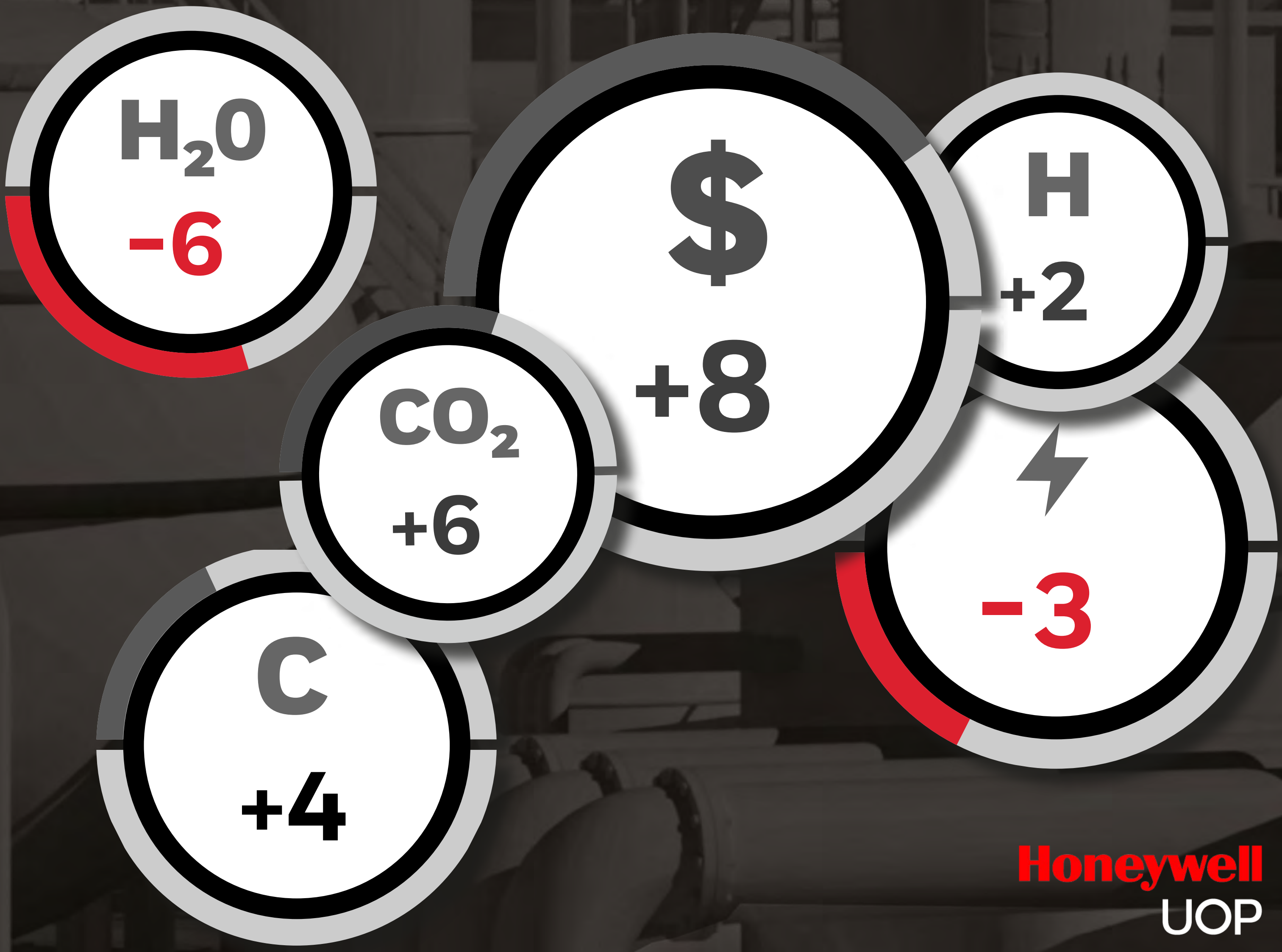
The Journey to Sustained Profitability

HOW TO BENCHMARK THE EFFICIENCY OF YOUR INVESTMENT



Honeywell
UOP

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A NEW METHODOLOGY: HONEYWELL UOP'S E6 FRAMEWORK

> The refining industry is critical to the world economy, providing essential energy and materials required for global development.

Refiners always have planned for success over a long-term time horizon, laying the foundation for sustained profitability and continued competitiveness. There are many factors affecting the success of a refining business — changing market conditions, available feedstocks, new technology, regulatory constraints, environmental policies and competition. As such, many refineries are under increasing pressure from shareholders, boards, institutional investors and their executive management to chart their path forward for sustained growth and prosperity.

Whether a refining business elects to remain in fuels production or expand into petrochemicals, it is critical to understand the profitability of the investment needed to achieve business objectives. Such investments are capital intensive and must be economically viable over their entire operational life. Determining the long-term viability of a project is complex and requires an understanding of the relationships between the factors that determine its success. A project built around principles that deliver a strong return on investment will ensure long lasting economic performance. However, the world is changing, and many refiners now are considering factors beyond financial performance when planning investment decisions.

In many cases, a project must be attractive to shareholders and investors in terms of profitability — and social and environmental responsibility. Because UOP has assisted customers — and their investors — to develop the most efficient and bankable projects possible, it has created a standard approach to assess total project performance, beyond profitability alone.

UOP identified six critical performance factors for evaluating investment in a standalone refinery, or one integrated with petrochemicals. These six factors form the UOP Six Efficiencies (E6) framework. The six components are carbon, hydrogen, utilities, emissions, water — treated as a scarce resource — and capital. The E6 framework permits evaluation of these efficiencies and ranking of any trade-offs that may result from certain project objectives.

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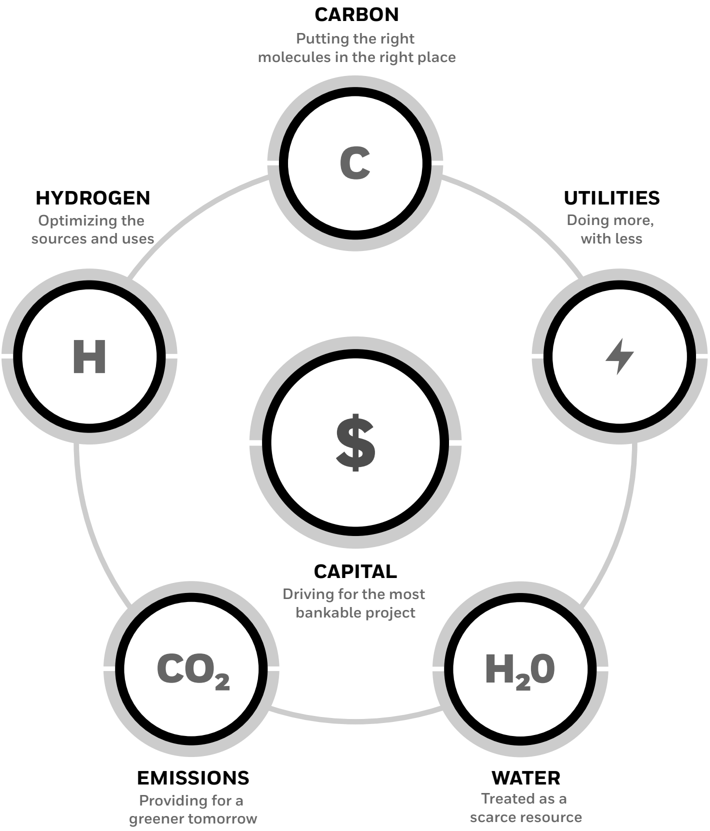


