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 factors[1], 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 (CO_2e) emissions relative to a carbon dioxide (CO_2) 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 $CO_2eActual$* is Solomon's calculation of CO_2-equivalent (CO_2e) emissions incurred
- *CEI $CO_2eStd.$* is the CO_2e 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 CO_2e emissions (*CEI CO_2eActual)* 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 CO_2 emissions equivalent for each fuel type is determined by multiplying the quantity of energy consumed (expressed in MBtu) by the appropriate CO_2 emission factor (CEF) in tonnes of CO_2 equivalent per MBtu, or tonne CO_2/MBtu. The description of Solomon's calculation of CO_2e 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 CO_2e 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 CO_2e 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 CO_2e 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.

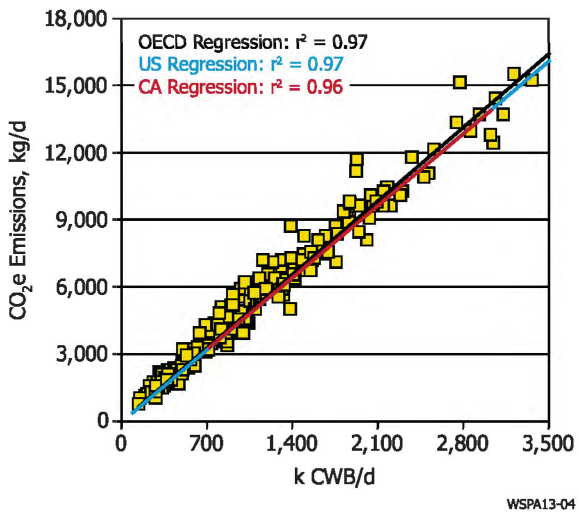

Figure 1a. 2004 OECD Refineries Total Emissions vs CWB

