

Low-carbon refinery: Dream or reality

These steps show how to implement an effective carbon management system at your facility

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Within an operating refinery, low-value feeds and products are upgraded into higher value products. “Low carbon” is the new buzz phrase used to denote facilities that are efficient with carbon dioxide (CO₂) emissions. The same applies to “carbon management,” which is about managing the carbon lost from the refinery—most is emitted as CO₂ to the environment.

The primary reason for a refinery to minimize carbon emissions is *cost*. Carbon is product; product is money. Therefore, the lesser amount of carbon emitted, the more profitable refinery operation becomes.

Global emissions is the secondary reason for reducing carbon emissions. Studies have shown that the moment the diesel or gasoline is about to ignite in the car engine, 17% of the original fuel from the well is lost. This concept of “well-to-wheel energy cycle” identifies the efficiency of producing crude oil, stabilizing, pumping to the terminal, shipping to the refinery, processing within the refinery, pumping again to ships or trucks, and finally distributing the product to retail outlets. This impacts the cycle efficiency of the vehicle. For a 30-mpg vehicle with a “petroleum refining and distribution efficiency” of 0.83, the car would only have about 25-mpg life-cycle efficiency.¹ It is important to reduce the 17% carbon lost. One of the best places to cut carbon losses is within the refinery where often more than half of these life-cycle carbon emissions are realized.

With the growing incentive to reduce greenhouse gas (GHG) emissions, refineries and petrochemical plants face large and new challenges in their operations. A combination of new and complex legislation, trading opportunities, public pressure and environmental consciousness brings this industry into a new age where the GHG emissions may set constraints on throughput and operating margins. However, many refineries are energy inefficient and, consequently, more carbon is emitted to the atmosphere than necessary. Typically, refineries produce more than 30% CO₂ as compared to best practices. A project in a North American refinery demonstrated that approximately 15% carbon emissions could be reduced with projects having a three-year simple payback. This article describes how to achieve these improvements by implementing a methodical approach and using the right tools.

Steps to a low-carbon facility. Several steps can be used to develop a carbon management program that helps the industry

implement a strategic plan for emission reductions while complying with legislation and remaining competitive.

Step 0: Do we need a market analysis? “Do we need a market review” can be answered in two ways. To implement carbon emission reduction (energy savings) projects with high oil prices is very beneficial. A carbon management system helps refineries reach their energy saving targets and make significant profits. However, current carbon trading mechanisms may help finance those projects that otherwise would not get over the hurdles of payback or internal rate of return. If the refinery is located in Europe, trading opportunities exist on the European Emissions Trading Scheme (ETS) to buy and sell some of the European Union (emission) Allowances (EUAs) that were distributed by the governments through their National Allocation Plans (NAPs). The value of these allowances have fluctuated around the 20 €/ton of CO₂, although the price of the first batch of allowances that were given to the European refineries in Phase 1 collapsed in late 2006. This happened as it became apparent that more allowances were granted than actual emissions realized. Also, the allowances could not be transferred to the second phase.

