TRANSFORMATIVE NAPHTHA TO ETHANE AND PROPANE PROCESS

Achieving the efficiency of ethane crackers, reducing by-products, and lowering CO_2 emissions

Honeywell
UOP

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INTRODUCTION

With an inventive new Naphtha to Ethane and Propane process (NEP), Honeywell UOP has transformed ethylene production to help producers meet challenging market conditions and outperform competitors.

NEP enables producers in regions where ethane and propane are scarce, to efficiently compete in the light olefins markets.

NEP helps create the lowest risk, lowest cost, and higher value compared to mixed-feed and naphtha crackers.

A transformational solution, NEP technology enables all regions in the world to realize the efficiency of ethane crackers, significantly reduce by-products, and lower their CO_2 emissions.

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THE GLOBAL PETROCHEMICAL INDUSTRY 1

GLOBAL DEMAND

> **Petrochemical products are everywhere in our modern society.**

Among many uses, they enable clean water, the clothes we wear, lighter-weight automobiles, and construction materials for the homes we live in and the furniture we use. They are broadly used across the medical industry and provide food packaging to reduce spoilage and enable food to be shipped around the world.

The demand for plastics has nearly doubled since 2000. Even though the industry has enjoyed record margins post-pandemic, the petrochemical industry faces several challenges. These include inflation, feedstock security and escalation in costs, geopolitical risks, competitiveness, sustainability, and access to the funding required to develop projects.

INCREASING DEMAND FOR ETHYLENE

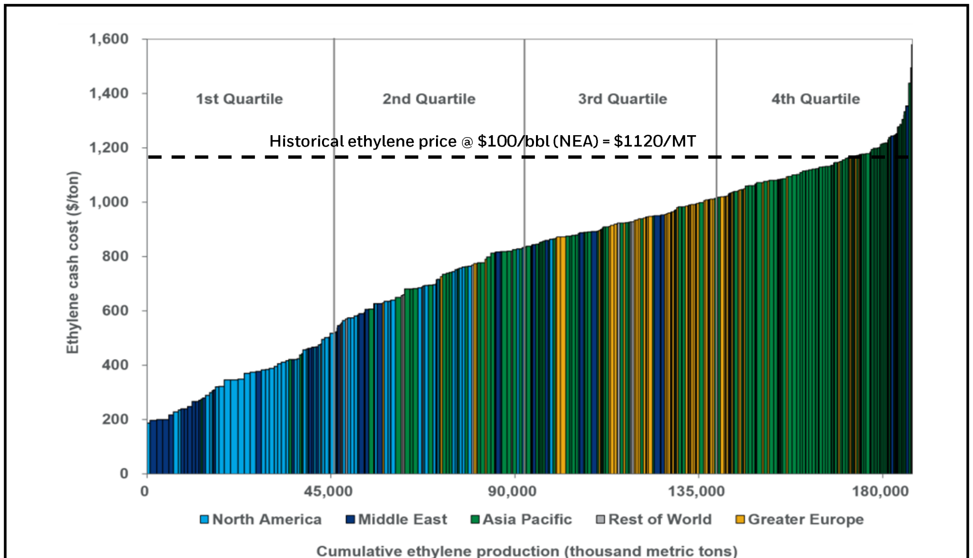
An additional challenge is the increasing demand for ethylene, an essential building block to produce many resins and plastics. Over 185 million tonnes of ethylene were produced in 2023. It is the largest tonnage of any petrochemical market. Over the period of 2023–2030, the ethylene market is forecasted to grow at a 4% CAGR (Compound Annual Growth Rate). To meet this growing global demand in a world increasingly focused on environmental concerns, we must meet that demand more efficiently, and do more with less.

A Steam Cracker is the primary process technology through which most of the world's ethylene is produced. Steam crackers operate at extremely high temperatures, upwards of 850ºC, and consume more than 1.0 wt% of steam. In this severe environment, hydrocarbons are cracked and dehydrogenated to the target molecule, ethylene.

COST OF PRODUCING ETHYLENE

The cost to produce ethylene varies globally. Production units that rely on ethane feedstock (gas crackers) are much more cost-efficient than those that rely on liquid feedstocks (liquid crackers). Gas crackers deliver a higher yield of ethylene per tonne of feed and per dollar invested. Gas crackers also have a lower CO_2 footprint per tonne of ethylene produced. These are very important considerations when trying to secure the cash to develop a project.

The chart below shows a cash cost-to-production curve for ethylene in 2023. Every ethylene production unit in the world is represented by a vertical bar. The height of the bar represents the cash cost of production for each asset, while the width of the bar represents the production tonnage. Each of the bars is color coded by global geographic region. The high-cost, less competitive producers are on the right side of the chart and are generally in Asia Pacific and Europe. Those producers predominantly rely on imported liquid feedstocks such as naphtha, which carry a higher cost per tonne of feed and deliver inferior results to ethane. In addition, liquid crackers are much more expensive to build per tonne of ethylene produced.



Source: WoodMac

The left side of the chart shows low-cost, more competitive producers, generally located in North America and the Middle East. Those producers use gas cracking units which are predominantly fed ethane, which has a much higher yield to ethylene and is more cheaply available in those regions. Gas crackers also require a much lower capital expenditure per tonne of ethylene produced and are, in total, much more profitable than the liquid crackers on the right.

