "Plant-wide" project evaluation
- Steam, fuel, BFW, condensate, and electrical system improvements
- Hydrogen purchase pricing and contract
- CO2 emissions mitigation projects, credits availability and/or new constraints

***Auditing & Accounting:*** Assistance for plant personnel in finding where steam waste is occurring in the utility system, providing information to account for utility use properly and identifying where the imbalances are occurring and how they may change over time.

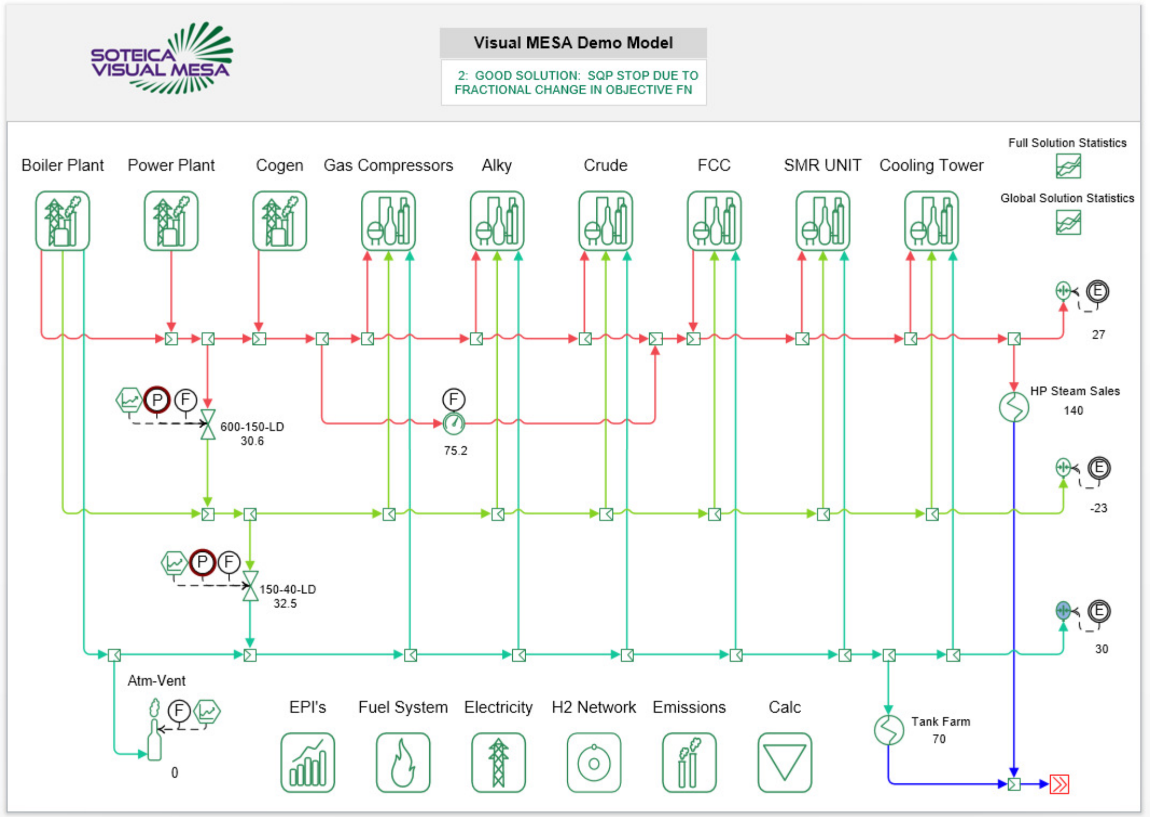
This on-line energy management system has been implemented at 80+ sites worldwide to model and optimize in real time the overall site energy and utilities systems for a variety of industries: petrochemical, refining, chemical, sugar & alcohol, district heating and cooling, combined heat and power, etc. Several of them have been published. Refs. 4 to 18 describe several recent industrial projects. Amongst them, a particular example will be presented and discussed.

## Refinery Hydrogen and Integrated Energy Systems Example

Although the Visual MESA based real time optimization system was installed in several refineries including the hydrogen and energy systems together, this example corresponds to an ad-hoc prepared model.

The hydrogen network representation includes the modeling and optimization of the in-house production (at an SMR), the external pure hydrogen purchase, the hydrogen vent and the Hydrocracker purge optimization.

The overall optimization of steam, fuel gas, hydrogen and power allows a reduction in overall operating costs, helping the site to work close to the optimum on a consistent basis since their start up. Some of our clients has calculated the savings achieved at the site due to Visual MESA's optimization to be in excess of $4 million per year.