Figure 1: UOP E6 Framework measures the efficiency of six components of an investment

The E6 framework measures how well a proposed investment compares, relative to a best-in-class benchmark. Hence, it enables identification of opportunities that will lead to improved project performance, balancing financial outcomes with social and environmental implications. The E6 model differs from other industry benchmarking metrics. It benchmarks an investment against the latest technologies currently available. Over time, existing technologies will advance, and new technologies will emerge. This continual innovation will result in improved benchmarks in each of the categories. Consequently, the benchmarks will be updated on an annual basis, which enables continuous classification of competitiveness against emerging technologies and in turn, will identify new improvement opportunities.

Essentially, the UOP E6 model is a planning tool that provides fundamental insight into an investment's profitability, including its social and environmental impact, and timing. It enables better investment decisions to ensure a long-term leading competitive position.

QUANTIFYING THE SIX CRITICAL EFFICIENCIES

> **The scope of application for the UOP E6 model may include a downstream complex producing any level of fuels or petrochemicals and is valid for the full range of available crudes.**

It also is applicable to new grassroots complexes and substantial revamps of existing complexes. This paper introduces a methodology for the refining and petrochemicals complex, but it also can be extended to the individual process technologies that make up the complex. The E6 methodology covers the complex and is not inclusive of the full life cycle analysis (LCA) of the net products.

A proposed configuration design for the complex should achieve optimum efficiency across all six factors. Optimum efficiency means that the configuration has achieved best-in-class performance compared with a benchmark. The benchmark for each category is based upon fully optimized configurations that include representations for the latest technologies available today.[1] The efficiency of each category for a configuration is measured by comparing against a benchmark configuration that is targeting similar objectives in terms of crude quality and product slate.

Designing a best-in-class complex today ensures long-term high performance and competitiveness. Therefore, it is critical to approach new projects with a flexible, future-forward mindset that enables creation of the right configuration and infrastructure for today and for the future.

For example, if water is expected to become a scarce resource, then invest in technology that minimizes water consumption today because it will be more expensive to retrofit an open circulating cooling water system later. Similarly, include an efficient utility system in the complex design, also to prevent a costly upgrade in the future. Fundamentally, the E6 methodology is used to identify a strategy for improving the design and the performance of both new and existing complexes. Each of the six efficiencies will now be reviewed in more detail.

CARBON EFFICIENCY

E6 starts with carbon. As crude oil is a valuable carbon-rich resource, the objective for any complex is to maximize its transformation into high-value products. This means putting the right molecules in the right processes while doing the minimum amount of work needed to convert them into high-value products.

The effectiveness of the conversion of carbon in the crude oil to high-value products is determined by the carbon metric for the configuration.[2, 11, 12 & 14] The reference line in Figure 2 represents benchmark carbon metric performance across the continuum from fuels to maximum petrochemicals, for an Arabian Light crude. Note that the benchmark line never fully achieves 100% petrochemicals. Crude barrels to the complex is used as the basis, not net products.[14] This correctly accounts for losses such as petroleum coke, fuel gas, sulfur and other lesser contributors.

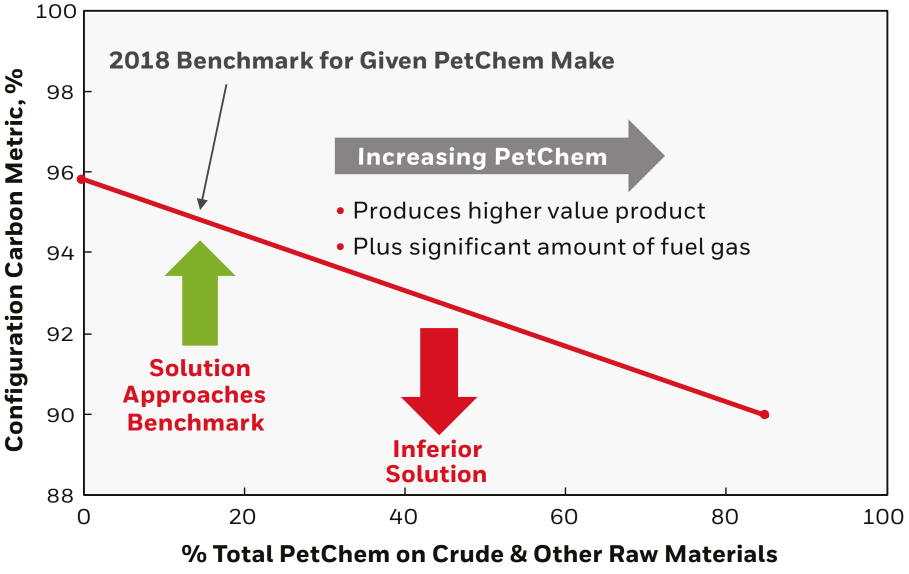


Figure 2: 2018 Carbon Metric Benchmark vs. % Total Petrochemicals on Feed for Arabian Light Crude[14 & 18]

The fundamental decision that a refiner must address when upgrading crude oil into lighter, more valuable products, is whether to reject carbon or add hydrogen. When evaluating carbon efficiency, the answer is the latter — hydrogen addition.

Each configuration across the range was optimized to include processes aligned with a carbon strategy that maximized the transformation of the incoming carbon into high-value products. For example, these configurations use only hydrocracking technologies to convert the vacuum gas oil (VGO) and residue fractions. Carbon rejection technologies such as a delayed coking unit or a fluidized catalytic cracking unit are not included in the benchmark for carbon. With these technologies, the resultant carbon metric will be below the benchmark line as carbon is lost to low-value coke by-product.

Comparing the carbon metric for the configuration against the benchmark configuration carbon metric permits measurement of carbon metric performance. Carbon efficiency is the term used for this measurement, and it is defined by Equation 1.[6]

$$\text{Carbon Efficiency, \%} = \begin{array}{l}100 * \text{Configuration Carbon Metric} / \\ \text{Benchmark Configuration Carbon Metric}\end{array}$$

Equation 1

A carbon metric below the line signals less-than-optimal performance and results in an efficiency less than 100%. This may highlight the need to re-optimize the configuration and/or review alignment of business objectives as they relate to carbon.

Many factors influence the carbon metric for a configuration. Some contributors include the quantity of petrochemicals being produced as seen in Figure 2, the quality of the crude being processed, and the ultimate design/complexity of the configuration. The configuration must drive towards benchmark carbon metric performance irrespective of these various factors. Therefore, the E6 methodology includes adjustments to determine a carbon metric benchmark for each situation. So, regardless of objectives, it is possible to achieve 100% carbon efficiency if a solution is optimally designed.

