



Prepared for
Western States Petroleum
Association (WSPA)

Report on CWT-CWB for California
Regulatory Support

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1.0 Use Restrictions

This report (“the Report”) is delivered under the agreement between HSB Solomon Associates LLC (Solomon) and Western States Petroleum Association (WSPA), containing information for the Complexity-Weighted Barrels methodology for California refineries (CA-CWB[™]). WSPA may use part or all information contained in this Report to the purpose (“the Purpose”) of implementing the CA-CWB methodology within the State of California for State carbon emission regulations, such as for California Air Resources Board (CARB) Greenhouse Gas Emissions Mandatory Reporting Regulation (MRR) advocacy, in allocating emission allowances under California’s greenhouse gas (GHG) cap-and-trade program, AB-32.

Within the State of California and limited to the Purpose, WSPA has unrestricted use of the Report and methodologies described therein, whether in verbal or written form (physical, electronic, or otherwise), in communicating with third parties.

2.0 *The Complexity-Weighted Barrels (CWB) Methodology for California Refineries*

Both of the Complexity-Weighted Barrels methodology (CWB[™]) and the Complexity-Weighted Tonnes methodology (CWT[™]) are proprietary to Solomon. Under each individual Consulting Service Agreement, Solomon grants the client, typically a regional Industry Association, limited rights to use or promote the CWB or CWT methodology for the purpose of GHG regulations only.

Under the Agreement between Solomon and Western States Petroleum Association (WSPA), Solomon conveys the ownership of the CA-CWB[™] methodology to WSPA. The analysis and calculations presented in the Report are based on the definitions and input data in Solomon's *Fuels Refinery Performance Analyses (Fuels Study)* and the *Worldwide Paraffinic Lube Refinery Performance Analysis (Lube Study)*. The lower heating value (LHV) was used in all energy calculations.

At the discretion of WSPA while working with Air Resources Board (ARB), the content of the methodologies within, including factors¹, calculations, and data collection protocol, may be modified for California refineries, since the CA-CWB methodology was originally developed for accommodating the entire refining industry around the world.

2.1 Background

Over the past decade, Solomon has developed several methods for benchmarking greenhouse gas (GHG) emissions performance. Unlike simplified approaches which are based solely on raw material input or product output volumes, Solomon's GHG benchmarking metrics take into account the process unit configuration and complexity of each individual refinery. The Carbon Emissions Index (CEI[™]) is Solomon's proprietary and most rigorously calculated benchmarking metric for assessing a refinery's carbon dioxide-equivalent (CO₂e) emissions relative to a carbon dioxide (CO₂) emissions standard.

In the CEI methodology, standard emissions are in large part derived from Solomon's proprietary Energy Intensity Index[™] (EII[®]) standard energy. CEI is calculated by the following equation:

$$CEI = \frac{CEICO_2eActual}{CEICO_2eStd.} \times 100$$

where

- *CEI CO₂eActual* is Solomon's calculation of CO₂-equivalent (CO₂e) emissions incurred
- *CEI CO₂eStd.* is the CO₂e emissions standard for the refinery

¹ It was suggested that the current CWB factor for coke calciners is not appropriate for California refineries, and will not be used for determining the allocation. Instead, coke calciners will receive allocation separately from refineries via a unique efficiency benchmark in cap-and-trade Regulation Section 10395 (Table 9-1). The determination of an appropriate benchmark for California coke calciners will be developed separately.

Solomon's calculation of CO₂e emissions (*CEI CO₂eActual*) are based on the detailed energy balance data (including actual energy types and quantities for imported, exported, and produced energy, as well as gas compositions) and process data (including process unit types, operating conditions, fresh feed compositions and characteristics, and product yields), reported in Solomon's *Fuels Study* and *Lube Study*. The CO₂ emissions equivalent for each fuel type is determined by multiplying the quantity of energy consumed (expressed in MBtu) by the appropriate CO₂ emission factor (CEF) in tonnes of CO₂ equivalent per MBtu, or tonne CO₂/MBtu. The description of Solomon's calculation of CO₂e emissions can be found in Section 2.6.

The concept of CWB was originally developed during an Emissions Allocation Study for WSPA around 2008. In this study, it was found that a Process-Based Model, i.e., a model based on specific refinery configuration using actual process unit yields or throughput, was superior to a simplistic approach based on actual barrels of total refinery product only (referred as the Simple Barrels Method) for achieving fairness and equity in allocations. This was accomplished by appropriately accounting for processing complexity (operating intensity) of a refinery. The CA-CWB methodology described in this report is based specifically on Complexity-Weighted Throughput Barrels (CWTB, referred as CWB hereafter), which is a modified version of the original Process-Based Model on the basis of throughput.

The CA-CWB methodology was developed with the objectives of minimal data requirements, simplicity, and suitability for public disclosure for the purpose of equitably allocating carbon emission allowances. The CWB factors were developed based on Solomon's proprietary EII methodology. Simplification was achieved by combining process units according to operating characteristics of more than 200 refineries operating in Organization for Economic Co-operation and Development (OECD) countries that participated in Solomon's *Fuels Study* and *Lube Study* for operating year 2006.² This data is sufficient to estimate both combustion- and process-related emissions at each refining site. Solomon has applied the CWB methodology for both fuels and lubricants refineries around the world and has found it to be sufficiently robust to benchmark the entire range of refining process configurations.

2.2 CWB Robustness in Allocating Emission Allowances

The robustness of Solomon's CWB methodology in allocating carbon emission allowances is determined in a regression analysis for the correlation between Solomon's calculation of CO₂e emissions (based on actual energy balance data) and CWB, for the following three peer groups:

- OECD refineries
- US refineries
- US California (CA) refineries

Figures 1a–1d (page 2-3) show the distribution of total CO₂e emissions (including indirect emissions arising from imported steam and electricity) vs calculated CWB for approximately 200 OECD refineries in operating years 2004, 2006, 2008, and 2010, with an r^2 coefficient (the coefficient of determination) in regression for all three peer groups. The intercept of the fitted lines was forced to the origin (0, 0) in each chart, with an r^2 coefficient ranging between 0.96 and 0.98 for all peer groups in all study years, as summarized in Table 1 (page 2-4). This indicates a strong predictability of CO₂e emissions by calculating the CWB. A certain degree of deviation from the distribution is anticipated, due to variance in emission efficiency among refineries in each peer group. A wide range of OECD refineries are covered in the

² Excludes refineries located in Eastern Europe, Greece, and Mexico.

analysis, processing crude oil from 17,000 b/d to over 700,000 b/d; the complexity of these refineries (indicated by a ratio of total Equivalent Distillation Capacity[™] (EDC[™]) of the refinery to its crude unit capacity) ranging from 3.5 to over 25. California refineries are typically more complicated than average, requiring more extensive processing facilities downstream of the crude unit for upgrading the products. The average complexity (Configuration Factor) for all 12 California refineries in Solomon's *2010 Fuels Study* was 17, versus the US average of 13 or the worldwide average of 11.7. It is thus particularly important to take processing complexity into account for equitably allocating emission allowances for California refineries.

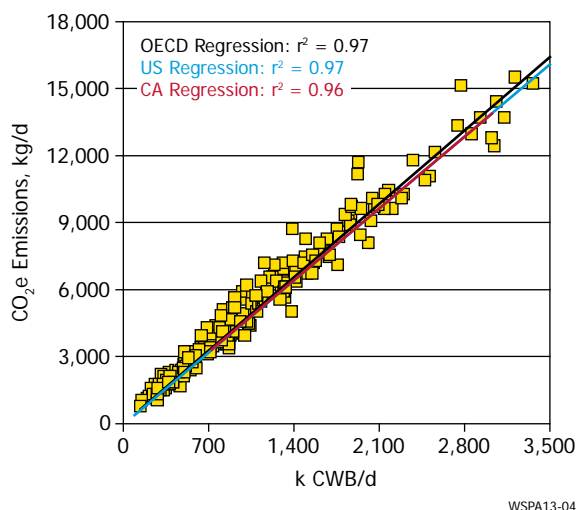


Figure 1a. 2004 OECD Refineries Total Emissions vs CWB

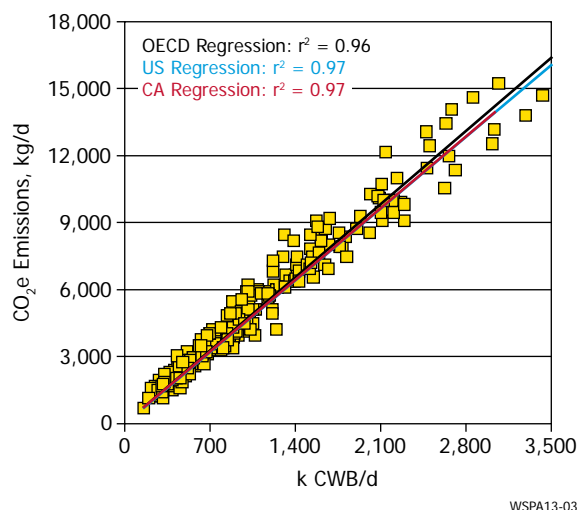


Figure 1b. 2006 OECD Refineries Total Emissions vs CWB

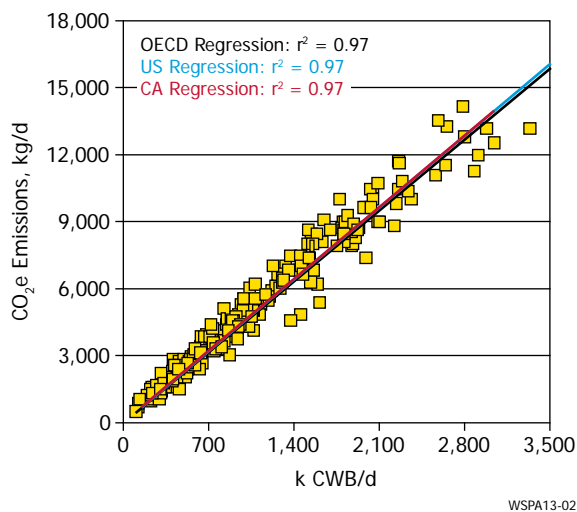


Figure 1c. 2008 OECD Refineries Total Emissions vs CWB

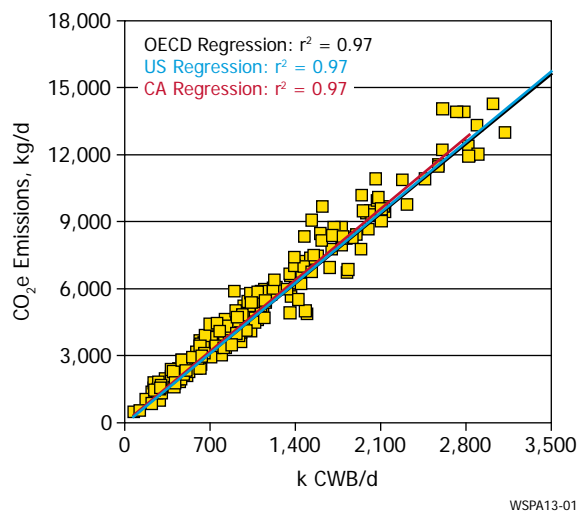


Figure 1d. 2010 OECD Refineries Total Emissions vs CWB

Table 1. Summary of r^2 in Regression Analysis for OECD, US, and US California Refineries in 2004–2010

	Operating Year 2004	Operating Year 2006	Operating Year 2008	Operating Year 2010
Number of OECD Refineries ⁽¹⁾	~200	~200	~200	~200
r^2	0.97	0.96	0.97	0.97
Number of US Refineries	88	86	86	80
r^2	0.97	0.97	0.97	0.97
Number of CA Refineries	11	12	12	12
r^2	0.96	0.97	0.97	0.97

⁽¹⁾ Excludes refineries located in Eastern Europe, Greece, and Mexico.

2.3 CWB versus CWT

Both of Solomon's CWB and its equivalent in metric unit, CWT, are intended for use as a reliable greenhouse gas (GHG) intensity metric or as a basis for GHG allocations in the regulatory arena. The CWT method was developed for refineries located in countries using metric units of measure, while the CWB method was developed for American refineries, measuring refinery throughput in barrels.

For the CWB or CWT application in regulations, Solomon works through local or regional Industry Associations, and conveys the ownership of the methodology to the Industry Association for working with regulators for legislation. Under each agreement, Solomon grants rights for use and promote the CWB or CWT methodology, limited to the specific region, and for the particular purpose of regulatory use only. After the official transfer of ownership, the Industry Association may work directly with regulators for modifying the content of the methodologies as needed. The potential roles and responsibilities of Solomon during the collaboration with an Industry Association, before and after the transfer of ownership of the CWB or CWT methodology, are briefly summarized in Appendix A.

Solomon was approached by CONCAWE (Conservation of Clean Air and Water in Europe) in 2008 to develop a complexity-weighted methodology for benchmarking CO₂ emissions for European Union (EU) refining industry, under the EU GHG Emissions Trading Scheme (ETS) Directive. The study was initiated in November 2008, and the final product, a report on the EU-CWT methodology, was delivered to CONCAWE at the end of February 2009. Under the agreement between Solomon and CONCAWE, CONCAWE acquired the rights to use and promote the EU-CWT methodology in Europe for the specific purpose of complying with the EU ETS. Starting in 2013, a modified version of Solomon's EU-CWT methodology since the transfer of ownership to CONCAWE, referred to as the "CONCAWE EU-CWT", is being implemented in the third phase of EU ETS Directive.