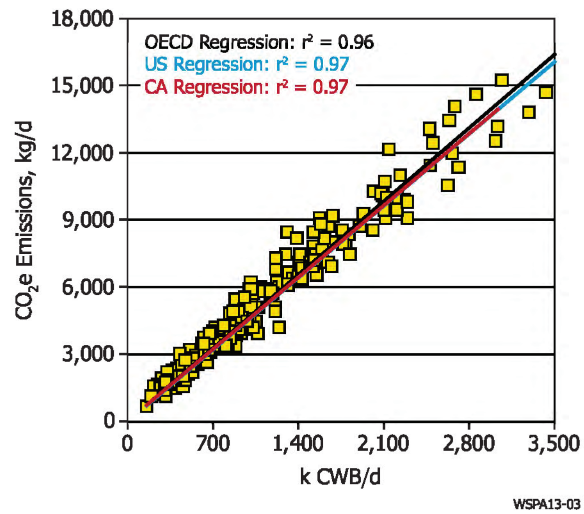

Figure 1b. 2006 OECD Refineries Total Emissions vs CWB

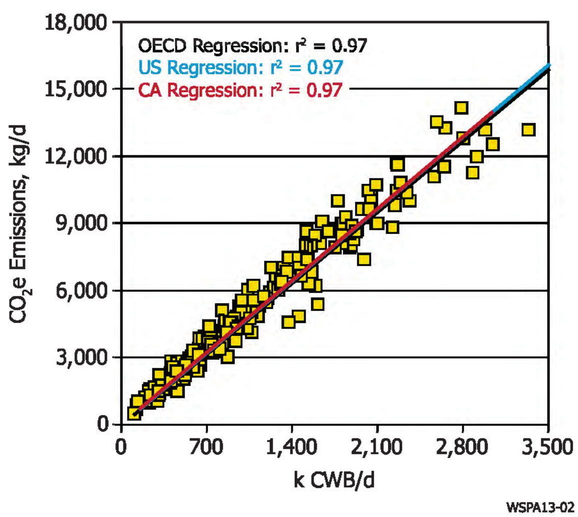

Figure 1c. 2008 OECD Refineries Total Emissions vs CWB

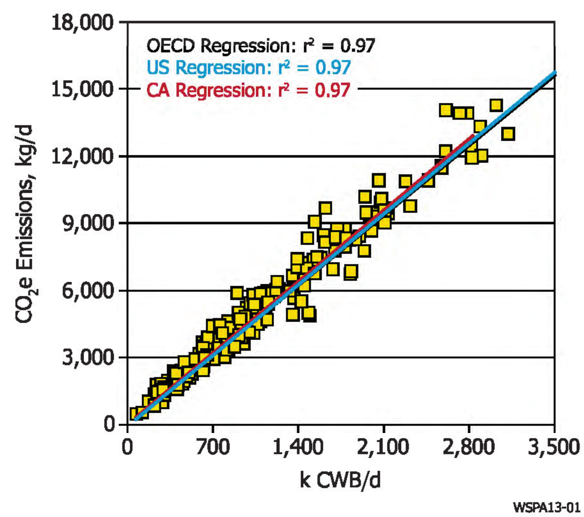

Figure 1d. 2010 OECD Refineries Total Emissions vs CWB

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 CO_2 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 CO_2 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 CO_2e per CWB or tonnes of CO_2 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
- Naphtha
- Jet fuel
- Bitumen and asphalt
- Unfinished oils
- Lube feedstock
- Sulfur by-product
- Propylene
- Lubricants and waxes
- Gasoline
- Distillate fuel
- Residual fuel
- Petroleum coke
- Specialty solvents
- Chemical feedstock
- Aromatic petrochemicals
- Liquefied CO_2 by-product for sales
- 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.

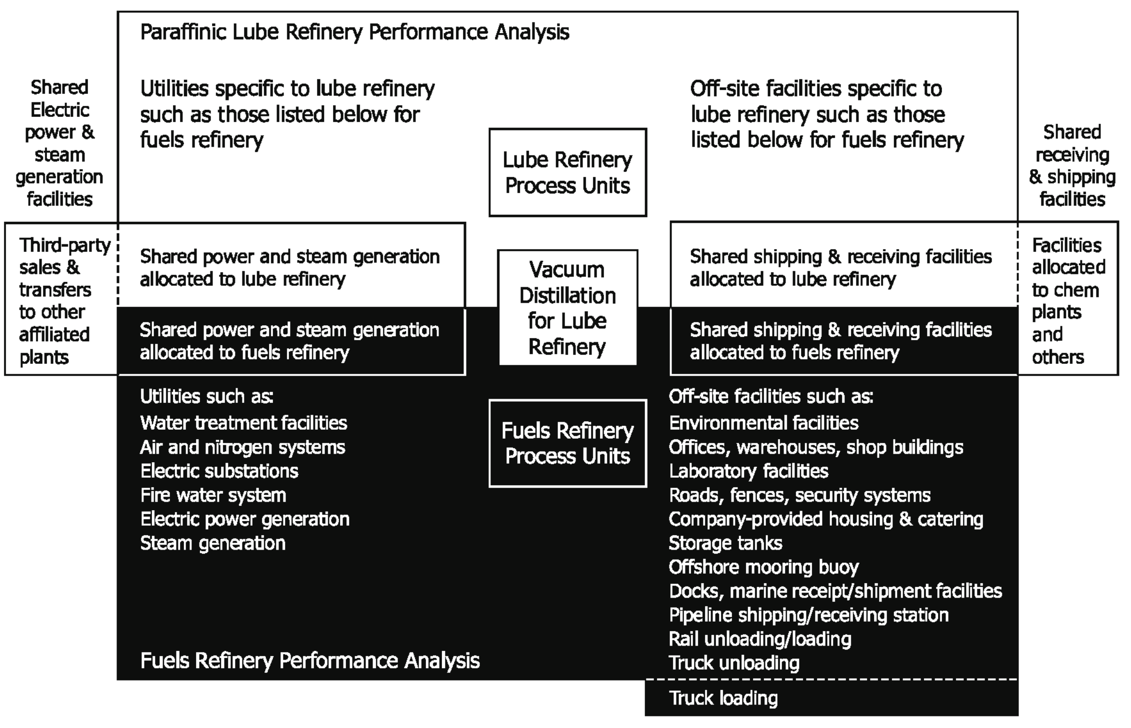

Figure 2. A Shared Complex Between a Fuels Refinery and a Lube Refinery

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).