Visual MESA Demo Model

2: GOOD SOLUTION: SQP STOP DUE TO FRACTIONAL CHANGE IN OBJECTIVE FN

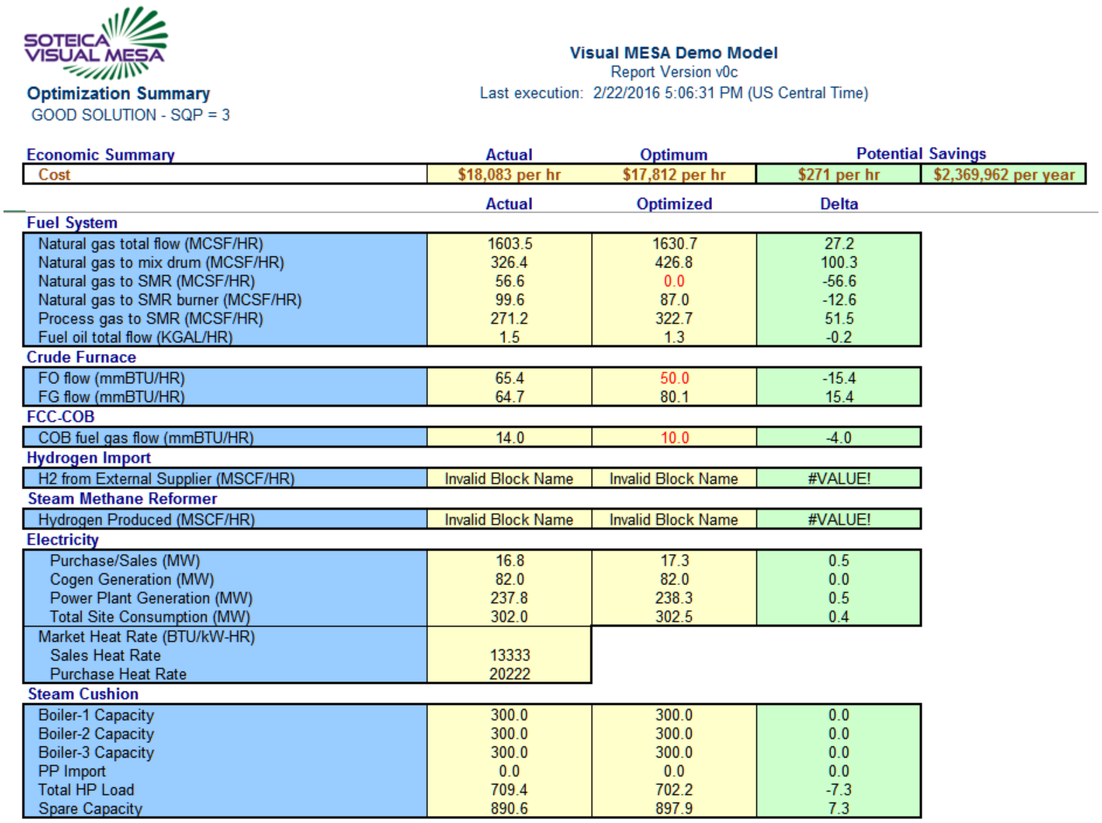
**Figure 2** – Visual MESA model main steam headers view, including the hydrogen unit (SMR)

In this example, a set of manual operating recommendations given by the optimizer during a particular execution have been:

- Turbine/motor swaps (i.e., the proper selection of the use of either the motor or the turbine for a given service)
- Steam to be imported from the neighboring hydrogen plant
- FG to be exported to neighboring plant or sent to internal plant
- Hydrogen streams imported/exported or processed internally

Because of the manual actions, adjustments to the following variables have been made by the control system:

- Steam production in boilers
- NG / Propane make-up to the fuels system
- Steam letdown and vent rates



SOTEICA VISUAL MESA

**Optimization Summary**

GOOD SOLUTION - SQP = 3

**Visual MESA Demo Model**

Report Version v0c

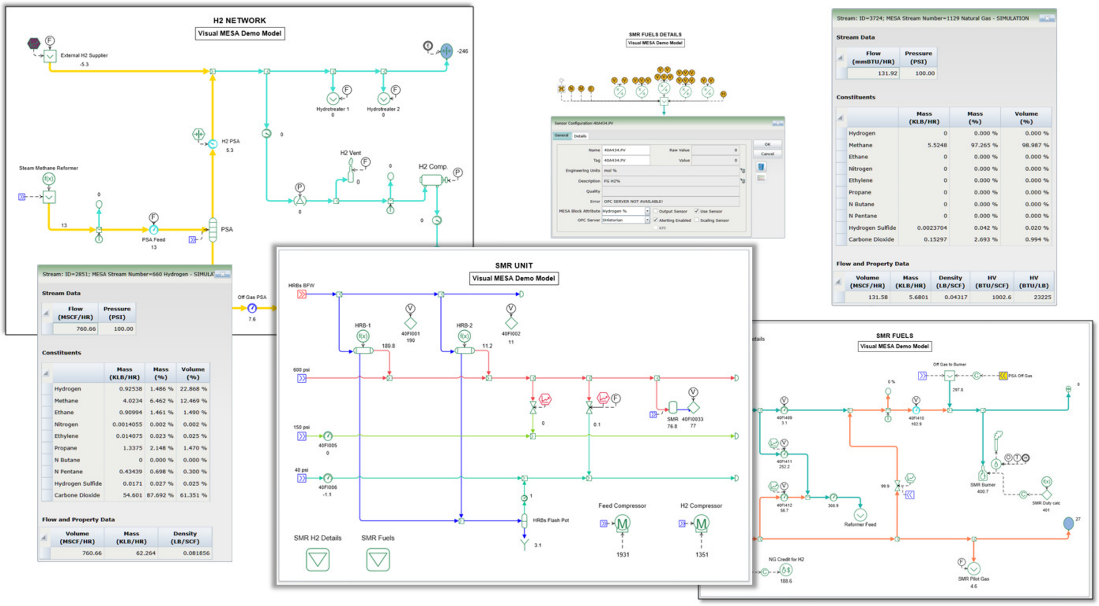
Last execution: 2/22/2016 5:06:31 PM (US Central Time)