The description of the CONCAWE EU-CWT methodology and the CWT factors can be found in a report published by CONCAWE, "*Developing a Methodology for an EU Refining Industry CO₂ Emissions Benchmark*" (Report No. 9/12).

The EU-CWT method was developed for EU refineries, which typically measure refinery throughput and production in tonnes. The CWB method was developed for American refineries, which typically use volumetric measures expressed in barrels of throughput, except for certain process units such as hydrogen generation and purification (in k SCF of hydrogen product or feed gas), sulfur recovery unit (in long tons, LT, of product sulfur), and coke calciner (in short tons, ST, of product), in accordance with industry convention.

As simplifications of Solomon's CEI methodology, the CWB and CWT factors are largely an adaptation of the EII standard energy. The CWB and CWT factors express the GHG emissions intensity inherent to various refinery processes relative to the emissions intensity of a standard atmospheric crude distillation unit. CWB and CWT are used in the denominator of an emission intensity metric, expressed in tonnes of CO₂e per CWB or tonnes of CO₂ per CWT, versus emissions standard used in CEI.

The EU-CWT methodology was developed for the purpose of allocating emission allowances under the EU ETS. To comply with the requirements of EU ETS, Solomon's EU-CWT methodology differs from the CWB methodology in several respects:

- Boundary Condition – Excludes actual or allocated emissions from all electricity generation and cogeneration that takes place within refineries
- Fuel Standard – Uses the EU refineries' average carbon intensity of refinery fuels as the reference fuel instead of pipeline natural gas, a standard used in Solomon's EII and CEI methodologies
- Customized EU Operating Characteristics – Uses EU refineries' average parameters for other refinery characteristics rather than average parameters developed from Solomon's entire database of refineries located in developed economies
- Level of Simplification – Employs a number of simplifications in process unit categories and process types, reducing the number of factors

The CWB and CWT factors differ due to the fundamental difference in unit of measure. In the CWB method, throughputs to most units are measured in barrels. In the CWT method, throughputs to most units are measured in tonnes. CWB and CWT factors are relative to the atmospheric crude distillation unit (CDU). The CWB factor for a process unit is the ratio of emissions from this particular unit, usually per barrel of feed, relative to an atmospheric crude distillation unit per barrel of feed. The CWT factor for a process unit is the ratio of emissions from this particular unit, usually per tonne of feed, relative to an atmospheric crude distillation unit per tonne of feed. Because the densities of crude and process unit feeds and products vary from one refinery to another, there was no simple and straightforward conversion between CWB and CWT.

A comparison of the CA-CWB methodology, Solomon EU-CWT methodology, and the CONCAWE EU-CWT methodology, is provided in Appendix B.

A comparison of the CWB and CWT factors between the CA-CWB methodology and Solomon EU-CWT methodology is summarized in Appendix C to highlight the differences in unit of measure and consolidation of process units.

2.4 CWB Boundary Conditions

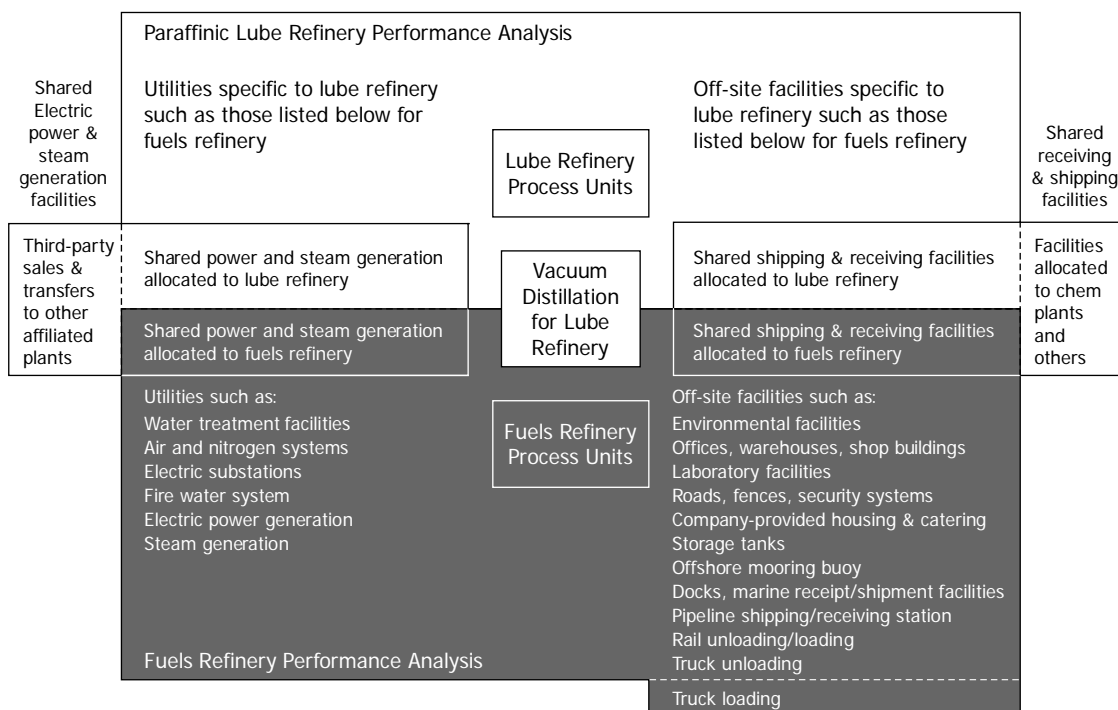
One key consideration in assessing the GHG emissions performance for a refinery is defining the "boundary" for benchmarking, in order to assure comparability of results.

The CA-CWB boundary includes the process units, utilities, and off-site infrastructure used at a refinery to produce the following petroleum products:

- Liquefied petroleum gas
- Gasoline
- Naphtha
- Distillate fuel
- Jet fuel
- Residual fuel
- Bitumen and asphalt
- Petroleum coke
- Unfinished oils
- Specialty solvents
- Lube feedstock
- Chemical feedstock
- Sulfur by-product
- Aromatic petrochemicals
- Propylene
- Liquefied CO₂ by-product for sales
- Lubricants and waxes
- Refinery-produced fuel gas and other fuels consumed

Although the refinery-produced propylene is reported in Solomon's *Fuels Study* as a product, olefin cracking plants and all derivative petrochemical plants are specifically excluded.

Figure 2 illustrates the allocation of utilities and off-site infrastructure shared among the fuels refinery and other plants in a refining and petrochemical manufacturing complex. The estimated or calculated GHG emissions (the numerator) must be consistent with the capacity and throughput of process units and supporting facilities defined, to calculate the appropriate CWB (the denominator) in an intensity metric.



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Figure 2. A Shared Complex Between a Fuels Refinery and a Lube Refinery

In this example, vacuum distillation may be either included as a fuels refinery function or excluded as a lubricant refinery function. For participants in both Solomon's *Fuels Study* and *Lube Study*, Solomon provides a consolidated report covering the integrated fuels/lube complex. Similarly, the CWB method can accommodate either a fuels refinery or an integrated fuels/lube complex. If electric power and steam generation systems are shared with non-refinery facilities, only the portion of the capacity required for the refinery under study is included. If raw material receiving or product shipment facilities are shared, allocation is also required for the refinery under study. Refer to Appendix D for complete listings of refinery process types and functions covered in the CA-CWB methodology, per Solomon definition.

Figure 3 illustrates how the CWB method applies to the physical boundary described above. The boundary condition for CWB is basically on a "Total Emissions" basis, including indirect emissions for purchased steam and electricity (but excludes by-product emissions due to imported hydrogen).

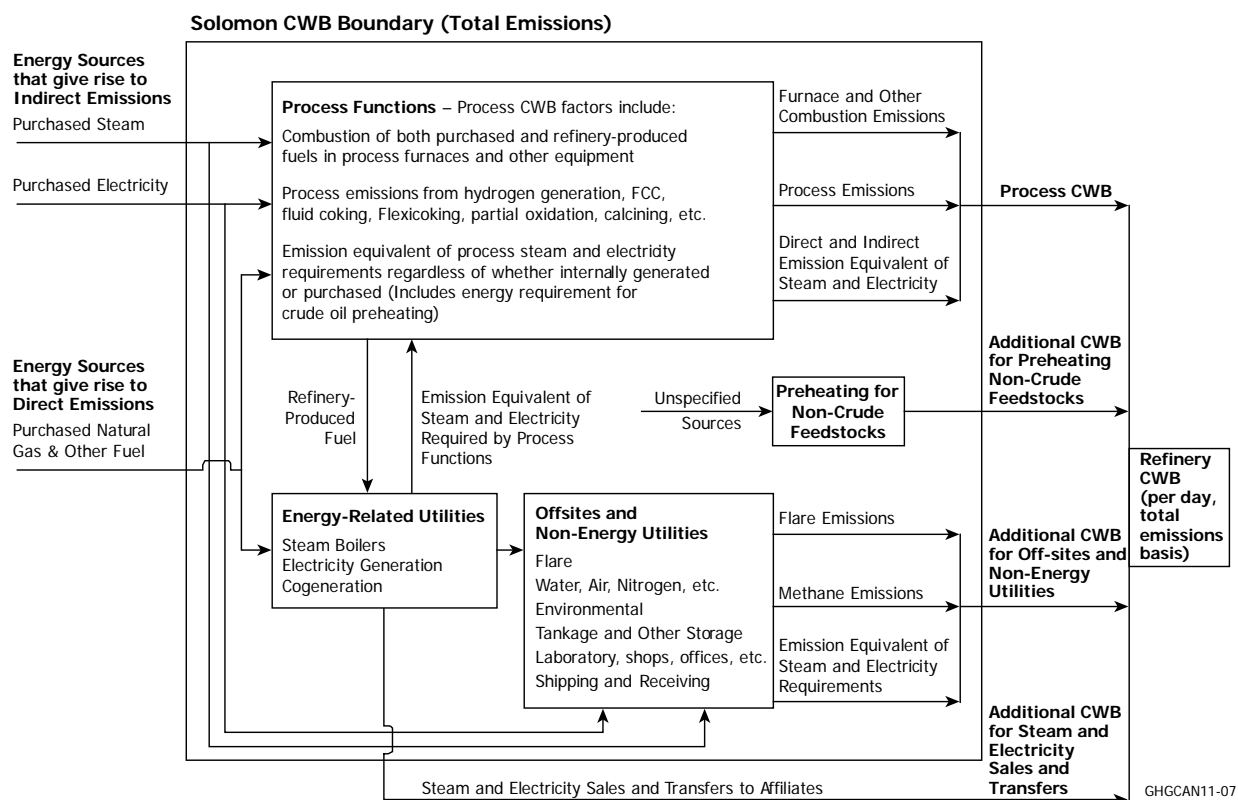


Figure 3. CWB Boundary Conditions

Figure 4 illustrates the difference in boundary conditions between Solomon's CWB and EU-CWT methodologies. The key difference is that electricity generation (in any form, either conventional or cogeneration) is carved out per EU ETS requirement.

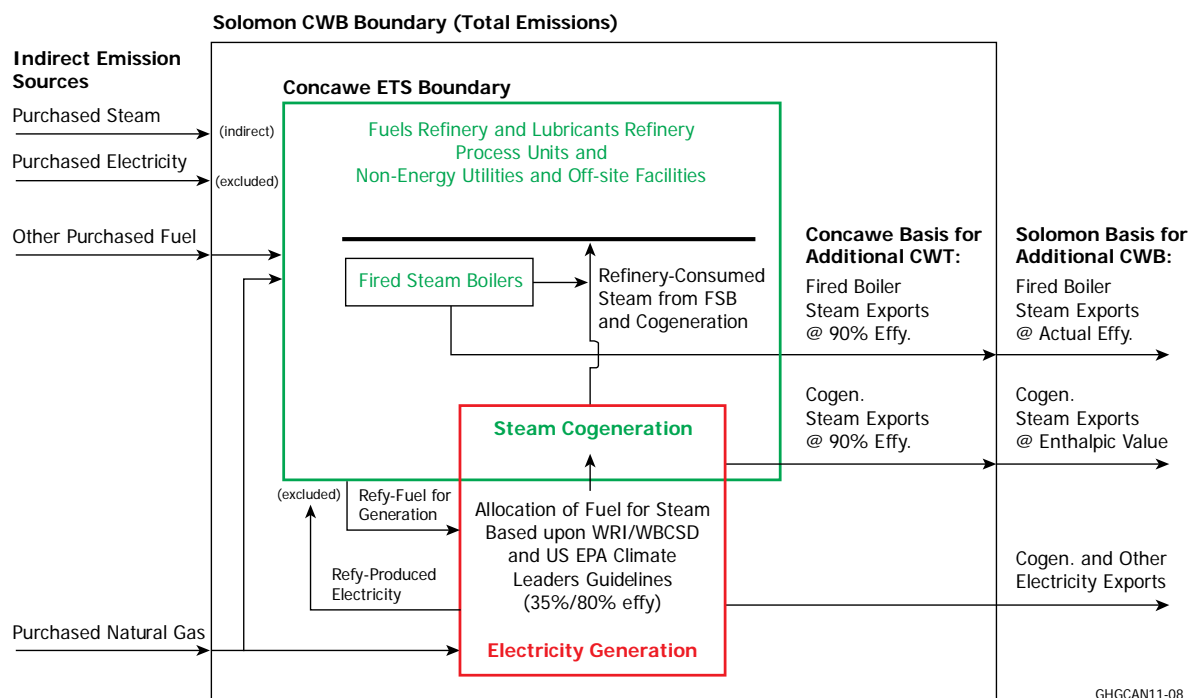


Figure 4. CWB vs CWT Boundary Conditions

In the CWB method, all purchased fuels, refinery-produced fuels, and process emissions of facilities located within its refinery boundary are included, as well as the emission equivalent of purchased steam and electricity, on a “Total Emissions” basis. The EU-CWT method developed for CONCAWE further excludes *on-site* emissions from fuels consumed in electricity generation within the refinery boundary. For refineries with cogeneration facilities, a specific method based on World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD) is employed to allocate emissions from electricity generation and steam generation, respectively. The EU-CWT method also employs a refinery-specific electricity utilization factor (EUF) to make appropriate adjustments for the extent of on-site electricity consumption.