Carbon efficiency is maximized by employing strategies that demonstrate a more efficient approach to carbon utilization. Minimize or avoid processes that reject carbon such as delayed coking or fluidized catalytic cracking. Implement technologies that are selective to high-value products and minimize low-value by-products. For instance, it is more carbon efficient to send propane and butane to a dehydrogenation unit for olefin production than processing in a steam cracker. These approaches exemplify effective molecule management which have a positive impact on carbon, hydrogen and capital efficiency.

HYDROGEN EFFICIENCY

Hydrogen use is most efficient when used as sparingly as possible to transform molecules and deliver the desired product slate. To maximize hydrogen efficiency, it is important to consider all the sources and uses within the facility. The incoming crude oil contains hydrogen, and therefore the objective is to maximize the use of this intrinsic crude hydrogen to make the desired product slate.

A significant amount of hydrogen by-product results from the rearrangement of molecules into higher-value products. For example, catalytic reforming, steam cracking and propane dehydrogenation units are major sources of hydrogen. Normally, this co-product hydrogen is recovered and used in the hydroprocessing units. Hydrotreating units add hydrogen to remove impurities such as sulfur. Hydrocracking units use it to crack larger molecules into smaller, higher-value molecules.

Additional hydrogen is typically needed to meet the production requirements of the complex. This additional hydrogen can be supplied via pipeline or a dedicated onsite hydrogen plant. Ultimately, the amount of this additional hydrogen depends on factors such as crude quality, target product slate and how efficiently the sources and uses of hydrogen are integrated. Inadequate management of the hydrogen results in waste.

Hydrogen efficiency is calculated directly rather than by comparison to a benchmark.[11, 13 & 14] Hydrogen efficiency is determined using Equation 2.[7]

$$\text{Hydrogen Efficiency, \%} = \begin{array}{l} 100 * \text{Hydrogen in Saleable Products} / \\ (\text{Hydrogen in the Feed} + \text{Hydrogen from Hydrogen Plant}) \end{array}$$

Equation 2

The line in Figure 3 is an example of hydrogen consumption across the continuum from fuels to maximum petrochemicals for an Arabian Light crude.

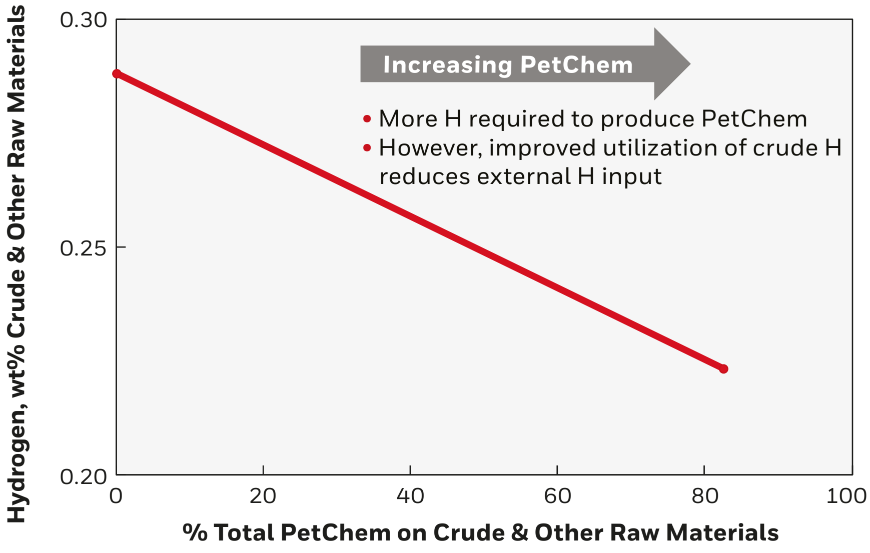


Figure 3: Hydrogen Consumption vs. % Total Petrochemicals on Feed for Arabian Light Crude [14 & 18]

Note that production of fuels requires a larger hydrogen plant than production of petrochemicals. When producing petrochemicals, a greater amount of hydrogen is required, and when optimally integrated, a significant amount of the crude hydrogen is recovered via dehydrogenation reactions. This reduces the required size of the hydrogen plant and increases hydrogen efficiency relative to fuels production.

Production of olefins generally requires hydrogen addition upfront of a dehydrogenation step. Hydrogen removal results in rejection of a portion of the added hydrogen to fuel gas. So, adding the right amount of hydrogen necessary for the target product slate will reduce hydrogen losses. Additionally, implementing more selective technologies will help to minimize hydrogen losses. For example, sending propane to a dehydrogenation unit produces more olefins and less fuel gas than a steam cracker.

If co-production of aromatics is desired, hydrogen must be removed, therefore an optimal solution will balance hydrogen addition and removal to produce the ideal combination of olefins and aromatics. This means optimization of the hydrogenation and dehydrogenation cycles. Ideally, these cycles should be combined where possible. For example, direct steam cracking of heavier fractions such as kerosene, diesel and VGO, will eliminate the need for hydrogen addition. However, the deterioration of yields via the steam cracker and the associated capital cost increase will dictate the economic maximum boiling point of the material that should be sent directly to the steam cracker.

Each crude will have a unique optimum product distribution. Lighter, hydrogen-rich crudes will produce more olefins while heavier, lower hydrogen crudes will produce more aromatics. A lighter crude, long on hydrogen, will require a smaller hydrogen plant and result in a higher efficiency. Conversely, a heavier crude, short on hydrogen, will result in a larger hydrogen plant and lower efficiency.

Ultimately, the hydrogen efficiency will depend upon the heavy oil upgrading strategy and the level of petrochemical production. Hydrogen addition will lower this efficiency, while carbon rejection will improve it. When balanced against capital, utilities and emissions, the challenge is to add and remove hydrogen only when required, and to minimize the quantity of each.

UTILITIES EFFICIENCY

The goal of utilities efficiency is to minimize consumption of utilities and ensure the best use of the energy required to convert feedstocks. Energy consumption is an operating expense and prime contributor to greenhouse gas (GHG) emissions. Utilities efficiency is used to determine the energy demand impact of fuel selection, utility system design, crude quality, complexity of the facility and level of petrochemical production.

Carbon and hydrogen efficiency can be improved by utilizing more effective processes. Accordingly, utilities efficiency is used to ensure that these strategies optimize the use of energy.

Several different processing steps are required to produce salable fuels and petrochemical products. Most of these processes are dependent on energy to generate utilities needed for mechanical transport of fluids, process heating/cooling, steam generation, endothermic heat of reaction, etc. For this reason, production of fuels and/or petrochemicals consumes a significant amount of energy.

It is estimated that this energy consumption contributes to approximately 30-40% of the operating cost of a best-in-class complex design. In the context of the E6 framework, utilities are considered as energy in terms of an equivalent methane consumption. The objective is to minimize this equivalent methane consumption to decrease the use of resources, reduce operating cost and lay the foundation for long-term competitiveness.

