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Developing a methodology for an EU refining industry CO_2 emissions benchmark

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Developing a methodology for an EU refining industry CO_2 emissions benchmark

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ABSTRACT

In the third trading period under the EU Emission Trading Scheme (EU ETS), refineries and other eligible industrial installations may be granted free CO_2 emission allowances according to a benchmark based on the 10% most efficient installations in the sector. This report describes the process whereby CONCAWE, on behalf of the refining industry, proposed a benchmark for oil refineries under the EU ETS based on the CWT (complexity weighted tonne) concept developed by Solomon Associates. This benchmark defines the basis on which free allowances are to be allocated to refineries between 2013 and 2020.

KEYWORDS

ETS, CWT methodology, CWT factor, product benchmark, CO_2 performance index, free allocation

INTERNET

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SUMMARY

Under the EU Greenhouse Gas Emissions Trading Scheme [1] (EU ETS), industrial emitters of greenhouse gases (GHG) must, every year, surrender emission allowances matching their actual emissions for the previous year. In the third EU ETS trading period, starting in 2013, the generic rule for allocation of allowances will be auctioning. As auctions would be directly influenced by the current carbon market price, this would place an unpredictable, uncertain and potentially heavy burden on EU industry. In order to alleviate this, those economic sectors exposed to international competition, including oil refining, will still be granted a proportion of the required allowances free of charge according to a sectoral benchmark developed on the basis of the performance of the "10% most efficient installations" in the sector.

In this context, CONCAWE, on behalf of the EU refining industry, cooperated with Solomon Associates (Solomon), a consultant to the oil industry for over 30 years, to develop a benchmarking scheme for EU refineries based on the "Complexity-Weighted Tonne"[1] (CWT) concept that would be fair, equitable, practical and would be consistent with the stipulations of the EU ETS. Under the agreement with Solomon, CONCAWE acquired the rights to use and promote the "EU-CWT" methodology in Europe for the specific purpose of complying with the EU ETS. A 2009 study [4] by the Ecofys consultancy on behalf of the EU Commission confirmed that CWT was an appropriate activity parameter on the basis of which a refinery benchmark could be developed.

In the CWT methodology a factor is assigned to each refinery process unit. Each unit's CWT factor is the ratio of the unit's CO_2 emissions to the CO_2 emissions of a crude distillation unit, with both units operating under "standard" conditions, i.e. at a standard level of energy performance and using a standard fuel. The refinery-wide CWT is the sum, over all the refinery units, of the product of each unit's CWT factor by the corresponding unit throughput over a given time period. An additional term accounts for other refinery activities outside of process units, such as blending, storage etc. A refinery's CWT is an activity function that correlates well with that refinery's CO_2 emissions at a standard level of CO_2 emissions performance, while its real CO_2 emissions reflect the actual level of CO_2 performance of the refinery. The ratio of real CO_2 emissions to CWT (CO_2/CWT) is therefore a performance index of refinery CO_2 efficiency.

In order to ensure consistency between emission sources included in actual emissions and in CWT and to comply with the specific requirements of the EU ETS Directive regarding electricity (no free allowance to be granted to electricity production) corrections had to be applied to both emissions (starting from the verified site emissions reported under the EU ETS) and CWT.

In order to calculate the CO_2 performance index of each EU refinery, relevant data had to be collected covering activity (plant throughputs), utilities data (for heat and electricity correction calculations) and verified emissions. A list of all 113 EU petroleum oil processing sites was established. For 15 mostly small sites performing specialised functions (mostly bitumen and lube oil manufacture) the CWT methodology was found to produce inconsistent and unpredictable results. These sites, designated as atypical, were not further considered as refineries and received allowances according to the fuel and heat benchmarks defined by the EU

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[1] Note that the original "Complexity Weighted Tonne", abbreviated to CWT, was subsequently renamed "CO_2 weighted tonne" in EU Commission documents.

Commission at a later stage. Data were collected by CONCAWE for the remaining 98 mainstream refineries.

A plot of the CO_2/CWT performance index in ascending order (see **Figure 3**) identified the 10% most CO_2 efficient performers (10 refineries). Consistent with the final interpretation of the EU ETS stipulation, the benchmark was defined as the arithmetic average of these 10 lowest performance indices, i.e. 29.5 t CO_2/kt CWT compared to the average of 37.0 t CO_2/kt CWT for the total mainstream refinery population. The reference period for this exercise was 2007-2008.

The benchmark is some 20% lower than the average. When considering the additional 13% of emissions related to electricity that do not qualify for free allowances, it is clear that the refining sector will receive a much smaller proportion of free allowances than what would be suggested by the overall EU ETS objective of 20% reduction by 2020.

In order to ensure consistency of treatment for number of process units which are found in refineries and also in the petrochemical or industrial gas production sectors or operated independently, discussions took place between the EU Commission, CONCAWE and the relevant industrial sector associations resulting in the adoption of the CWT concept for all such plants.

The final step in the process was to determine the “baseline” activity (i.e. CWT) on the basis of which individual refineries would receive free allowances. The baseline period was defined as either 2005-2008 or 2009-2010 at the discretion of the operator. Appropriate data were collected from individual operators by the EU Member States after verification by independent verifiers. In order to facilitate this process and build on the experience acquired during the benchmark setting process, CONCAWE developed a detailed data collection template.

The preliminary free allocations to a refinery are calculated as the product of the baseline CWT (corrected for electricity consumption) and the benchmark. This number may have to be further adjusted to allow for the so-called “cross-sectoral” correction when the sum of all free allocations in all sectors is compared to the total emissions allowed by the EU ETS Directive reduction path. This may result in a correction uniformly applied to all sectors and all installations.

1. INTRODUCTION

Under the EU Greenhouse Gas Emissions Trading Scheme (EU ETS), industrial emitters of greenhouse gases (GHG) must, every year, surrender emission allowances matching their physical emissions for that year. Emissions allowances are issued by national governments in a limited quantity as stipulated in the Directive. Once issued, allowances may be exchanged or “traded” amongst industry players, giving rise to the so-called “carbon market”.

The EU ETS introduced a number of mechanisms for distributing emission allowances amongst industry players. In the first and second emission trading periods under the original EU ETS Directive, the majority of allowances were distributed free of charge using historical emissions as the distribution key (so-called “grandfathering”) with a uniform reduction percentage.

In the third trading period, starting in 2013, the generic rule will be auctioning i.e. allowances will be put on the market on a regular basis by governments and sold to the highest bidder. Trading of allowances already issued will still be possible on the open market. While this process is relatively simple and provides strong market-related signals, it does result in a potentially heavy and uncertain financial burden on EU industry, to which equivalent installations outside the EU are not subjected. This could affect the competitiveness of EU industry. In addition, and of crucial significance in a programme designed to reduce GHG emissions, this could result in so-called “carbon leakage” i.e. moving of carbon emitting activities from inside the EU to other regions that are not submitted to similar restrictions. Not only would global emissions not decrease, they could actually increase as a result of additional need for transport of goods and possibly less energy-efficient manufacturing outside of the EU.

The EU Commission has recognised these concerns and, as a result, those economic sectors exposed to international competition will still be granted a portion of the required allowances free of charge. The amount of free allowances will be based on a sectoral benchmark developed on the basis of the performance of the “10% most efficient installations” in the sector in 2007 and 2008. Free allowances will be granted on the basis of actual activity between either 2005 and 2008 or 2009 and 2010.

In this context, the EU Commission and sectoral industry stakeholders set out to develop robust benchmarking schemes for each sector. This report describes the development of the refinery benchmarking scheme, the determination of the benchmark and the calculation of the free emission allowances to EU refineries.

2. GENERIC OBJECTIVES OF A BENCHMARKING SCHEME

The ultimate EU ETS policy goal is to encourage GHG emission reductions through investment and adoption of good practices. In order to achieve this, a benchmarking scheme has to be seen as fair and equitable rather than arbitrary and it must recognise and reward early movers. The benchmarking methodology must seek to single out differences in emissions that are due to performance (in this case GHG efficiency) i.e. “how well things are done”, rather than to structural differences related to the level and type of activity i.e. “what is being done”.

In order to minimise administrative burden and provide a high level of transparency the scheme has to be as simple as possible. This has, however, to be balanced by the need for realism and equity which is likely to impose a minimum level of complexity. So the scheme should be simple but not simplistic.

Finally the scheme should be based on operating data which need to be verifiable and auditable.

3. THE CHALLENGE OF GAUGING THE RELATIVE PERFORMANCE OF REFINERIES

When attempting to compare the performance of oil refineries (be it in terms of cost, energy or emissions), one encounters a fundamental difficulty. Although most refineries process crude oil to make a broadly similar range of products (LPG, gasoline, kerosene, gasoil/diesel and fuel oils), they are all different in terms of size, number and types of process units, the specific grades of products they make and the types of crude oil they use. As a result their energy consumption and CO_2 emissions vary a great deal in absolute terms and do not readily correlate with simple indicators such as crude throughput, product output or the like.

A simple refinery may just separate crude oil into its fractions and perform a minimum of treating (e.g. desulphurisation) and upgrading (e.g. gasoline octane improvement). Its energy consumption per tonne of crude will be low, maybe 3-4% of its intake, and so will its CO_2 emissions relative to crude intake. A complex refinery will do all of the above and, in addition, convert heavy molecules into lighter ones to make more of the products that the market requires out of a given crude oil resource. That refinery will consume considerably more energy, at least 7-8% of its intake, and have much higher CO_2 emissions per tonne of crude processed.

This by no means suggests that the simple refinery is “good” and the complex one “bad”. The fact of the matter is that complex refineries are essential to match crude oil supply and petroleum product demand. Simple refineries can survive only because complex ones exist. Both types of installation are complementary parts of a “system” that is required to supply the market with the right products in quantitative and qualitative terms. The real measure of refinery performance in emissions terms is the efficiency with which they carry out the various operations. A simplistic benchmark based on refinery production or intake would favour simple refineries and lead towards an increase in crude oil consumption and a surplus of heavy fuel oil.

Individual product benchmarking is not a practical approach either for oil refineries. Indeed they produce a variety of products simultaneously and it is notoriously difficult to apportion resources used to each individual product in a technically sound manner.

In order to benchmark refineries one therefore needs a common activity parameter which irons out differences related to what the refinery does, leaving only the variability related to how efficiently it does it.

4. THE CWT METHODOLOGY

To resolve this difficult problem CONCAWE cooperated with Solomon Associates (Solomon), a consultant to the oil industry for over 30 years. Over many years Solomon has developed a management benchmarking concept for refineries that is used by the majority of refiners worldwide and covers all aspects of the refining business, including energy efficiency and, more recently carbon efficiency. This is supported by a large and unique database of detailed refinery operation information provided by industry over an extended period.