| Economic Summary | Actual | Optimum | Potential Savings | |
|---|---|---|---|---|
| Cost | $18,083 per hr | $17,812 per hr | $271 per hr | $2,369,962 per year |

| | Actual | Optimized | Delta |
|---|---|---|---|
| **Fuel System** | | | |
| Natural gas total flow (MCSF/HR) | 1603.5 | 1630.7 | 27.2 |
| Natural gas to mix drum (MCSF/HR) | 326.4 | 426.8 | 100.3 |
| Natural gas to SMR (MCSF/HR) | 56.6 | 0.0 | -56.6 |
| Natural gas to SMR burner (MCSF/HR) | 99.6 | 87.0 | -12.6 |
| Process gas to SMR (MCSF/HR) | 271.2 | 322.7 | 51.5 |
| Fuel oil total flow (KGAL/HR) | 1.5 | 1.3 | -0.2 |
| **Crude Furnace** | | | |
| FO flow (mmBTU/HR) | 65.4 | 50.0 | -15.4 |
| FG flow (mmBTU/HR) | 64.7 | 80.1 | 15.4 |
| **FCC-COB** | | | |
| COB fuel gas flow (mmBTU/HR) | 14.0 | 10.0 | -4.0 |
| **Hydrogen Import** | | | |
| H2 from External Supplier (MSCF/HR) | Invalid Block Name | Invalid Block Name | #VALUE! |
| **Steam Methane Reformer** | | | |
| Hydrogen Produced (MSCF/HR) | Invalid Block Name | Invalid Block Name | #VALUE! |
| **Electricity** | | | |
| Purchase/Sales (MW) | 16.8 | 17.3 | 0.5 |
| Cogen Generation (MW) | 82.0 | 82.0 | 0.0 |
| Power Plant Generation (MW) | 237.8 | 238.3 | 0.5 |
| Total Site Consumption (MW) | 302.0 | 302.5 | 0.4 |
| Market Heat Rate (BTU/kW-HR) | | | |
| Sales Heat Rate | 13333 | | |
| Purchase Heat Rate | 20222 | | |
| **Steam Cushion** | | | |
| Boiler-1 Capacity | 300.0 | 300.0 | 0.0 |
| Boiler-2 Capacity | 300.0 | 300.0 | 0.0 |
| Boiler-3 Capacity | 300.0 | 300.0 | 0.0 |
| PP Import | 0.0 | 0.0 | 0.0 |
| Total HP Load | 709.4 | 702.2 | -7.3 |
| Spare Capacity | 890.6 | 897.9 | 7.3 |

**Figure 3** – Excel custom report where the operational actionable items are reported

The following figures 4 to 7 show some details of the hydrogen, steam and FG networks interconnection, where the impact of the hydrogen sourcing decision can be seen.



Stream: ID=2851; MESA Stream Number=660 Hydrogen - SIMULA

Stream Data

| Flow (MSCF/HR) | Pressure (PSI) |
|---|---|
| 760.66 | 100.00 |

Constituents

| | Mass (KLB/HR) | Mass (%) | Volume (%) |
|---|---|---|---|
| Hydrogen | 0.92538 | 1.486 % | 22.868 % |
| Methane | 4.0234 | 6.462 % | 12.469 % |
| Ethane | 0.90994 | 1.461 % | 1.490 % |
| Nitrogen | 0.0014055 | 0.002 % | 0.002 % |
| Ethylene | 0.014075 | 0.023 % | 0.025 % |
| Propane | 1.3375 | 2.148 % | 1.470 % |
| N Butane | 0 | 0.000 % | 0.000 % |
| N Pentane | 0.43439 | 0.698 % | 0.300 % |
| Hydrogen Sulfide | 0.0171 | 0.027 % | 0.025 % |
| Carbone Dioxide | 54.601 | 87.692 % | 61.351 % |

Flow and Property Data

| Volume (MSCF/HR) | Mass (KLB/HR) | Density (LB/SCF) |
|---|---|---|
| 760.66 | 62.264 | 0.081856 |

