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# EII Analysis Methodology

## Gap Analysis vs World's Best EII

### *2008 Fuels Refinery Performance Analysis*

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## Introduction

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Solomon introduced EII in its first *Fuels Study* of approximately 45 US refineries in 1980. Study participation and the resulting database have grown substantially since then. More than 350 refineries, which make up approximately 85% of worldwide capacity, were benchmarked in the 2008 *Fuels* and *Lube Studies*. Solomon's proprietary database includes detailed data on more than 500 refineries world-wide. Solomon's refinery efficiency methodologies are the standard within the refining industry.

In recent years, energy has come to represent 18–82% of a refinery's operating expense. As such, Solomon developed tools that allow *Fuels* and *Lube Study* participants to better focus their efforts toward making measurable improvements in energy efficiency.

One such tool is EII Analysis versus World's Best EII, which is supplied in the **EII Analysis** tab of the *_PA.xls* file. This analysis illustrates the main reasons underlying the EII performance gap between an individual refinery's EII and that of a "World's Best" EII peer group. This tool was introduced to *Fuels Study* participants during the 2008 *Fuels Study* results presentations and graphically presented as a waterfall diagram, refer to Figure 1. While this tool has been well received, many questions have been raised regarding the methodology employed in its development.

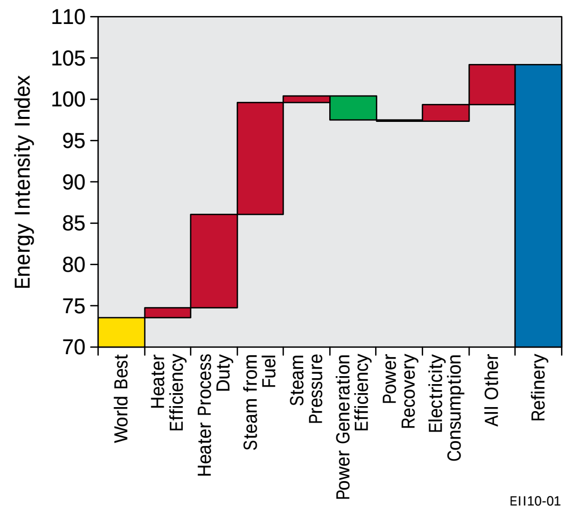


*Figure 1. EII Gaps*

This document describes the EII Analysis methodology in sufficient detail to enable each 2008 *Fuels Study* participant to self-calculate the main elements of the EII Gap. An updated version of the EII Gap is provided for each refinery in the attached *_EIIGap.xls* file. Solomon will continue to improve this product in the upcoming studies. All questions should be directed to Fuels@SolomonOnline.com.

[1] EII® is a registered trademark of Solomon. The absence of any indication as such does not constitute a waiver of any and all intellectual property rights that Solomon has established.

## EII Analysis Methodology, Gap Analysis vs World's Best EII

Solomon defines "World's Best" as the weighted average data of six of the best individual refineries with excellent EII performance from the three *Fuels Study* regions:

- two from North and South America
- two from Europe, Africa, and the Middle East
- two from Asia/Pacific/Indian Ocean

Each of the World's Best EII refineries has an EDC greater than 1.5 million and a typical refining configuration. The composite 2008 World's Best EII is 73.5. The EII used in this analysis is the EII calculated and reported for each refinery participating in the 2008 *Fuels Study* using the 2008 *Fuels Study* validated input.