Before benchmarking was introduced in the EU ETS, Solomon had already started working on a new concept, the so-called “Complexity Weighted Barrel” (CWB™), based on an analysis of the complexity and size of refineries, that had the potential to provide a robust technical solution. In 2008 the European Commission retained the Oeko Institute and Ecofys to carry out a study [2] of options for benchmarking of CO_2 emissions in a number of sectors including oil refining. The study narrowed down the field to two possible methodologies for refining based on broadly similar principles: The Solomon CWB^{TM} approach and a “hybrid” system combining size and complexity factors. The refining industry’s experience of more than 30 years of refinery benchmarking with Solomon made it clear that working with them would be more likely to lead to a practical and reliable methodology than embarking on a new approach with everything to be developed and validated.

Solomon was therefore contracted by CONCAWE to develop a specific benchmarking methodology based on “EU-CWT[1]” that would fulfil the generic objectives laid out in chapter 2. The study was initiated in November 2008 and the final report released to CONCAWE at the end of February 2009. Under the agreement with Solomon, CONCAWE acquired the rights to use and promote the “EU-CWT” methodology in Europe for the specific purpose of complying with the EU ETS.

A second Ecofys study [3] identified a set of principles for product benchmarks (defined as t CO_2 per t product), four of which are of particular relevance to the refining sector:

- Do not use technology-specific benchmarks for technologies producing the same product
- Do not differentiate between existing and new plants
- Do not apply corrections for plant age, plant size, raw material quality and climatic circumstances
- Do not use fuel-specific benchmarks for individual installations or for installations in specific countries

Finally, in November 2009 a further study by Ecofys [4] confirmed that, in the case of refining, individual product benchmarks would not be suitable and that CWT was an appropriate activity parameter on the basis of which a refinery benchmark could be developed in the context of the EU ETS and be consistent with the above principles.

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[1] Solomon’s original CWB concept based on barrels was modified into CWT referring to tonnes to be in line with European industry practice. The principle remains the same.

4.1. DEVELOPMENT OF THE CWT METHODOLOGY

In order to define a performance benchmark, one must first make data from the diversity of refineries comparable. The Solomon concept is to derive a “proxy” activity function that correlates well with CO_2 emissions at a given level of performance.

To compare the energy performance of refineries, Solomon developed the Energy Intensity Index^{TM} (EII®). The EII methodology assigns a “standard” specific energy consumption factor to each process unit operated by a refinery. These factors have been developed by Solomon from their extensive database of similar process units and broadly represent an average energy performance. The “standard” energy consumption of a refinery can be derived by summing up the products of these standard factors by the actual throughput of each process unit over a certain period of time. In 2003 Solomon extended this concept to greenhouse gases with the development of the Carbon Emissions Index (CEI™).

For this benchmarking exercise, Solomon proposed a concept termed “Complexity Weighted Tonne” (CWT) focussed on CO_2 emissions but based on a similar principle:

- A list of generic process units is defined, representing the diversity of processes applied in the (EU) refinery population to be benchmarked.
- Each process unit is assigned a CWT factor which is the ratio of the unit’s CO_2 emissions to the CO_2 emissions of a crude distillation unit, with both units operating under “standard” conditions, i.e. at a standard level of energy performance and using a standard fuel (the average fuel mix consumed by EU-27 refineries in 2006). The factor also includes, where appropriate, a term for process emissions (see further in 4.2).
- For each process unit the factor is multiplied by its throughput during a given period and all such products are summed up. The sum total is the “process” CWT of the refinery.
- A CWT allowance is added for so-called “off-sites”, i.e. ancillary refinery facilities that are not directly attributable to individual processes, such as tankage, blending, etc. (see further in 4.3).

CWT can be considered as the combined activity of the different process units generating CO_2 emissions at a standard level of performance. The ratio of actual emissions to CWT (CO_2/CWT) is therefore a performance index of refinery CO_2 efficiency.

It is of course crucial that, in the CO_2/CWT ratio, numerator and denominator refer to the same boundaries. As a “proxy” for CO_2 emissions, CWT refers to all emissions related to producing the refinery products, including those that may have been incurred outside of the refinery through energy import (essentially electricity and/or heat) and excluding emissions incurred for on-site production of energy that is then exported. Verified emission figures under the EU ETS Directive, however, pertain to a site so do not take account of energy import but do include energy export. The EU ETS Directive also includes a specific rule according to which no free allowances may be granted to electricity production. As a result, appropriate corrections have to be applied to CWT and/or verified emissions to make them mutually consistent as well as compliant with the Directive. The mechanisms developed to achieve this are described in the next section.

4.2. $CWT_{PROCESS}$

The EII® and CEI™ algorithms include a large number of factors (over 200) to account in detail for every process unit operated by refineries worldwide. EU refineries operate an equally wide variety of process units, in excess of 150 different processes. Developing a CWT factor for each of these processes would result in an overly complex methodology, particularly in terms of data requirement. Simplification was therefore essential and had to aim for a compromise between accuracy of the representation and practicality. During the process of developing the method, several opportunities for simplification, mostly by pooling similar process units, were identified and most of them implemented. In order to ensure full representation of the refinery population, a small number of factors were derived for specific process units operated by a single or a few refineries. The final list (***Appendix 1***) includes 56 CWT "functions", the majority of which are only used by a handful of refineries. Describing a typical refinery of medium complexity would require about 15 functions.

Steam cracker complexes are not included in the envelope of the methodology as they are handled as part of the chemicals sector. Whenever a steam cracker is physically integrated into a refinery it is therefore not included in the calculations and the corresponding CO_2 emissions have to be subtracted from the total. Plants for production of aromatic hydrocarbons and some associated downstream processes are included when they are located within- and operated by- the refinery. Base lube oil production and bitumen plants are also included.

The CWT factor for a particular process unit is the ratio of the standard CO_2 emissions per tonne of throughput of that unit divided by that of a crude distiller per tonne of crude throughput. Although CO_2 emissions from refinery process units are mostly related to fuel combustion, some process units generate "process" emissions resulting from specific chemical reactions (e.g. hydrogen manufacturing) or from combustion of an internally produced fuel as an integral part of the process (e.g. FCC, gasifiers, coke calciners).

The combustion terms of the CWT factors are based on the standard energy consumption of the unit as defined by Solomon for its EII® energy intensity indicator (with some simplifications). Because they are relative to the crude distiller's and all refer to the same fuel emission factor, these energy-based CWT factors are in effect independent of that emission factor. Based on the average fuel emission factor of EU refineries, the CO_2 emission equivalent of 1 CWT was calculated by Solomon to be 37.8 kg.

Where appropriate a process emission term was included in the CWT factor to account for additional CO_2 emissions resulting from chemical reactions or fuel sources that are intrinsic to the operation of certain process units (e.g. CO_2 produced in hydrogen production reactions and in combustion of coke on catalytic cracking catalyst). These CO_2 emissions were converted into CWT terms using the above equivalence of 37.8 kg CO_2 per CWT.

$CWT_{process}$ (kt/a) for a refinery is the "sumproduct" of the relevant CWT factor by the actual kilotonnes of throughput of each process unit (or by the kilotonnes of production for certain units) during a given period of time[2].

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[2] Other measures, such as unit capacity, for the CWT activity basis were considered. The ETS Directive, however, is very clear that the basis should be throughput which was used here.

In effect, $CWT_{process}$ represents the notional crude distillation capacity that would emit the same quantity of CO_2 as the actual combination of process units.

4.3. $CWT_{OFF\text{-}SITES}$

Solomon's algorithm for the determination of EII® includes two additional terms over and above those directly related to process units:

- An "off-sites" term that is meant to cover the ancillary energy-consuming facilities operating inside the refinery fence-line, such as water treatment, common facilities, tankage, blending etc.
- A "non-crude sensible heat" term that provides an additional allowance for heating up non-crude feedstocks entering the refinery to the temperature at which they would normally be available from e.g. the crude distiller.

The derivation of these terms is complex and involves a number of additional parameters and factors leading to a level of complexity that was not warranted in view of their impact. Solomon was requested to pool these two elements into a single term which resulted in a simple formula:

$$CWT_{off\text{-}sites}\,(kt/a) = 298\,(kt/a) + 0.315 * CDU^{\dagger}\ intake\,(kt/a) + 0.0183 * CWT_{process}\,(kt/a)$$

† Crude Distillation Unit

Note that if the CWT and intake terms are expressed in any other unit (e.g. t/d), the fixed term has to be recalculated accordingly.

This term reflects the fact that off-site energy consumption is impacted by the total hydrocarbon throughput (CDU intake) as well as by complexity (CWT).

$CWT_{off\text{-}sites}$ is simply added to $CWT_{process}$ to give the total CWT representing the activity of the refinery for the purpose of producing its petroleum products.

4.4. ACHIEVING CONSISTENCY BETWEEN EMISSIONS AND CWT

In order to ensure consistent boundaries for actual emissions and CWT and to comply with the specific requirements of the EU ETS Directive regarding electricity production, a detailed analysis of heat import/export and electricity balance was required.

There was considerable debate as to the way heat import/export should be handled. The ETS Directive specifies that an operator is responsible for his "direct" emissions i.e. those generated on the site. Applying this principle in the benchmarking methodology would, however, have created a significant distortion. In a sector exposed to international competition (and therefore qualifying for free allowances), internally generated heat would have generated free allowances. However, as the heat production sector is not considered to be exposed to international competition, any heat imported from that sector would not have qualified for free allowances (the problem is of course not limited to refineries and can be even more serious in industry where heat is the main energy vector).

The Commission and their consultant recognised the problem and concluded that an allocation based on the consumer benchmark would be the best way to achieve the stated objective to give the same allocation to heat, irrespective of whether it is produced on site or outside. Once this has been accepted, the simplest and most pragmatic solution was to grant the allocation to the consumer.

With regard to electricity, the methodology had to comply with a specific stipulation of the EU ETS Directive that no free allowances can be granted for electricity production, irrespective of where and how it takes place (with the exception of electricity produced from waste gases and some transitional measures related to the modernisation of electricity production) and of where the electricity is consumed. This implied that deemed emissions from electricity imports did not need to be considered and no free allocations could be claimed regarding emissions generated by internal production of electricity, whether used internally or exported.

Note that there is no call for any correction for import/export of other streams such as hydrogen. If hydrogen is produced on site, it generates direct emissions and the production plant is integrated in the CWT methodology. If hydrogen is imported, the emissions are not generated on site and there is no contribution to the refinery CWT from this external hydrogen production.