Stream: ID=3724; MESA Stream Number=1129 Natural Gas - SIMULATION

Stream Data

| Flow (mmBTU/HR) | Pressure (PSI) |
|---|---|
| 131.92 | 100.00 |

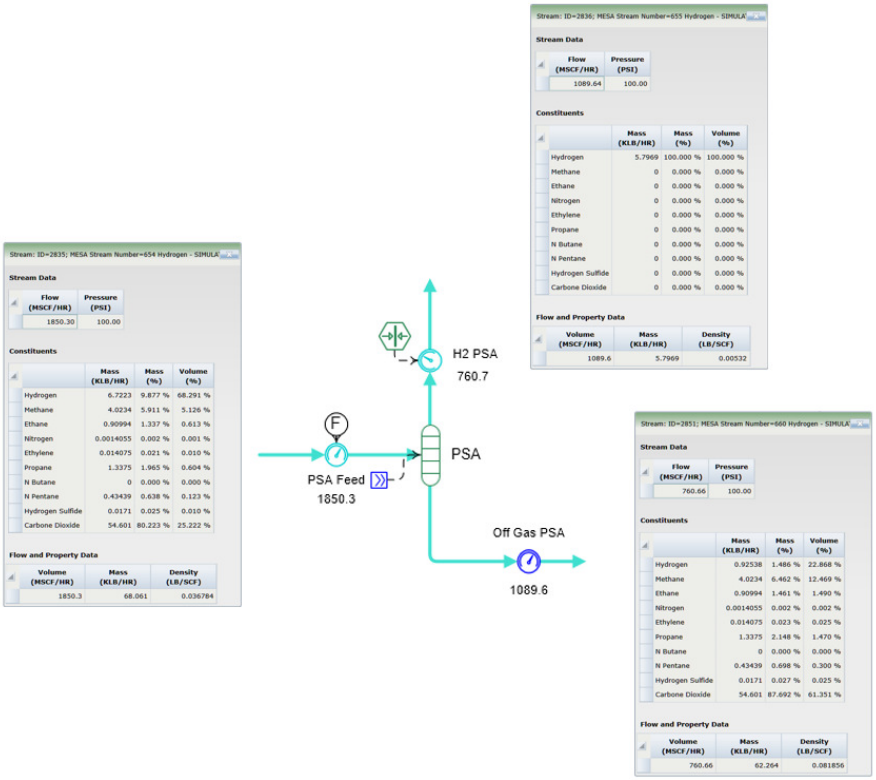
Constituents

| | Mass (KLB/HR) | Mass (%) | Volume (%) |
|---|---|---|---|
| Hydrogen | 0 | 0.000 % | 0.000 % |
| Methane | 5.5248 | 97.265 % | 98.987 % |
| Ethane | 0 | 0.000 % | 0.000 % |
| Nitrogen | 0 | 0.000 % | 0.000 % |
| Ethylene | 0 | 0.000 % | 0.000 % |
| Propane | 0 | 0.000 % | 0.000 % |
| N Butane | 0 | 0.000 % | 0.000 % |
| N Pentane | 0 | 0.000 % | 0.000 % |
| Hydrogen Sulfide | 0.0023704 | 0.042 % | 0.020 % |
| Carbone Dioxide | 0.15297 | 2.693 % | 0.994 % |

Flow and Property Data

| Volume (MSCF/HR) | Mass (KLB/HR) | Density (LB/SCF) | HV (BTU/SCF) | HV (BTU/LB) |
|---|---|---|---|---|
| 131.58 | 5.6801 | 0.04317 | 1002.6 | 23225 |

**Figure 4** – Hydrogen PSA area model, showing the streams entering and leaving the PSA unit and the providers of external high purity hydrogen at the bottom left



Stream: ID=2835; MESA Stream Number=654 Hydrogen - SIMULA

Stream Data

| Flow (MSCF/HR) | Pressure (PSI) |
|---|---|
| 1850.30 | 100.00 |

Constituents

| | Mass (KLB/HR) | Mass (%) | Volume (%) |
|---|---|---|---|
| Hydrogen | 6.7223 | 9.877 % | 68.291 % |
| Methane | 4.0234 | 5.911 % | 5.126 % |
| Ethane | 0.90994 | 1.337 % | 0.613 % |
| Nitrogen | 0.0014055 | 0.002 % | 0.001 % |
| Ethylene | 0.014075 | 0.021 % | 0.010 % |
| Propane | 1.3375 | 1.965 % | 0.604 % |
| N Butane | 0 | 0.000 % | 0.000 % |
| N Pentane | 0.43439 | 0.638 % | 0.123 % |
| Hydrogen Sulfide | 0.0171 | 0.025 % | 0.010 % |
| Carbone Dioxide | 54.601 | 80.223 % | 25.222 % |