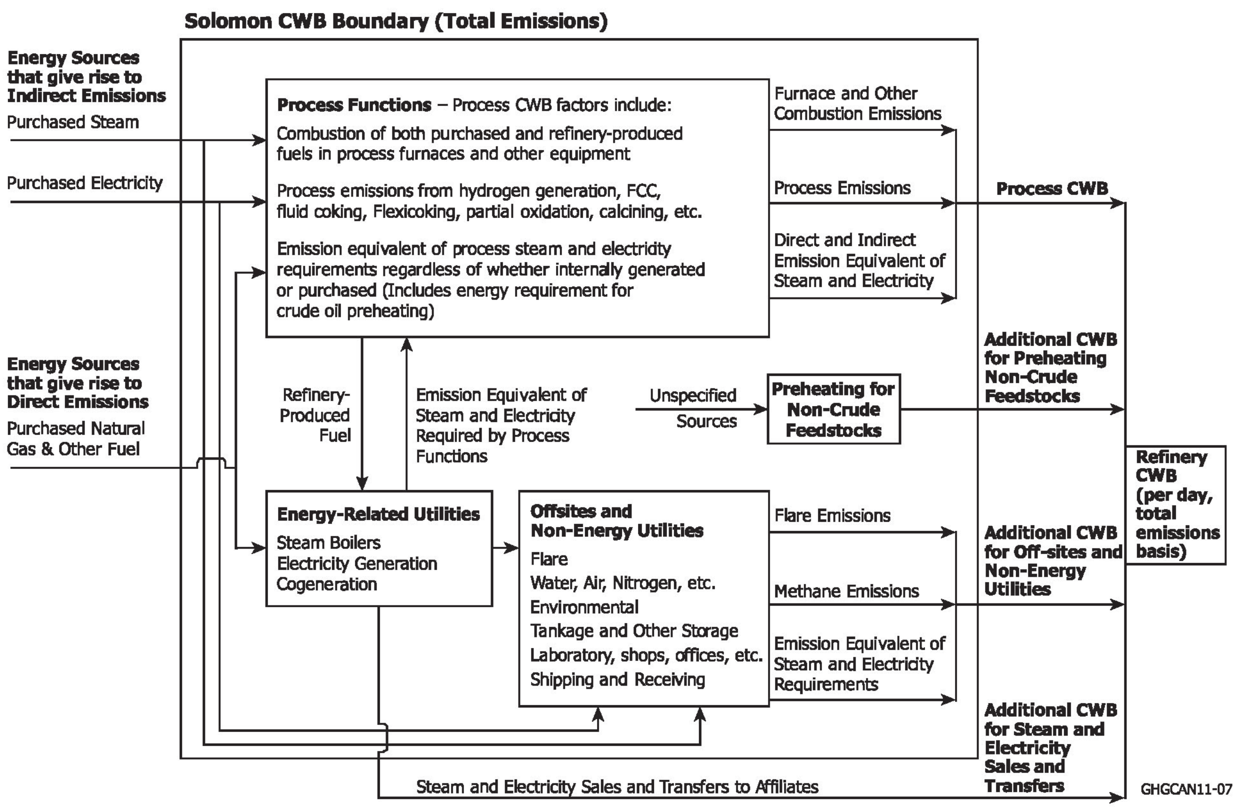

Figure 3. CWB Boundary Conditions

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.