4.4.1. CO_2 emissions as the numerator of the performance index

For the CO_2 emissions numerator of the performance index, the starting point was the “direct” verified site emissions (D) as reported under the EU ETS.

In accordance with the Directive’s stipulation, no emissions adjustment was allowed for electricity import. However, actual emissions arising from on-site electricity production (GE) needed to be subtracted to yield the electricity-free site emissions (R):

$R = D – GE$

Refineries produce electricity in a number of different ways, often in combination with the production of useful heat. As a result, estimation of the emissions associated with on-site electricity production (GE) requires a large amount of data as well as a robust methodology to separately account for heat and electricity. Details of the data collection and adopted methodology are given in **Appendix 1**.

R includes any emissions incurred for producing exported heat (SE) but does not include emissions that would have been incurred to produce imported heat (SI). A further adjustment is therefore required to ensure consistency with the principle of allocating heat-related emissions to the consumer. This yields the emissions related to refining activities excluding any electricity and including net heat imports (U):

$U = R – SE + SI = D – GE – SE + SI$

SI and SE are calculated as the product of the measured heat stream by a deemed emission factor. In the original CONCAWE methodology used for determining the benchmark (see chapter 5), the following emission factors were used:

For SI: 0.0724 (t CO_2/GJ) = 0.0652 (average for all EU refineries) / 0.9 (deemed efficiency of heat production)

For SE: (Average direct fuel emission factor for the specific refinery) / 0.9

This was later modified on request of the EU Commission to use the same factor for both SE and SI of 0.0623 (t CO_2/GJ), representative of natural gas (0.0561 t

CO_2/GJ) with a 90% deemed efficiency of heat production. This single factor, which in effect applies to the net steam import or export, was used for the determination of the baseline activity data (see chapter 6) for all EU ETS sectors.

Note that the export heat stream used to calculate SE excludes low level heat (very low pressure steam or hot water) that would otherwise been wasted as this heat is not produced deliberately and does not generate additional emissions. This is typically the case for heat export to urban heating systems.

4.4.2. CWT as the denominator of the performance index

CWT defines the tendency of a refinery to emit CO_2 under standard conditions and irrespective of the source and type of energy actually used. It therefore includes both emissions generated on site and emissions that would have been generated when producing any imported energy in the form of either heat or electricity. It also excludes additional emissions generated in order to produce exported heat or electricity.

This CWT “envelope” is consistent with the agreed method of granting allocations to the heat consumer and therefore correction to CWT was not required for the purpose of accounting for heat import/export.

However CWT needed to be corrected to eliminate the impact of on-site electricity consumption. This was achieved through a refinery-specific electricity utilisation factor (EUF) expressed as:

EUF = U / (U + EC)

Where EC is the deemed emissions for producing all the electricity consumed by the refinery, irrespective of where it is produced. EC is calculated with a standard emission factor of 0.465 t CO_2/MWh representing the EU grid average (this figure was imposed by the EU Commission).

U represents the emissions related to refining activities including net heat imports and <u>excluding</u> any electricity.

U + EC represents the emissions related to refining activities including net heat imports and <u>including</u> all electricity consumed.

4.4.3. CO_2/CWT as the performance index

This ratio can be expressed as:

CO_2/CWT = U / (CWT*EUF)

Where both numerator and denominator refer to the same boundaries, consistent with the requirements of the EU ETS Directive.

In effect this can also be expressed as

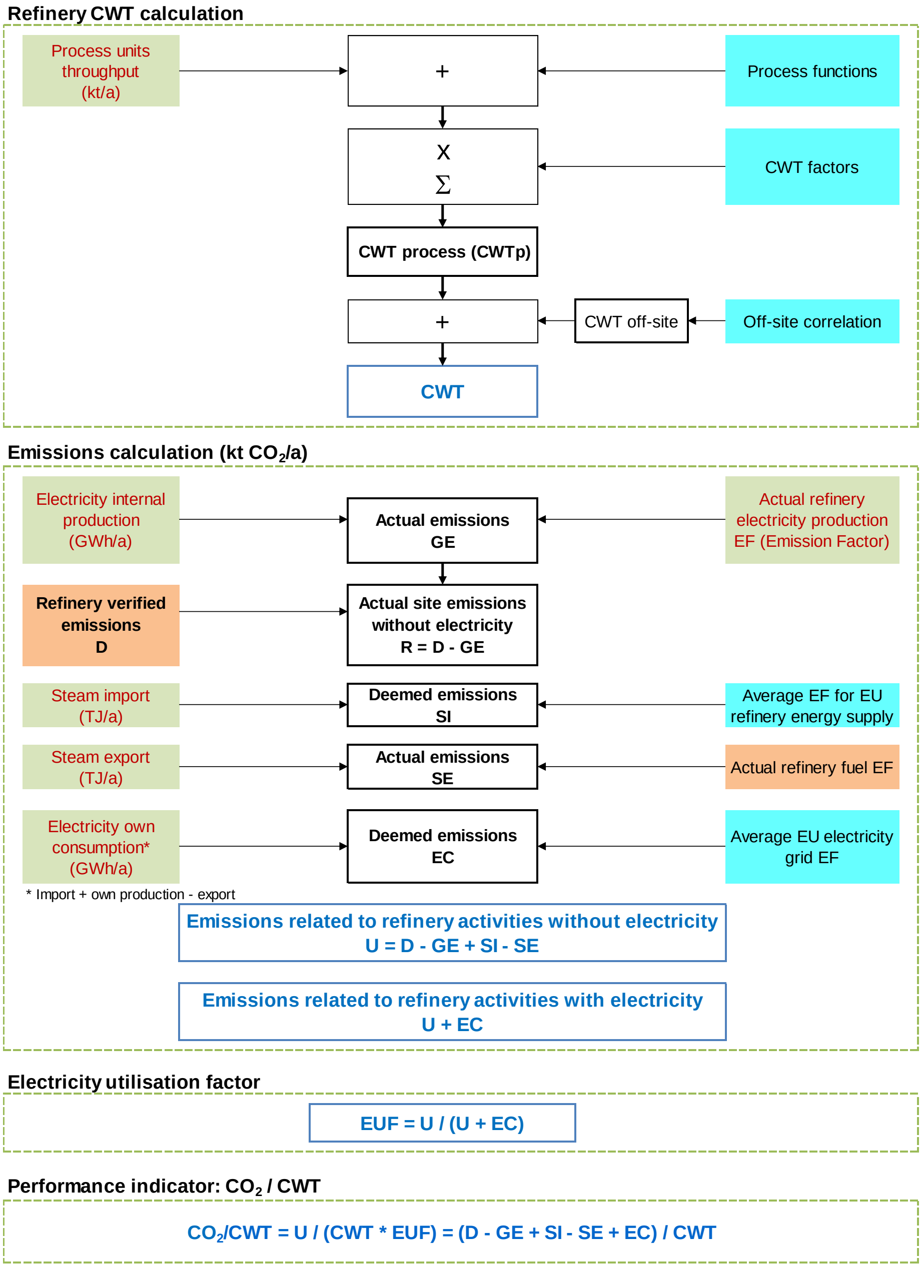
CO_2/CWT = U / (CWT*(U / U+EC) = (U+EC) / CWT = (D-GE+SI-SE+EC) / CWT

The rationale for the EUF correction becomes clearer when considering the CO_2/CWT ratio: as GE increases, D should increase by the same amount (because more electricity is being produced on site and therefore more emissions incurred) while EC (which represents emissions from internal electricity consumption with a standard emission factor) remains unchanged. The EUF correction therefore ensures that a given refinery keeps the same CO_2/CWT ratio irrespective of how the electricity it uses is produced.

This method of correcting for electricity consumption is fully consistent with the more generic correction for “exchangeability of heat and electricity” defined by the EU Commission in their detailed guidance [5].

Figure 1 summarises the derivation of CO_2/CWT.

Figure 1 CO_2/CWT calculation algorithm



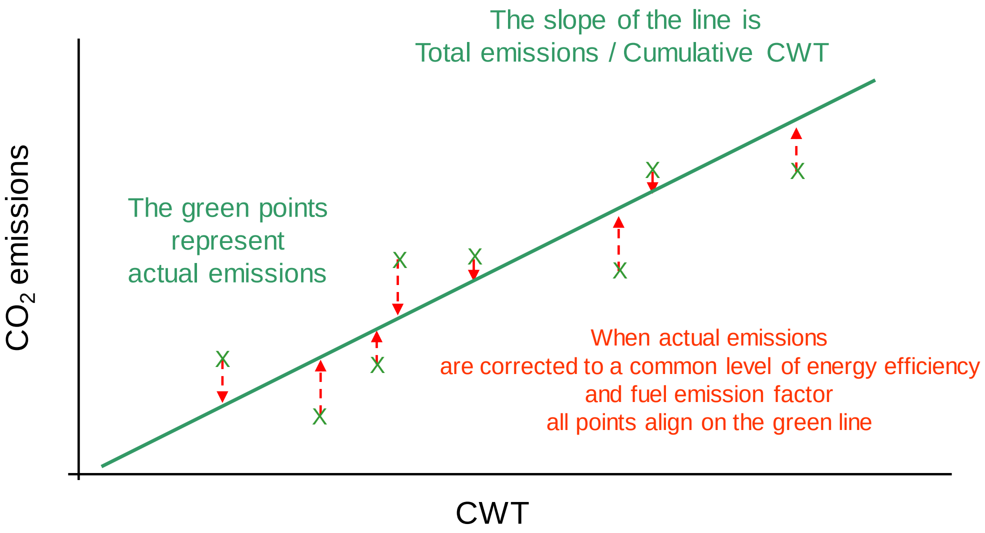
CWT is an activity function that represents both the magnitude of the activity (i.e. the throughput of the plants) and their relative complexity, but does not make any assumption with regards to emission performance. Two refineries having the same CWT should have the same emissions if they achieve the same level of performance. Conversely if one of the refineries achieves the same CWT with fewer emissions, it is a better performer.

The corrected actual emissions U+EC reflects the complexity and size of the refinery as well as its energy efficiency and the emission factor of the fuels it burns.

A plot of corrected actual CO_2 emissions U+EC versus CWT will of course show a form of correlation (larger and more complex refineries tend to emit more) but with a measure of scatter due to performance differences (**Figure 2**).

One critical step in the Solomon analysis was to verify that CWT, with its simplified representation of reality, still appropriately takes into account the complexity and size aspects. This was done by correcting actual emissions of all refineries in the population to bring them back to a common level of energy efficiency (based on EII®) and a common emission factor. By this method, Solomon were able to demonstrate that 99% of the scatter was indeed attributable to differences in performance rather than in activity.