Flow and Property Data

| Volume (MSCF/HR) | Mass (KLB/HR) | Density (LB/SCF) |
|---|---|---|
| 1850.3 | 68.061 | 0.036784 |

Stream: ID=2836; MESA Stream Number=655 Hydrogen - SIMULA

Stream Data

| Flow (MSCF/HR) | Pressure (PSI) |
|---|---|
| 1089.64 | 100.00 |

Constituents

| | Mass (KLB/HR) | Mass (%) | Volume (%) |
|---|---|---|---|
| Hydrogen | 5.7969 | 100.000 % | 100.000 % |
| Methane | 0 | 0.000 % | 0.000 % |
| Ethane | 0 | 0.000 % | 0.000 % |
| Nitrogen | 0 | 0.000 % | 0.000 % |
| Ethylene | 0 | 0.000 % | 0.000 % |
| Propane | 0 | 0.000 % | 0.000 % |
| N Butane | 0 | 0.000 % | 0.000 % |
| N Pentane | 0 | 0.000 % | 0.000 % |
| Hydrogen Sulfide | 0 | 0.000 % | 0.000 % |
| Carbone Dioxide | 0 | 0.000 % | 0.000 % |

Flow and Property Data

| Volume (MSCF/HR) | Mass (KLB/HR) | Density (LB/SCF) |
|---|---|---|
| 1089.6 | 5.7969 | 0.00532 |

Stream: ID=2851; MESA Stream Number=660 Hydrogen - SIMULA