2.5 CWB Calculations

In this section, the calculation of Total CWB for a refinery is discussed.

There are four components in calculating the Total CWB for a refinery:

- Process CWB – CWB for all refining process units
- Off-Sites and Non-Energy Utilities – CWB credit for supporting off-site facilities and utilities (excluding steam and electricity) allocated based on the refinery Process CWB and total input barrels (including both crude and non-crude inputs)
- Non-Crude Sensible Heat – CWB credit for heating up non-crude raw materials into a refinery

- Adjustments for Sales and Exports of Steam and Electricity – CWB credit for thermal equivalent of exported steam and electricity

2.5.1 Process CWB

For each process unit, CWB is calculated by multiplying actual process unit throughput by a dimensionless coefficient, i.e., the CWB factor, and is thus expressed in barrels per day (b/d). The CWB factor is the ratio of CO₂e emissions standard per barrel for a certain process unit over the CO₂e emissions standard per barrel for a crude distillation unit. Appendix C summarizes the CWB factors for various process units and types included in the CA-CWB methodology, mapped to Solomon definition of standard refining process units. This extensive list encompasses all process units reported by California refineries in Solomon's *Fuels Study* and *Lube Study*.

Because GHG emissions originate mostly from energy consumption, the CO₂e emissions standard for a certain process unit is determined by its *energy standard* multiplying the CO₂ emission factor of the fuel. For each major refinery function, the standard energy requirement is determined by the weighted-average EII standard energy of all relevant process units operated by participating refineries located in developed economies, in operating year 2006. Pipeline natural gas with a CO₂ emission factor of 0.059 tonne CO₂/MBtu is the reference fuel used to convert EII standard energy to emissions standard regardless of geographic location or actual fuel mix.³ EII standard energy includes all of the energy required for a refinery regardless of whether it gives rise to direct CO₂e emissions on site.

As examples, below are the descriptions of CWB factors for three major process units or functions:

- Atmospheric Crude Distillation – Its emissions standard is calculated by the average EII standard energy (Solomon proprietary information) for atmospheric crude distillation units in Solomon's *Fuels Study* database, in k Btu per barrel of throughput, multiplying the CO₂ emission factor of 0.059 tonne CO₂/MBtu for pipeline natural gas. Since all CWB factors are relative to CO₂ emissions per barrel of atmospheric crude distillation, the factor for a CDU is precisely 1.00.
- Vacuum Distillation – Its CWB factor, 0.91, represents the ratio of its emission standard, i.e., the average EII standard energy for all vacuum distillation units multiplying the CO₂ emission factor of 0.059 tonne CO₂/MBtu for pipeline natural gas, to the emission standard for CDU.
- Fluid Catalytic Cracker (FCC) – The evaluation of the CWB factor for a FCC is more complicated. The emission standard of a FCC is based on a proprietary multi-variable function statistically derived from nearly one thousand (1,000) reactor-years of FCC in Solomon's *Fuels Study* database, depending on variables such as the unit type, ConCarbon, UOP-K factor, etc. The resulting expression for its CWB factor is simplified as $1.15 + 1.041 \times \text{FCC Coke on Catalyst vol \%}$. For example, for a FCC unit with coke on catalyst consumption equal to 5 vol% of fresh feed, its CWB factor would be 6.355.⁴

³ Pipeline natural gas is the reference fuel used in the CWB methodology. The average mix of fuels consumed by EU refineries is the reference fuel for EU-CWT factors, with a CO₂ emission factor of 65.21 tonne CO₂/TJ or 0.069 tonne CO₂/MBtu.

⁴ The EU-CWT factors for FCC units are further simplified. It is a constant based on average EU refineries' coke on catalyst rather than calculated by actual coke on catalyst yield for each refinery. Other process unit simplifications in EU-CWT factors include combining kerosene and diesel hydrotreating into one single factor, using EU average by-product CO₂ emissions for both steam-methane reforming and steam-naphtha reforming, and eliminating the requirement to separately identify and quantify capacity for most special fractionation units.

The summation of CWB's for all refinery process units or functions yields the total Process CWB for a refinery:

$$\text{Process CWB} = \Sigma (\text{Daily Throughput Barrel} \times \text{CWB Factor})$$

2.5.2 Off-Sites and Non-Energy Utilities

The "Off-Sites and Non-Energy Utilities" component of CWB include the emissions standard arising from the energy requirements for "Off-Sites and Utilities", such as product and intermediate movements, water treatment, air compression, other non-fired utilities, environmental treatment facilities, tankage outside battery limits, flares, truck, rail, and marine shipping facilities, etc.

In Solomon's EII method, the standard energy (in k Btu per daily input barrel) for "Off-Sites and Utilities" is expressed as a linear equation, Constant A + (Constant B × Complexity), where the Complexity of a refinery is calculated as the refinery Equivalent Distillation Capacity (EDC) divided by its crude distillation unit capacity.

In the CA-CWB method, a regression analysis was performed for allocating energy contribution by the refinery Complexity, in order to eliminate the need for calculating each individual refinery's Complexity. This yields the final equation for calculating CWB for "Off-Sites and Non-Energy Utilities" based on the Process CWB and total input barrels:

$$\begin{aligned} \text{Off-Sites and Non-Energy Utilities CWB} = \\ 0.327 \times \text{Total Input Barrels} + 0.0085 \times \text{Process CWB} \end{aligned}$$

In this equation, *Total Input Barrels* to a refinery includes the following:

- Crude oil & condensate, excluding basic sediment and water (BS&W)
- Finished product additives (dyes, diesel pour point depressants, cetane improvers, etc.)
- Antiknock compounds
- Other raw materials, including crude diluents, feedstock processed in other process units or blend stock blended into refinery products

2.5.3 Non-Crude Sensible Heat

In Solomon's EII method, a standard energy credit (in k Btu per bbl of throughput) is assigned for preheating non-crude raw materials prior to entering the process units, such as for raising the temperatures of naphtha and vacuum gas oil (VGO) streams by approximately 200–220 °F. The CWB factor for "Non-Crude Sensible Heat" is simply:

$$\text{Non-Crude Sensible Heat CWB} = 0.44 \times \text{Non-Crude Input Barrels}$$

In this equation, *Non-Crude Input Barrels* refers the daily non-crude input barrels of raw materials processed in process units, excluding returns from a lube refinery or a chemical plant within a refining/petrochemical complex, and non-processed blend stock.

2.5.4 Sales and Exports of Steam and Electricity

For a refinery, the sale and export of steam and electricity receives additional credit for CWB, because the emissions arising from purchased steam and electricity is included in Solomon's calculation of CO₂e emissions. The CWB for the steam and electricity exported or sold is calculated by a constant factor multiplying their thermal equivalents in k Btu per day:

$$\text{CWB Adjustments for Sales and Exports of Steam and Electricity} = 0.0125 \times \text{Thermal Equivalent in k Btu/d}$$

The thermal equivalent of steam and electricity transferred should be reported as follows:

- **Steam** – Estimate the energy required to generate this steam, rather than heat content of the steam. This estimate should include boiler efficiency, boiler feedwater treatment energy, and boiler feedwater sensible heat, etc. If the steam was produced in a cogeneration unit, use the enthalpy of the vapor at pressure and temperature less saturated feedwater at 220 °F (100% efficiency). In all cases, if the condensate is not returned to the refinery condensate system, be sure to include an estimate of the energy required to produce the boiler feedwater make up from raw water.
- **Electricity** – If a refinery both imports and exports electricity, a factor of 9,090 Btu/kWh is used to calculate the energy required for generating the electricity sold or exported, up to the point when the quantity sold/exported is equal to the quantity purchased/imported. Since the thermal energy of all purchased/imported electricity is calculated based on 9,090 Btu/kWh, this netting method would avoid gaining from importing/exporting the electricity. If the quantity of electricity sale and export is greater than purchased/imported, the energy requirement for this difference is calculated by the refinery's weighted average efficiency for producing the electricity, i.e., the summation of Btu per kWh multiplying the MWh of each respective power generation unit (such as generators with steam condensing turbines or steam-topping turbine drivers, or fired-turbine cogen) divided by total MWh produced.

2.5.5 Total CWB for a Refinery

A refinery's Total Complexity-Weighted Throughput Barrels per day is determined as the sum of the four components described above, and can be expressed as follows:

Total CWB

= Process CWB + Off-Sites and Non-Energy Utilities CWB + Non-Crude Sensible Heat CWB + CWB Adjustments for Sales and Exports of Steam and Electricity

= Σ (Daily Throughput Barrel \times CWB Factor) + 0.327 \times Total Input Barrels + 0.0085 \times Σ (Daily Throughput Barrel \times CWB Factor) + 0.44 \times Non-Crude Input Barrels + 0.0125 \times Thermal Equivalent in k Btu/d

= 1.0085 \times Σ (Daily Throughput Barrel \times CWB Factor) + 0.327 \times Total Input Barrels + 0.44 \times Non-Crude Input Barrels + 0.0125 \times Thermal Equivalent in k Btu/d

Appendix F provides an example for calculation of Total CWB for a refinery in the CA-CWB.

The calculation of Total CWB requires the input of daily throughput (expressed as the utilized capacity) for all process units as defined in Solomon's *Fuels Study* and *Lube Study*, mapped to the CA-CWB methodology. A detailed description of process units and process types in each grouping, as well as the

capacity basis (feed- or product-based) and unit of measure are provided in Appendix D, which sufficiently cover all process units reported by California refineries in Solomon's *Fuels Study* and *Lube Study*.

Following are a few tips for calculating the CWB for a refinery, as outlined in the calculation example (Appendix F):

- *Identify the Process Type* – For example, in calculating the CWB for the catalytic cracking process, a fluid catalytic cracking (FCC) unit was identified, i.e., Feed ConCarbon less than 2.25 wt % per Solomon definition.
- *Report the Throughput* – Per Solomon definition, the capacity for catalytic cracking units is based on fresh feed only, excluding slop and recycle rates. The daily throughput of process units was calculated based on the capacity and utilization data reported in Solomon's *Fuels Study*, i.e., annualized stream day capacity multiplying the utilization rate and then divided by 365 (or 366) days in operating year.
- *Calculate the CWB for FCC* – In this example, the FCC coke on catalyst in vol %, 4.413 vol %, was calculated from the “Full Burn Coke yield, wt % Fresh Feed” reported in Solomon's *Fuels Study*. The CWB for a FCC is calculated as $1.150 + 1.041 \times (\text{FCC Coke on Catalyst vol \%})$, as defined in Appendix D. This yields a refinery-specific CWB factor for FCC as 5.74, and the CWB for FCC as 353,276 b/d, in the calculation example.
- *Combine the Reporting of Process Units Under the Same Group (Streamlining)* – As defined in Appendix D, the daily throughput for the “Alkylation/Poly/Dimerol” group indicates a combined throughput on product basis for all process units under this group including polymerization of C₃ or C₃/C₄, dimersol, and alkylation with either hydrofluoric acid or sulfuric acid. Similarly, the daily throughput under “Sulfur” includes the combined throughput of product sulfur for Sulfur Recovery Unit, Tail Gas Recovery Unit, and sulfur sprung for H₂S Springer Unit.
- *Recognize CWB Embedded in Other Major Process Units* – For simplification, the CWB for certain process units are embedded in other major process units by elevating their CWB factors. For example, there are no CWB factors for ancillary lube functions such as Wax/Acid/Clay Treating, Wax Sweating, Lotox, and so on. These are allocated among other major lubricant refining units. Similarly, the CWB factors for Hydrogen Purification are allocated among Hydrogen Generation units.

The streamlining and simplification applied in the CA-CWB methodology can be further evaluated and tailored for the California refining industry as needed.

For comparison, a calculation example for CWT using Solomon's EU-CWT methodology is provided in Appendix F, for the same refinery.

2.6 Solomon's Calculation of CO₂e Emissions

Solomon's calculation of CO₂e emissions is used in the numerator of the benchmark, in both CEI and the CA-CWB method. It is calculated using the data reported by study participants in Solomon's *Fuels Study* and *Lube Study*. The CO₂ emissions equivalent for each fuel type is determined by multiplying the quantity of energy consumed (expressed in MBtu) by the appropriate CO₂ emission factor (in tonnes of CO₂ equivalent per MBtu, or tonne CO₂/MBtu).