Figure 2 Emissions vs. CWT: the scatter represents performance differences



CWT is the activity function that represents the tendency of a refinery to emit CO_2 at constant energy efficiency and emission factor. The ratio of the corrected actual emissions U+EC over CWT is therefore a common measure of emission performance according to which diverse refineries can be compared and ranked.

Criticisms of the methodology have been raised, arguing that fully compensating for refinery configuration amounts to grand-fathering i.e. perpetuating the status quo rather than rewarding the best processing routes. We do not believe these criticisms are justified for two reasons:

Firstly, the task of refineries is to turn a given crude slate into a certain product slate. This requires physical and chemical processes for which a large part of the energy is related to reshuffling hydrogen and carbon between the fractions. Given a product slate, the energy that is required for this is not very dependent on the processing route selected.

Secondly, irrespective of the processing scheme, the energy used in a refinery is to a large extent determined by the way the heat and electricity utilities requirements are satisfied and the way units are integrated together. Heat integration is one of the main drivers of the energy performance of the whole refinery and is widely used to achieve a better overall efficiency than would be implied by summing the nominal efficiency of each individual unit.

5. SETTING THE BENCHMARK

The EU ETS Directive stipulates that the benchmark must be based on “the average performance of the 10% most efficient installations in a sector in the Community in the years 2007-2008”.

Having established the methodology, determining the benchmark required collecting data to calculate CWT, emissions and the performance index CO_2/CWT for all relevant installations in the appropriate time period.

5.1. DATA COLLECTION FORMAT

The Solomon database includes the majority of EU refineries but not all and only has data for every two years (when developing the benchmark in 2009, the most recent set of data was for 2006). A complete data set had therefore to be collected from all EU refineries. On the basis of the information available at the time it was decided to collect data for 2006, 2007 and 2008. It was later confirmed that the reference period for determining the benchmark would be 2007-08.

In order to cover the full calculation algorithm, three categories of data needed to be collected:

- Activity data i.e. plant throughputs for each year required to calculate CWT.
- Utilities data required for heat and electricity correction calculations
- Verified emissions

Data was collected by the CONCAWE secretariat via a comprehensive template. During the early collection process it soon became clear that, to ensure data would be fully verifiable and auditable and that the calculation rules were consistency applied, data should be collected at a fairly detailed level, all calculations being integrated into the template.

Excerpts of the main sections of the template, filled in with data from a hypothetical refinery, are shown in **Appendix 1**.

5.1.1. Activity data

As mentioned above the CWT “functions” provide a simplified representation of the diversity of actual refinery plants, most functions representing several slightly different plant types. There was therefore a need to accurately map real process units to CWT functions for which actual plant data was required, translation into CWT function being integrated into the template.

Starting from the comprehensive list used by Solomon for the EII® calculation, an exhaustive list of actual refinery process plants was compiled and mapped to the CWT functions. Some units, although physically present in refineries, are not typical refinery units and, if fed mostly or exclusively by non-refinery feeds, were eliminated. These are treated as chemical units according to the benchmarks developed for that sector. In a small number of cases additional CWT factors were created for specific units, often only available in one or a few refineries. The final list includes 56 functions (**Appendix 1**).

Annual throughput data were collected for all actual plants and translated in the template into throughputs for each of the 56 CWT functions.

Note: the original template also included capacity and stream day data. As it was later confirmed that the benchmark would be based on actual throughputs, this was not used and was eliminated in the subsequent activity data collection (see *chapter 6*).

5.1.2. Utilities data

The emissions and CWT correction algorithm required data on electricity imports, exports and internal production, internally-generated electricity emission factor, heat imports and exports. All this data is generally available in refineries, with the exception of the electricity emission factor which presented the biggest challenge. Refineries produce electricity in a number of different ways, in most cases in conjunction with steam in co-generation systems, including gas turbines, steam turbines and power recovery systems. A detailed methodology was devised to systematically and consistently apportion emissions to steam and electricity production, which required detailed data on both steam and electricity in the different electricity production systems.

5.1.3. Fuel and emissions data

The total refinery verified emissions was required in order to calculate the CO_2/CWT performance indicator. For the sake of completeness and clarity as well as to provide a cross-check for emissions, it was also decided to collect refinery fuel composition and quality data.

Some refineries operate jointly with other plants, mostly petrochemicals, on the same site. In such cases, utilities systems are normally common while verified emissions under the EU ETS pertain to the entire site. In such cases, refiners had to split emissions as well as utility consumption between the refinery and the rest of the site.

5.2. EU REFINERY POPULATION

A complete list of “refineries” in Europe had to be established. The EU ETS Directive basis for defining a sector is the NACE code which for refineries is 23.20. Unfortunately there are a significant number of installations listed under this code that are definitely not oil refineries. Another source of information is the CITL database of verified emissions where entries from the “OG” sector, activity 2, should yield oil refineries. This is not quite the case as some installations have been wrongly classified while refinery-based utility plants sometimes appear as separate entries. A more reliable source is the CONCAWE membership which covers all refineries in Europe with the exception of a handful of mostly small sites in Bulgaria and Romania the status of which is not known.

At the time of the EU ETS benchmarking process in 1Q 2010 there were 111 confirmed refinery sites in operation in the EU, plus 2 in Norway.

Amongst the 113 identified refineries, there is a number of mostly small sites that perform specialised functions, mostly bitumen and lube oil manufacture as well as a small number of specific activities. The CWT methodology was developed from a database that did not include such installations. Its straight application to these installations yields somewhat unpredictable results for several reasons.

Some such plants process very heavy crude and although they have both an atmospheric and vacuum column, the energy actually expended in the former is much less than in a conventional crude distiller whereas they receive full CWT contributions from both.

The “off-site” correlation includes a fixed term of 298 CWT (kt/a). This is perfectly justified for mainstream refineries with a CWT of several tens of thousands. For sites with a process CWT of 1000 or less, this fixed term becomes proportionally very large. The correlation also includes a large term proportional to the crude distiller throughput. Some sites do not have a crude distiller and therefore lose this term completely.

It therefore appeared that inclusion of such “atypical” sites in the benchmark population would possibly distort the benchmark and also result in unrealistic ranking (and eventually allowances) for some of the sites.

“Mainstream” refineries were defined as processing mainly crude oil to produce more than 40% light products (as defined by the list of RAMON codes[3] in **Table 1** below). All other sites were considered “atypical” and were taken out of the benchmark population.

Table 1 RAMON statistical codes for light refined products

Statistical Classification of Products by Activity in the European Economic Community, 2008 version		
Level	Code	Description
6	19.20.21	Motor spirit (gasoline), including aviation spirit
6	19.20.22	Spirit type (gasoline type) jet fuel
6	19.20.23	Light petroleum oils, light preparations n.e.c.
6	19.20.24	Kerosene
6	19.20.25	Kerosene-type jet fuel
6	19.20.26	Gas oils

This resulted in the elimination of 15 sites leaving 98 mainstream refineries.

A list showing both categories is shown in **Appendix 2**.

Atypical sites were further not considered as refineries and received allowances based on their fuel or heat consumption over the baseline period according to the fuel and heat benchmarks defined by the EU Commission at a later stage.

5.3. DATA COLLECTION AND VERIFICATION

Data were collected in the course of 2009 which provided early information on the distribution of CO_2/CWT and a short list of those refineries that were likely to be included in the benchmark population (i.e. the 10% most efficient installations).

The fairly tight schedule imposed by the EU Commission to finalise and verify the benchmark by 30 April 2010 precluded a comprehensive independent verification of all data. In order to ensure the sub-population setting the benchmark was correctly selected and the data behind the benchmark was sound, it was agreed that verification of the 20 best performers would be sufficient. This was organised and

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[3] RAMON is Eurostat’s Metadata server where standard code lists, classifications, glossaries, concepts and definitions are published

carried out in time and resulted in only minor changes to the original data submitted to CONCAWE.

One of the issues facing refineries in this respect was that the data to be collected related to past years in which the future need for such information had not been anticipated. Depending on the type and sophistication of the information system operated by the refinery the quality of the data and therefore the uncertainty attached to it was likely to be variable.

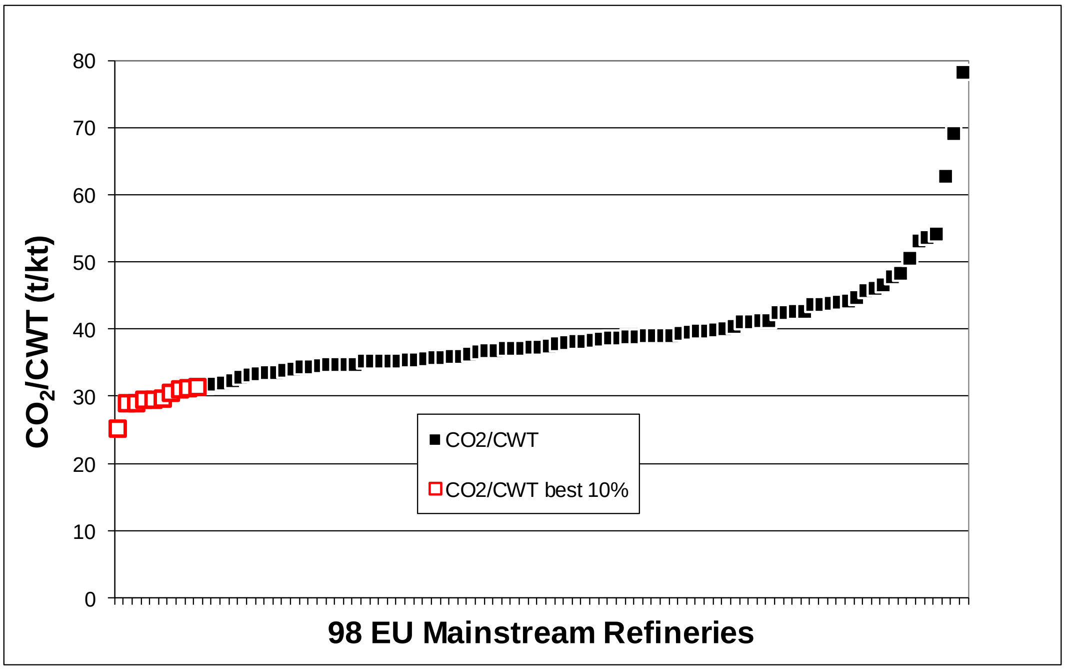
The verification process included a requirement to evaluate the uncertainty attached to the data and consequently to the resulting CWT and CO_2/CWT ratio. The template included fields to collect uncertainty factors on individual unit throughput data as well as on utilities inputs (import/export etc.) and calculate a simple statistical assessment of the overall uncertainty on CWT. Use of this feature was left to the discretion of individual refiners and their verifier.