Stream Data

| Flow (MSCF/HR) | Pressure (PSI) |
|---|---|
| 760.66 | 100.00 |

Constituents

| | Mass (KLB/HR) | Mass (%) | Volume (%) |
|---|---|---|---|
| Hydrogen | 0.92538 | 1.486 % | 22.868 % |
| Methane | 4.0234 | 6.462 % | 12.469 % |
| Ethane | 0.90994 | 1.461 % | 1.490 % |
| Nitrogen | 0.0014055 | 0.002 % | 0.002 % |
| Ethylene | 0.014075 | 0.023 % | 0.025 % |
| Propane | 1.3375 | 2.148 % | 1.470 % |
| N Butane | 0 | 0.000 % | 0.000 % |
| N Pentane | 0.43439 | 0.698 % | 0.300 % |
| Hydrogen Sulfide | 0.0171 | 0.027 % | 0.025 % |
| Carbone Dioxide | 54.601 | 87.692 % | 61.351 % |

Flow and Property Data

| Volume (MSCF/HR) | Mass (KLB/HR) | Density (LB/SCF) |
|---|---|---|
| 760.66 | 62.264 | 0.081856 |

**Figure 5** – Compressor sending the PSA off gas purge (from left) to the FG system (to right)

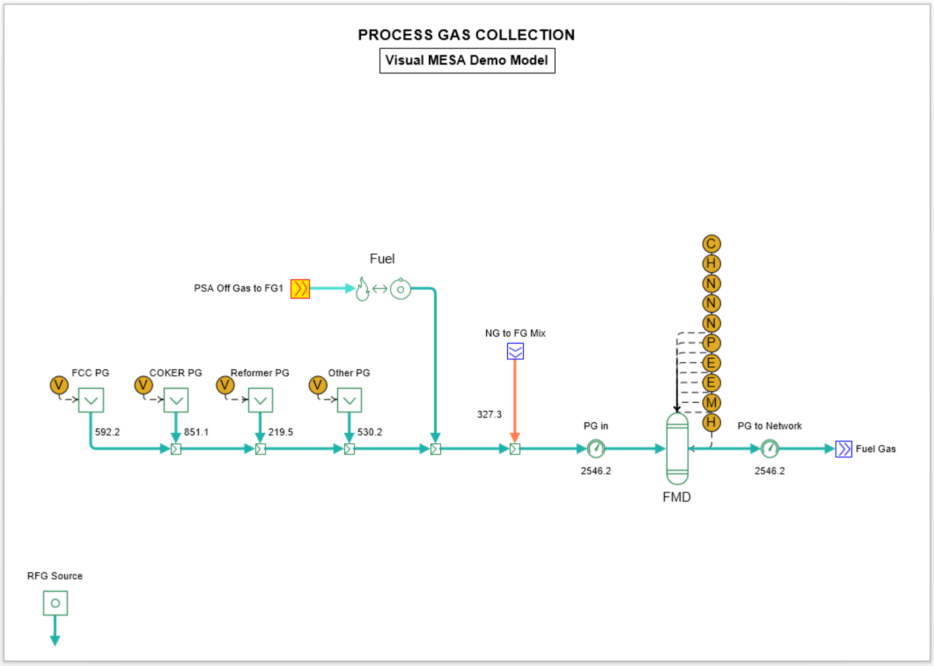
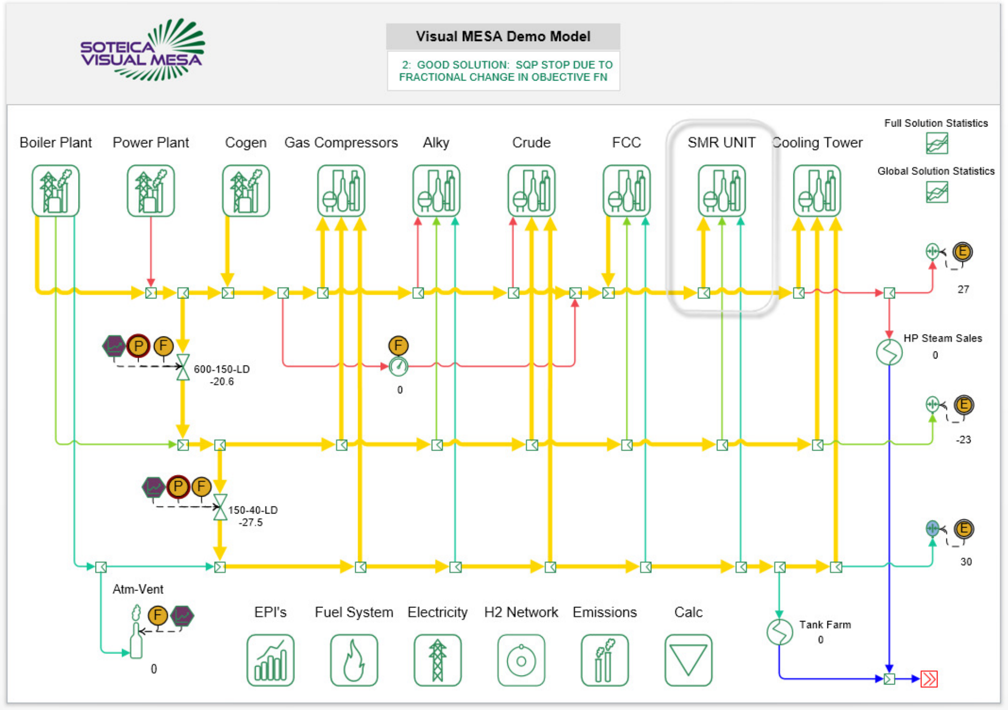