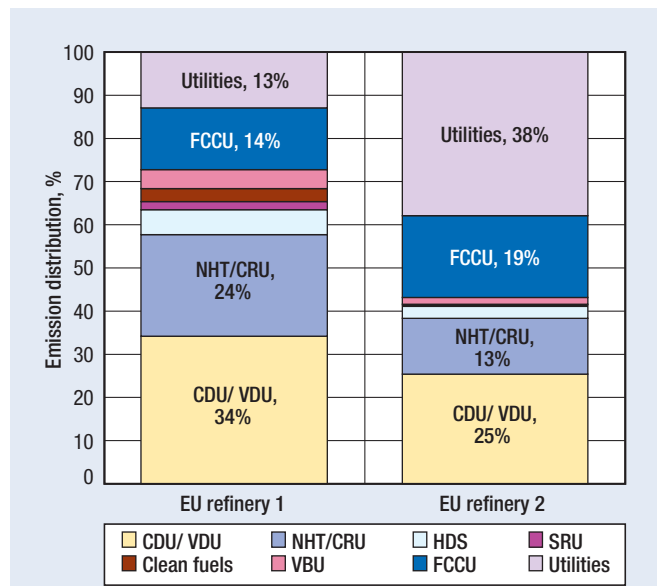


FIG. 1 Emission distribution for two European refineries.²

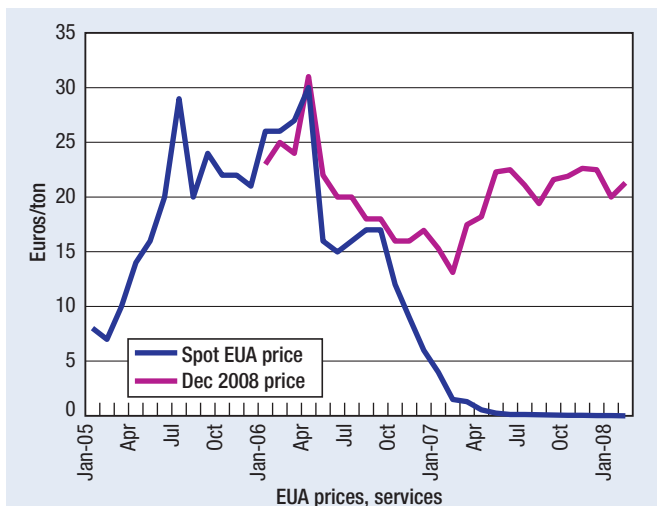


FIG. 2 Pricing trend for emission credit trading in the European Union.

A refinery with a carbon management system could anticipate such developments, be actively involved in the carbon market and control actual refinery emissions through its emission forecasting tools.

In countries that have ratified the Kyoto protocol, other opportunities exist. Although not as straightforward, carbon credits can be secured through the UNFCCC Clean Development Mechanism (CDM). Certified Emission Reductions (CERs) can be traded, provided that the emission reduction is realized on a site in a developing country and that an investment is required to realize that reduction. Also, in the US, there is the possibility of Voluntary Emission Reductions (VERs) that work under the same mechanism as the CDM, although the emission reductions are not registered under an official government or UN body.

At present, these voluntary markets are insignificant in terms of value and turnover compared to the EU ETS (EUA) and CER markets (Fig. 2). However, they will become more relevant when they are transformed into cap-and-trade schemes. In addition, since both US presidential candidates favor cap-and-trade, the introduction of legislation on a federal level is anticipated. Accordingly, the US may kick-off a potentially huge North American GHG emissions market in 2009.

Step 1: Current emission levels and footprints. After three years of ETS experience, measurement of current carbon emissions has been well established in Europe. Governments are required to strictly monitor emission levels with the possibility of trading these allowances. This is described in a set of policies that require the refineries to measure emissions and report results following strict formats and standards.^{3,4} There may be an advantage of using these standards elsewhere to determine a refinery's carbon footprint, although not always the most efficient or accurate way. New measurement practices have been developed for fuel gas and steam models, as well as a hydrogen balance. These models calculate current and estimate future emissions. Applying such tools can aid in establishing a base line for future GHG reductions (Fig. 3).

This methodology addresses some of the main gaps in European legislation for a refinery.^{3,4} This legislation is suitable for installations that have a single fuel flow, like power plants, fertilizer plants, or steam crackers. However, it does not really address the complexity of a refinery. Several issues are not covered by the legislation, such as:

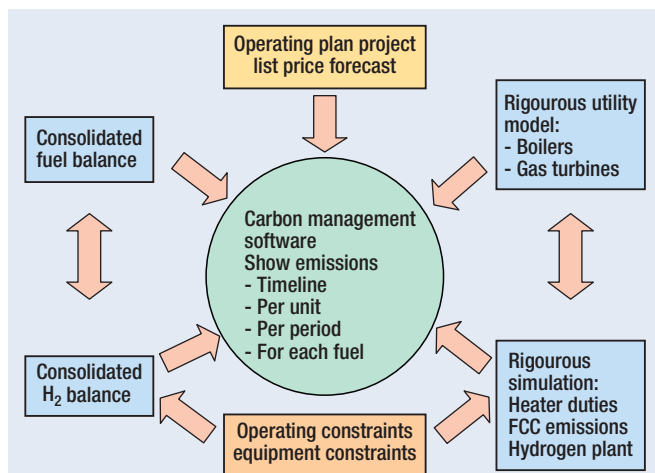


FIG. 3 Data flow for carbon emissions monitoring program.