5.4. MAINSTREAM REFINERY BENCHMARK

Figure 3 summarises the results. The figure shows the CO_2/CWT data for all 98 mainstream refineries, in ascending order from the best (lowest) to the worst performer. Data points for the 10 best performers, i.e. the benchmark sub-population, are highlighted.

Detailed analysis of the data demonstrated that there is no particular relationship between CWT and the performance index CO_2/CWT i.e. that the population is not biased towards either small or large refineries. There are good and mediocre performers in all size classes although it is true to say that the worst performers are found amongst the smallest and least complex refineries. This was to be expected as these refineries are likely to be the ones that have received the least investment over the years.

Figure 3 EU refining CO_2 performance curve (2007-08 average)



According to the final interpretation of the EU ETS stipulation, the benchmark was defined as the average of the performance of the 10% best performers [6]. ***Table 2*** summarises the population statistics and shows the actual **benchmark value of 29.5 t CO_2 / kt CWT** against an overall average of 37.0 for the whole population.

Table 2 Summary of refinery population data (annualised over 2007-2008 period)

Population	**Total Mainstream**		**Benchmark**
No of refineries	98		10
	Total or ratio	Average per refinery	Average per refinery
Emissions (kt/a)			
Direct verified	138436	1413	1537
Without electricity generation	128983		
Direct fuel emission factor (kg CO_2/GJ)		0.0626	0.0627
Share of electricity in total emissions			
Total consumption	12.7%	13.9%	13.5%
Own production	6.8%	5.4%	7.0%
Electricity utilisation factor		0.88	0.87
CWT and benchmark			
Corrected CWT (Mt/a)	3602	36.8	48.6
Corrected emissions (kt/a)	133106		
CO_2 / CWT (kt/Mt)	**37.0**	39.1	**29.5**

Table 2 shows that the average emission factor of refineries in the benchmark population is virtually identical to that of the total population, alleviating concerns that light fuel firing would give a systematic advantage. There are obviously other factors that are more determinant. The share of electricity in total emissions is also very close for both populations.

Concerns were also raised that the CWT approach might systematically disadvantage those refineries that may be structurally less efficient such as large “multi-train” sites often built over a long period of time in several phases. Solomon have found no evidence that site-specific parameters such as the number of units would have a systematic and discernible impact on the performance of refineries and have confirmed that such parameters have never been considered in the EII® calculation.

Although our data do not include specific information on number of main units, it can be reasonably surmised that “multi-train” refineries are mostly fairly large and complex. Detailed analysis of the data showed that larger refineries form a more homogeneous population than smaller ones and tend to be at least as carbon-efficient if not more, than smaller ones.

The benchmark is some 20% lower than the average. When considering the additional 13% of emissions related to electricity and that do not qualify for free allowances, it is clear that the refining sector will receive a much smaller proportion of free allowances than what would be suggested by the overall EU ETS objective of 20% reduction by 2020.

5.5. INTERFACE WITH PETROCHEMICALS AND INDUSTRIAL GASES

A number of process units found in refineries are also found in the petrochemical or industrial gas production sectors or operated independently. This is the case for aromatics processing, hydrogen plants and residue gasification units (also known as Partial Oxidation or POX units). It is logical that such plants should receive the same or a similar treatment irrespective of who operates them (for instance the same hydrogen plant, supplying a refinery, can be notionally in or out of the refinery perimeter depending on its ownership and/or the historical permit structure).

CONCAWE therefore established contact with these associated sectors to explore alternatives and arrive at the best solutions. For hydrogen and POX plants it has been found acceptable to use the CWT methodology as a basis. The benchmark for such plants was defined as their CWT factor multiplied by the refinery benchmark. As an example, the hydrogen plants received a benchmark calculated as follows:

300 CWT per t hydrogen production * 0.0295 t CO2 per CWT
= 8.85 t CO2 per t hydrogen production

The situation was somewhat more complex for aromatics plants because of the great diversity of configurations. However, the CWT approach and the list of functions used for refinery-based plants were also adopted.

5.6. NEW ENTRANTS

It is unlikely that new refineries will be built in Europe in the next 10-15 years. However, a number of major capacity addition projects (hydrocrackers, cokers, other conversion units and desulphurisation units) are currently being designed or built and some more are likely to occur. On the other hand, it is also likely that declining demand for refined products will lead to capacity reductions by means of permanent closures of process units in some EU refineries.

The CWT methodology provides a simple and effective way to fairly treat these capacity additions or reductions. Indeed such plant capacity changes simply result in an addition or reduction to the CWT activity level of the refinery according to the appropriate CWT factors, the capacity change and a standard capacity utilisation factor (SCUF). The SCUF will be determined in 2012 by the Commission as the 80-percentile of the average annual capacity utilisation factors of CWT benchmark refineries over the period 2005-2008.

Capacity changes must meet certain criteria in order to qualify as “significant” and therefore be eligible for an adjustment to the allocation of free allowances. The EC Decision of 27 April 2011 on free allocation of emission allowances specifies these criteria as follows:

The capacity change must involve one or more physical changes leading to:

- a capacity increase or decrease of at least 10% OR
- an increase or decrease in allocation of more than 50,000 emission allowances (in tonnes per annum of CO_2) representing at least 5% of the allowances before the physical change

6. DETERMINING FREE ALLOCATIONS

6.1. BASELINE ACTIVITY DATA COLLECTION

The EU ETS stipulates that free allowances are to be granted annually for the entire trading period (2013-2020) on the basis of a fixed benchmark determined from 2007-08 data, and of a fixed historical reference activity level.

After the benchmark had been established, the next step was therefore to determine the baseline activity, i.e. the CWT that would be attributed to each refinery in order to calculate the number of annual allowances that it would receive as the product of its reference CWT by the benchmark.

Of crucial importance was the selection of the baseline period, in terms of which years and how many years would be used (a long enough period being important to properly account for regular turnarounds as well as fluctuations in economic activity). In addition, significant capacity changes during the course of the reference period also needed to be properly taken into account to ensure allowances were based on the current refinery configuration.

In the final EC decision the baseline period was set at 2005-2008 or 2009-2010 at each site's discretion.

A methodology was also devised to determine whether there had been significant capacity changes during the reference period and the manner in which the final reference CWT should be adjusted. This included a definition of (installed) "capacity" as the average of the two highest monthly CWTs during the reference period.

The EC developed a comprehensive and generic so-called "NIMs" template applicable to all sectors. Member States were encouraged to use the NIMs template and many, though not all, did. In order to minimise rework and build on previous work by refineries CONCAWE adapted the refinery CWT benchmarking data template to include the additional data (additional years and monthly throughput data) and included a "bridging" tool in order to identify and preselect the data that needed to be entered into the NIMs template.

The final CWT and allowance calculation algorithm is complex and is described in detail in [7].

6.2. CALCULATION OF FREE ALLOCATIONS TO EU REFINERIES

The generic formula for calculating the preliminary free allocations to each EU refinery is

A = CWT * EUF * B

Where

A is the refinery's annual free allocations, in kt CO_2/a

CWT is the median of the refinery's annual actual CWT values for the baseline period including adjustment for capacity changes, in kt/a

EUF is the refinery's electricity utilisation factor as defined in section 4.4.2, averaged over the baseline period

B is the EU refining CO_2/CWT benchmark value of 0.0295 (kt/a CO_2 per kt/a CWT)

B has the dimension of ***U/ (CWT * EUF)*** for the benchmark population (where U is the emissions related to refining activities excluding any electricity and including net heat imports). This demonstrates that the electricity correction EUF is applied consistently and that the calculated free allocations meet the requirement that allocations shall not be awarded for electricity-related emissions.

It is to be noted, however, that a further adjustment to free allowances may be applied by the Commission. When sectoral benchmarks have been defined and free allocations calculated for individual installations across the EU, the sum of all free allocations will be compared to the total emissions allowed by the EU ETS Directive reduction path. This may result in a correction uniformly applied to all sectors and all installations, the so-called "cross-sectoral" correction factor.

7. GLOSSARY

A	Annual free EU ETS emissions allocation
B	Sector benchmark value
CDU	Crude Distillation Unit
CEI^{TM}	Carbon Emissions Index
CO_2	Carbon dioxide
CO_2/CWT	Refinery CO_2 emissions performance index
CWB^{TM}	Complexity-Weighted Barrel
CWT	Complexity-Weighted Tonne (also referred to as CO_2-Weighted Tonne)
EF	Emission Factor (mass of CO_2 emitted per unit of energy)
EII®	Energy Intensity Index^{TM}
ETS	Emissions Trading System
EU	European Union
EUF	Electricity utilisation factor
GHG	Greenhouse gases
LPG	Liquid Petroleum Gas
NACE	Statistical Classification of Economic Activities in the European Community
NIMs	National Implementation Measures
POX	Partial Oxidation unit
RAMON	Eurostat’s Metadata server where standard code lists, classifications, glossaries, concepts and definitions are published
SCUF	Standard capacity utilisation factor

CO_2 emissions terminology used in defining the CO_2/CWT performance index:

D	Verified site emissions
EC	Deemed emissions for producing all the electricity consumed by the refinery, irrespective of where it is produced
GE	Emissions associated with on-site electricity generation
R	Electricity-free site emissions (= D – GE)
SE	Emissions incurred for producing exported heat
SI	Emissions that would have been incurred to produce imported heat
U	Emissions related to refining activities excluding any electricity and including net heat imports (= D – GE – SE + SI)

8. REFERENCES

1. EU (2009) Directive 2009/29/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community. Official Journal of the European Union No. L140, 05.06.2009

2. Matthes, F.C. et al (2008) Pilot on benchmarking in the EU ETS. Report prepared for the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety and the Dutch Ministry of Economic Affairs. Berlin/Utrecht: Öko-Institut e.V. / Ecofys

3. Ecofys (2009) Methodology for the free allocation of emission allowances in the EU ETS post 2012. Report on the project approach and general issues. EC study contract 07.0307/2008/515770/ETU/C2. Utrecht: Ecofys

4. Ecofys (2009) Methodology for the free allocation of emission allowances in the EU ETS post 2012. Sector report for the refinery industry. EC study contract 07.0307/2008/515770/ETU/C2. Utrecht: Ecofys