The following individual elements help explain the EII gap between the World's Best EII peer group and an individual refinery:

- Process Unit Fired-Heater Efficiency
- Process Unit Fired-Heater Process Duty
- Steam from Fuel Combustion
- Steam System Pressure
- Electric Power Generation Efficiency
- Power Recovery – Fluid Catalytic Cracker (FCC) Expander
- Electricity Consumption
- All Other

## Process Unit Fired-Heater Efficiency

This element of the EII Analysis shows how the efficiency of the absorbed process duty in Process Unit Fired-Heaters impacts a refinery's EII. The EII delta between the efficiency of the Process Unit Fired-Heaters in the World's Best EII peer group and the efficiency of the Process Unit Fired-Heaters in an individual refinery is determined using *Equation 1*:

$$[(100 \div L51) - (100 \div J51)] \times J49 \times (J46 \div J45)$$

*Equation 1*

*Where:*

- J51[2] = Weighted-average Efficiency of Process Unit Fired-Heaters (Refinery Value), %
- L51 = Weighted-average Efficiency of Process Unit Fired-Heaters (World's Best Value), %
- J49 = Absorbed Process Unit Fired-Heater Process Duty (Refinery Value), % of Process Standard Energy
- J46 = Process Unit Standard Energy, energy units
- J45 = Total Standard Energy, energy units

[2] These cell references tie directly to the included *_EIIGap.xls* workbook.

The Process Unit Fired-Heaters efficiency calculations used in the analysis are similar to those that are found at http://vganapathy.tripod.com/efficy.html. Solomon indicated in the 2008 *Fuels Study* input instructions that participants could report flue gas $O_2$ on a wet or dry basis and should comment if they reported on a dry basis. In the 2010 *Fuels Study*, Solomon will require that the flue gas $O_2$ be reported on a wet basis.

Note that the air preheater associated with a Process Unit Fired-Heater is within the boundary for this element of the EII Analysis. Furthermore, Process Unit Fired-Heater efficiency is the overall efficiency for the heater.

## Process Unit Fired-Heater Process Duty

This element of the EII Analysis shows how process absorbed duty in Process Unit Fired-Heaters impacts refinery EII. The EII delta between the Process Unit Fired-Heater Process Duty in the World's Best EII peer group and the Process Unit Fired-Heater Process Duty in an individual refinery is determined using *Equation 2*:

$$(L49 - J49) \times (J46 \div J45) \times 100/L51$$

*Equation 2*

*Where:*

- J49 = Process Unit Fired-Heater Process Duty (Refinery Value), % of Process Standard Energy
- L49 = Process Unit Fired-Heater Process Duty (World's Best Value), % of Process Standard Energy
- J46 = Process Unit Standard Energy, energy units
- J45 = Total Standard Energy, energy units
- L51 = Weighted-average Efficiency of Process Unit Fired-Heaters (World's Best Value), %

Note that the Process Unit Fired-Heater Process Duty and the Process Unit Standard Energy exclude process units that can have intrinsic coke combustion (i.e., FCC, POX, Fluid Coker, Flexicoking™, Coke Calciner, etc.).

## Steam from Fuel Combustion

This element of the EII Analysis shows how fuel combustion to generate steam impacts a refinery's EII. This area provides the largest EII improvement opportunity for the majority of *Fuels Study* participants, and is the key differentiator of first-quartile performance. The EII delta between the steam produced and purchased in the World's Best EII peer group and the steam produced and purchased in an individual refinery is determined using *Equation 3*:

$$L60 - J60$$

*Equation 3*

*Where:*

- J60 = Steam from Fuel Combustion (Refinery Value), % of Total Standard Energy
- L60 = Steam from Fuel Combustion (World's Best Value), % of Total Standard Energy

There are four sources of Steam from Fuel Combustion:

- Input Table 1 – Steam produced from boilers assessed at a world-wide *Fuels Study* average firing rate of 1,225 Btu/lb (2,847 kJ/kg)
- Input Table 1 – Steam produced from cogeneration at 1,100 Btu/lb (2,557 kJ/kg)
- Input Table 3 – Steam produced in process unit heaters calculated by summing the steam duty divided by heater efficiency of all process heaters that generate steam
- Input Table 16 – Net Purchased Steam

Energy reported for steam purchases and sales already include generation inefficiencies as required by Input Table 16 Instruction 11.

Steam produced from waste heat recovery equipment other than fired-heater convection sections is not included.