The assignment or calculation of appropriate carbon emission factors is essential to the measurement of CO₂e emissions. A complete description of Solomon's calculation of CO₂e emissions is beyond the scope of this Report. The determination of carbon emission factors for various fuel types is briefly described as follows:

- Fuels such as ethane, propane, LPG, naphtha, distillates, pipeline natural gas, and residual fuels – based on the *API Compendium of Greenhouse Gas Emissions Methodologies for the Oil and Gas Industry (API Compendium)*; adjusted according to the sulfur content for residual fuels
- Refinery Fuel Gas – based on its composition as reported in Solomon's *Fuels Study*
- FCC Coke on Catalyst – derived from a proprietary multivariable, non-linear model developed by Solomon for this purpose. Independent variables used in this model include the type of FCC unit, feedstock density, coke yield, and other relevant operating parameters reported in Solomon's *Fuels Study*.
- Low-Btu Gas (LBG) – depends on the energy consumption of various types of process units that produce LBG (such as flexicoker, fluid coker, POX, hydrogen purification pressure swing adsorption off-gas)
- Marketable Coke – depends on the extent of coke calcining at the refinery

Solomon's calculation of CO₂e emissions also include CO₂ from flaring and by-product from hydrogen production and asphalt blowing. CO₂e emissions may be reduced by the amount of carbon disposed in liquefied CO₂ sale and synthesized in methanol production. The CO₂ equivalent of actual methane emissions is estimated using the US EPA's Annex F methodology. A simple estimate of the CO₂ equivalent of actual nitrous oxide (N₂O) emissions is also incorporated in Solomon's calculation. For indirect emissions from steam imports, an emission factor of pipeline natural gas, 0.059 tonne CO₂/MBtu, is used to multiply the actual energy reported on a fuel-equivalent basis. For indirect emissions from purchased electricity, a national average carbon intensity of electricity, Electricity Emission Factor (EEF), expressed in tonne CO₂e/MWh, is used for estimating emissions. Values for EEF are based on data published in the *API Compendium* and by the World Bank.

The sum of the energy-related CO₂ emissions, non-energy CO₂ emissions, indirect emissions, and the CO₂ equivalent of emissions other than carbon dioxide yields the total CO₂e emissions for the refinery. The equation below illustrates a simplified version for Solomon's estimate of actual CO₂e emissions.

$$\frac{CEI}{Actual} CO_{2e} = \left[\left(\sum_{\substack{\text{Fuel} \\ \text{Consumption}}} AE_i \times CEF_i \right) + CE_{Steam} + CE_{Elect} + CE_{H_2 \text{ and} \text{ Other} \text{ Mfg.}} + CE_{Flare} + CE_{CH_4 \text{ and} \text{ N}_2\text{O}} - CE_{MeOH \text{ and} \text{ CO}_2 \text{ Sales}} \right]$$

where

- *CEI CO_{2e}Actual* is Solomon's estimate of actual carbon dioxide equivalent emissions
- *AE_i* is the quantity of actual energy from fuel type *i* consumed on-site as reported in Solomon's *Fuels Study*
- *CEF_i* is CO₂ emission factor applicable to fuel type *i*
- *CE_{Steam}* is the quantity of actual CO₂ emissions from steam imports (indirect emissions)
- *CE_{Elect}* is the quantity of actual CO₂ emissions from purchased electricity (indirect emissions)

- $CE_{H_2 \text{ and Other Mfg.}}$ is the quantity of non-energy CO₂ emissions from hydrogen production and other manufacturing operations, based upon process stoichiometrics and actual unit loss rates reported in Solomon's *Fuels Study*
- CE_{Flare} is the estimate of CO₂ emission from flaring, which is based upon actual refinery flare losses and a standard CO₂ emission factor
- $CE_{CH_4 \text{ and } N_2O}$ is the estimated CO₂e of methane and nitrous oxide emissions
- $CE_{MeOH \text{ and } CO_2 \text{ Sales}}$ is a reduction for carbon rejection in methanol synthesis and for sales of liquefied carbon dioxide

About Solomon Associates (www.SolomonOnline.com)

Based in Dallas, TX, Solomon is the world's leading performance improvement company for the refining industry. Solomon's greenhouse gas (GHG) benchmarking and consulting methodologies stem from the industry's largest proprietary database of energy and process units and in-depth understanding of the industry.

As a trusted industry advisor, Solomon has worked with study participants and their respective industry associations in Europe, Canada, Japan, Singapore, New Zealand, and the United States for benchmarking GHG emission efficiency. The key metrics include EII[®], CEI[™], CWB[™], and CWT[™]. Services are tailored for each specific goal and objective, such as custom peer analysis, *pro forma* analysis, trend analysis, combined energy/GHG analysis, allocation studies for regulatory support, or other custom consulting services for identifying gaps and capturing improvement opportunities.

For any inquiries on GHG benchmarking and consulting services, please contact:

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Appendix A Roles of Solomon in Supporting CWB/CWT Application in Regulatory Use

A.1 Before the Transfer of CWB or CWT Methodology Ownership

- Solomon met with members of the Industry Association for explaining the methodology.
- Solomon met with key stakeholders and regulators for educational sessions with Q&A on the methodology.
- Solomon met with other technology firms or consultants for exchanging professional opinions.
- Solomon worked with the Industry Association in developing the region-specific methodology, such as adding additional factors, modifying the existent factors or process type consolidations (streamlining), and defining the boundary conditions. The requirements for customization would be driven by the Industry Association.
- Solomon developed a Report on the Methodology suitable for public disclosure. A Consulting Service Agreement conveyed ownership of the Report and methodology to the Industry Association and granted a perpetual, non-transferable, non-exclusive and indivisible right to use all information in the Report for the purpose of GHG regulations, limited to the particular region.

A.2 After the Transfer of CWB or CWT Methodology Ownership

On an as-needed basis,

- Solomon assisted the Industry Association in performing internal industry review meetings to work out details on key assumptions, process type consolidations, unique process unit considerations, harmonization of metrics, etc.
- Solomon assisted the Industry Association in developing the strategy for carrying the methodology forward to the regulatory arena.
- Solomon assisted the Industry Association in discussions with regulators and government sub-groups/committees to review and seek approval.
- Solomon assisted the Industry Association in responding to inquiries from regulatory agencies following detailed technical reviews by outside technical reviewers.
- Solomon assisted the Industry Association in continued performance benchmarking and review & update of the factors.

Appendix B Comparison Matrix

Comparison of CA-CWB, EU-CWT, and CONCAWE EU-CWT			
	CA-CWB	Solomon EU-CWT ⁽¹⁾	CONCAWE EU-CWT ⁽¹⁾
Owner	WSPA	Solomon	CONCAWE
Region	Applied to California Refineries	Developed for European Refineries	Applied to European Union (EU) Refining Industry
Year Developed	2013	2008–2009	Transferred to CONCAWE in 2009 ⁽¹⁾
Foundation	Solomon EII® Methodology	Solomon EII® Methodology	Solomon EII® Methodology
Basis	Throughput	Throughput	Throughput
Operating Characteristics for Grouping	>200 Select OECD Refineries (2006)	>200 Select OECD Refineries (2006)	>200 Select OECD Refineries (2006)
Units of Measure	barrels per day	tonnes per day	tonnes per day
Reference Fuel	Pipeline Natural Gas (0.059 tonne CO ₂ /MBtu)	EU Average Fuel Mix (0.069 tonne CO ₂ /MBtu)	EU Average Fuel Mix (0.069 tonne CO ₂ /MBtu)
Boundary Condition(s)	Total Emissions ⁽²⁾	EU GHG ETS* Directive (excluding on-site electricity production)	EU GHG ETS* Directive (excluding on-site electricity production)
Level of Complexity ⁽³⁾	Higher	Simplified vs CWB	Simplified vs CWB
Number of Factors for Process Units	~60	~52	56 (a few added by CONCAWE)
<i>Factors for Fluid Catalytic Cracking</i> ⁽⁴⁾	3	1	1
<i>Factors for Hydrogen Production</i> ⁽⁴⁾	3	2	2
r² for Regression Analysis ⁽⁵⁾	0.97	0.92	Expected to be similar to Solomon EU-CWT
Emissions	CO ₂ -equivalent	CO ₂	CO ₂
Factor Adjustments by Feed/Product Quality	None	Customized using EU Refineries' Average Properties	Customized using EU Refineries' Average Properties

* ETS = Emissions Trading Scheme

⁽¹⁾ Solomon EU-CWT was developed specifically for CONCAWE. The ownership was transferred to CONCAWE in 2009.

⁽²⁾ Total Emissions include indirect emissions from purchased steam and electricity.

⁽³⁾ Solomon's proprietary CEI™ is the most complete and rigorously calculated methodology for benchmarking GHG emissions efficiency. Solomon's CEI, CWB, and EU-CWT all originate from the EII methodology. The level of complexity is CEI > CWB > EU-CWT.

⁽⁴⁾ In CWB, there are three factors for FCC, based on FCC Coke on Catalyst (vol %) and type of FCC for individual refineries. In EU-CWT, the factor for FCC is simplified as one constant based on EU average. Other process unit simplifications in EU-CWT factors include combining kerosene and diesel hydrotreating into one single factor, using EU average by-product CO₂ emissions for both steam-methane reforming and steam-naphtha reforming, and eliminating the requirement for reporting most special fractionation units separately.

⁽⁵⁾ Referred to a regression analysis (data from Solomon's *Fuels Study* and *Lube Study*) for the correlation between Solomon's calculation for CO₂e emissions and CWB for all select OECD refineries for operating year 2010; or between Solomon's calculation for CO₂ emissions and EU-CWT for all EU refineries for operating year 2006.

Appendix C Comparison of CWB and CWT Factors for Process Units (CA-CWB vs Solomon EU-CWT)

A side-by-side comparison of CWB factors (in CA-CWB) and CWT factors (in Solomon EU-CWT) is provided in the following table. This is for sole use in California regulatory support.

	Units of Measure ⁽¹⁾	CWB Factor	CWB Factor, FCC Coke on Catalyst		Units of Measure ⁽¹⁾	CWT Factor
Atmospheric Crude Distillation	T b/cd	1.00		Atmospheric Crude Distillation	tonne/cd	1.00
Vacuum Distillation	T b/cd	0.91		Vacuum Distillation	tonne/cd	0.85
Visbreaker	T b/cd	1.60		Visbreaker	tonne/cd	1.40
Delayed Coker	T b/cd	2.55		Delayed Coker	tonne/cd	2.20
Fluid Coking				Fluid Coking		
Fluid Coker	T b/cd	10.30		Fluid Coker	tonne/cd	7.60
Flexicoker	T b/cd	23.60		Flexicoker	tonne/cd	16.60
Catalytic Cracking				Catalytic Cracking		
FCC	T b/cd	1.15	1.041	FCC	tonne/cd	5.50
Mild Residual FCC	T b/cd	0.66	1.1075	Mild Residual FCC	tonne/cd	5.50
Residual FCC	T b/cd	0.00	1.1765	Residual FCC	tonne/cd	5.50
Other FCC	T b/cd	4.65		Other FCC	tonne/cd	4.10
Thermal Cracking	T b/cd	2.95		Thermal Cracking	tonne/cd	2.70
Naphtha/Distillate Hydrocracker	T b/cd	3.15		Naphtha/Distillate Hydrocracker	tonne/cd	2.85
Residual Hydrocracker (H-Oil; LC-Fining and Hycon)	T b/cd	4.40		Residual Hydrocracker (H-Oil; LC-Fining and Hycon)	tonne/cd	3.75
Naphtha Hydrotreater	T b/cd	0.91		Naphtha Hydrotreater	tonne/cd	1.10
Kerosene Hydrotreater	T b/cd	0.75		Kerosene Hydrotreater	tonne/cd	0.90
Diesel/Selective Hydrotreater	T b/cd	0.90		Diesel/Selective Hydrotreater	tonne/cd	0.90
Residual Hydrotreater	T b/cd	1.80		Residual Hydrotreater	tonne/cd	1.55
VGO Hydrotreater	T b/cd	1.00		VGO Hydrotreater	tonne/cd	0.90
Reformer – including AROMAX	T b/cd	3.50		Reformer – including AROMAX	tonne/cd	4.95
Solvent Deasphalter	T b/cd	2.80		Solvent Deasphalter	tonne/cd	2.45
Alkylation / Poly / Dimersol	P b/cd	5.00		Alkylation / Poly / Dimersol	P tonne/cd	7.25
C ₄ Isomer Production	P b/cd	1.25		C ₄ Isomer Production	P tonne/cd	3.25
C ₅ /C ₆ Isomer Production – including ISOSIV	P b/cd	1.80		C ₅ /C ₆ Isomer Production – including ISOSIV	P tonne/cd	2.85
Coke Calciner	ST/cd	96.00		Coke Calciner	P tonne/cd	12.75
Hydrogen Generation				Hydrogen Generation		