5. EU (2011) Guidance document n°9 on the harmonized free allocation methodology for the EU-ETS post 2012. Sector-specific guidance. Brussels: European Commission

6. EU (2011) Commission decision of 27 April 2011 determining transitional union-wide rules for the harmonised free allocation of emission allowances pursuant to article 10a of Directive 2003/87/EC. Brussels: European Commission

7. CONCAWE (2012) ETS Directive. Collection of reference period activity data and determination of free allowances. Guidance for use of CONCAWE MkIV template and EC NIMs template. Brussels: CONCAWE

APPENDIX 1 DATA COLLECTION TEMPLATE

List of tables

INPUT DATA

Originally collected for 2006/07/08 (2007-08 was used for setting the benchmark, see *chapter 5*), later extended to 2005, 2009/10 for reference activity data / CWT determination (see *chapter 6*)

Process units activity	Yearly throughput of actual process units according to “Solomon type”. Also includes estimated uncertainty.
Site fuels and emissions	Refinery fuel composition, emission factors, process emissions and verified emissions. Also split between entire site and refinery activities where appropriate.
Utilities data and balances	Electricity and steam data required to calculate the actual emission factor of internally produced electricity Steam and electricity import/export

OUTPUT

CWT calculation	CWT functions, aggregated process unit throughputs
Notes	Notes on CWT calculation
Actual Emissions	Fuel and emissions summary
Electricity utilisation factor	Calculation of emission terms for calculation of EUF

Additional table for activity data collection (see chapter 6)

Initial and new installed capacity	CWT functions, aggregated process unit throughputs

PROCESS UNITS ACTIVITY

Activity data of actual units should be filled in for each year (cells highlighted in yellow). When several actual units contribute to a common CWT function the activities will be added up.

The contribution of some units has already been incorporated in the appropriate CWT factors so that these units (in italic) do not give rise to an additional contribution and no data should be entered. In order to calculate the final CWT to the nearest kt/a, a minimum number of decimals is required for each capacity/throughput depending on the magnitude of the CWT factor.

Please fill in data with the preformatted number of decimals.

** Processing of slops is excluded of the throughput of all the units*

** Unless otherwise indicated in "Activity basis" column*

Process Unit	**Solomon Process ID**	**Solomon Process Type**	**Activity b i**	**2006**	**2007**	**2008**	**Uncertainty on Throughput**			**CWT factor**	**Notes**
					Throughput (kt/a)*		**2006**	**2007**	**2008**		
MAINSTREAM UNITS											
Atmospheric Crude Distillation	CDU		Fresh feed							1.00	
Mild Crude Unit		MCU		0	0	0	0.0%	0.0%	0.0%		
Standard Crude Unit		SCU		4594	7211	6411	0.1%	0.1%	0.1%		
Vacuum Distillation	VAC		Fresh feed							0.85	CWT factor also includes average energy and emissions for
Mild Vacuum Fractionation		MVU		0	0	0	0.0%	0.0%	0.0%		
Standard Vacuum Column		VAC		1391	2591	2065	3.0%	3.0%	3.0%		
Vacuum Fractionating Column		VFR		0	0	0	0.0%	0.0%	0.0%		
Vacuum Flasher Column		*VFL*									
Heavy Feed Vacuum Unit		*HFV*									
Solvent Deasphalting	SDA		Fresh feed							2.45	
Conventional Solvent		CONV		0.0	0.0	0.0	0.0%	0.0%	0.0%		
Supercritical Solvent		SCRT		0.0	0.0	0.0	0.0%	0.0%	0.0%		
Visbreaking	VBR		Fresh feed							1.40	CWT factor also includes average energy and emissions for
Atmospheric Residuum (w/o a Soaker Drum)		VAR		0	0	0	0.0%	0.0%	0.0%		
Atmospheric Residuum (with a Soaker Drum)		VARS		0	0	0	0.0%	0.0%	0.0%		
Vacuum Bottoms Feed (w/o a Soaker Drum)		VBF		0	0	0	0.0%	0.0%	0.0%		
Vacuum Bottoms Feed (with a Soaker Drum)		VBFS		727	739	531	3.0%	3.0%	3.0%		
Thermal Cracking	TCR		Fresh feed	0.0	0.0	0.0	0.0%	0.0%	0.0%	2.70	CWT factor also includes average energy and emissions for Vacuum Flasher Column (VAC/VFL) but capacity is not counted separately.
Coking	COK		Fresh feed								
Delayed Coking		DC		0.0	0.0	0.0	0.0%	0.0%	0.0%	2.20	
Fluid Coking		FC		0.0	0.0	0.0	0.0%	0.0%	0.0%	7.60	
Flexicoking		FX		0.0	0.0	0.0	0.0%	0.0%	0.0%	16.60	
Coke calcining	CALCIN		Product							12.75	
Vertical-Axis Hearth		HRTH		0.0	0.0	0.0	0.0%	0.0%	0.0%		
Horizontal-Axis Rotary Kiln		KILN		0.0	0.0	0.0	0.0%	0.0%	0.0%		
Fluid Catalytic Cracking	FCC		Fresh feed							5.50	FCC/MRCC/RCC are merged together.
Fluid Catalytic Cracking		FCC		1556.1	1614.3	1290.2	3.0%	3.0%	3.0%		
Mild Residuum Catalytic Cracking		MRCC		0.0	0.0	0.0	0.0%	0.0%	0.0%		
Residual Catalytic Cracking		RCC		0.0	0.0	0.0	0.0%	0.0%	0.0%		
Houdry Catalytic Cracking		HCC		0.0	0.0	0.0	0.0%	0.0%	0.0%	4.10	
Thermofor Catalytic Cracking		TCC		0.0	0.0	0.0	0.0%	0.0%	0.0%		

SITE FUELS AND EMISSIONS

In order to calculate the final CWT to the nearest kt/a, a minimum number of decimals is required for each data item. *Please fill in data with the preformatted number of decimals.*

	2006						2007						2008					
	Activity (TJ/a)		EF t CO2/GJ		CO2 emissions (kt/a)		Activity (TJ/a)		EF t CO2/GJ		CO2 emissions (kt/a)		Activity (TJ/a)		EF t CO2/GJ		CO2 emissions (kt/a)	
	Entire site	Attributable to refinery[1]	Entire site	Attributable to refinery	Entire site	Attributable to refinery	Entire site	Attributable to refinery	Entire site	Attributable to refinery	Entire site	Attributable to refinery	Entire site	Attributable to refinery	Entire site	Attributable to refinery	Entire site	Attributable to refinery
Fuel burned on site																		
Natural/imported gas	1860	1860	0.0560	0.0560	104.2	104.2	1300	1300	0.0560	0.0560	72.8	72.8	1500	1500	0.0560	0.0560	84.0	84.0
Fuel gas	8700	8700	0.0580	0.0580	504.6	504.6	12000	12000	0.0580	0.0580	696.0	696.0	10500	10500	0.0560	0.0560	588.0	588.0
Liquid	2400	2400	0.0770	0.0770	184.8	184.8	5200	5200	0.0770	0.0770	400.4	400.4	4050	4050	0.0758	0.0758	307.0	307.0
Direct fuel	12960	12960	0.0612	0.061	793.6	793.6	18500	18500	0.0632	0.063	1169.2	1169.2	16050	16050	0.0610	0.061	979.0	979.0
FCC Coke	2800	2800	0.0860		240.8	240.8	2700	2700	0.0860		232.2	232.2	2400	2400	0.0850		204.0	204.0
Calciner coke	0	0	0.0000		0.0	0.0	0	0	0.0000		0.0	0.0	0	0	0.0000		0.0	0.0
Total	15760	15760	0.0656	0.066	1034.4	1034.4	21200	21200	0.0661	0.066	1401.4	1401.4	18450	18450	0.0641	0.064	1183.0	1183.0
Other site emissions																		
Flaring					84.0	84.0					37.0	37.0					34.0	34.0
Hydrogen process emissions[2]					0.0	0.0					0.0	0.0					0.0	0.0
Others[3]					0.0	0.0					0.0	0.0					0.0	0.0
Total calculated emissions					1118.4	1118.4					1438.4	1438.4					1217.0	1217.0
Reconciliation term[4]					51.6						11.6						3.0	
Site verified emissions					1170.0						1450.0						1220.0	
Site emissions allocated to refinery						**1170.0**						**1450.0**						**1220.0**
Refinery energy consumption (% on crude)		8.2%						7.0%						6.9%				

[1] Consistent with process units included in "Process" sheet and their ancillary and off-sites faciltities

[2] Light feeds only i.e. excluding hydrogen from residue gasification

[3] Including emissions from residue gasification and flexicokers

[4] Verified emissions must be used for further calculations. Emission calculation based on fuel flow and composition may not fully match verified emissions which may have been calculated in a different way. In this case the difference is allocated to the refinery in the same ratio as the calculated emissions.

UTILITIES DATA AND BALANCES

Refineries produce electricity in a number of ways. The most straightforward is to use steam to drive a turbine itself driving a generator. If the steam is condensed, only electricity is produced. If, however, steam is extracted (at a lower pressure than the input), less electricity is produced but the extracted steam can be used to some useful purpose. This is the simplest form of cogeneration. In more recent years gas turbines have been increasingly used to directly generate electricity. In most cases the hot flue gases from the gas turbine are used to produce high pressure steam which is in turn used to generate electricity (in the so-called combined cycle).

Where only electricity is produced the assessment of associated emissions is straightforward and limited to the identification of the quantity and quality of the fuel used. Because refineries consume both heat and electricity, cogeneration is commonly applied. In all cases of cogeneration heat and electricity are produced simultaneously and a methodology is required to allocate fuel use and therefore emissions to each of these two products. In this case we have adopted the convention that steam is deemed to have been produced by a state-of-the-art boiler with an efficiency of 90% using the same fuel. For gas turbines the actual fuel can be identified and its emission factor is used. For steam turbines the average emission factor of all fuels consumed in the particular refinery is used.

In order to achieve consistency in the calculations, refineries were requested to provide actual steam conditions at the turbine inlet and outlet and a standard enthalpy calculation was used.

UTILITIES DATA AND BALANCES

In order to calculate the final CWT to the nearest kt/a, a minimum number of decimals is required for each data item. Please fill in data with the preformatted number of decimals.