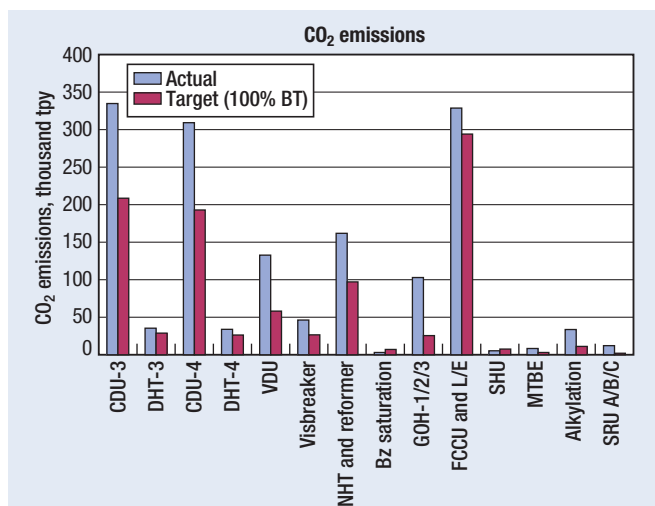


FIG. 4 Comparison between actual CO₂ emissions and best practice for CO₂ emissions.

- A large number of fuel users, heaters and boilers, often each with its own combination of fuels (liquid and gas) and different compositions of fuel gas
 - Fuel gas is produced at many units at various compositions and injected into the fuel gas network often at different locations
 - A significant amount of CO₂ is generated in flares, incinerators and the biotreatment plants, which is poorly measured or not addressed at all
 - For a typical refinery unit, such as the fluid catalytic cracking (FCC) unit, CO₂ emissions are not easy to measure directly. EU regulations suggest calculating the emissions based on mass balance of the unit. The uncertainty using this method introduces a significant error in the emission calculation.
 - Hydrogen plant emission calculation of the EU directive assumes 100% conversion of carbon in feed to CO₂, which is correct if no carbon leaves the unit with the hydrogen stream. This is true for most but not all hydrogen plants with pressure swing adsorption (PSA) purification and always incorrect for units in which hydrogen is purified through CO₂ absorption.

Measurements do not give an accurate picture of the emissions due to inaccuracies, which makes it worthwhile to use more

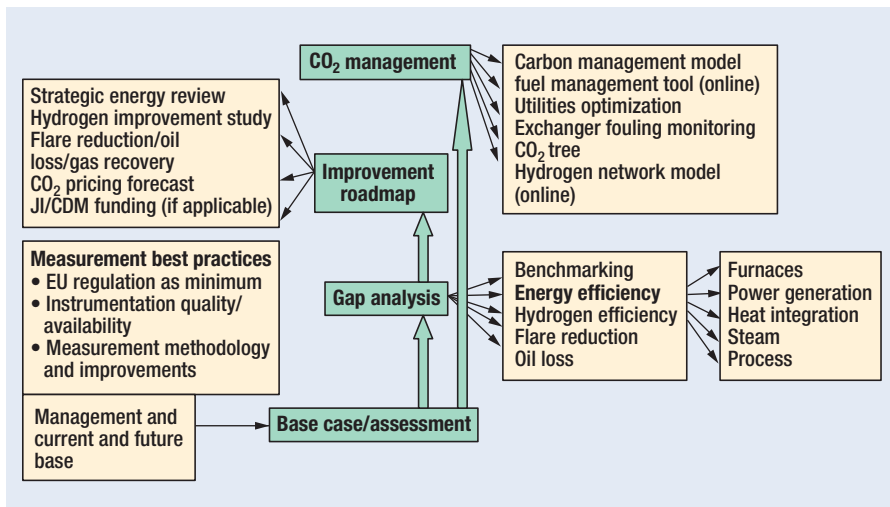


FIG. 5 Four steps to a carbon management system.