## Steam System Pressure

This element of the EII Analysis shows how steam system pressure impacts a refinery's EII. The EII delta between the steam system pressure in the World's Best EII peer group and the steam system pressure in an individual refinery is determined using *Equation 4*:

$$54.3 \text{ x } LN[(J62 + 14.7) \div (L62 + 14.7)] \text{ x } J60 \div 1,225$$

*Equation 4*

*Where:*

- 54.3 = Slope of Fit of Steam Enthalpy vs Pressure [Btu/lb = 54.3 LN (psia) – 68.3]
- Enthalpy in Refinery Steam vs World Best, Btu/lb = 54.3 LN (Refinery Pressure, psia) – 54.3 LN (World Best Pressure, psia) = LN (Refinery Pressure/World Best Pressure)
- LN = Natural Logarithm
- J62 = Steam System Pressure (Refinery Average Value), psig
- L62 = Steam System Pressure (World's Best Average Value), psig
- 14.7 = Addition to Bring Gauge Pressure to psi Absolute
- J60 = Steam Consumed, % of Total Standard Energy
- 1,225 = Btu/lb Steam (Enthalpy vs Pressure is Derived as Btu/lb Steam, 2,847 kJ/kg)

There may be some double-counting in this element of the EII Analysis, yet Solomon found that the contribution of the steam system pressure in explaining the EII Gap is minimal. Solomon will eliminate this element of the EII Analysis in the next *Fuels Study*, including it with the produced and purchased steam element.

## Electric Power Generation Efficiency

This element of the EII Analysis shows how Electric Power Generation Efficiency impacts a refinery's EII. The reference values are the *weighted average* for each refinery, with purchases at 9,090 Btu/kWh. The EII delta between the average Electric Power Generation Efficiency in the World's Best EII peer group and the average Electric Power Generation Efficiency in an individual refinery is determined using *Equation 5*:

$$(L57 - J57) \div J57 \times J61$$

*Equation 5*

*Where:*

- J57 = Average Refinery Electricity Generation Efficiency (purchases at 9,090 Btu/kWh, 9.590 MJ/kWh)
- L57 = Average World's Best Electricity Generation Efficiency (purchases at 9,090 Btu/kWh, 9.590 MJ/kWh)
- J61 = Electricity Consumed (Refinery Value), % of Total Standard Energy

## Power Recovery – FCC Expander

This element of the EII Analysis shows how power recovery from an FCC Expander impacts a refinery's EII. The first step is to determine the net power recovered as described by *Equation 6*:

$$\text{FCC Expander BHP} * 0.7475 * (9{,}090 - 4{,}000) * 24 * 366$$

*Equation 6*

*Where:*

- *FCC Expander BHP* = Input Table 1 FCC Power Recovery Train, brake horsepower
- 0.7475 = Conversion of Horsepower to kW
- 9,090 = Standard Heat Rate of Purchased Electricity (9,090 Btu/kWh, 9.590 MJ/kWh)
- 4,000 = Assumed Heat Rate of FCC Expander Power Generation (4,000 Btu/kWh, 4.22 MJ/kWh)
- 24 = Hours per Day
- 366 = Days per Year (2008 was a Leap Year)

The assumed 4,000 Btu/kWh (4.22 MJ/kWh) heat rate of FCC Expander Power Generation represents the minimum theoretical rate of 3,413 Btu/kWh (3.598 MJ/kWh) plus heat losses and motor-gear-generator inefficiencies.

The EII delta between the power recovery in the World's Best EII peer group and the power recovery in an individual refinery is determined using *Equation 7*:

J59-L59

*Equation 7*

*Where:*

- J59 = Refinery FCC Expander impact, % of Total Standard Energy
- L59 = World's Best FCC Expander impact, % of Total Standard Energy

If a study participant does not have an FCC Unit or an FCC Expander, this element of the analysis is still valid as it demonstrates the efficiencies achieved by the World's Best EII peer group.