	Units of Measure ⁽¹⁾	CWB Factor	CWB Factor, FCC Coke on Catalyst		Units of Measure ⁽¹⁾	CWT Factor
Steam-Methane Reforming	k SCF/cd	5.70		Gas Feed	tonne/cd	296.00
Steam-Naphtha Reforming	k SCF/cd	6.70		Naphtha Feed	tonne/cd	348.00
Partial Oxidation	k SCF/cd	7.10		POX Syngas to H ₂ or Methanol	tonne SG/cd	44.00
POX Syngas for Fuel	k SCF/cd	2.75		Air Separation Plant	k nm ³ O ₂ /cd	8.80
				POX Syngas for Fuel	tonne SG/cd	8.20
Sulfur	LT/cd	140.00		Sulfur	tonne/cd	18.60
Aromatics Production (All)	T b/cd	3.30		Aromatics Production (All)	P tonne/cd	5.25
Hydrodealkylation	P b/cd	2.50		Hydrodealkylation	P tonne/cd	2.45
Toluene Disproportionation / Transalkylation	P b/cd	1.90		Toluene Disproportionation / Transalkylation	P tonne/cd	1.85
Cyclohexane Production	P b/cd	2.80		Cyclohexane Production	P tonne/cd	3.00
Xylene Isomerization	P b/cd	1.90		Xylene Isomerization	P tonne/cd	1.85
Paraxylene Production	P b/cd	6.50		Paraxylene Production	P tonne/cd	6.40
Ethylbenzene Production	P b/cd	1.60		Ethylbenzene Production	P tonne/cd	1.55
Cumene Production	P b/cd	5.00		Cumene Production	P tonne/cd	5.00
Lubricants				Lubricants		
Solvent Extraction	T b/cd	2.20		Solvent Extraction	tonne/cd	2.10
Solvent Dewaxing	T b/cd	4.55		Solvent Dewaxing	tonne/cd	4.55
Catalytic Dewaxing	T b/cd	1.60		Wax Isomerization	tonne/cd	1.60
Lube Hydrocracking	T b/cd	2.50		Lube Hydrocracking	tonne/cd	2.50
Wax Deoiling	T b/cd	11.80		Wax Deoiling	tonne/cd	12.00
Lube and Wax Hydrofining	T b/cd	1.15		Lube and Wax Hydrofining	tonne/cd	1.15
Asphalt Production	P b/cd	2.70		Asphalt Production	P tonne/cd	2.10
Oxygenates	P b/cd	4.90		Oxygenates	P tonne/cd	5.60
Methanol Synthesis	P b/cd	(36.00)		Methanol Synthesis	P tonne/cd	(36.20)
CO ₂ Liquefaction	ST/cd	(160.00)		CO ₂ Liquefaction	tonne/cd	(19.20)
Desalination	k gal/cd	32.70		Desalination	P tonne/cd	1.15
Special Fractionation	T b/cd	0.80		Special Fractionation – Purchased NGL Only	tonne/cd	1.00

	Units of Measure ⁽¹⁾	CWB Factor	CWB Factor, FCC Coke on Catalyst			Units of Measure ⁽¹⁾	CWT Factor
Propane/Propylene Splitter (Propylene Production)	P b/cd	2.10			Propane/Propylene Splitter (Propylene Production)	tonne/cd	3.45
Fuel Gas Sales Treating & Compression	hp	2.52			Fuel Gas Sales Treating & Compression	kW	0.45
Sulfuric Acid Regeneration	ST/cd	37.80					
Ammonia Recovery Unit	ST/cd	453.00					
Cryogenic LPG Recovery	k SCF/cd	0.25					
Flare Gas Recovery	k SCF/cd	0.13					
Flue Gas Desulfurizing	k SCF/cd	0.02					
					Solvents		
					Solvent Hydrotreating	tonne/cd	1.25
					Solvent Fractionation	tonne/cd	0.90

⁽¹⁾ Please refer to Appendix G.

Appendix D Solomon Definition of Standard Refining Process Units and CWB Factors

Solomon definitions of standard refining process units and the corresponding CWB factors in CA-CWB are provided in the following table. This list is for the sole use by California refineries only, encompassing all process units in California refineries reported in Solomon's *Fuels Study* and *Lube Study*.

Processing Facilities	Process Type	Process ID	Process Type ID	Feed	Products	Typical Equipment	Capacity Basis	Unit of Measure	CWB Factor
Atmospheric Crude Distillation	Mild Crude Unit	CDU	MCU	Crude Oil, Condensate, & Commingled Liquids	Fuel Gas, Propane, Mixed Butanes, Light & Heavy Naphtha, Kerosene, Diesel, Atmospheric Gas Oil, & Atmospheric Resid	Heaters, Preflash Tower, Outboard Flash Tower, Desalters, Crude Distillation Column, Sidestream Stripper Columns, Pumparound Circuits, Merox Treating, Saturate Gas Plant (including: Gas Compression, Absorber, Stripper, Deethanizer, Depropanizer, Debutanizer, Naphtha Splitter, & Sour Water Stripper)	Feed	b/sd	1.00
	Standard Crude Unit	CDU	SCU						
Vacuum Distillation	Mild Vacuum Fractionation	VAC	MVU	Atmospheric Resid	Fuel Gas, Vacuum Gas Oils to Vacuum Resid	Heater, Vacuum Distillation Column, multiple towers in series counted as one unit	Feed	b/sd	0.91
	Standard Vacuum Column	VAC	VAC						
	Vacuum Fractionating Column	VAC	VFR						
	Vacuum Flasher Column	VAC	VFL						
	Heavy Feed Vacuum Unit	VAC	HFV						
Visbreaking	Processing Atmospheric Resid (w/o a Soaker Drum)	VBR	VAR	Atmospheric or Vacuum Resid	Fuel Gas, Naphtha, Distillates, Heavy Gas Oil, & Resid	Furnace, Soaker Drum, Atmospheric Product Fractionator, Sidestream Column	Feed	b/sd	1.60
	Processing Atmospheric Resid (with a Soaker Drum)	VBR	VAR ^S						
	Processing Vacuum Bottoms Feed (w/o a Soaker Drum)	VBR	VBF						
	Vacuum Bottoms Feed (with a Soaker Drum)	VBR	VBFS						
Coking	Fluid Coking	COK	FC	Vacuum Resid	Fuel Gas, C ₃ s, C ₄ s, Naphtha, Distillates, Heavy Gas Oil, Coke	Reactor, Coke Handling, Coke Burner, Fractionator, Light Ends Processing (incl. Unsat Gas Plant), Waste Heat Steam Generation, CO Boiler	Feed	b/sd	10.30
	Flexicoking	COK	FX	Vacuum Resid	Fuel Gas, C ₃ s, C ₄ s, Naphtha, Distillates, Heavy Gas Oil, Low-Btu Gas	Reactor, Coke Burner, Gasifier, Fractionator, Light Ends Processing, Waste Heat Steam Generation	Feed	b/sd	23.60
	Delayed Coking	COK	DC	Vacuum Resid	Fuel Gas, C ₃ s, C ₄ s, Naphtha, Distillates, Heavy Gas Oils, Coke	Heater, Coke Drums, Fractionator, Sidestream Column, Light Ends Processing (incl. Unsat Gas Plant), Coke Cutting (Resources for coke handling & storage are reported separately)	Feed	b/sd	2.55
Thermal Cracking	Thermal Cracking	TCR		Vacuum Gas Oil	Fuel Gas, Naphtha, Distillates, Heavy Gas Oil, & Bottoms	Gas Oil Furnace, Product Fractionator	Feed	b/sd	2.95
Catalytic Cracking	Fluid Catalytic Cracking (Feed ConCarbon <2.25 wt %)	FCC	FCC	Vacuum Gas Oil, Atmospheric Resid	Fuel Gas, C ₃ s, C ₄ s, Gasoline, Cycle Oils, Decant Oil	Feed Preheater, Reactor, Fractionator, Regenerator, CO Boiler, Waste Heat Steam Generator, Tertiary Flue Gas Separator, Electrostatic Precipitators, Catalyst Hoppers	Feed	b/sd	1.150+1.041×(FCC Coke on Catalyst vol %)
	Mild Residual Catalytic Cracking (Feed ConCarbon 2.25–3.5 wt %)	FCC	MRCC				Feed	b/sd	0.6593+1.1075×(FCC Coke on Catalyst vol %)
	Residual Catalytic Cracking (Includes two-stage regeneration; Feed ConCarbon ≥3.5 wt %)	FCC	RCC				Feed	b/sd	1.1765×(FCC Coke on Catalyst vol %)
	Houdry Catalytic Cracking	FCC	HCC				Feed	b/sd	4.65
	Thermoform Catalytic Cracking	FCC	TCC						
Naphtha/Distillate Hydrocracking	Mild Hydrocracking (Normally less than 1,500 psig and consumes between 100 and 1,000 SCF H ₂ /b)	HYC	HMD	Heavy Naphthas through Resid, Hydrogen	Fuel Gas, Propane, Isobutane, Normal Butane, Light & Heavy Naphtha, Kerosene, Diesel, Heavy Gas Oil, Resid	Heater; Reactors; Fractionator; Hydrogen Compression, Scrubbing & Recycle	Feed	b/sd	3.15
	Severe Hydrocracking (Normally more than 1,500 psig and consumes more than 1,000 SCF H ₂ /b)	HYC	HSD			Saturate Gas Plant (including: Fuel Gas Treating, Absorber Stripper, Deethanizer, Depropanizer, Debutanizer, Deisobutanizer, Naphtha Splitter, Sour Water Stripper)			
	Naphtha Hydrocracking	HYC	HNP						
H-Oil	H-Oil	HYC	HOL	Resid, Hydrogen	Fuel Gas, Propane, Isobutane, Normal Butane, Naphtha, Kerosene, Diesel, Heavy Gas Oil, Resid	Heaters; Reactors; Regenerator; CO Boiler; Hydrogen Compression, Scrubbing & Recycle; Catalyst Hoppers; Atmospheric & Vacuum Fractionation	Feed	b/sd	4.40
LC-Fining™ and Hycon	LC-Fining™ and Hycon	HYC	LCF	Atmospheric or Vacuum Resid, Hydrogen	Fuel Gas, Propane, Isobutane, Normal Butane, Naphtha, Kerosene, Diesel, Heavy Gas Oil, Resid	Heaters; Reactors; Hydrogen Compression, Scrubbing & Recycle; Atmospheric & Vacuum Fractionation	Feed	b/sd	4.40

Processing Facilities	Process Type	Process ID	Process Type ID	Feed	Products	Typical Equipment	Capacity Basis	Unit of Measure	CWB Factor
Gasoline/Naphtha Desulfurization & Treating	Benzene Saturation	NHYT	BSAT	Naphtha/Gasoline, Hydrogen	Low Benzene Content Naphtha/Gasoline	Heater, Guard Bed, Reactor, Separators, Fractionator, Hydrogen Compression & Recycle System	Feed	b/sd	0.91
	Desulfurization of C ₄ –C ₆ Feeds	NHYT	C4C6	C ₄ –C ₆ , hydrogen	Fuel Gas, Low Sulfur C ₄ –C ₆	Heater, Guard Bed, Reactor, Separators, Fractionator, Hydrogen Compression & Recycle System			
	Conventional Naphtha Hydrotreating	NHYT	CONV	Naphtha, Gasoline, Hydrogen	Fuel gas, Low sulfur naphtha, gasoline	Heater, Guard Bed, Reactor, Separators, Fractionator, Hydrogen Compression & Recycle System			
	Diolefin to Olefin Saturation of Gasoline	NHYT	DIO	Light Naphtha, Hydrogen	Treated Light Naphtha	Heater, Guard Bed, Reactor, Separators, Fractionator, Hydrogen Compression & Recycle System			
	FCC Gasoline Hydrotreating with Minimal Octane Loss	NHYT	GOCT	Heavy FCC Naphtha/Gasoline, Hydrogen	Fuel Gas, Low Sulfur Heavy FCC Gasoline	Heater, Guard Bed, Reactor, Separators, Fractionator, Hydrogen Compression & Recycle System			
	Olefinic Alkylation of Thiophenic Sulfur	NHYT	OATS	Full range FCC Naphtha/Gasoline	Low Sulfur FCC Gasoline	Exchangers, Reactors, Separators, & Recycling System			
	Selective Hydrotreating of Pyrolysis Gasoline/Naphtha Combined with Desulfurization	NHYT	PYGC	Pyrolysis Naphtha/Gasoline, Hydrogen	Fuel Gas, Low-Sulfur, Low-Olefin Pyrolysis Gasoline	Heater, Guard Bed, Reactor, Separators, Fractionator, Hydrogen Compression & Recycle System			
	Pyrolysis Gasoline/Naphtha Desulfurization	NHYT	PYGD	Pyrolysis Naphtha/Gasoline, Hydrogen	Fuel Gas, Low Sulfur Pyrolysis Gasoline	Heater, Guard Bed, Reactor, Separators, Fractionator, Hydrogen Compression & Recycle System			
	Selective Hydrotreating of Pyrolysis Gasoline/Naphtha Combined with Desulfurization	NHYT	PYGS	Pyrolysis Naphtha/Gasoline, Hydrogen	Fuel Gas, Low Olefin Pyrolysis Gasoline	Heater, Guard Bed, Reactor, Separators, Fractionator, Hydrogen Compression & Recycle System			
	Reactor for Selective Hydrotreating	NHYT	RXST	Light FCC Naphtha/Gasoline	Low Sulfur Light FCC Gasoline	Reactors			
	S-Zorb™ Process	NHYT	ZORB	Full range FCC Naphtha/Gasoline	Low Sulfur FCC Gasoline	Heater, Reactor, Recycle Compressor, Exchangers, Separators, Stabilizer, & Sorbent Regenerator			
Kerosene Desulfurization & Treating	Aromatic Saturation of Kerosene	KHYT	ASAT	Kerosene, Hydrogen	Fuel Gas, Low Sulfur Kerosene	Heater, Reactor, Separator, Stripper/Stabilizer, Hydrogen Compression & Recycle System	Feed	b/sd	0.75
	Conventional Hydrotreating of Kerosene/Jet Fuel	KHYT	CONV	Kerosene, Hydrogen	Fuel Gas, Low Sulfur Kerosene	Heater, Guard Bed, Reactor, Separators, Fractionator, Hydrogen Compression & Recycle System			
	High Severity Hydrotreating of Kerosene/Jet Fuel	KHYT	KUS	Kerosene, Hydrogen	Fuel Gas, Low Sulfur Kerosene	Heater, Guard Bed, Reactor, Separators, Stripper/Stabilizer, Hydrogen Compression & Recycle System			
Distillate Desulfurization & Treating	Aromatic Saturation of Distillates	DHYT	ASAT	Low Sulfur Distillate, Hydrogen	Low Olefins Distillate	Heater, Reactor, Separator, Stripper/Stabilizer, Hydrogen Compression & Recycle System	Feed	b/sd	0.90
	Conventional Distillate Hydrotreating	DHYT	CONV	Distillate/Light Gasoil, Hydrogen	Fuel Gas, Low Sulfur Distillate/Gasoil	Heater, Guard Bed, Reactor, Separators, Stripper/Stabilizer, Hydrogen Compression & Recycle System			
	High Severity Distillate Hydrotreating	DHYT	DHS	Distillate/Light Gasoil, Hydrogen	Fuel Gas, Low Sulfur Distillate/Gasoil	Heater, Guard Bed, Reactor, Separators, Stripper/Stabilizer, Hydrogen Compression & Recycle System			
	Ultra-High Severity Hydrotreating	DHYT	DUS	Distillate/Light Gasoil, Hydrogen	Fuel Gas, Low Sulfur Distillate/Gasoil	Heater, Guard Bed, Reactor, Separators, Stripper/Stabilizer, Hydrogen Compression & Recycle System			
	Middle Distillate Dewaxing	DHYT	MDDW	Distillate/Light Gasoil, Hydrogen	Fuel Gas, Low Wax Content Distillate/Gasoil	Heater, Guard Bed, Reactor, Separators, Stripper/Stabilizer, Hydrogen Compression & Recycle System			
	S-Zorb™ Process	DHYT	ZORB	Distillate/Gasoil	Low Sulfur Distillate	Heater, Reactor, Recycle Compressor, Exchangers, Separators, Stabilizer, & Sorbent Regenerator			