The amount of energy consumed by a complex is quantified by the utilities metric.[3, 11, 14, & 15] The reference line in Figure 4 represents benchmark performance across the spectrum from fuels to maximum petrochemicals for an Arabian Light crude utilizing a higher efficiency combined cycle gas turbine power plant. All the power requirements are provided by a natural gas-fueled turbine generator.

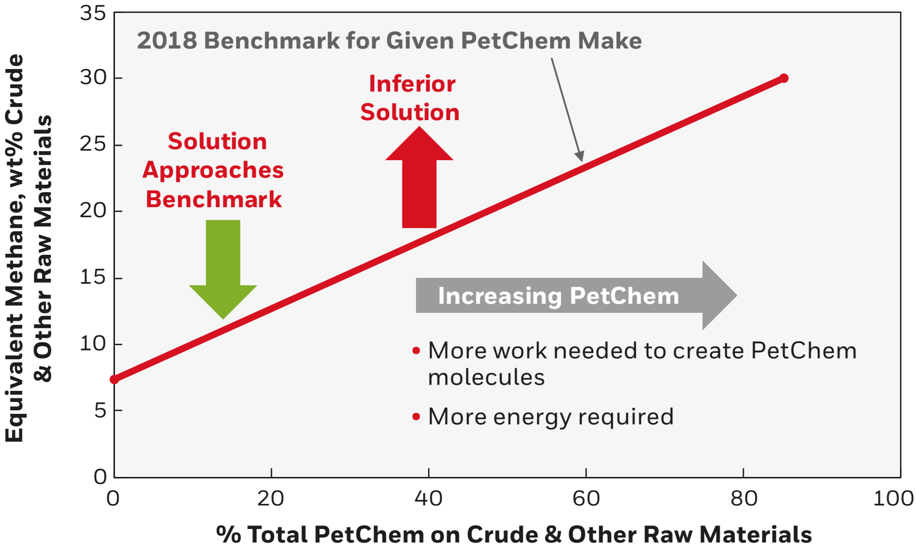


Figure 4: 2018 Utilities Metric Benchmark vs. % Total Petrochemicals on Feed for Arabian Light Crude [14 & 18]

Utilities efficiency measures how effectively the configuration has used energy/utility resources by comparing against benchmark performance. Utilities efficiency is calculated using Equation 3.[8 & 17]

$$\textit{Utilities Efficiency, \%} = 100 * \textit{Benchmark Configuration Utilities Metric} / \textit{Configuration Utilities Metric}$$

Equation 3

To minimize consumption of utilities, it is crucial to view the process unit utility requirements and the utility system design as a single integrated network. The total consumption of each utility establishes the total energy usage for the complex.

The total energy consumption is specific to the utility system and the fuel type under consideration. To simplify the quantification of utility consumption and enable comparison on a consistent basis, the energy utilization is converted to an equivalent methane requirement. When utilities are purchased, they also are converted to an equivalent methane requirement and included in the energy balance. In this way, the utilities efficiency considers the impact of different utility system designs. It accounts for utility supply systems such as purchased electricity, natural gas-fired fuel heater, turbine generator, conventional boiler and coal gasification.

The utilities metric does not consider the cost of utilities, this is considered by capital efficiency. For example, expensive natural gas may drive a project to consider coal gasification as a means of generating fuel gas and hydrogen. This will reduce operating cost but will lower the utilities efficiency.

A well-designed complex with an efficient utility system should be able to achieve benchmark performance regardless of objectives.

EMISSIONS EFFICIENCY

Emissions efficiency measures GHG emissions and the goal is to minimize the carbon dioxide (CO_2) footprint.

Production of fuels and/or petrochemicals is an energy intensive process resulting in GHG emissions to the atmosphere. Today, GHG emissions are being viewed with greater focus, so the objective of the E6 model is to minimize GHG emissions. CO_2 is the predominant contributor to the GHG emissions from a complex. The E6 model accounts for the major sources of CO_2 including combustion emissions and production of CO_2 as a reaction by-product.

The amount of CO_2 emitted from a complex is quantified by the emissions metric.[4, 11, 14 & 16] The reference line in Figure 5 is based on Arabian Light crude and was created to represent benchmark performance across the range of fuels to maximum petrochemicals.

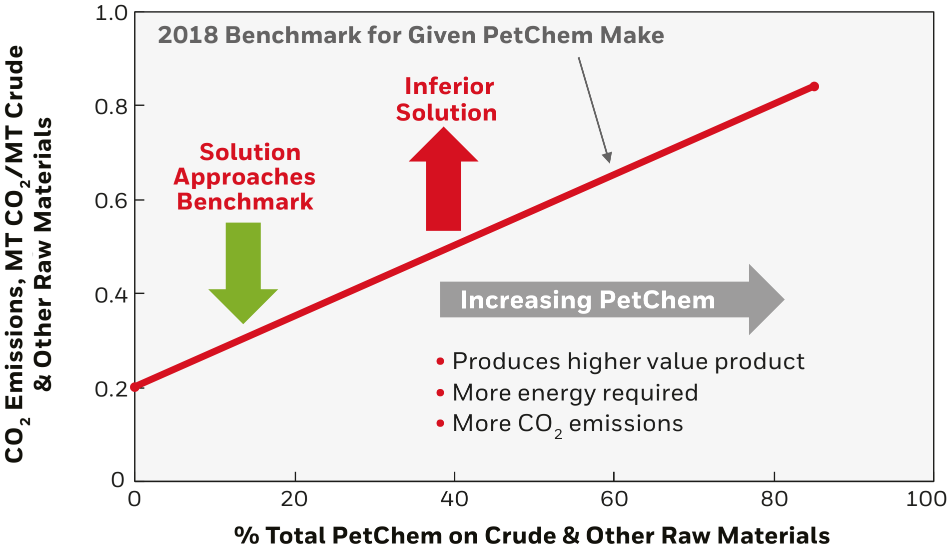


Figure 5: 2018 Emissions Metric Benchmark vs. % Total Petrochemicals on Feed for Arabian Light Crude[14 & 18]

Emissions efficiency measures how well the configuration has minimized CO_2 emissions by comparing against benchmark performance. Emissions efficiency is determined in the same way as utilities efficiency.[9 & 17]

Similar to the utilities efficiency, the emissions efficiency accounts for the impact of fuel selection, crude quality, complexity of the complex and level of petrochemical production. The selection of fuel for the utility system is critical. For example, lower heating value coal will decrease emissions efficiency. This is due to an increase in emissions relative to the benchmark which reflects the use of natural gas.

Emissions efficiency is directly related to utilities efficiency, hence driving to maximum utilities efficiency will improve emissions efficiency.

WATER EFFICIENCY

Water is a scare resource in many locations around the world. The E6 methodology values minimum water use and aspires to zero discharge.

Water has most often been treated as a utility in the design and operation of industrial plants. However, social, civil, agricultural and industrial users all compete for access to water. Uneven distribution of water resources, pollution and growing human demand are resulting in stressed freshwater availability around the world. As such, water usage has earned its own distinction, separate from the utilities category.