2006

ELECTRICITY INTERNAL GENERATION

1. Generation from gas turbine with or without combined cycle generation

*(fuel energy content - (enthalpy of generated steam - enthalpy of condensate) / std steam production efficiency) / net electricity produced * EF of fuel*

			Total	GT1	GT2	GT3	GT4	Comments
Fuel consumption (including secondary firing)	QF1	TJ/a	500	500	0	0	0	Actual fuel consumed by GT
Net electricity produced	E1	GWh/a	35.0	35.0	0.0	0.0	0.0	Actual net total electricity production (from GT and downstream steam turbined as applicable)
Steam produced without generation	QS1ng	kt/a		100	0	0	0	Steam produced at HRSG outlet and not used for electricity generation
		bara		*0*	*0*	*0*	*0*	*Typical steam conditions for this installation*
		degC		*0*	*0*	*0*	*0*	
	SH1ng	MJ/t		3200	0	0	0	Steam enthalpy
Steam extraction a								
Steam produced	QS1a	kt/a		0	0	0	0	Actual steam produced
Steam conditions		*bara*		*0*	*0*	*0*	*0*	*Typical steam conditions for this installation*
		degC		*0*	*0*	*0*	*0*	
	SH1a	MJ/t		0	0	0	0	Steam enthalpy
Steam extraction b								
Steam produced	QS1b	kt/a		0	0	0	0	Actual steam produced
Steam conditions		*bara*		*0*	*0*	*0*	*0*	*Typical steam conditions for this installation*
		degC		*0*	*0*	*0*	*0*	
	SH1b	MJ/t		0	0	0	0	Steam enthalpy
Condensate (at 93°C)	CO	MJ/t	390					Condensate enthalpy at 93°C (200°F)
Direct energy in steam produced	SE1 = ∑(QSx * (SHx - CO)) / 1000	TJ/a	281	281	0	0	0	Energy content of steam produced (difference to condensate enthalpy)
Standard efficiency for steam production	STEFF		90%					
Deemed primary energy for steam production	SP1 = SE1 / STEFF	TJ/a	312	312	0	0	0	Deemed primary energy consumed for production of the of the steam with standard efficiency of 90%
Deemed primary energy consumed for electricity	EP1 = QF1 - SP1	TJ/a	188	188	0	0	0	Net primary energy attributed to electricity (fuel consumed - primary energy for steam)
Fuel emission factor	FF1	tCO2/GJ	0.0560	0.0560	0.0000	0.0000	0.0000	Emission factor of the actual fuel used in the GT
CO2 emissions from electricity generation	EM1 = EP1 * FF1	kt/a CO2	10.5	10.5	0.0	0.0	0.0	
Average generation emission factor		**tCO2/MWh**	**0.3004**	81%	#DIV/0!	#DIV/0!	#DIV/0!	

UTILITIES DATA AND BALANCES

In order to calculate the final CWT to the nearest kt/a, a minimum number of decimals is required for each data item. Please fill in data with the preformatted number of decimals.

2006

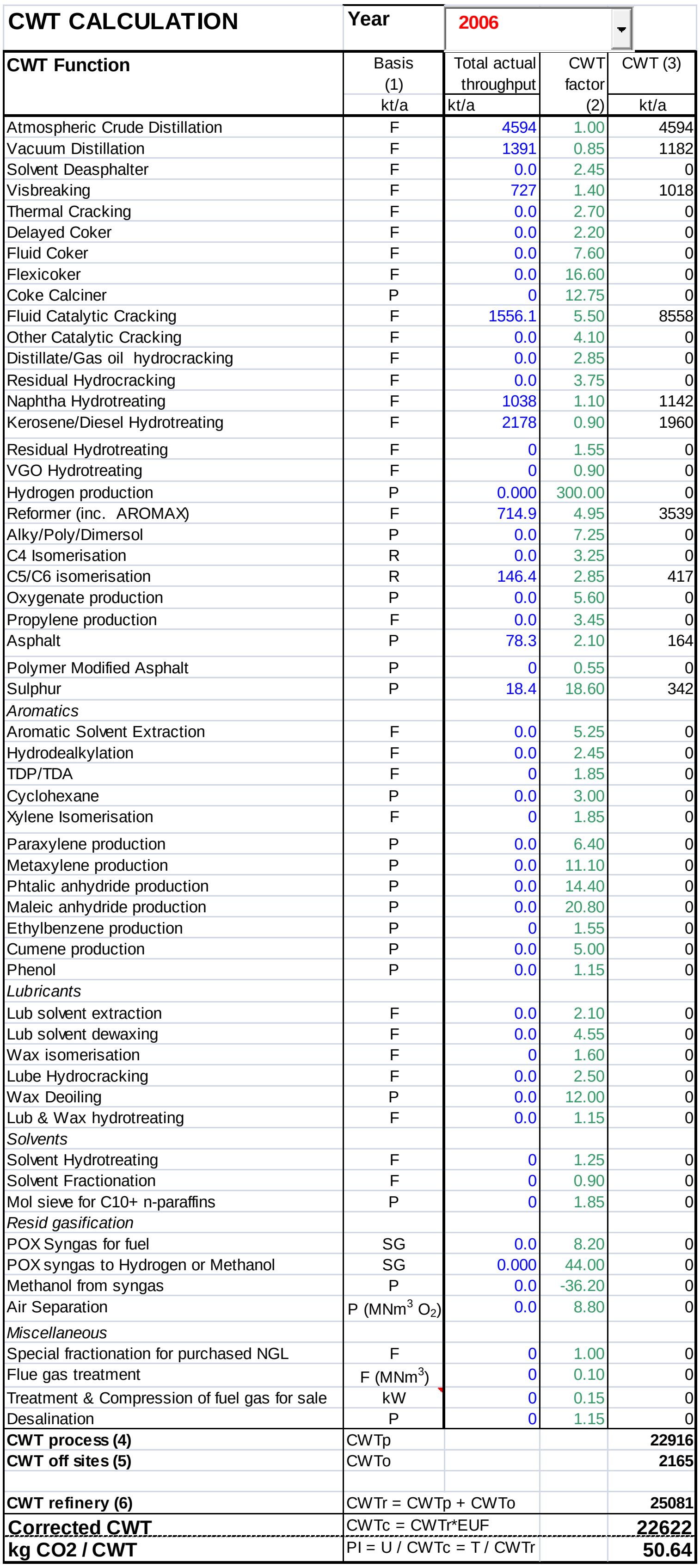
ELECTRICITY INTERNAL GENERATION

2. Generation from extraction/condensation steam turbines

*(enthalpy of inlet steam - enthalpy of outlet steam/water)/MWh produced /0.9 *EF(average fuel)*

Each turbine to be reported separately. Multi-stage turbines to be reported as separate turbines.

Backpressure turbine			Total	T1	T2	T3	T4	
Steam consumption	QS2	kt/a		933.8	6	340	931.007	Actual steam flow through turbine
Steam conditions								
Inlet		*bara*		*66*	*25*	*66*	*22*	*Typical inlet steam conditions for this installation*
		deg C		*465*	*365*	*465*	*330*	
	SH2i	MJ/t		3331	3161	3331	3088	Steam enthalpy
Outlet (as steam)		*bara*		*25*	*0*	*22*	*8*	*Typical outlet steam conditions for this installation (no value if it is a condensing turbine)*
		deg C		*365*	*44*	*335*	*230*	
	SH2o	MJ/t		3161	184	3100	2907	Steam enthalpy
Outlet as condensate (at 93°C)	CO	MJ/t	390	0	0	0	0	Condensate enthalpy at 93°C (only used for condensing turbines), used when no values for steam outlet
Direct energy consumed	SE2 = QS2 * (SH2i - SH2o - CO) / 1000	TJ/a	424	159	18	79	169	Energy extracted from steam to produce electricity
Standard efficiency for steam production			90%					
Primary energy consumed	SP2 = SE2 / STEFF	TJ/a	471	176	20	87	187	Deemed primary energy for production of steam energy extracted to produce electricity
Electricity produced	E2	GWh/a	69.8	34.8	0.0	35.0	0.0	Actual electricity production
Electricity generation efficiency	EGEFF = SP2 / E2	GJ/MWh	6.75	5.07		2.50		Deemed primary energy consumed for production of 1 MW
Average refinery fuel emission factor	AFEM	tCO2/GJ	0.0614	79%	0%	160%	0%	The average refinery direct fuel emission factor excluding GT fuel, is used as it is normally not possible to isolate specific/relevant factor for steam. It excludes the fuel used by gas turbines
CO2 emissions from electricity generation	EM2 = SP2 * AFEM	kt/a CO2	28.9					
Average generation emission factor	**EF2 = EM2 / E2**	**tCO2/MWh**	**0.4146**					
			59%					
3. Generation from expanders and other energy recovery devices								
(assumed to produce no CO2 emissions)								
		GWh/a	3.0					
Combined electricity generation and emission factor								
Total generation			**107.8**					
Combined average emission factor			**0.3660**					
ELECTRICITY IMPORT/EXPORT		GWh/a						These figures must be consistent with the refinery envelope
Import			160.0					
Export			0.0					
HEA IMPORT/EXPORT		TJ/a						These figures must be consistent with the refinery envelope
Import			300					
Export as steam			100					
Export as low grade heat (<120°C)			50					