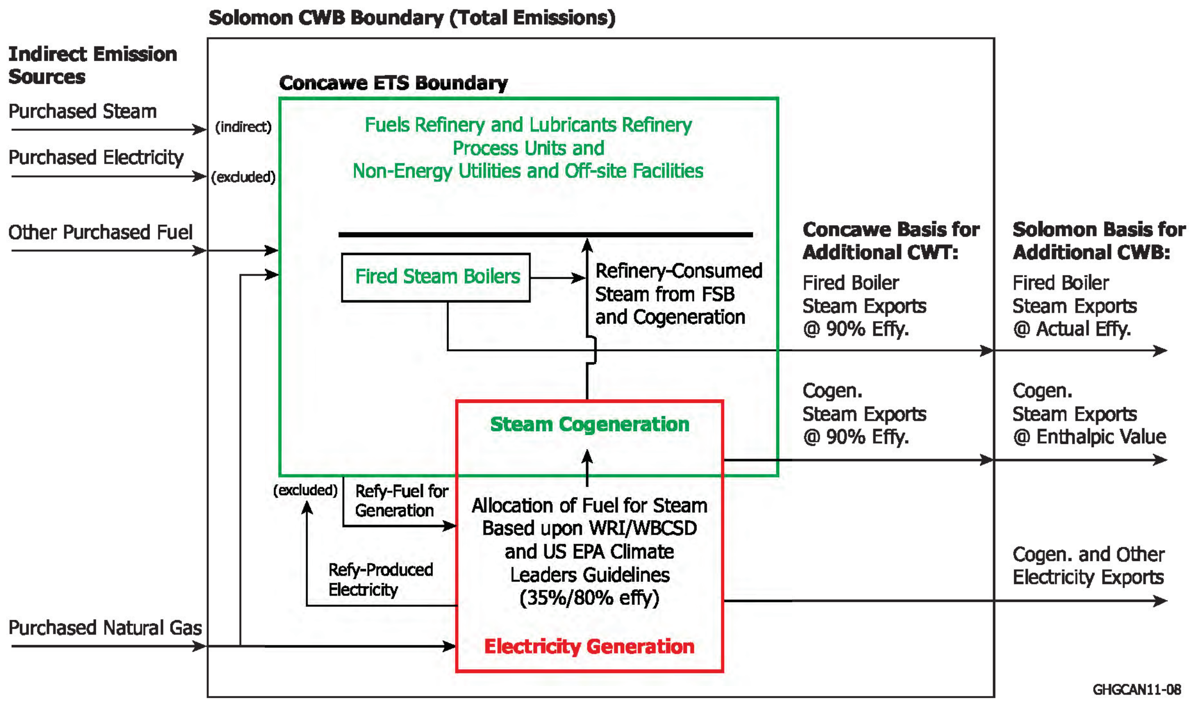

Figure 4. CWB vs CWT Boundary Conditions

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 CO_2e emissions standard per barrel for a certain process unit over the CO_2e 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 CO_2e emissions standard for a certain process unit is determined by its *energy standard* multiplying the CO_2 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 CO_2 emission factor of 0.059 tonne CO_2/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 CO_2e 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 CO_2 emission factor of 0.059 tonne CO_2/MBtu for pipeline natural gas. Since all CWB factors are relative to CO_2 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 CO_2 emission factor of 0.059 tonne CO_2/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× 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]

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[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 CO_2 emission factor of 65.21 tonne CO_2/TJ or 0.069 tonne CO_2/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 CO_2 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:

Process CWB = Σ (Daily Throughput Barrel × 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:

Off-Sites and Non-Energy Utilities CWB =
0.327 × Total Input Barrels + 0.0085 × Process CWB

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:

Non-Crude Sensible Heat CWB = 0.44 × 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 CO_2e 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:

CWB Adjustments for Sales and Exports of Steam and Electricity =
0.0125 × 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 × CWB Factor) + 0.327 × Total Input Barrels + 0.0085 × Σ (Daily Throughput Barrel × CWB Factor) + 0.44 × Non-Crude Input Barrels + 0.0125 × Thermal Equivalent in k Btu/d

= 1.0085 × Σ (Daily Throughput Barrel × CWB Factor) + 0.327 × Total Input Barrels + 0.44 × Non-Crude Input Barrels + 0.0125 ×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×(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 C_3 or C_3/C_4, 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 H_2S 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 CO_2e Emissions

Solomon's calculation of CO_2e 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 CO_2 emissions equivalent for each fuel type is determined by multiplying the quantity of energy consumed (expressed in MBtu) by the appropriate CO_2 emission factor (in tonnes of CO_2 equivalent per MBtu, or tonne CO_2/MBtu).

The assignment or calculation of appropriate carbon emission factors is essential to the measurement of CO_2e emissions. A complete description of Solomon's calculation of CO_2e 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 CO_2e emissions also include CO_2 from flaring and by-product from hydrogen production and asphalt blowing. CO_2e emissions may be reduced by the amount of carbon disposed in liquefied CO_2 sale and synthesized in methanol production. The CO_2 equivalent of actual methane emissions is estimated using the US EPA's Annex F methodology. A simple estimate of the CO_2 equivalent of actual nitrous oxide (N_2O) emissions is also incorporated in Solomon's calculation. For indirect emissions from steam imports, an emission factor of pipeline natural gas, 0.059 tonne CO_2/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 CO_2e/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 CO_2 emissions, non-energy CO_2 emissions, indirect emissions, and the CO_2 equivalent of emissions other than carbon dioxide yields the total CO_2e emissions for the refinery. The equation below illustrates a simplified version for Solomon's estimate of actual CO_2e emissions.