To minimize the impact on fresh water systems, many new projects are treating water as a scarce resource. Production of fuels and/or petrochemicals requires a significant amount of water. For example, heat addition by steam, heat removal via cooling water and hydrogen generation are some of the primary water uses.

Daily water makeup from fresh water sources is much less than actual usage and is based on the losses from the major water users, such as evaporative/blowdown losses from cooling towers and blowdown losses from steam generation. Crude quality, crude capacity and processing intensity also are factors contributing to daily water consumption. Therefore, the objective is to use water sustainably and to minimize fresh water makeup.

The amount of water consumed by a complex is quantified by the water metric for the configuration.[5, 11 & 14] The reference line in Figure 6 represents typical performance across the range, from fuels to maximum petrochemicals, for an Arabian Light crude.

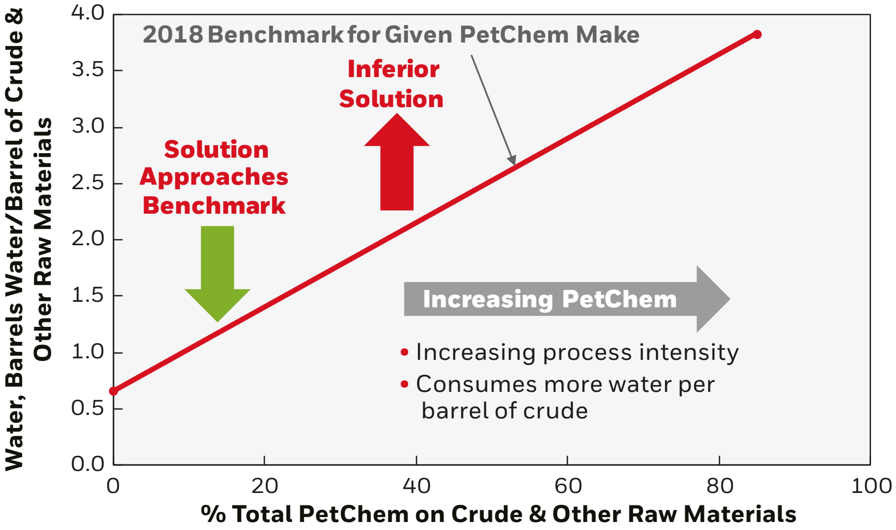


Figure 6: 2018 Water Metric Benchmark vs. % Total Petrochemicals on Feed for Arabian Light Crude [14 & 18]

Water efficiency measures how well the configuration has minimized the use of the primary water source by comparing against typical performance. Water efficiency is determined in the same way as the utilities and emissions efficiencies. [10 & 17]

Increasing petrochemical production increases the number of processing units, processing complexity and processing intensity. This in turn, increases the cooling water and steam demand. Hence, the associated increase in fresh water makeup.

The benchmark line is based on utilization of a standard evaporative circulating cooling water system. This is the typical type of cooling water system used in the industry today. Adopting strategies that conserve water will reduce fresh water makeup and result in best-in-class performance, but they will incur additional capital expense. The use of air-cooled exchangers as opposed to cooling water exchangers or a closed circulating cooling water system using sea water are possible solutions for minimizing water loss. Additional capital may be justified where water resources are strained or if there is an expectation that they will be under pressure in the future.

As with carbon, utilities and emissions, the E6 methodology adjusts to establish the water metric benchmark specific to crude quality, configuration complexity and the level of petrochemicals being produced.

CAPITAL EFFICIENCY

The sixth efficiency is capital. This rating measures how effectively capital is deployed on a project. Carbon, hydrogen, utilities, emissions, and water — as a scarce resource, are all balanced against capital efficiency.

These six efficiencies are not all optimized at the same point. They provide tension in any project, from which a refiner can balance enterprise-level business objectives with a complex's operational goals, market demands, regulatory restrictions and other factors. In the end, a refiner must have a bankable growth strategy to ensure a sustainable business plan that realizes their vision. Capital efficiency is the most critical of the six efficiencies as it directly relates to the quality of the investment being considered.

While many refiners will say they want to be world-class in the previous five efficiencies, they may not be willing to pay for that performance. To secure capital investment, a project must be profitable and generate a high enough return on capital to be attractive to investors. Every project has a unique set of objectives, but the six categories evaluated by the E6 model are generally the drivers that are common across all projects. Ultimately, the six efficiencies are used to balance the refiner's operational goals with market demand, regulatory restrictions and other factors, with the goal of deploying capital as efficiently as possible to ensure a maximum return on investment.

The internal rate of return (IRR) is the metric used to measure the effectiveness of this efficiency. Each of the previous five efficiencies are essential factors for driving the IRR. If an efficiency is lacking, there may be potential opportunities for improvement. Driving an increase in one of the previous five efficiencies may improve or reduce the IRR. Understanding the trade-offs helps a refiner understand and balance the impact of the many individual objectives to enable better project decisions.

Within the E6 model, the IRR is developed based upon a standardized set of economic inputs. It is determined from a standard market-based price set and capital cost framework. Additionally, this approach is applied regionally. A standardized IRR will differ from actual project economics, but it enables comparison of configuration design effectiveness for different projects across different regions on a common basis. The E6 model benchmarks technology-based performance independent of project specific execution models and regional variable cost components. As a project moves towards a final investment decision, capital efficiency is used as a benchmark component in differential analysis to regional profitability, to help a refiner better understand and manage its competitive position in the market.

The E6 model is used to achieve the required project objectives as efficiently and profitably as possible, to help a refiner develop the most bankable projects and achieve sustained competitiveness into the future.

HOW TO USE THE E6 MODEL TO DRIVE EFFICIENCY IMPROVEMENTS AND OPTIMIZED ECONOMICS

> Developing an optimal solution during the early phases of a project is essential to sustaining profitability over the operational life of the project.

Using the E6 framework to compare concepts against best-in-class benchmarks enables objective evaluation of the optimality of various configuration options. Identifying the right scope in early project development is critical for a successful project as it prevents costly rework and delays in later stages. An optimal configuration that aligns with business drivers improves the likelihood that the project will remain competitive over its life cycle.