**Figure 6** – Overall FG system diagram, showing the interconnection with the PSAs purge and H2 bypass streams

Figure 6, shows a portion of the fuel gas network model representation. On the top, NG and PSA off gas suppliers are represented, and on the left, the site FG producers are displayed. A fuel mix-drum is represented, having real time indication of composition via an online gas chromatograph.



2: GOOD SOLUTION: SQP STOP DUE TO FRACTIONAL CHANGE IN OBJECTIVE FN

**Figure 7** – Main steam headers diagram, showing the interconnection between all the units of the site, delta view (difference between the optimum and the current case)

As a consequence of the manual changes in the hydrogen and steam sources plus the turbine and motor swaps, the FG header pressure control system made the necessary adjustments that resulted in the need to reduce the NG makeup, resulting in significant savings.

The effects of the hydrogen production on steam and fuel gas consumption/production are taken into account by assuming a linear relationship with respect to the current use/production for both Units.

The main steam headers diagram of the site is shown in Fig. 7, were the internal hydrogen production plants are also exposed (delta view, which is the difference between the optimum and the current case).

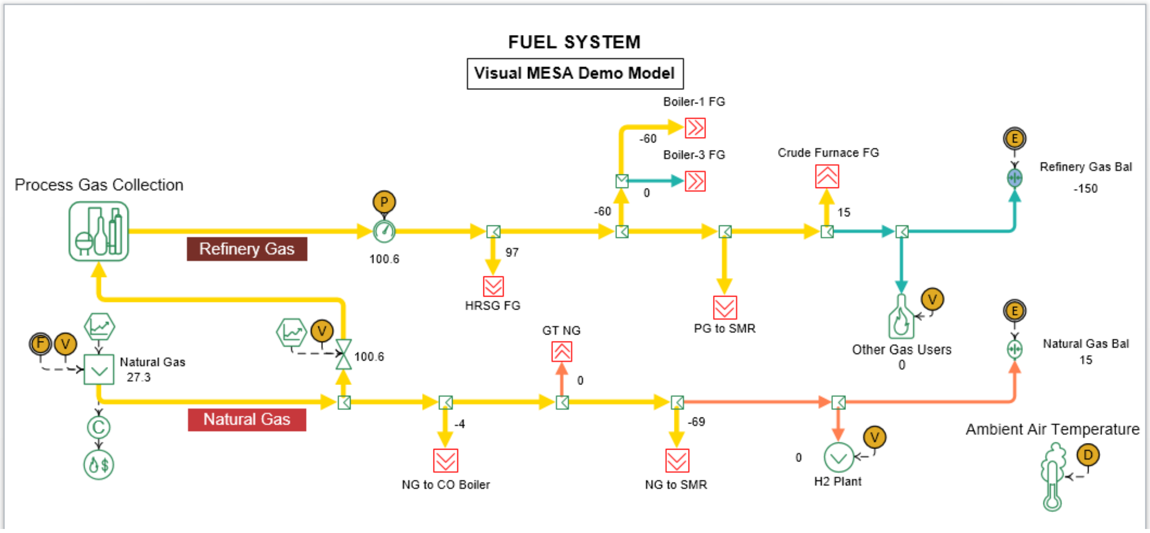
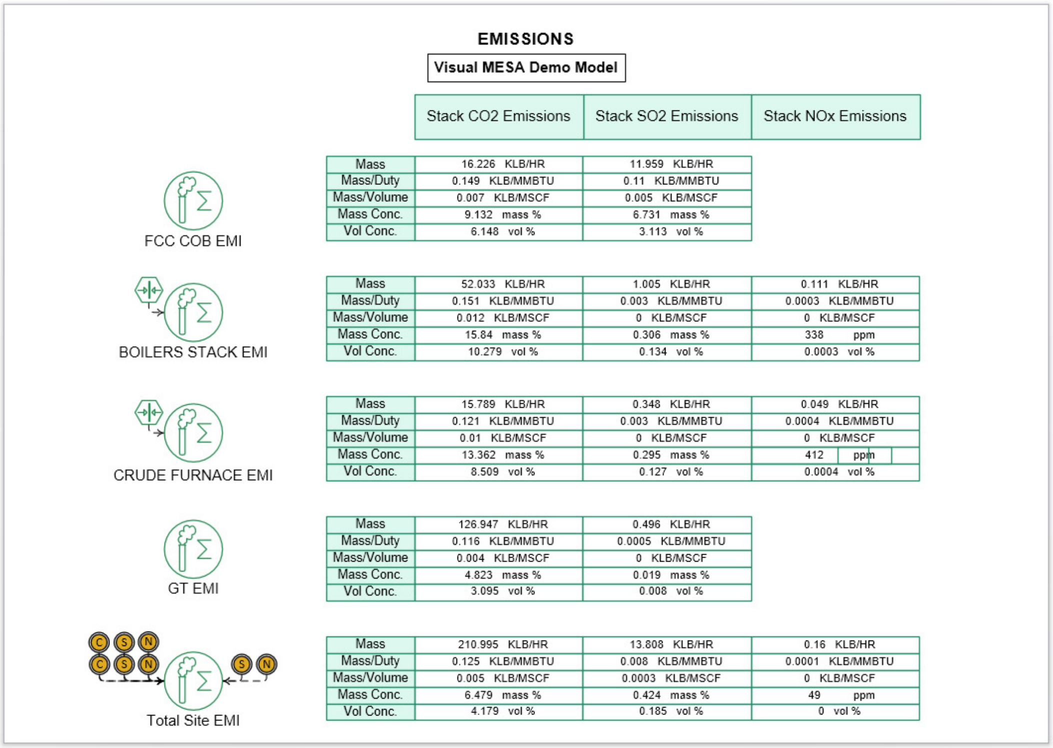


**Figure 8** – Fuel gas sub-system, delta view (difference between the optimum and the current case)

Energy cost reductions can be obtained taking advantage of the real time energy management system software functionalities including all the site sub-systems.  In Fig. 8 the schematics of the FG system is presented.

The NG makeup mix with the process off gas streams into the mix drum, from which the FG is distributed to all the users of the site (Fig. 9).  The NG as well as some process off gas streams can be used as feed to the SMR also.  Therefore, the tradeoff between hydrogen production and FG use was modeled and optimized along with the rest of the sub-systems.