$$\begin{matrix} CEI \\ CO2e \\ Actual \end{matrix} = \left[\left(\sum_{\substack{Fuel \\ Consumption}} AE_i \times CEF_i \right) + CE_{Steam} + CE_{Elect} + CE_{\substack{H2\ and \\ Other \\ Mfg.}} + CE_{Flare} + CE_{\substack{CH4 \\ and \\ N2O}} - CE_{\substack{MeOH \\ and\ CO2 \\ Sales}} \right]$$

where

- *CEI $CO_2eActual$* 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 CO_2 emission factor applicable to fuel type *i*
- CE_{Steam} is the quantity of actual CO_2 emissions from steam imports (indirect emissions)
- CE_{Elect} is the quantity of actual CO_2 emissions from purchased electricity (indirect emissions)

- $CE_{H_2\ and\ Other\ Mfg.}$ is the quantity of non-energy CO_2 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 CO_2 emission from flaring, which is based upon actual refinery flare losses and a standard CO_2 emission factor
- $CE_{CH4\ and\ N2O}$ is the estimated CO_2e of methane and nitrous oxide emissions
- $CE_{MeOH\ and\ CO_2\ Sales}$ 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.

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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)*
Factors for Fluid Catalytic Cracking (4)	3	1	1
Factors for Hydrogen Production (4)	3	2	2
r^2 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 CO_2 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 CO_2e emissions and CWB for all select OECD refineries for operating year 2010; or between Solomon's calculation for CO_2 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
					Air Separation Plant	k nm^3 O_2/cd	8.80
POX Syngas for Fuel	k SCF/cd	2.75			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	
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	Heate Desal Stripp Treati Comp Depro Sour
	Standard Crude Unit	CDU	SCU			
Vacuum Distillation	Mild Vacuum Fractionation	VAC	MVU	Atmospheric Resid	Fuel Gas, Vacuum Gas Oils to Vacuum Resid	Heate tower
	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	Furna Fracti
	Processing Atmospheric Resid (with a Soaker Drum)	VBR	VARS			
	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_3s, C_4s, Naphtha, Distillates, Heavy Gas Oil, Coke	React Fracti Gas P CO B
	Flexicoking	COK	FX	Vacuum Resid	Fuel Gas, C_3s, C_4s, Naphtha, Distillates, Heavy Gas Oil, Low-Btu Gas	React Light Gener
	Delayed Coking	COK	DC	Vacuum Resid	Fuel Gas, C_3s, C_4s, Naphtha, Distillates, Heavy Gas Oils, Coke	Heate Colun Plant) handl
Thermal Cracking	Thermal Cracking	TCR		Vacuum Gas Oil	Fuel Gas, Naphtha, Distillates, Heavy Gas Oil, & Bottoms	Gas C
Catalytic Cracking	Fluid Catalytic Cracking (Feed ConCarbon <2.25 wt %)	FCC	FCC	Vacuum Gas Oil, Atmospheric Resid	Fuel Gas, C_3s, C_4s, Gasoline, Cycle Oils, Decant Oil	Feed Regen Gener Electr
	Mild Residual Catalytic Cracking (Feed ConCarbon 2.25–3.5 wt %)	FCC	MRCC			
	Residual Catalytic Cracking (Includes two-stage regeneration; Feed ConCarbon ≥3.5 wt %)	FCC	RCC			
	Houdry Catalytic Cracking	FCC	HCC			
	Thermofor 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	Heate Comp
	Severe Hydrocracking (Normally more than 1,500 psig and consumes more than 1,000 SCF H_2/b)	HYC	HSD			Satura Absor Debut Sour
	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	Heate Hydro Catal Fracti