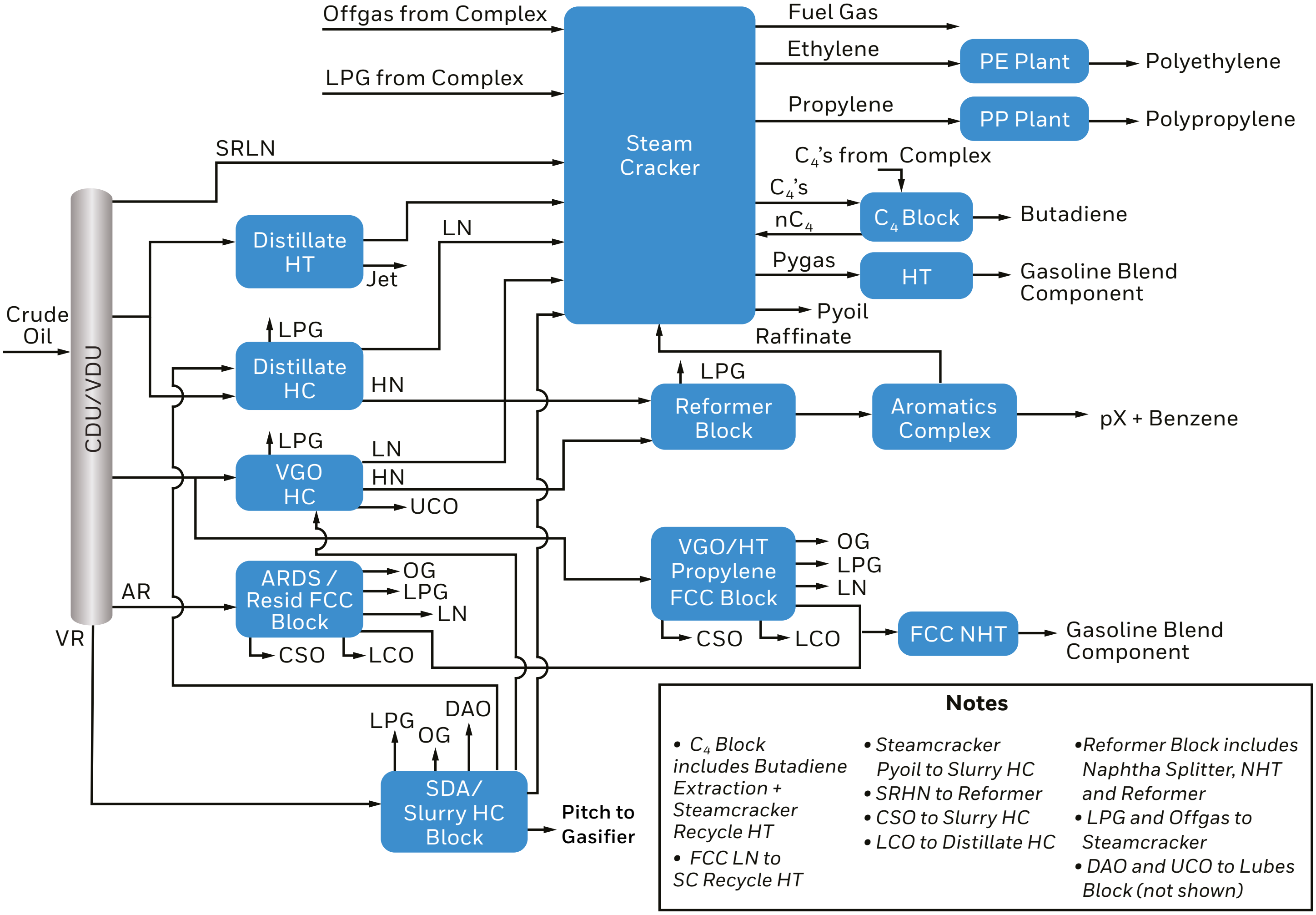
This section includes an active commercial project example where the E6 framework was applied to identify a solution that delivered an improved economic outcome compared to the customer's original configuration. The customer's original configuration offered a valid technical and economic solution, but it was not optimal. The E6 model was applied to analyze the complex configuration. This analysis considered the application of technologies and how the hydrocarbon streams were routed; i.e., how molecule management was applied within and around each technology block.

A linear program (LP) model was used to match the base case configuration material balance and to analyze potential improvements. It also provided the output necessary to establish the performance in terms of the E6 framework.

COMMERCIAL EXAMPLE

This commercial example is based on a 20,000 kMTA (410,000 BPD) grass roots complex producing both transportation fuels and petrochemicals, primarily to meet growing domestic demand for petrochemicals in the country of construction. The objective of the complex is to profitably maximize olefins and minimize transport fuels from a 50:50 mix of Arabian Light and Kuwaiti crudes. In addition, para-xylene (pX) production was limited to a defined maximum of 3,000 kMTA. The configuration shown in Figure 7 presents the customer's original minimum fuels-focused configuration.

Petrochemicals production from the original design was significant at 60 wt.% on crude and other raw materials. Transportation fuels production was low at 21 wt.% crude and other raw materials. This configuration delivered an IRR of 24.0% and net present value (NPV) of 32,300 $MM. The customer asked UOP if it was possible to (1) increase the profitably of the base configuration and (2) simultaneously increase the production of petrochemicals from this deeply integrated configuration. The E6 model was used to answer this question.