Processing Facilities	Process Type	Process ID	Process Type ID	Feed	Products	Typical Equipment	Capacity Basis	Unit of Measure	CWB Factor
Selective Hydrotreating	Diolefin to Olefin Saturation of Alkylation Feed	SHYT	DIO	C ₃ s, C ₄ s, C ₅ s containing Dienes & Acetylenes, Light Cracked Gasoline, Light Distillate, Hydrogen	C ₃ s, C ₄ s, C ₅ s with no Dienes or Acetylenes, Low-Olefin Cracked Gasoline, Light Distillate	Reactor	Feed	b/sd	0.90
	Selective Hydrotreating of Distillate Fuels	SHYT	DIST	Distillate	Low Contaminant Distillate	Heater, Reactor, Separator, Stripper/Stabilizer			
Residual Desulfurization	Desulfurization of Atmospheric Resid	RHYT	DAR	Hydrogen, Atmospheric Resid	Fuel Gas, Atmospheric Resid	Heater, Guard Bed, Reactor, Separators, Stripper/Stabilizer, Hydrogen Compression & Recycle System	Feed	b/sd	1.80
	Desulfurization of Vacuum Resid	RHYT	DVR	Hydrogen, Vacuum Resid	Fuel Gas, Vacuum Resid	Heater, Guard Bed, Reactor, Separators, Hydrogen Compression & Recycle System			
Cracking Feed or Vacuum Gas Oil Desulfurization	Cracking Feed or Vacuum Gas Oil Hydrodesulfurization and Hydrodenitrification	VHYT	VHDN	Vacuum Gas Oil/Cracking Feed, Hydrogen	Fuel Gas, Distillate, Vacuum Gas Oil/Cracking Feed	Heater, Guard Bed, Reactor, Separators, Stripper/Stabilizer, Hydrogen Compression & Recycle System	Feed	b/sd	1.00
	Cracking Feed or Vacuum Gas Oil Hydrodesulfurization	VHYT	VHDS	Vacuum Gas Oil/Cracking Feed, Hydrogen	Fuel Gas, Distillate, Vacuum Gas Oil/Cracking Feed	Heater, Guard Bed, Reactor, Separators, Stripper/Stabilizer, Hydrogen Compression & Recycle System			
Catalytic Reforming	Continuous Regeneration	REF	RCR	Naphtha	Fuel Gas, Butanes, Reformate, Hydrogen	Heaters, Reactors, Regenerator, Debutanizer, Light Ends Processing, Hydrogen Compression & Recycle System	Feed	b/sd	3.50
	Cyclic	REF	RCY						
	Semi-Regenerative	REF	RSR						
AROMAX®	AROMAX	U60							
Fuels Solvent Deasphalting	Conventional Solvent	SDA	CONV	Resid, Solvent	Deasphalted Oil, Asphalt	Heater plus Contactors & Separators or Extraction Column & Strippers, Solvent Recovery	Feed	b/sd	2.80
	Supercritical Solvent	SDA	SCRT						
Alkylation	Polymerization of C ₃ Olefin Feed	POLY	PC3	Propane/Propylene	LPG, Polymer Naphtha, Low-Boiling Paraffins	Reactors, Product Fractionator	C5+ Product	b/sd	5.00
	Polymerization of C ₃ /C ₄ Feed	POLY	PMIX	Mixed C ₃ & C ₄ Olefins & Paraffins	LPG, Polymer Naphtha, Low-Boiling Paraffins	Reactors, Product Fractionator			
	Dimersol	DIM		Propane/Propylene	Dimate (Nonene), LPG	Reactors, Catalyst Removal, Stabilizer, Fractionator			
	Alkylation with Hydrofluoric Acid	ALKY	AHF	Olefins, Isobutane	Alkylate, Normal Butane, Isobutane, Propane	Feed Drums, Acid Contactor, Acid Recovery, Acid Regeneration (HF only), Depropanizer, Debutanizer, Deisobutanizer, Refrigeration System	C5+ Alkylate	b/sd	
	Alkylation with Sulfuric Acid	ALKY	ASA						
Sulfuric Acid Regeneration	Sulfuric Acid Regeneration	ACID		Spent Acid	Sulfuric Acid	Combustor, Waste Heat Boiler, Converter, Absorber, SO3 Recycle, Gas Cleaning including Electrostatic Precipitator, Amine Regenerator	Product	ST/sd	37.80
Aromatics Production	Aromatic Solvent Extraction: Extraction Distillation	ASE	ED	C ₆ –C ₈ Aromatic Rich Stream from Reformate or Pyrolysis Gasoline	High Purity Aromatic Stream	Extractor, Raffinate Wash, Stripper, Recovery Column, Solvent Regenerator, Water Stripper, Clay Treaters	Feed	b/sd	3.30
	Aromatic Solvent Extraction: Liquid/Liquid Extraction	ASE	LLE				Feed	b/sd	
	Aromatic Solvent Extraction: Liquid/Liquid Extraction w/ Extraction Distillation	ASE	LLED				Feed	b/sd	
	Benzene Column	BZC		Mixed C ₆ + Aromatics from extraction process	Benzene (95+%), C ₇ + Aromatics	Fractionating Column	Feed	b/sd	
	Toluene Column	TOLC		Mixed C ₇ + Aromatics from extraction process	Toluene, C ₈ + Aromatics	Fractionating Column	Feed	b/sd	
	Xylene Rerun Column	XYLC		Mixed C ₈ + Aromatics	Mixed Xylenes, C ₉ + Aromatics	Fractionating Column	Feed	b/sd	
	Heavy Aromatics Column	HVYARO		Mixed C ₉ + Aromatics	C ₉ Aromatics, C ₁₀ + Aromatics	Fractionating Column	Feed	b/sd	
Hydrodealkylation	Hydrodealkylation	HDA		Toluene, Heavy Alkylbenzenes, Hydrogen	Mixed Benzene & Heavy Aromatics	Heater, Reactor, Separator, Stripper, Clay Treaters, Fractionators, Hydrogen Compression	Feed	b/sd	2.50
Toluene Disproportionation/ Transalkylation	Toluene Disproportionation / Transalkylation	TDP/TDA		Toluene, C ₉ Aromatics, Hydrogen	Mixed Benzene, C ₈ Aromatics, C ₁₀ + Aromatics	Heater, Reactor, Clay Treating, Light Ends Stripper, Separator, Recycle Gas Compressor	Feed	b/sd	1.90
Cyclohexane Production	Cyclohexane	CYC6		Benzene, Hydrogen	Cyclohexane	Reactor, Separator, Stabilizer, Steam Generator, Recycle Compressor, Makeup Compressor	Cyclohexane Product	b/sd	2.80

Processing Facilities	Process Type	Process ID	Process Type ID	Feed	Products	Typical Equipment	Capacity Basis	Unit of Measure	CWB Factor
Xylene Isomerization	Xylene Isomerization	XYISOM		Mixed Xylenes low in p-xylene content, Hydrogen	Mixed Xylenes in Equilibrium	Heater, Reactor, Stabilizer, Deheptanizer	Feed	b/sd	1.90
Paraxylene Production	Paraxylene: Adsorption	PXYL	ADS	Mixed Xylenes	p-Xylene, Mixed Xylenes low in p-Xylene Content	Adsorption Chamber, Rotary Valve, Extract & Raffinate Columns, Finishing Column	Paraxylene Product	b/sd	6.50
	Paraxylene: Crystallization	PXYL	CRY	Mixed Xylenes	p-Xylene, Mixed Xylenes low in p-Xylene Content	Crystallizers, Centrifuge	Paraxylene Product	b/sd	
	Xylene Splitter	XYLS		Mixed C ₈ + Aromatics	Mixed p-/m-Xylenes, Mixed o-Xylene & C ₉ + Aromatics	Fractionating Column	Feed	b/sd	
	Orthoxylene Rerun Column	OXYLRC		Mixed o-Xylene & C ₉ + Aromatics	o-Xylene, C ₉ + Aromatics	Fractionating Column	Feed	b/sd	
Ethylbenzene	Ethylbenzene Manufacture	EBZ		Benzene, Ethylene or Refinery Off-Gas Containing Ethylene	Ethylbenzene	Reactors, Heater, Benzene Recycle Column, Fractionator, Recycle Compressor, Makeup Compressor	Ethylbenzene Product	b/sd	1.60
	Ethylbenzene Distillation	EBZD		Mixed C ₈ Stream	Ethylbenzene, Mixed C ₈ Stream	Fractionator, Heat Exchange	Feed	b/sd	
Cumene	Cumene	CUM		Propylene, Benzene	Propane, Cumene, Heavy Aromatics	Reactor, Hot Oil or Steam Heater, Flash Towers, Benzene Recovery Column, Clay Treater, Fractionator	Cumene Product	b/sd	5.00
Asphalt Production	Asphalt Production	ASP		Short Resid	Fuel Gas, Asphalt	Steam Generation, Oxidizer, Air Blower, Incinerator	Total Asphalt Production	b/sd	2.70
C ₄ Isomerization	C ₄ Isomerization	C4ISOM		Normal Paraffins, Hydrogen	Mixed Isoparaffins & Normal Paraffins	Once through operation with no feed preparation or internal recycle of unconverted products. Heater, Reactor, Stabilizer, Hydrogen Recycle	Feed	b/sd	1.25
C ₅ /C ₆ Isomerization	C ₅ /C ₆ Isomerization	C5ISOM					Feed	b/sd	1.80
ISOSIV	ISOSIV	U18		Mixed C ₅ /C ₆ Paraffins	Isoparaffins, Normal Paraffins	Sieve Beds	Feed	b/sd	1.80
Lubricants ⁽¹⁾	Extraction: Solvent is Duo-Sol	SOLVEX	DOS	Vacuum Gas Oil, Deasphalted Oil, Vacuum Tower Bottoms	Raffinates, Extracts	Heater, Extraction Tower, Raffinate and Extract Solvent Recovery	Feed	b/sd	2.20
	Extraction: Solvent is Furfural	SOLVEX	FUR						
	Extraction: Solvent is NMP	SOLVEX	NMP						
	Extraction: Solvent is Phenol	SOLVEX	PHE						
	Extraction: Solvent is SO ₂	SOLVEX	SDO						
	Dewaxing: Solvent is Chlorocarbon	SDWAX	CHL	Extracted Gas Oil, Hydrocrackates, Vacuum Distillates	Dewaxed Oils, Slack Wax, Scale Wax	Solvent/Oil Refrigeration, Scraped Surface Coolers/Chillers, Filter Feed Drum, Crystallizer, Rotary Filters, Solvent Recovery, Solvent Dehydration, Solvent Splitter	Feed	b/sd	4.55
	Dewaxing: Solvent is MEK/Toluene	SDWAX	MEK						
	Dewaxing: Solvent is MEK/MIBK	SDWAX	MIB						
	Dewaxing: Solvent is propane	SDWAX	PRP						
	Catalytic Wax Isomerization and Dewaxing	CDWAX	ISO	Extracted Gas Oil, Hydrocrackates, Vacuum Distillates	Dewaxed Oils, Light Ends, Distillates	Heater, Reactor, Hydrogen Recycle and Make-up Compression , HP Separator, LP Separator, Recycle Gas Treater, Atmospheric Product Fractionation and/or Stripping. Additionally, an Iso-Dewaxer includes a Hydrofinishing Reactor and Product Stripper	Feed	b/sd	1.60
	Selective Wax Cracking	CDWAX	SWC						
	Lube Hydrocracker with Multi-fraction Distillation	LHYC	HCM	Vacuum Gas Oil	Base Oil Feedstocks, C ₃ to 650 °F+ Clean Products, Fuel Gas	Heater, Reactor, Product Fractionation, Hydrogen Recycle and Make-up Compression, Hydrogen Scrubbing and Recycle, Atmospheric and Vacuum Distillation Columns	Feed	b/sd	2.50
	Lube Hydrocracker with Vacuum Stripper	LHYC	HCS						
	Lube Hydrofinishing with Vacuum Stripper	LHYFT	HFS	Raffinate or Dewaxed Oil	Base Oil Feedstocks, Dewaxed Oils, Fuel Gas	Heater, Reactor, Separators, Fractionation, Hydrogen Recycle and Make-up Compression , Atmospheric Product Fractionation and/or Stripping	Feed	b/sd	1.15
	Lube Hydrotreating with Multi-fraction Distillation	LHYFT	HTM			Heater, Reactor, Fractionation, Hydrogen Recycle and Make-up Compression , Atmospheric Product Fractionation and/or Stripping			
	Lube Hydrotreating with Vacuum Stripper	LHYFT	HTS						
	Deoiling: Solvent is Chlorocarbon	WDOIL	CHL	Slack Wax	Refined (Hard) Wax, Foots Oil/Soft Wax	Refrigeration, Rotary Filter, Solvent Recovery	Product	b/sd	11.80
	Deoiling: Solvent is MEK/Toluene	WDOIL	MEK						
	Deoiling: Solvent is MEK/MIBK	WDOIL	MIB						
	Deoiling: Solvent is propane	WDOIL	PRP						
	Wax Hydrofinishing with Vacuum Stripper	WHYFT	HFS	Refined Wax, Slack Wax, Scale Wax	HF Refined Wax, HF Scale Wax, HF Slack Wax	Heater, Reactor, Separators, Fractionation, Hydrogen Recycle and Make-up Compression	Feed	b/sd	1.15
	Wax Hydrotreating with Multi-fraction Distillation	WHYFT	HTM						
	Wax Hydrotreating with Vacuum Stripper	WHYFT	HTS						