CWT CALCULATION	Year	2006		
CWT Function	Basis (1) kt/a	Total actual throughput kt/a	CWT factor (2)	CWT (3) kt/a
Atmospheric Crude Distillation	F	4594	1.00	4594
Vacuum Distillation	F	1391	0.85	1182
Solvent Deasphalter	F	0.0	2.45	0
Visbreaking	F	727	1.40	1018
Thermal Cracking	F	0.0	2.70	0
Delayed Coker	F	0.0	2.20	0
Fluid Coker	F	0.0	7.60	0
Flexicoker	F	0.0	16.60	0
Coke Calciner	P	0	12.75	0
Fluid Catalytic Cracking	F	1556.1	5.50	8558
Other Catalytic Cracking	F	0.0	4.10	0
Distillate/Gas oil hydrocracking	F	0.0	2.85	0
Residual Hydrocracking	F	0.0	3.75	0
Naphtha Hydrotreating	F	1038	1.10	1142
Kerosene/Diesel Hydrotreating	F	2178	0.90	1960
Residual Hydrotreating	F	0	1.55	0
VGO Hydrotreating	F	0	0.90	0
Hydrogen production	P	0.000	300.00	0
Reformer (inc. AROMAX)	F	714.9	4.95	3539
Alky/Poly/Dimersol	P	0.0	7.25	0
C4 Isomerisation	R	0.0	3.25	0
C5/C6 isomerisation	R	146.4	2.85	417
Oxygenate production	P	0.0	5.60	0
Propylene production	F	0.0	3.45	0
Asphalt	P	78.3	2.10	164
Polymer Modified Asphalt	P	0	0.55	0
Sulphur	P	18.4	18.60	342
Aromatics				
Aromatic Solvent Extraction	F	0.0	5.25	0
Hydrodealkylation	F	0.0	2.45	0
TDP/TDA	F	0	1.85	0
Cyclohexane	P	0.0	3.00	0
Xylene Isomerisation	F	0	1.85	0
Paraxylene production	P	0.0	6.40	0
Metaxylene production	P	0.0	11.10	0
Phtalic anhydride production	P	0.0	14.40	0
Maleic anhydride production	P	0.0	20.80	0
Ethylbenzene production	P	0	1.55	0
Cumene production	P	0.0	5.00	0
Phenol	P	0.0	1.15	0
Lubricants				
Lub solvent extraction	F	0.0	2.10	0
Lub solvent dewaxing	F	0.0	4.55	0
Wax isomerisation	F	0	1.60	0
Lube Hydrocracking	F	0.0	2.50	0
Wax Deoiling	P	0.0	12.00	0
Lub & Wax hydrotreating	F	0.0	1.15	0
Solvents				
Solvent Hydrotreating	F	0	1.25	0
Solvent Fractionation	F	0	0.90	0
Mol sieve for C10+ n-paraffins	P	0	1.85	0
Resid gasification				
POX Syngas for fuel	SG	0.0	8.20	0
POX syngas to Hydrogen or Methanol	SG	0.000	44.00	0
Methanol from syngas	P	0.0	-36.20	0
Air Separation	P (MNm^3 O$_2$)	0.0	8.80	0
Miscellaneous				
Special fractionation for purchased NGL	F	0	1.00	0
Flue gas treatment	F (MNm^3)	0	0.10	0
Treatment & Compression of fuel gas for sale	kW	0	0.15	0
Desalination	P	0	1.15	0
CWT process (4)	CWTp			**22916**
CWT off sites (5)	CWTo			**2165**
CWT refinery (6)	CWTr = CWTp + CWTo			**25081**
Corrected CWT	CWTc = CWTr*EUF			**22622**
kg CO2 / CWT	PI = U / CWTc = T / CWTr			**50.64**

(1) Annual throughput mostly based on fresh feed (F). For a small number of units based on reactor feed (R, includes recycle) or on product (P). Based on syngas production for POX unit.

(2) Dimentionless factor representing the propensity of each unit to emit CO2 (per tonne of throughput/product) relative to atmospheric distillation. Factors are common to all refineries. The diversity of duties performed by EU refineries requires 56 factors to be defined. Typically 10-15 factors are relevant to any given refinery. The maximum used by any EU refinery is 26.

(3) CWT of each unit is the product of its throughput by its CWT factor.

(4) CWT process is the sum of all CWTs for individual units.

(5) CWT off-sites includes an allowance for tankage/terminals/blending facilities as well as ancillary

(6) CWT refinery refers to all emissions relative to the refining activity of the site, i.e. direct and well as indirect.

Fuel and Emissions summary

Fuel burned on site allocated to refinery	Activity	EF	Emissions		
	TJ/a	t CO2/GJ	kt/a CO2	Code	
Natural/imported gas	1860	0.0560	104.2		Fuel and emissions data as reported/calculated in "Util input" tab. Provided for reference only.
Fuel gas	8700	0.0580	504.6		
Liquid	2400	0.0770	184.8		
Direct fuel burned on site	**12960**	**0.0612**	**793.6**		
FCC Coke	2800	0.0860	240.8		
Calciner coke	0	0.0000	0.0		
Total site fuel producing emissions	**15760**	**0.0656**	**1034.4**		
Other GHG emissions					
Flaring			84.0		
Hydrogen process emissions			0.0		
Others			0.0		
Site emissions allocated to refineries			**1170.0**	D	Actual emissions from the refining activity of the site, excluding any activity not included in the CWT envelope, and in particular steam cracker complexes. Must be consistent with officially reported emissions.

Electricity utilisation factor calculation

Electricity balance

	Activity	EF	Emissions		
	GWh/a	t CO2/MWh	kt/a CO2	Code	
Import	160.0				Electricity import/export/internal generation + actual emissions from internal electricity generation as reported/calculated in "Elec input" tab.
Export	0.0				
Internal generation	107.8	0.366	39.4	GE	
Consumption	267.8	0.4650	124.5	EC	Deemed emissions from electricity consumption using EU grid average emission factor **now using EC figure**. This represents the notional indirect emissions incurred by importing all electricity consumed on the site.

Steam import/export

	Activity	EF	Emissions		
	TJ/a	t CO2/GJ	kt/a CO2	Code	Steam import/export as reported in "Util Input" tab.
Import	300	0.0724	21.700	SI	Average fuel emission factor for EU refineries, divided by standard steam production efficiency of 90%, expressed in tCO2/GJ of steam energy content.
Export	100	0.0680	6.800	SE	Actual fuel emission factor for this refinery, divided by standard steam production efficiency of 90%, expressed in tCO2/GJ of steam energy content.

Correction factor for electricity

Actual site emissions without electricity	kt/a CO2	1130.600	R = D-GE	The ETS Directive requires that all emissions relative to electricity generation be removed
Emissions related to refinery activities without electricity	kt/a CO2	1145.500	U = R+SI-SE	Emissions incurred at the site (excluding steam exports) plus deemed emissions from steam imports but excluding emissions from internally generated electricity.
Emissions related to refinery activities	kt/a CO2	1270.0	T = U+EC	As above but now including emissions from electricity consumed either imported or internally generated calculated with a standard factor.
CWT correction factor for electricity generation		0.9020	EUF = U / T	CWT must be made consistent with the electricity-free emissions in such a way that the corrected CWT is independent of the actual generation efficiency.

APPENDIX 2 LIST OF EU REFINERIES IN 2007-2008 BENCHMARKING PERIOD

Mainstream refineries[1]

	Country	Refinery	Ownership
1	AT	Schwechat	OMV
2	BE	Antwerp	ExxonMobil
3		Antwerp	TOTAL
4		Antwerp (BRC)	Petroplus
5	BG	Burgas	Lukoil
6	CZ	CRC (Kralupy)	PKN Orlen/ENI/Shell
7		CRC (Litvinov)	PKN Orlen/ENI/Shell
8		Paramo/Kolin	PKN Orlen
9	DK	Fredericia	Shell
10		Kalundborg	Statoil
11	FI	Naantali	Neste
12		Porvoo	Neste
13	FR	Lavera	Ineos
14		CRR (Reichstett)	Petroplus
15		Fos	ExxonMobil
16		Port-Jerome	ExxonMobil
17		Berre	LyondellBasell
18		Petit Couronne	Petroplus
19		Donges	TOTAL
20		Feyzin	TOTAL
21		Grandpuits	TOTAL
22		Dunkerque	TOTAL
23		Gonfreville	TOTAL
24		La Mede	TOTAL
25		SARA	SARA
26	DE	Bayern oil (Vohburg)	BP/ENI/OMV
27		Wilhelmshaven	ConocoPhillips
28		Heide	Shell
29		Rheinland	Shell
30		Ingolstadt	Petroplus
31		Harburg (Holborn)	Tamoil
32		Leuna	TOTAL
33		MIRO (Kalrsruhe)	BP/ConocoPhillips/ExxonMobil/Shell
34		Burghausen	OMV
35		PCK (Schwedt)	BP/Shell/Total/ENI
36		Harburg	Shell
37		Gelsenkirchen	BP
38		Lingen	BP
39	EL	Thessaloniki	Hellenic
40		Aspropyrgos	Hellenic
41		Elefsis	Hellenic
42		Agii Theodori	Motor Hellas
43	HU	Szazhalombata	MOL
44		Tisza	MOL
45	IE	Whitegate	ConocoPhillips
46	IT	Livorno	ENI
47		Porto Marghera	ENI
48		Sannazzaro	ENI
49		Taranto	ENI
50		Gela	ENI
51		Falconara	API
52		Augusta	ExxonMobil
53		Mantova	MOL
54		Priolo (+Melilli)	ERG/Lukoil
55		RAM (Milazzo)	ENI/KPI
56		Roma	TOTAL/ERG
57		Trecate	ExxonMobil/ERG
58		Busalla	IPLOM
59		Sarroch	SARAS
60		Cremona	TAMOIL
61	LT	Mazeikiu	PKN Orlen
62	PL	Gdansk	Lotos
63		Jedlicze	PKN Orlen
64		Plock	PKN Orlen
65	PT	Leca	Petrogal
66		Sines	Petrogal
67	RO	Arpechim	OMV
68		Petrobrazi	OMV
69		Petrotel	Lukoil
70		Petromidia	Rompetrol
71	SK	Slovnaft (Bratislava)	MOL
72	ES	Castellon	BP
73		Tenerife	CEPSA
74		Huelva (La Rabida)	CEPSA
75		San Roque	CEPSA
76		Petronor (Somorrostro)	Repsol
77		Cartagena	Repsol
78		La Coruna	Repsol
79		Puertollano	Repsol
80		Tarragona	Repsol
81	SE	Gothenburg	Preemraff
82		Lysekil	Preemraff
83		Gothenburg	Shell
84	NL	Rotterdam	ExxonMobil
85		Rotterdam	KPC
86		NRC (Rotterdam)	BP
87		Pernis	Shell/Statoil
88		Vlissingen	TOTAL/Lukoil
89	*NO*	*Slagen*	*ExxonMobil*
90		*Mongstad*	*Statoil/Shell*
91	UK	Coryton	Petroplus
92		Grangemouth	Ineos
93		Killingholme	ConocoPhillips
94		Fawley	ExxonMobil
95		Humberside	TOTAL
96		Stanlow	Shell
97		Pembroke	Chevron
98		Milford Haven	Murco

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[1] This list shows the status of ownership of active refineries in the 2007-2008 benchmarking period. Several of these refineries have subsequently changed ownership or are no longer operating.

Sites designated as atypical and excluded from the refining benchmark population

	Country	Refinery	Ownership
1	DE	Hamburg/ Neuhoff	H&R
2		Salzbergen	H&R
3		Brunsbuttel	TOTAL
4	ES	Lubrisur	CEPSA
5		ASESA (Tarragona)	CEPSA/REPSOL
6	FR	Dunkerque	SRD Dunkerque
7	HU	Zala	MOL
8	IT	Ravenna	ALMA
9	PL	Asfalt Plock/Trzebinia	PKN Orlen
10		Trzebinia	PKN Orlen
11	RO	Vega	Rompetrol
12	SE	Nynasham	Nynas
13		Gothenburg	Nynas
14	UK	Eastham	Nynas/Shell
15		Dundee	Nynas

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