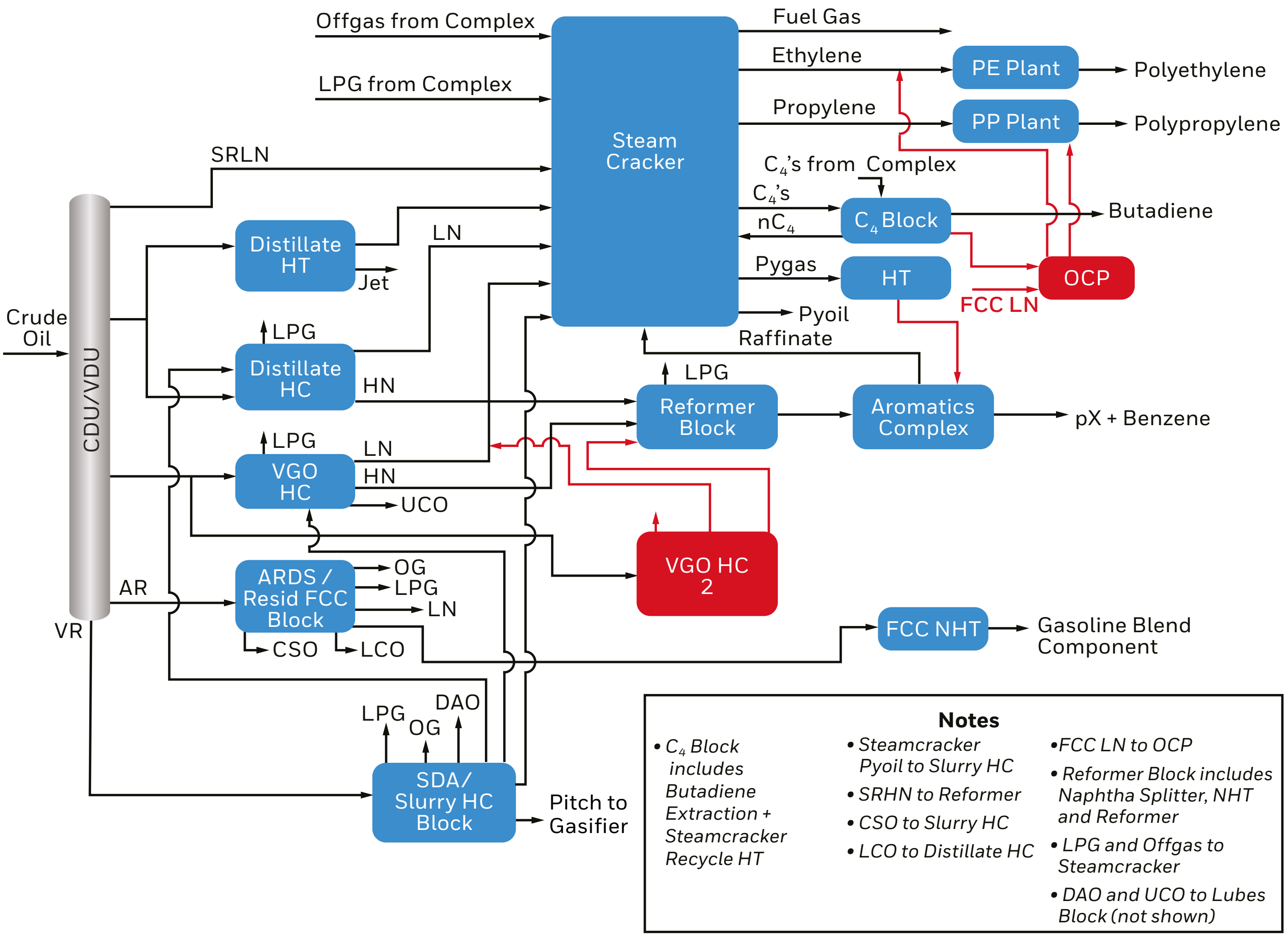


Notes

- C_4 Block includes Butadiene Extraction + Steamcracker Recycle HT
- FCC LN to SC Recycle HT
- Steamcracker Pyoil to Slurry HC
- SRHN to Reformer
- CSO to Slurry HC
- LCO to Distillate HC
- Reformer Block includes Naphtha Splitter, NHT and Reformer
- LPG and Offgas to Steamcracker
- DAO and UCO to Lubes Block (not shown)

Figure 7: Customer Configuration

Several improvements were made to the base configuration. Refer to Figure 8 for the final optimized configuration.



Notes

- *C_4 Block includes Butadiene Extraction + Steamcracker Recycle HT*
- *Steamcracker Pyoil to Slurry HC*
- *SRHN to Reformer*
- *CSO to Slurry HC*
- *LCO to Distillate HC*
- *FCC LN to OCP*
- *Reformer Block includes Naphtha Splitter, NHT and Reformer*
- *LPG and Offgas to Steamcracker*
- *DAO and UCO to Lubes Block (not shown)*

Figure 8: Optimized Configuration

These updates are strategies that demonstrate examples of the effective molecular management practices needed to develop an optimized configuration:

– **Routed steam cracker pyrolysis gasoline to the aromatics complex.** This change leveraged synergies between the steam cracker and the aromatics complex. Gasoline production was reduced, pX production was maintained and naphtha was backed out of the reformer. This naphtha was redirected to the steam cracker to increase olefin production. Putting the right molecules in the right processes.

– **Added a VGO hydrocracker and eliminated the VGO hydrotreater and high propylene fluidized catalytic cracking unit (FCC).** This improvement decreased FCC coke production by 31% and made additional material available for olefins production. Capital cost and complexity were also reduced in this step.

– **Routed C_4/C_5 olefins from the steam cracker and remaining FCC to the Olefins Cracking Process (OCP) for light olefins production.** These C_4/C_5 streams would otherwise be hydrotreated, saturated and recycled back to the steam cracker. Don't unnecessarily add hydrogen in one unit, only to remove it in another. Naphtha was used to backfill the steam cracker capacity freed by rerouting the C_4/C_5 olefins to the OCP, maintaining production of olefins from the steam cracker. Additional net olefins were produced from the OCP, which is more efficient at converting the C_4 and C_5 olefins to propylene and ethylene. Deeper integration into petrochemicals inherently results in the production of more fuel gas. In this case, improved steam cracker feed and more selective conversion in the OCP minimized the increase in fuel gas production.

The proposed configuration enabled a petrochemicals production increase from 60 to 68 wt.% while fuels production decreased from 21 to 13 wt.% on crude and other raw materials. The following section breaks this down in the E6 framework: carbon, hydrogen, utilities, emissions, water — as a scarce resource, and capital.

CARBON EFFICIENCY

The carbon efficiency of the base case configuration was 85.8%, indicating that the customer configuration was sub-optimal in relation to the crude slate and processing objectives.
See Table 1.

	Carbon Efficiency, %	Hydrogen Efficiency, %	Utilities Efficiency, %	Emissions Efficiency, %	Water Efficiency, %	Capital Efficiency (as IRR, %)
Customer Configuration	85.8	94.7	56.7	40.0	68.5	24.0
Optimized Configuration	86.5	96.0	57.4	40.4	69.8	25.8
Efficiency Delta	+0.7	+1.3	+0.7	+0.4	+1.3	+1.8

Table 1: E6 Results — Customer Configuration vs. Optimized Configuration

The customer configuration included two FCC units that rejected carbon in the form of coke. Suboptimal routing of streams also contributed to a lower carbon efficiency. The strategies employed to optimize the configuration addressed these two issues and improved the carbon efficiency despite the downward pressure associated with increased petrochemicals. Carbon efficiency increased from 85.8 to 86.5%.

Removing the constraints specified by the customer would enable additional integration and molecule management opportunities between the steam cracker and aromatics complex, resulting in an additional carbon efficiency improvement. Furthermore, removal of the remaining FCC unit would also contribute to a carbon efficiency improvement. These changes would require a redesign of the configuration and reevaluation under the E6 framework.

HYDROGEN EFFICIENCY

The hydrogen efficiency of the customer configuration was 94.7%. This high efficiency resulted from deep integration into petrochemicals where a substantial amount of hydrogen was available from the stream cracking and high severity reforming operations. This offset the hydrogen requirement and minimized hydrogen plant capacity.

The additional hydrogen required by the new VGO hydrocracker was offset by removal of the VGO hydrotreater, decreasing the naphtha hydrotreater capacity, reducing the steam cracker recycle hydrotreater and increasing hydrogen production from the steam cracker.

Hydrogen efficiency was further improved by eliminating the high propylene FCC. Eliminating the excessive severity FCC operation reduced the hydrogen lost to coke and dry gas. Instead, it was converted into additional petrochemicals via the steam cracker and OCP units.

This led to a minimal increase in hydrogen plant capacity, but better integrated efficiency. Hydrogen efficiency increased with the new configuration from 94.7 to 96.0%.

UTILITIES EFFICIENCY

The project is based upon utilization of coal as a fuel source since it is a cheap and abundant resource local to the project site. Coal gasification was used to generate hydrogen and fuel gas for utilities. This approach resulted in a utilities efficiency of 56.7% for the customer configuration. For the optimized case, additional energy was required to raise petrochemical production from 60 to 68 wt.% on crude and other raw materials.

The utilities efficiency increased from 56.7 to 57.4% indicating that the optimization strategies enabled more efficient energy utilization. In other words, energy usage grew at a lower rate than the benchmark for the same 8 wt.% petrochemical increase.

Additional improvements in utility efficiency are technically viable, but these improvements must be balanced with capital efficiency.

EMISSIONS EFFICIENCY

CO_2 emissions trend with the consumption of utilities/energy and were heavily influenced by the selection of coal as a fuel. The high carbon content/low heating value of coal results in a low emissions efficiency of 40.0% for the customer configuration.