Processing Facilities	Process Type	Process ID	Process Type ID	Feed	Products	
Gasoline/Naphtha Desulfurization & Treating	Benzene Saturation	NHYT	BSAT	Naphtha/Gasoline, Hydrogen	Low Benzene Content Naphtha/Gasoline	Heate Fracti Syster
	Desulfurization of C_4–C_6 Feeds	NHYT	C4C6	C_4–C_6, hydrogen	Fuel Gas, Low Sulfur C_4–C_6	Heate Fracti Syster
	Conventional Naphtha Hydrotreating	NHYT	CONV	Naphtha, Gasoline, Hydrogen	Fuel gas, Low sulfur naphtha, gasoline	Heate Fracti Syster
	Diolefin to Olefin Saturation of Gasoline	NHYT	DIO	Light Naphtha, Hydrogen	Treated Light Naphtha	Heate Fracti Syster
	FCC Gasoline Hydrotreating with Minimal Octane Loss	NHYT	GOCT	Heavy FCC Naphtha/Gasoline, Hydrogen	Fuel Gas, Low Sulfur Heavy FCC Gasoline	Heate Fracti Syster
	Olefinic Alkylation of Thiophenic Sulfur	NHYT	OATS	Full range FCC Naphtha/Gasoline	Low Sulfur FCC Gasoline	Excha Syster
	Selective Hydrotreating of Pyrolysis Gasoline/Naphtha Combined with Desulfurization	NHYT	PYGC	Pyrolysis Naphtha/Gasoline, Hydrogen	Fuel Gas, Low-Sulfur, Low-Olefin Pyrolysis Gasoline	Heate Fracti Syster
	Pyrolysis Gasoline/Naphtha Desulfurization	NHYT	PYGD	Pyrolysis Naphtha/Gasoline, Hydrogen	Fuel Gas, Low Sulfur Pyrolysis Gasoline	Heate Fracti Syster
	Selective Hydrotreating of Pyrolysis Gasoline/Naphtha Combined with Desulfurization	NHYT	PYGS	Pyrolysis Naphtha/Gasoline, Hydrogen	Fuel Gas, Low Olefin Pyrolysis Gasoline	Heate Fracti Syster
	Reactor for Selective Hydrotreating	NHYT	RXST	Light FCC Naphtha/Gasoline	Low Sulfur Light FCC Gasoline	React
	S-Zorb™ Process	NHYT	ZORB	Full range FCC Naphtha/Gasoline	Low Sulfur FCC Gasoline	Heate Excha Regen
Kerosene Desulfurization & Treating	Aromatic Saturation of Kerosene	KHYT	ASAT	Kerosene, Hydrogen	Fuel Gas, Low Sulfur Kerosene	Heate Hydro
	Conventional Hydrotreating of Kerosene/Jet Fuel	KHYT	CONV	Kerosene, Hydrogen	Fuel Gas, Low Sulfur Kerosene	Heate Fracti Syster
	High Severity Hydrotreating of Kerosene/Jet Fuel	KHYT	KUS	Kerosene, Hydrogen	Fuel Gas, Low Sulfur Kerosene	Heate Stripp Recyc
Distillate Desulfurization & Treating	Aromatic Saturation of Distillates	DHYT	ASAT	Low Sulfur Distillate, Hydrogen	Low Olefins Distillate	Heate Hydro
	Conventional Distillate Hydrotreating	DHYT	CONV	Distillate/Light Gasoil, Hydrogen	Fuel Gas, Low Sulfur Distillate/Gasoil	Heate Stripp Recyc
	High Severity Distillate Hydrotreating	DHYT	DHS	Distillate/Light Gasoil, Hydrogen	Fuel Gas, Low Sulfur Distillate/Gasoil	Heate Stripp Recyc
	Ultra-High Severity Hydrotreating	DHYT	DUS	Distillate/Light Gasoil, Hydrogen	Fuel Gas, Low Sulfur Distillate/Gasoil	Heate Stripp Recyc
	Middle Distillate Dewaxing	DHYT	MDDW	Distillate/Light Gasoil, Hydrogen	Fuel Gas, Low Wax Content Distillate/Gasoil	Heate Stripp