EMISSIONS

Visual MESA Demo Model

| | | Stack CO2 Emissions | Stack SO2 Emissions | Stack NOx Emissions |
|---|---|---|---|---|
| FCC COB EMI | Mass | 16.226 KLB/HR | 11.959 KLB/HR | |
| | Mass/Duty | 0.149 KLB/MMBTU | 0.11 KLB/MMBTU | |
| | Mass/Volume | 0.007 KLB/MSCF | 0.005 KLB/MSCF | |
| | Mass Conc. | 9.132 mass % | 6.731 mass % | |
| | Vol Conc. | 6.148 vol % | 3.113 vol % | |
| BOILERS STACK EMI | Mass | 52.033 KLB/HR | 1.005 KLB/HR | 0.111 KLB/HR |
| | Mass/Duty | 0.151 KLB/MMBTU | 0.003 KLB/MMBTU | 0.0003 KLB/MMBTU |
| | Mass/Volume | 0.012 KLB/MSCF | 0 KLB/MSCF | 0 KLB/MSCF |
| | Mass Conc. | 15.84 mass % | 0.306 mass % | 338 ppm |
| | Vol Conc. | 10.279 vol % | 0.134 vol % | 0.0003 vol % |
| CRUDE FURNACE EMI | Mass | 15.789 KLB/HR | 0.348 KLB/HR | 0.049 KLB/HR |
| | Mass/Duty | 0.121 KLB/MMBTU | 0.003 KLB/MMBTU | 0.0004 KLB/MMBTU |
| | Mass/Volume | 0.01 KLB/MSCF | 0 KLB/MSCF | 0 KLB/MSCF |
| | Mass Conc. | 13.362 mass % | 0.295 mass % | 412 ppm |
| | Vol Conc. | 8.509 vol % | 0.127 vol % | 0.0004 vol % |
| GT EMI | Mass | 126.947 KLB/HR | 0.496 KLB/HR | |
| | Mass/Duty | 0.116 KLB/MMBTU | 0.0005 KLB/MMBTU | |
| | Mass/Volume | 0.004 KLB/MSCF | 0 KLB/MSCF | |
| | Mass Conc. | 4.823 mass % | 0.019 mass % | |
| | Vol Conc. | 3.095 vol % | 0.008 vol % | |
| Total Site EMI | Mass | 210.995 KLB/HR | 13.808 KLB/HR | 0.16 KLB/HR |
| | Mass/Duty | 0.125 KLB/MMBTU | 0.008 KLB/MMBTU | 0.0001 KLB/MMBTU |
| | Mass/Volume | 0.005 KLB/MSCF | 0.0003 KLB/MSCF | 0 KLB/MSCF |
| | Mass Conc. | 6.479 mass % | 0.424 mass % | 49 ppm |
| | Vol Conc. | 4.179 vol % | 0.185 vol % | 0 vol % |

**Figure 9** – Total emissions of the site, delta view (difference between the optimum and the current case)

Total calculated savings and other results from the Optimization are saved to history in the plant information system. In Fig. 10 a real industrial application trend demonstrates how the savings are captured as the optimization variables, including the one shown in the screen, are properly adjusted by the operators.

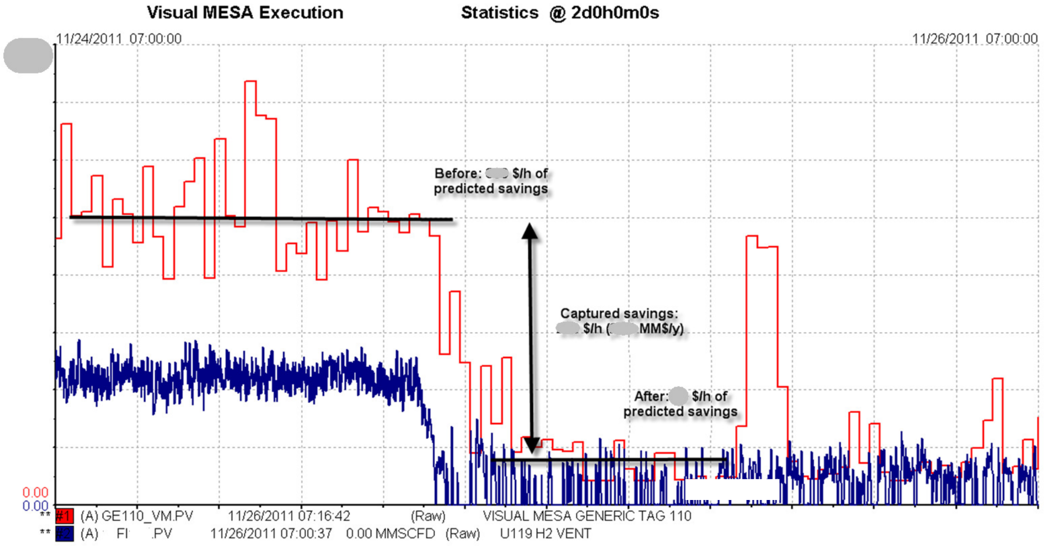


**Figure 10** – Total savings, in $/h, captured after the closing of the hydrogen vent in one of the Units

## Conclusions

Energy cost reductions can be obtained by taking advantage of modern energy management system software functionalities including together all the site sub-systems, including the important interaction of hydrogen systems. Such reductions can only be achieved with the use of a robust optimizer that should be very well suited to be used on-line and providing optimization recommendations to the operators on a routine basis.

The authors, working closely with clients and Soteica Visual MESA engineering team members, have participated in many successful implementations which resulted in significant economic benefits for the refining and petrochemical industries involved, oftentimes topping $2MM+ per year in documented savings.

The success of the industrial real time project deployments has been enabled by following a set of simple rules and ensuring a proper knowledge transfer to both the client Operations and Engineering personnel. Coordination among plant areas in order to implement the proposed optimization recommendations, as well as management involvement to ensure the initiative's success, are both critical issues. The quality of the recommendations from the tool helps Operators to gain confidence in the overall optimization system.

Application sustainability, which includes both maintenance and support from Soteica Visual MESA, is critical to continuing capture of the economic benefits after commissioning. This helps ensure the model stays "evergreen" and bringing value to the owner for many years after commissioning of the project.

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