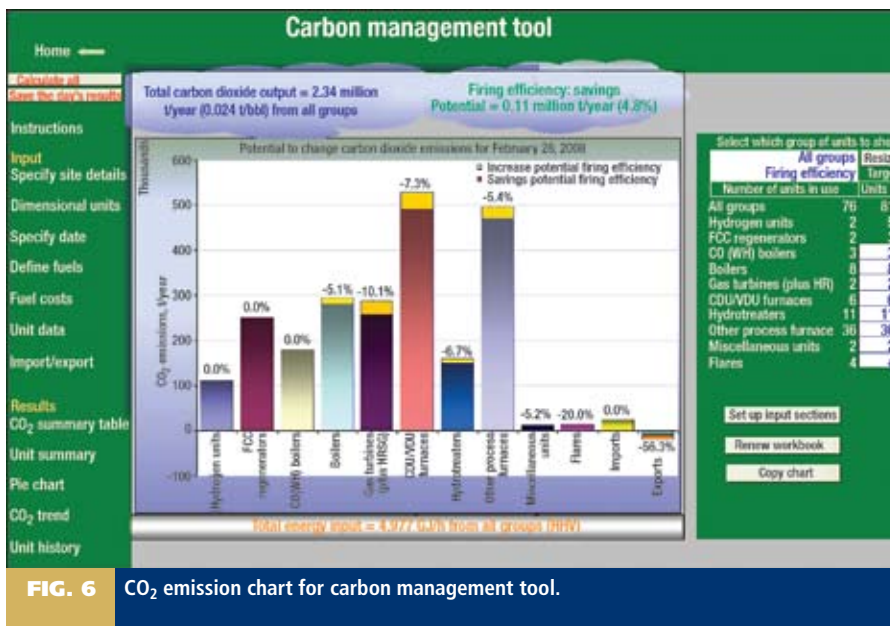


FIG. 6 CO₂ emission chart for carbon management tool.

sophisticated reconciliation and modeling software to validate such measurements. Since the directive only establishes measurement and reporting guidelines, it does not help to estimate future emissions, and does not address how the emissions can be compared to best practices. To address these concerns, a combined benchmark and gap analysis is required.

Step 2. Benchmarking/gap analysis. We can compare the plant performance with current best technology and best practices to determine the maximum potential of GHG reduction. The best technology benchmark for a refinery can be described as the same refinery with the same feed and product mix, but now built according to the *best practice* with the most efficient technology. For example, this includes efficient heaters and boilers with more than 92% efficiency, heat integration implemented using pinch tools and with a minimum approach temperature of approximately 20°C, no flaring and power generation efficiency of at least 80%. The actual refinery that is benchmarked is compared on unit-by-unit level with best tech-

nology and it becomes clear, which units have main emission “gaps” are (Fig. 4.)

The largest potential for CO₂ emissions reductions is through energy efficiency improvement. However, other CO₂ gaps can be identified, too, such as in oil loss, flaring, fuel switching and hydrogen network optimization. Typically, most refineries are inefficient and produce 30%–100% more CO₂ as compared to best practices units. The gap analysis will show for each unit in detail how much of the emissions are contributed through inefficient fuel usage, wrong fuel type, poor energy integration or high usage of inefficient power, utilities and/or hydrogen.

Step 3. Reduction roadmap.

Although the gap analysis shows the maximum potential for a refinery to reduce emissions, only projects that can be practically implemented are considered for the investment roadmap. Projects on this roadmap are ranked with the most beneficial projects receiving the highest priority. Depending on the site location, additional funding for implementation as a joint implementation or CDM project can be considered. Projects in the roadmap typically can be classified in three categories:⁵

- **Fired heater efficiency.** This can be improved by the installation of a increased convection area, waste-heat boilers or an air preheat system. While the first two options do not increase the NO_x emissions, the last one only becomes attractive on inefficient furnaces with a fired duty of more than 25 MMBtu/hr, resulting in a payback of three years or less.

- **Power generation efficiency.** There is a wide range of options possible for the improvement of power generations. This

varies from simple operational improvements, such as maximizing use of backpressure steam turbines, vent management, reduction of let-downs and a strategy on power import/export. Also, significant investments can be justified by installing a cogeneration plant or a power-recovery turbine in the FCC regenerator flue gas.

- **Energy integration.** This requires pinch analysis to determine the maximum cost-efficient installation of heat exchangers. Significant changes to the unit sometimes can be avoided by the installations of special tube or baffle arrangements such as twisted-tubes or helical baffles.