Processing Facilities	Process Type	Process ID	Process Type ID	Feed	Products	
Selective Hydrotreating	Diolefin to Olefin Saturation of Alkylation Feed	SHYT	DIO	C_3s, C_4s, C_5s containing Dienes & Acetylenes, Light Cracked Gasoline, Light Distillate, Hydrogen	C_3s, C_4s, C_5s with no Dienes or Acetylenes, Low-Olefin Cracked Gasoline, Light Distillate	React
	Selective Hydrotreating of Distillate Fuels	SHYT	DIST	Distillate	Low Contaminant Distillate	Heate
Residual Desulfurization	Desulfurization of Atmospheric Resid	RHYT	DAR	Hydrogen, Atmospheric Resid	Fuel Gas, Atmospheric Resid	Heate Stripp Recyc
	Desulfurization of Vacuum Resid	RHYT	DVR	Hydrogen, Vacuum Resid	Fuel Gas, Vacuum Resid	Heate Hydro
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	Heate Stripp Recyc
	Cracking Feed or Vacuum Gas Oil Hydrodesulfurization	VHYT	VHDS	Vacuum Gas Oil/Cracking Feed, Hydrogen	Fuel Gas, Distillate, Vacuum Gas Oil/Cracking Feed	Heate Stripp Recyc
Catalytic Reforming	Continuous Regeneration	REF	RCR	Naphtha	Fuel Gas, Butanes, Reformate, Hydrogen	Heate Light & Rec
	Cyclic	REF	RCY			
	Semi-Regenerative	REF	RSR			
AROMAX®	AROMAX	U60				
Fuels Solvent Deasphalting	Conventional Solvent	SDA	CONV	Resid, Solvent	Deasphalted Oil, Asphalt	Heate Extrac Recov
	Supercritical Solvent	SDA	SCRT			
Alkylation	Polymerization of C_3 Olefin Feed	POLY	PC3	Propane/Propylene	LPG, Polymer Naphtha, Low-Boiling Paraffins	React
	Polymerization of C_3/C_4 Feed	POLY	PMIX	Mixed C_3 & C_4 Olefins & Paraffins	LPG, Polymer Naphtha, Low-Boiling Paraffins	React
	Dimersol	DIM		Propane/Propylene	Dimate (Nonene), LPG	React Fracti
	Alkylation with Hydrofluoric Acid	ALKY	AHF	Olefins, Isobutane	Alkylate, Normal Butane, Isobutane, Propane	Feed Acid Debut Syster
	Alkylation with Sulfuric Acid	ALKY	ASA			
Sulfuric Acid Regeneration	Sulfuric Acid Regeneration	ACID		Spent Acid	Sulfuric Acid	Comb Absor Electr
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	Extrac Colun Clay
	Aromatic Solvent Extraction: Liquid/Liquid Extraction	ASE	LLE			
	Aromatic Solvent Extraction: Liquid/Liquid Extraction w/ Extraction Distillation	ASE	LLED			
	Benzene Column	BZC		Mixed C_6+ Aromatics from extraction process	Benzene (95+%), C_7+ Aromatics	Fracti
	Toluene Column	TOLC		Mixed C_7+ Aromatics from extraction process	Toluene, C_8+ Aromatics	Fracti
	Xylene Rerun Column	XYLC		Mixed C_8+ Aromatics	Mixed Xylenes, C_9+ Aromatics	Fracti

Processing Facilities	Process Type	Process ID	Process Type ID	Feed	Products	
Xylene Isomerization	Xylene Isomerization	XYISOM		Mixed Xylenes low in p-xylene content, Hydrogen	Mixed Xylenes in Equilibrium	Heate
Paraxylene Production	Paraxylene: Adsorption	PXYL	ADS	Mixed Xylenes	p-Xylene, Mixed Xylenes low in p-Xylene Content	Adsor Raffin
	Paraxylene: Crystallization	PXYL	CRY	Mixed Xylenes	p-Xylene, Mixed Xylenes low in p-Xylene Content	Crysta
	Xylene Splitter	XYLS		Mixed C_8+ Aromatics	Mixed p-/m-Xylenes, Mixed o-Xylene & C_9+ Aromatics	Fracti
	Orthoxylene Rerun Column	OXYLRC		Mixed o-Xylene & C_9+ Aromatics	o-Xylene, C_9+ Aromatics	Fracti
Ethylbenzene	Ethylbenzene Manufacture	EBZ		Benzene, Ethylene or Refinery Off-Gas Containing Ethylene	Ethylbenzene	React Fracti Comp
	Ethylbenzene Distillation	EBZD		Mixed C_8 Stream	Ethylbenzene, Mixed C_8 Stream	Fracti
Cumene	Cumene	CUM		Propylene, Benzene	Propane, Cumene, Heavy Aromatics	React Benze Fracti
Asphalt Production	Asphalt Production	ASP		Short Resid	Fuel Gas, Asphalt	Steam Incine
C_4 Isomerization	C_4 Isomerization	C4ISOM		Normal Paraffins, Hydrogen	Mixed Isoparaffins & Normal Paraffins	Once or inte Heate
C_5/C_6 Isomerization	C_5/C_6 Isomerization	C5ISOM				
ISOSIV	ISOSIV	U18		Mixed C_5/C_6 Paraffins	Isoparaffins, Normal Paraffins	Sieve
Lubricants [1]	Extraction: Solvent is Duo-Sol	SOLVEX	DOS	Vacuum Gas Oil, Deasphalted Oil, Vacuum Tower Bottoms	Raffinates, Extracts	Heate Solver
	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	Solver Coole Rotary Dehyd
	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	Heate Comp Recyc Fracti Iso-De and Pr
	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	Heate Hydro Hydro and V
	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	Heate Hydro Atmos Stripp
	Lube Hydrotreating with Multi-fraction Distillation	LHYFT	HTM			Heate Recyc
	Lube Hydrotreating with Vacuum Stripper	LHYFT	HTS			