Deeper integration into petrochemicals results in more CO_2 emissions. The key is to minimize increases in energy consumption as the level of petrochemicals production rises. For the optimized case, additional energy was required to increase petrochemical production, and this increased CO_2 emissions. However, as energy was used more efficiently, the emissions efficiency improved from 40.0 to 40.4%.

WATER EFFICIENCY

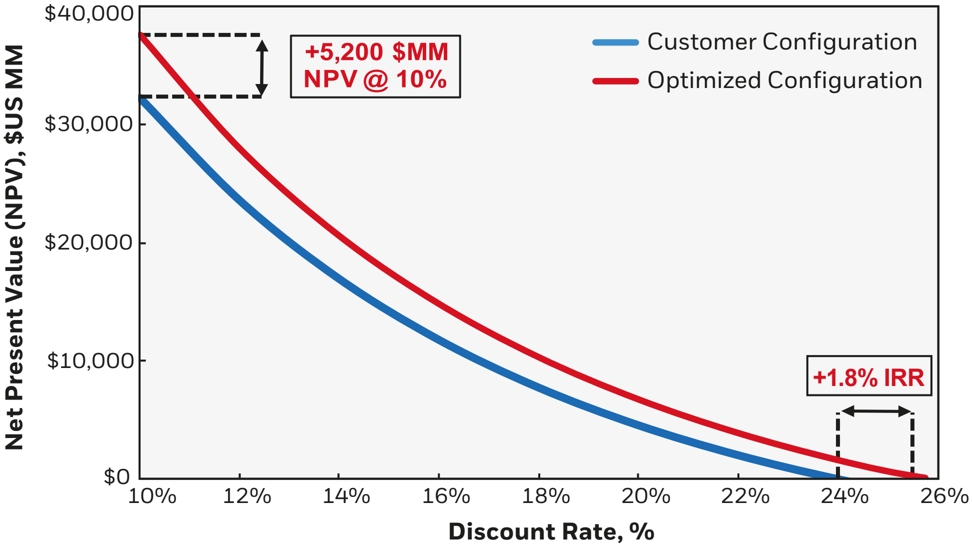
Similar to utilities and emissions, the water efficiency improved even though petrochemical production increased. Water conservation was not a customer objective of this early stage evaluation, therefore options to minimize fresh water consumption and improve water efficiency have not yet been explored. However, two substantial improvements are listed below:

- Elimination of the high severity FCC unit removed the need to generate steam for use in the reactor, and to drive the main air blower and wet gas compressor steam turbines. This reduced the complex boiler feed water consumption by 3,520 kMTA. In turn, blowdown water losses from the boiler feed water system dropped by 180 kMTA.
- Removal of the FCC fractionation section reduced cooling water load by 1,340 million m^3/year, resulting in a reduction in blowdown/evaporative cooling losses of 27 million m^3/year.

Removal of this excessive water consumer enabled water to be used more efficiently elsewhere in the complex. Specifically, it was used for the additional cooling water and steam required to produce additional petrochemicals from the increased capacity steam cracker and aromatics complex.

CAPITAL EFFICIENCY

Increasing production of petrochemicals at better efficiencies has strengthened the profitability of the project. The modifications result in a minimal 1% capital cost increase, while net cash margin grew by 6 $/BBL or 890 $MM/year. The IRR increases from 24.0 to 25.8% and NPV grew by 5,200 $MM. See Figure 9 and Table 2.



	Customer Configuration	Optimized Configuration
Products, kMTA		
Benzene	736	1,547
pX	3,000	3,000
Total Olefins & Derivatives	8,187	9,040
Naphtha & Gasoline	2,839	1,609
Jet	1,035	1,035
Lubes	917	917
Economic Performance		
Net Cash Margin (NCM), $MM/year	9,060	9,950
Net Cash Margin (NCM), $MM/BBL	63.1	69.3
Net Present Value (NPV), $MM (10% discount rate; 20-year term)	32,300	37,500
Internal rate of Return (IRR), %	24.0	25.8

Table 2: Summary of Results — Production Profile & Economic Performance

CONCLUSION

> **The UOP E6 is a future-forward, decision-making framework and methodology that provides a data-driven approach to more profitable performance and growth.**

It is a tool that helps focus and simplify investment analysis. The framework helps balance operational goals, market demand, and regulatory constraints. The methodology shows how a new or existing facility compares to the latest technology benchmark for each of the constrained resources. The E6 methodology helps facilitate alignment amongst a refiner's needs, wants and budget to help develop a strategy to improve the performance of new or existing assets.

The UOP E6 — better decisions for a better future.

LEARN MORE ABOUT THE REFINERY OF THE FUTURE AND UOP E6 AT
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NOTES

1. Optimization of configurations was performed utilizing Aspen PIMS Linear Programing (LP) planning software.
2. Configuration Carbon Metric, % = 100 * Carbon in High-Value Products / Carbon in the Feed.
3. Configuration Utilities Metric = 100* Metric Tons of Equivalent Methane Consumed / Metric Ton of Feed.
4. Configuration Emissions Metric = Metric Tons of CO_2 Emissions / Metric Ton of Feed.
5. Configuration Water Metric = Barrels of Water Consumed / Barrel of Feed.
6. Carbon Efficiency, % = 100 * Configuration Carbon Metric / Benchmark Configuration Carbon Metric.
7. Hydrogen Efficiency, % = 100 * Hydrogen in Saleable Products / (Hydrogen in the Feed + Hydrogen from Hydrogen Plant).
8. Utilities Efficiency, % = 100 * Benchmark Configuration Utilities Metric / Configuration Utilities Metric.
9. Emissions Efficiency, % = 100 * Benchmark Configuration Emissions Metric / Configuration Emissions Metric.
10. Water Efficiency, % = 100 * Benchmark Configuration Water Metric / Configuration Water Metric.
11. The inputs to the configuration formulae in notes 2 through 5 and note 7 are obtained from the output of the LP model.
12. High-Value products do not include materials that are combusted within the complex for energy (e.g. FCC coke or fuel gas) and they do not include low-value by-products such as coke from the delayed coking unit.
13. Saleable products do not include materials that are combusted within the complex for energy (e.g. FCC coke or fuel gas).
14. The feed to the complex includes crude oil plus any other raw materials converted to products (e.g. methanol, VGO, etc.), but excludes any raw materials combusted as a fuel (e.g. purchased natural gas, crude oil used as fuel, etc.).
15. The utility requirements for each individual unit are combined into a total requirement for each utility (net usage of electrical power, steam, fuel gas, etc.). Each total utility consumption is converted to an equivalent methane requirement. This conversion step is included in the LP model scope and the amount of equivalent methane consumption is provided as an output.
16. CO_2 emissions include process releases (e.g. hydrogen plant by-product) and combustion emissions. Combustion emissions are determined from the total utility needs converted to an equivalent methane consumption requirement (see note 15).
17. Since this category is one where minimization of the configuration metric is desirable, dividing the benchmark value by the configuration value, yields a result that increases with improved efficiency.
18. %Total petrochemicals include all of the olefins and aromatics produced by the complex.

For More Information

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