Projects should be evaluated on a site-wide basis using the proper simulation tools. For example, if CO₂ emissions on an FCC were reduced due to a conversion reduction, then the impact on the utilities would be significant. Reduced conversion loss in this FCC unit results in a lost steam production from the regenerator, which must be made-up for by the boilers.⁶

Step 4: Implementing and sustaining. The last step in the development of a carbon management system is to install and

to support tools for implementing and sustaining carbon-emission reductions. To aid in sustaining the lowest emissions, monitoring and forecasting tools that can be closely tied in to the energy management system are available.

Carbon management tools. New modeling tools (Fig. 5) can be used for management level representation of site CO₂ emissions with a clear breakdown of sources. The program can calculate CO₂ produced from individual combustion equipment—not only from emission factors, but also from combustion equations. All combustion equipment within a refinery, including hydrogen production and catalytic cracking units, are included in the model. This carbon management tool compares CO₂ emissions from all units with best technology and evaluates the potential to reduce CO₂ emissions through energy efficiency and fuel switching. When linked to a distributed control system (DCS), a carbon management program can be used to trend the historical CO₂ emission pattern of the site.

Fig. 6 is a screenshot that illustrates the carbon management program. This tool is used and designed for CO₂ emissions calculation, monitoring and reporting. With the Excel interface, a carbon management tool can easily be linked to the DCS for real-time emissions calculations.

The carbon management model can be used to:

- Plot calculated emissions
- Improve the understanding from different sources
- Reconcile emission measurements
- Get historical trends and monitor performance
- Compare actual emissions against best practices or cap, if applicable.
 - Predict emission changes, such as:
 - o Fuel switches
 - o Improve heat integration on units
 - o Hydrogen recovery from the fuel gas in PSA units and the impact on emissions
 - o Changing FCC feed quality and unit operation.

Study case: North American refinery. Pressure is mounting on the petrochemical and refining industry to reduce GHG emissions. Many states in the US are facing similar challenges. For example, in California, some of the strictest legislations are enforced by the California Air Resources Board, where the local target is to reduce GHG emissions by 25% by 2020.

A CO₂ reduction strategy was developed with best practices for emission measurement and applying new carbon management modeling tools. This project used an integrated approach for monitoring, reporting and forecasting CO₂ emissions. Legislation was not the only driver for a reduction in emissions at this facility. Due to higher crude oil pricing, a 10%–15% reduction in emissions can be accomplished with investments that lead to a simple payback of just over two to three years.

Low-carbon refinery: Dream or reality. Refineries are not energy efficient; as a result, more CO₂ is lost to the atmosphere than necessary. A gap analysis and roadmap development can help a refinery address those inefficiencies and identify projects that are very beneficial. To implement and sustain these emissions reductions, a carbon management system should be developed that helps the refinery to monitor and report current emissions and forecast these emissions based on the refinery operating plan. Since energy is the largest part of a refinery's operating costs, this approach will improve the refinery's energy performance and operation margin. These projects result in energy and emissions efficient refineries, which can collectively lead to an improvement to the cycle efficiency of fuel usage. **HP**

LITERATURE CITED

- ¹ 10 CFR Part 474, Department of Energy, 2000.
- ² Spoor, M., "The Refinery CO₂ Challenge, Part 1: Measuring, reporting an reduction of CO₂ Emissions," *Petroleum Technology Quarterly*, Winter 2006.
- ³ Establishing Guidelines for the Monitoring and Reporting of Greenhouse Gas Emissions Pursuant to Directive 2003/87/EC of the European Parliament and of the Council, *Official Journal of the European Union*, Feb. 26, 2004.
- ⁴ 2007/589/EC, Establishing guidelines for the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council, July 2007.
- ⁵ Polanco, D., "Monitoring and reducing a refinery's carbon footprint," NPRA Annual Meeting, March 2008, San Diego.
- ⁶ Spoor, M., K. Minks and J. Mertens, "The Refinery CO₂ challenge. Part III: predicting refinery wide CO₂ emissions by Rigorous Simulation," *Petroleum Technology Quarterly*, Autumn 2006.

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