## Electricity Consumption

This element of the EII Analysis shows the effect that electricity consumption has on a refinery's EII. The reference values are the *weighted average* for each refinery, with purchases at 9,090 Btu/kWh (9.590 MJ/kWh). If a refinery generates at greater than 9,090 Btu/kWh and sells power, the generation inefficiency is charged to refinery consumed power (refinery sells at 9,090 Btu/kWh or lower, never higher). This energy netting methodology is standard throughout in the study. The EII delta between the electricity consumed in the World's Best EII peer group and the electricity consumed in an individual refinery is determined using *Equation 8*:

L61 – (J61 x L57 ÷ J57)

*Equation 8*

*Where:*

- J61 = Electricity Consumed (Refinery Value), % of Total Standard Energy
- L61 = Electricity Consumed (World's Best Value), % of Total Standard Energy
- J57 = Average Refinery Electricity Generation Efficiency (purchases at 9,090 Btu/kWh, 9.590 MJ/kWh)
- L57 = Average World's Best Electricity Generation Efficiency (purchases at 9,090 Btu/kWh, 9.590 MJ/kWh)

## All Other

This element of the EII Analysis completes the EII waterfall diagram by closing the remaining gap. This EII delta, representing the unexplained portion of the EII waterfall diagram, is determined using *Equation 9*. It is explainable by improving the quality of the input in Input Tables 2, 3, and 16.

L20 – L8 – SUM(N11:N17)

*Equation 9*

*Where:*

- L8 = Refinery EII
- L20 = World's Best EII
- N11:N17= Sum of EII-Deltas Calculated using Equations 1-6 and 8

All Other may include impacts from coke combustion, SRU energy, TRU energy, hydrotreater compression energy, etc. that are not completely captured in the other elements of this EII Analysis. This All Other category should be small if the data reported is consistent with the input instructions.

If a refinery has a significant unexplained EII-delta of more than 5 EII numbers in this All Other category, then Solomon encourages the refinery to review the following checklist:

- Review the instructions in Input Table 3, including the Reference 3A and FAQ.
- Review the Refinery Fuel Gas Balance. Does Input Table 3 Fired Duty plus Input Table 2 Fired-Turbine Cogeneration Total Fuel to Unit equal Input Table 16 Fuels Consumed in the Fuels Refinery column (not including process coke, steam, and electricity)?
- Review the Steam Balance. Does Input Table 1 Steam Generation (Fired Boilers) capacities and utilizations correspond to Input Table 3 Boiler Steam Duty? Be aware that boilers making steam for electrical production with condensing turbines should be reported on Input Table 3 and not reported on Input Table 1. Is Steam Duty in fired-heaters (such as in the convection section) reported in Input Table 3 consistent with Input Table 16A Steam from Fired Process Heater Convection Section?
- Confirm that the Input Table 1 utilized boiler capacity is not overstated. Examples include: 1) steam allocated to an excluded facility but the total boiler capacity is reported, and 2) electric power generation boilers are included in steam generation in Input Table 1.
- Confirm that all data reported in Input Table 3 was reported on a process throughput or fuel-fired weighted average basis. The weighting should be based on fired duty or utilized capacity.
- Review the reporting of Hydrogen Plant steam production. Only report the net steam production for Hydrogen Plants in Input Table 3 (gross steam minus process steam). Net steam includes steam for $CO_2$ recovery solvent regeneration and to drive fan and pump turbines.
- Review the percent contribution of heater process duty to a typical process unit's EII standard energy. The fired-heater absorbed duty divided by unit standard energy should be at least 20–30% of the standard energy for most process units.
- Review all third-party energy transfers in and/or out of the Fuels Refinery Boundary reported incorrectly.
- Review the reporting of convection air preheat systems as Other Duty in Input Table 3.
- Confirm the inclusion as Other Duty in Input Table 3 items such as CO boilers, calciners, and shaft work for gas turbines or any other external source of duty entering/leaving the Fuels Refinery Boundary (i.e., hot oil). See the attached FAQ.
- Review accuracy of electrical production efficiency reported on Input Table 16 for electric power generation and for cogeneration.
- Was a gas turbine that is not integrated into a cogeneration unit reported?