Processing Facilities	Process Type	Process ID	Process Type ID	Feed	Products	Typical Equipment	Capacity Basis	Unit of Measure	CWB Factor
Hydrogen Generation ⁽²⁾	Steam Methane Reforming	HYG	HSM	Fuel Oil, Naphtha, Natural Gas	Hydrogen, Carbon Dioxide	Desulfurizer, Heaters, Reformer or Partial Oxidizer, Shift Converter, Methanation, CO2 Rejection, Hydrogen Compression	Product	k SCF/sd	5.70
	Steam Naphtha Reforming	HYG	HSN				Product	k SCF/sd	6.70
	Partial Oxidation Units	HYG	POX				Product	k SCF/sd	7.10
Sulfur	Sulfur Recovery Unit	SRU		Acid Gas	Sulfur, Tail Gas	Burner/Reactor, Waste Heat Boiler, Converters, Condensers, Amine Unit Regenerator, Sour Water Stripper (exclude pelletizers)	Product Sulfur	LT/sd	140.00
	Tail Gas Recovery Unit	TRU		Tail Gas	Sulfur, Off-Gas	Reactor, Quench Tower, Absorber, Regenerator for SCOT Process & equivalent for other processes	Product Sulfur	LT/sd	
	H ₂ S Springer Unit	U32		H ₂ S Rich Gas, Spent Caustic	Sweet Gas, Sulfur/H ₂ S		Sulfur Sprung	LT/sd	
Special Fractionation ⁽³⁾	All Special Fractionation ex Solvents, Propylene, and Aromatics	Various		Various	Various	Fractionator, Heat Exchange	Feed	b/sd	0.80
Oxygenates – MTBE	Distillation Units	MTBE	DIST	Methanol, C ₄ Olefins	MTBE, Unreacted C ₄ Olefins	Reactor & Fractionator or Catalytic Distillation Vessel	Product	b/sd	4.90
	Extraction Units	MTBE	EXT	Methanol, C ₄ Olefins	MTBE, Unreacted C ₄ Olefins	Reactor & Fractionator or Catalytic Distillation Vessel; Methanol Recovery & Recycle	Product	b/sd	
Oxygenates – ETBE	ETBE	ETBE		Ethanol, C ₄ Olefins	ETBE, Unreacted C ₄ Olefins	Reactors, Fractionator, Ethanol Extraction & Recycle	Product	b/sd	
Oxygenates – TAME	TAME	TAME		Methanol, C ₄ –C ₆ Mixed Olefins	Mixed Ethers, Unreacted C ₄ –C ₆ Mixed Olefins	Reactors, Fractionator, Methanol Extraction & Recycle	Product	b/sd	
Coke Calciner	Vertical-Axis Hearth	CALCIN	HRTH	Green Petroleum Coke	Calcined Coke	Combustion Chamber, Vertical Rotary Kiln, Electrostatic Precipitator or other air pollution control equipment (Coke Handling & Storage Equipment reported separately. Report Waste Heat Recovery under Fired Boilers – Solid)	Product	ST/sd	96.00
	Horizontal-Axis Rotary Kiln	CALCIN	KILN	Green Petroleum Coke	Calcined Coke	Combustion Chamber, Horizontal Rotary Kiln, Electrostatic Precipitator or other air pollution control equipment (Coke Handling & Storage Equipment reported separately. Report Waste Heat Recovery under Fired Boilers – Solid)	Product	ST/sd	
Methanol Synthesis	Methanol Synthesis	U70		Hydrogen & CO	Methanol	Reactor Section, Steam Generation, Distillation	Product	b/sd	-36.00
POX Syngas for Fuel	POX Syngas for Fuel	U73		Resid	H ₂ , CO, CO ₂	POX Reactor, Scrubber, Soot Recovery, Gas Cleanup & Sulfur Removal	Product	k SCF/sd	2.75
	Air Separation Unit	U79		Air	Oxygen, Nitrogen	Compressor, Cold Box, Separation Equipment	Product	k SCF/sd	
Solvent Hydrotreating	Solvent Hydrotreating	U1		Solvents, Hydrogen	Treated Solvents	Reactor, Stabilizer	Feed	b/sd	N.A. (Included in Hydrotreating and Special Fractionation)
	Solvent Fractionation	SOLVF		Distillate Mixture	High Purity Solvent, By-Product Stream	Special Fractionation for Solvent Purification	Feed	b/sd	
Propane/Propylene Splitter	Chemical Grade	C3S	CHEM	Mixed C ₃ s	High Purity Propylene, Propane	Splitter Column	Feed	b/sd	
	Polymer Grade	C3S	POLY	Mixed C ₃ s	High Purity Propylene, Propane, C ₂ - Off-Gas	Deethanizer, Splitter Column, Compressor, Driers, Treaters	Feed	b/sd	2.10
Desalination	Desalination	DESAL		Sea or Contaminated Water	Potable Water, Brine	Heater, Boilers, Fractionation	Product	k gal/sd	32.70
CO ₂ Liquefaction	CO ₂ Liquefaction	CO ₂		Gaseous CO ₂	Liquid CO ₂	Multi-Stage Compression, Dehydrators, Stripper	CO ₂ Product	ST/sd	-160.00
Ammonia Recovery Unit	PHOSAM	U59		Sour Water Stripper Overhead	Ammonia, Treated Water	Adsorber, Stripper, Fractionator	Product	ST/sd	453.00
Cryogenic LPG Recovery	Cryogenic LPG Recovery	U60		Refinery Gas Streams	C ₃ s, C ₄ s, Other Gases	Refrigeration, Drier, Compressor, Absorber Stripper, Fractionation	Feed	k SCF/sd	0.25
Flare Gas Recovery	Flare Gas Recovery	U9		Waste Gases, Steam	Compressed Gases	Compressor, Separator	Feed	k SCF/sd	0.13
Fuel Gas Sales Treating & Compression	Fuel Gas Sales Treating & Compression	U31		Raw Fuel Gas	High-Pressure Sweet Fuel Gas	H ₂ S Absorber, Compressor, Miscellaneous Purification	Horsepower	hp	2.52
Flue Gas Desulfurizing	Flue Gas Desulfurizing	U35		Flue Gas with Contaminants	Clean Flue Gas	Contactora, Catalyst/Reagent Regeneration,Scrubbing Circulation, Solids Handling	Feed	k SCF/sd	0.02

⁽¹⁾ The CWB factors for additional lubricants refinery units, such as Wax/Acid/Clay Treating, Wax Sweating, Lotox, and Rerun Vacuum Distillation are allocated among major lubricant refining units.

⁽²⁾ The CWB factors for hydrogen purification units, such as Cryogenic Unit, Membrane Separation Unit, and Pressure Swing Adsorption (PSA) unit, as well as U71 (CO Shift & H₂ Purification) and U72 (POX Syngas for H₂ Generation), are allocated among Hydrogen Generation units.

⁽³⁾ Special Fractionation units include the following: Deethanizer, Depropanizer, Deisobutanizer, Debutanizer, Deisopentanizer, Depentanizer, Deisohexanizer, Debutanizer, Deisopentanizer, Depentanizer, Deisohexanizer, Dehexanizer, Deisoheptanizer, Deheptanizer, Naphtha Splitter, Alkylate Splitter, and Reformate Splitter.

Appendix E Example for Calculating Total CWB for a Refinery (CA-CWB)

The following table illustrates the calculation of Total CWB for an example refinery.

	Utilized Capacity	Units of Measure ⁽¹⁾	CWB Factor	FCC Coke on Catalyst, vol %	CWB Factor, FCC Coke on Catalyst	CWB (b/d)
Atmospheric Crude Distillation	214,009	T b/cd	1.00			214,009
Vacuum Distillation	114,933	T b/cd	0.91			104,589
Visbreaker	-	T b/cd	1.60			-
Delayed Coker	73,236	T b/cd	2.55			186,752
Fluid Coking						
Fluid Coker	-	T b/cd	10.3			-
Flexicoker	-	T b/cd	23.6			-
Catalytic Cracking						
FCC	61,510	T b/cd	1.150	4.41	1.041	353,276
Mild Residual FCC	-	T b/cd	0.659	4.41	1.1075	-
Residual FCC	-	T b/cd	-	4.41	1.1765	-
Other FCC	-	T b/cd	4.65			-
Thermal Cracking	-	T b/cd	2.95			-
Naphtha/Distillate Hydrocracker	30,290	T b/cd	3.15			95,412
Residual Hydrocracker (H-Oil; LC-Fining and Hycon)	-	T b/cd	4.40			-
Naphtha Hydrotreater	95,000	T b/cd	0.91			86,450
Kerosene Hydrotreater	23,100	T b/cd	0.75			17,325
Diesel/Selective Hydrotreater	70,366	T b/cd	0.90			63,329
Residual Hydrotreater	-	T b/cd	1.80			-
VGO Hydrotreater	46,930	T b/cd	1.00			46,930
Reformer – including AROMAX	30,019	T b/cd	3.50			105,066
Solvent Deasphalter	-	T b/cd	2.80			-
Alkylation / Poly / Dimersol	16,720	P b/cd	5.00			83,601
Sulfuric Acid Regeneration	-	ST/cd	37.80			
C ₄ Isomer Production	-	P b/cd	1.25			-
C ₅ /C ₆ Isomer Production – including ISOSIV	-	P b/cd	1.80			-
Coke Calciner	-	ST/cd	96			-
Hydrogen Generation						
Steam-Methane Reforming	-	k SCF/cd	5.70			-
Steam-Naphtha Reforming	-	k SCF/cd	6.70			-
Partial Oxidation	-	k SCF/cd	7.10			-
Sulfur ⁽²⁾	783	LT/cd	140			109,674
Aromatics Production (All)	-	T b/cd	3.30			-
Hydrodealkylation	-	P b/cd	2.50			-
Toluene Disproportionation / Transalkylation	-	P b/cd	1.90			-
Cyclohexane Production	-	P b/cd	2.80			-
Xylene Isomerization	-	P b/cd	1.90			-
Paraxylene Production	-	P b/cd	6.50			-