Processing Facilities	Process Type	Process ID	Process Type ID	Feed	Products	
Hydrogen Generation [2]	Steam Methane Reforming	HYG	HSM	Fuel Oil, Naphtha, Natural Gas	Hydrogen, Carbon Dioxide	Desul Oxidi CO2 I
	Steam Naphtha Reforming	HYG	HSN			
	Partial Oxidation Units	HYG	POX			
Sulfur	Sulfur Recovery Unit	SRU		Acid Gas	Sulfur, Tail Gas	Burne Conde Water
	Tail Gas Recovery Unit	TRU		Tail Gas	Sulfur, Off-Gas	React for SC proce
	H_2S Springer Unit	U32		H_2S Rich Gas, Spent Caustic	Sweet Gas, Sulfur/H_2S	
Special Fractionation[3]	All Special Fractionation ex Solvents, Propylene, and Aromatics	Various		Various	Various	Fracti
Oxygenates – MTBE	Distillation Units	MTBE	DIST	Methanol, C_4 Olefins	MTBE, Unreacted C_4 Olefins	React Vesse
	Extraction Units	MTBE	EXT	Methanol, C_4 Olefins	MTBE, Unreacted C_4 Olefins	React Vesse
Oxygenates – ETBE	ETBE	ETBE		Ethanol, C_4 Olefins	ETBE, Unreacted C_4 Olefins	React Recyc
Oxygenates – TAME	TAME	TAME		Methanol, C_4–C_6 Mixed Olefins	Mixed Ethers, Unreacted C_4–C_6 Mixed Olefins	React Recyc
Coke Calciner	Vertical-Axis Hearth	CALCIN	HRTH	Green Petroleum Coke	Calcined Coke	Comb Electr contro Equip Heat I
	Horizontal-Axis Rotary Kiln	CALCIN	KILN	Green Petroleum Coke	Calcined Coke	Comb Electr contro Equip Heat I
Methanol Synthesis	Methanol Synthesis	U70		Hydrogen & CO	Methanol	React
POX Syngas for Fuel	POX Syngas for Fuel	U73		Resid	H_2, CO, CO_2	POX I Clean
	Air Separation Unit	U79		Air	Oxygen, Nitrogen	Comp
Solvent Hydrotreating	Solvent Hydrotreating	U1		Solvents, Hydrogen	Treated Solvents	React
	Solvent Fractionation	SOLVF		Distillate Mixture	High Purity Solvent, By-Product Stream	Speci
Propane/Propylene Splitter	Chemical Grade	C3S	CHEM	Mixed C_3s	High Purity Propylene, Propane	Splitt
	Polymer Grade	C3S	POLY	Mixed C_3s	High Purity Propylene, Propane, C_2- Off-Gas	Deeth Driers
Desalination	Desalination	DESAL		Sea or Contaminated Water	Potable Water, Brine	Heate
CO_2 Liquefaction	CO_2 Liquefaction	CO_2		Gaseous CO_2	Liquid CO_2	Multi-
Ammonia Recovery Unit	PHOSAM	U59		Sour Water Stripper Overhead	Ammonia, Treated Water	Adsor
Cryogenic LPG Recovery	Cryogenic LPG Recovery	U60		Refinery Gas Streams	C_3s, C_4s, Other Gases	Refrig Stripp
Flare Gas Recovery	Flare Gas Recovery	U9		Waste Gases, Steam	Compressed Gases	Comp
Fuel Gas Sales Treating &	Fuel Gas Sales Treating & Compression	U31		Raw Fuel Gas	High-Pressure Sweet Fuel Gas	H_2S A