	Utilized Capacity	Units of Measure ⁽¹⁾	CWB Factor	FCC Coke on Catalyst, vol %	CWB Factor, FCC Coke on Catalyst	CWB (b/d)
Ethylbenzene Production	-	P b/cd	1.60			-
Cumene Production	-	P b/cd	5.00			-
Lubricants						
Solvent Extraction	-	T b/cd	2.20			-
Solvent Dewaxing	-	T b/cd	4.55			-
Catalytic Dewaxing	-	T b/cd	1.60			-
Lube Hydrocracking	-	T b/cd	2.50			-
Lube Hydrofining	-	T b/cd	1.15			-
Wax Deoiling	-	T b/cd	11.80			-
Wax Hydrofining	-	T b/cd	1.15			-
Asphalt Production	-	P b/cd	2.70			-
Oxygenates	-	P b/cd	4.90			-
POX Syngas for Fuel	-	k SCF/cd	2.75			-
Methanol Synthesis	-	P b/cd	(36.00)			-
CO ₂ Liquefaction	-	ST/cd	(160.00)			-
Ammonia Recovery Unit		ST/cd	453			
Desalination	-	k gal/cd	32.70			-
Special Fractionation	25,725	T b/cd	0.80			20,580
Propane/Propylene Splitter (Propylene Production)	-	P b/cd	2.10			-
Cryogenic LPG Recovery	-	k SCF/cd	0.25			
Flare Gas Recovery	-	k SCF/cd	0.13			
Fuel Gas Sales Treating & Compression	-	hp	2.52			
Flue Gas Desulfurizing	-	k SCF/cd	0.02			
Subtotal: Process CWB						1,486,994
Off-Sites and Non-Energy Utilities	Total Throughput	Units of Measure⁽¹⁾	CWB Factor for Throughput		CWB Factor for Process CWB	
Total Input Barrels	248,128	T b/cd	0.327		0.0085	93,777
Non-Crude Sensible Heat	Total Throughput	Units of Measure⁽¹⁾	CWB Factor			
Qual. Non-Crude Input Barrels	20,863	T b/cd	0.44			9,180
Sales and Exports of Steam and Electricity	Thermal Equivalent	Units of Measure⁽¹⁾	CWB Factor			
Steam Transfers to Affiliates	-	k Btu/cd	0.0125			-
Steam Sales	9,165,492	k Btu/cd	0.0125			114,569
Electricity Transfers to Affiliates	-	k Btu/cd	0.0125			-
Electricity Sales	987,240	k Btu/cd	0.0125			12,340
Subtotal: CWB for Sales and Exports of Steam and Electricity						126,909
Total CWB						1,716,860

⁽¹⁾ Units of measure in this column are as follows:

T b/cd – Throughput on feed basis in barrels per calendar day

P b/cd – Throughput on product basis in barrels per calendar day

ST/cd – Throughput in short tons per calendar day; 1 ST = 2,000 lbs

k SCF/cd – Throughput in thousand standard cubic feet (dry @ 60 °F and 14.696 psia or 15 °C and 1 atmosphere) per calendar day

LT/cd – Throughput in long tons per calendar day; 1 LT = 2,240 lbs

k gal/cd – Throughput in thousand gallons (US liquid) per calendar day

hp – Horsepower

k Btu/cd – Thousand British thermal units per calendar day; 1 Btu = 1,055 joules

⁽²⁾ Includes the combined throughput of product sulfur for Sulfur Recovery Unit and Tail Gas Recovery Unit, and sulfur sprung for H₂S Springer Unit.

Appendix F Example for Calculating Total CWT for a Refinery (Solomon EU-CWT)

The following table illustrates the calculation of Total CWT for the same example refinery used in Appendix E.

	Utilized Capacity	Units of Measure ⁽¹⁾	EU-CWT Factor	FCC Coke on Catalyst, wt %	CWT (tonne/d)
Atmospheric Crude Distillation	31,591	tonne/cd	1.00		31,591
Vacuum Distillation	18,525	tonne/cd	0.85		15,746
Visbreaker	-	tonne/cd	1.40		-
Delayed Coker	10,864	tonne/cd	2.20		23,900
Fluid Coking		tonne/cd			
Fluid Coker	-	tonne/cd	7.60		-
Flexicoker	-	tonne/cd	16.60		-
Catalytic Cracking		tonne/cd			
FCC	8,951	tonne/cd	5.50	4.68	49,229
Mild Residual FCC	-	tonne/cd	5.50		-
Residual FCC	-	tonne/cd	5.50		-
Other FCC	-	tonne/cd	4.10		-
Thermal Cracking	-	tonne/cd	2.70		-
Naphtha/Distillate Hydrocracker	4,667	tonne/cd	2.85		13,302
Residual Hydrocracker (H-Oil; LC-Fining and Hycon)	-	tonne/cd	3.75		-
Naphtha Hydrotreater	9,592	tonne/cd	1.10		10,552
Kerosene Hydrotreater	3,006	tonne/cd	0.90		2,706
Diesel/Selective Hydrotreater	9,819	tonne/cd	0.90		8,838
Residual Hydrotreater	-	tonne/cd	1.55		-
VGO Hydrotreater	7,090	tonne/cd	0.90		6,381
Reformer – including AROMAX	3,564	tonne/cd	4.95		17,642
Solvent Deasphalter	-	tonne/cd	2.45		-
Alkylation / Poly / Dimersol	1,858	P tonne/cd	7.25		13,468
C ₄ Isomer Production	-	P tonne/cd	3.25		-
C ₅ /C ₆ Isomer Production – including ISOSIV	-	P tonne/cd	2.85		-
Coke Calciner	-	P tonne/cd	12.75		-
Hydrogen Generation					
Gas Feed	-	tonne/cd	296.00		-
Naphtha Feed	-	tonne/cd	348.00		-

	Utilized Capacity	Units of Measure ⁽¹⁾	EU-CWT Factor	FCC Coke on Catalyst, wt %	CWT (tonne/d)
Sulfur	796	tonne/cd	18.60		14,805
Aromatics Production (All)	-	P tonne/cd	5.25		-
Hydrodealkylation	-	P tonne/cd	2.45		-
Toluene Disproportionation / Transalkylation	-	P tonne/cd	1.85		-
Cyclohexane Production	-	P tonne/cd	3.00		-
Xylene Isomerization	-	P tonne/cd	1.85		-
Paraxylene Production	-	P tonne/cd	6.40		-
Ethylbenzene Production	-	P tonne/cd	1.55		-
Cumene Production	-	P tonne/cd	5.00		-
Lubricants					
Solvent Extraction	-	tonne/cd	2.10		-
Solvent Dewaxing	-	tonne/cd	4.55		-
Wax Isomerization	-	tonne/cd	1.60		-
Lube Hydrocracking	-	tonne/cd	2.50		-
Wax Deoiling	-	tonne/cd	12.00		-
Lube and Wax Hydrotreating	-	tonne/cd	1.15		-
Asphalt Production	-	P tonne/cd	2.10		-
Oxygenates	-	P tonne/cd	5.60		-
POX Syngas for Fuel		tonne SG/cd	8.20		-
POX Syngas to H ₂ or Methanol	-	tonne SG/cd	44.00		-
Methanol Synthesis	-	P tonne/cd	(36.20)		-
CO ₂ Liquefaction	-	tonne/cd	(19.20)		-
Desalination	-	P tonne/cd	1.15		-
Special Fractionation – Purchased NGL Only	1,153	tonne/cd	1.00		1,153
Propane/Propylene Splitter (Propylene Production)	-	tonne/cd	3.45		-
Solvents					
Solvent Hydrotreating	-	tonne/cd	1.25		-
Solvent Fractionation	-	tonne/cd	0.90		-
Treatment & Compression of Fuel Gas for Sale	-	kW	0.45		-
Air Separation Plant	-	k nm ³ O ₂ /cd	8.80		-
Subtotal: Process EU-CWT					209,312
Off-Sites, Non-Energy Utilities, and Non-Crude Sensible Heat					14,599
Sales and Other Exports of Steam	Thermal Equivalent	Units of Measure	EU-CWT Factor		
Steam Transfers & Sales	9,670	GJ/cd	1.62		15,665
Subtotal: EU-CWT Before Adjustments for Steam Imports and Electricity					239,576
Total CWT – per EU-ETS Boundary ⁽²⁾					140,152

- ⁽¹⁾ Units of measure in this column are as follows:

tonne/cd – Throughput on feed basis in tonnes per calendar day

P tonne/cd – Throughput on product basis in tonnes per calendar day

ST/cd – Throughput in short tons per calendar day; 1 ST = 2,000 lbs

tonne SG/cd – Throughput in tonnes of syngas per calendar day

LT/cd – Throughput in long tons per calendar day; 1 LT = 2,240 lbs

k gal/cd – Throughput in thousand gallons (US liquid) per calendar day

kW – Kilowatts; 1,000 watts

k nm³ O₂/cd – Throughput in thousand normal cubic meters of oxygen (dry @ 0 °C and 1 atmosphere) per calendar day

GJ/cd – Gigajoules per calendar day; 1 GJ = 109 joules

- ⁽²⁾ The adjustments were made by multiplying Solomon's Electricity Utilization Factor (EUF) and Steam Import Factor.

Appendix G Glossary and Solomon Units of Measure

Solomon Usage	Description
°C	Degrees Celsius
°F	Degrees Fahrenheit
9,090 Btu per kilowatt-hour (kWh)	Conversion Factor for Purchased/Imported Electricity to Thermal Energy
ASTM	American Society for Testing and Materials
b, bbl, barrels	API barrels; 42 US liquid gallons; 0.159 cubic meters
b/cd	Barrels per calendar day
b/sd	Barrels per stream day
bar a	Bar absolute; 14.504 lb-force per square inch absolute; 1.0197 kg-force per m ² absolute; 100 kilopascal absolute; 0.987 atmosphere absolute
bar g	Bar gauge; 14.504 lb-force per square inch gauge; 1.0197 kg-force per m ² gauge; 100 kilopascal gauge; 0.987 atmosphere gauge
bhp	Brake horsepower, 745.7 watts
BS&W	Bottom sediment and water
Btu	British thermal unit; 1,055 joules
CA	California
CA-CWB™	The Complexity-Weighted Barrels Methodology for California Refineries
CDU	Atmospheric Crude Distillation Unit
CEF	CO ₂ Emission Factor; in tonne CO ₂ /MBtu
CEI	Carbon Emissions Index
CO ₂	Carbon Dioxide
CO ₂ e	Carbon Dioxide-Equivalent
Complexity	Configuration Factor; a ratio of Total Equivalent Distillation Capacity (EDC) of the Refinery to its Crude Unit Capacity
CONCAWE	Conservation of Clean Air and Water in Europe
cu ft, ft ³	Cubic feet; 0.02832 cubic meters for liquids & solids. SCF; 0.02679 for NM ³ for gases
CWB	Complexity-Weighted Barrels
CWTB	Complexity-Weighted Throughput Barrels, referred as CWB
CWT	Complexity-Weighted Tonnes
EDC	Equivalent Distillation Capacity
EEF	Electricity Emission Factor
EII	Energy Intensity Index
EU	European Union
EU ETS	European Union Emissions Trading Scheme
EU-CWT	The Complexity-Weighted Tonnes Methodology for European Union Refining Industry

EUF	Electricity Utilization Factor
FCC	Fluid Catalytic Cracking
FOE (bbl)	Fuel Oil Equivalent barrel (Lower Heating Value); 6.05 MBtu; 6,383 MJ
gal	Gallon (US liquid)
GHG	Greenhouse Gas
GJ	Gigajoule; 10^9 joules
hp	Horsepower
k	Thousands of units specified
kg	Kilogram
kg/m ³	Kilograms per cubic meter (density)
k lb/h	Thousand pounds per hour
kW	Kilowatts; 1,000 watts
kWh	Kilowatt-hour
L	Liter
lb	Pound (avoirdupois)
LBG	Low-Btu Gas
LHV	Lower Heating Value; used in Energy Reporting in Solomon Studies
LPG	Liquefied Petroleum Gas
LT	Long ton; 2,240 lb (avoirdupois)
M	Millions of units specified
m ³	Cubic meter; 6.289 bbl
MJ	Megajoule; 10 ⁶ joules
mm	Millimeters
mol %	Molecular fraction (expressed as a percent)
nm ³	Normal cubic meters; dry @ 0 °C and 1 atmosphere
°API	Specific gravity (SG) expressed in °API; $((141.5/SG) - 131.5)$
OECD	Organization for Economic Co-operation and Development
POX	Partial Oxidation Unit
ppm (vol)	Parts per million (volume)
ppm (wt)	Parts per million (weight)
psia	Pounds per square inch absolute (pressure)
psig	Pounds per square inch gauge (pressure)
SCF	Standard cubic feet; dry @ 60 °F and 14.696 psia or 15 °C and 1 atmosphere
Solomon	HSB Solomon Associates LLC
ST	Short Ton; 2,000 lb (avoirdupois)
TJ	Terajoule; 10^{12} joules
US EPA	United States Environmental Protection Agency
vol %	Percent by volume
WBCSD	World Business Council for Sustainable Development
WRI	World Resources Institute
WSPA	Western States Petroleum Association

wt %	Percent by weight
GJ/cd	Gigajoules per calendar day; 1 GJ = 109 joules
k Btu/cd	Thousand British thermal units per calendar day; 1 Btu = 1,055 joules
k gal/cd	Throughput in thousand gallons (US liquid) per calendar day
k gal/cd	Throughput in thousand gallons (US liquid) per calendar day
k nm ³ O ₂ /cd	Throughput in thousand normal cubic meters of oxygen (dry @ 0 °C and 1 atmosphere) per calendar day
k SCF/cd	Throughput in thousand standard cubic feet (dry @ 60 °F and 14.696 psia or 15 °C and 1 atmosphere) per calendar day
LT/cd	Throughput in long tons per calendar day; 1 LT = 2,240 lbs
LT/cd	Throughput in long tons per calendar day; 1 LT = 2,240 lbs
tonne SG/cd	Throughput in tonnes of syngas per calendar day
tonne/cd	Throughput on feed basis in tonnes per calendar day
P b/cd	Throughput on product basis in barrels per calendar day
P tonne/cd	Throughput on product basis in tonnes per calendar day
ST/cd	Throughput in short tons per calendar day; 1 ST = 2,000 lbs
ST/cd	Throughput in short tons per calendar day; 1 ST = 2,000 lbs
T b/cd	Throughput on feed basis in barrels per calendar day
Tonne	Metric Ton; 1 tonne = 1,000 kilograms