Producers in parts of the world that do not have ethane available in region, have traditionally had only two choices: 1) rely on imported liquid feeds and accept the higher cost of production and lower yields, or 2) import ethane from the U.S. Gulf Coast, or the Middle East.

Though a valuable comparison, this snapshot of the current global situation is not expected to stand.

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VOLATILITY IN THE SUPPLY AND PRICE OF ETHANE

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It is important to note that one does not drill an ethane well. Ethane is the coproduct of oil and gas extraction.

Before 2010, the cost of ethane and naphtha was close to parity in North America. The large developments in U.S. shale gas production brought forth a surge in Natural Gas Liquids (NGLs) and condensate production. As supply exceeded demand there was a rapid decline in the price of ethane, which has since traded at a discount to naphtha in North America. With limited demand, much of the ethane was "rejected," or left in the natural gas stream and sold for its fuel value, rather than being extracted and sold for a higher petrochemical feedstock value.

By 2020, 26 countries used ethane as a feedstock for ethylene production.[1] However, as global demand grew, and regional ethane production declined due to aging wells. the U.S. found new ethane markets, primarily in Europe, India, and China. Each of these markets includes investments for the importation of ethane, most of which are planned to be sourced from the U.S.

Investments in merchant ethane are expensive. It requires specially designed and dedicated ships. The quantity of ethane required to feed a single 2,000 kMTA gas cracker would require 10 world-scale ships, terminals, and infrastructure costing close to $2.5 billion U.S. dollars. With much of the shipping fleet converting to lower CI (Carbon Intensity) fuels such as methanol, ammonia, and LNG, many shipyards are backlogged. Efficiently securing a 10-ship fleet with near simultaneous delivery carries a lot of risk.

Investing in a dedicated supply chain to enable the importation of ethane also carries a lot of risk exposure to the LNG markets. LNG markets routinely cycle between boom and bust. The conflict between Russia and Ukraine drove extremely high gas prices in Europe, followed by a flood of LNG projects in major gas producing countries around the world. This swing in LNG markets is poised to cause the pendulum to swing back the other way. Many LNG traders see this as imminent and are managing the risk through shorter LNG supply contracts and driving volatility in the ethane market.

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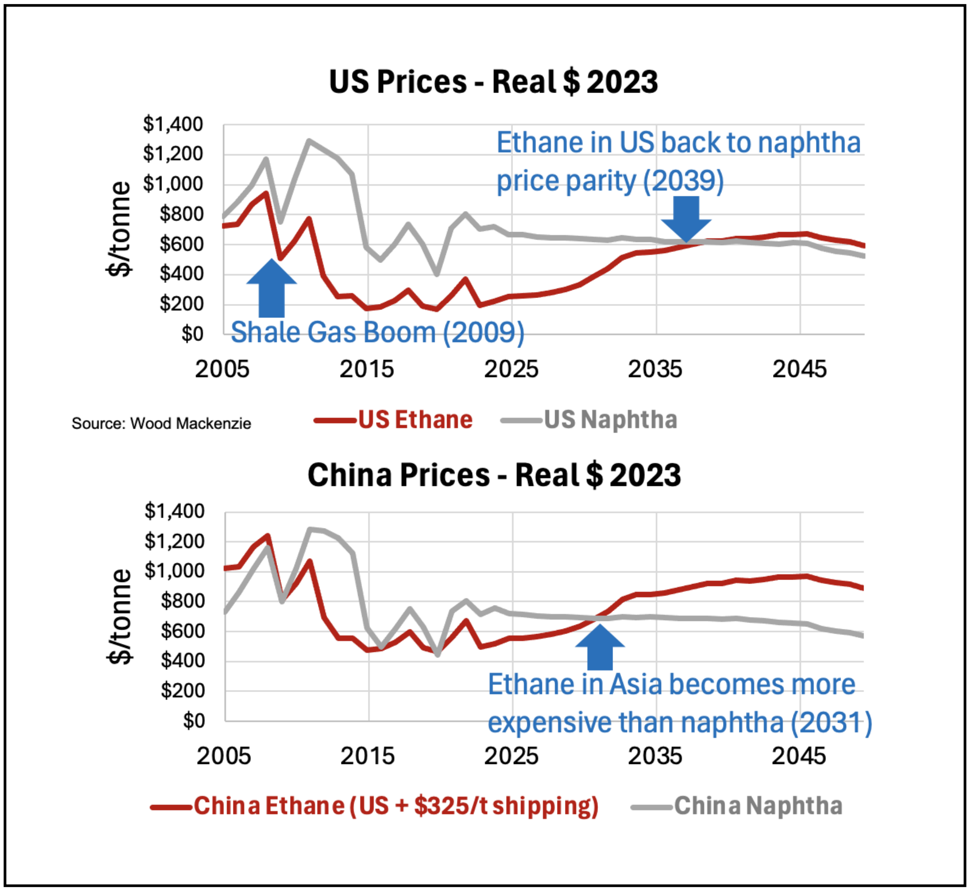
RISING PRICE OF ETHANE

Amidst increased volatility in the ethane market, the overabundance of cheap North American ethane is expected to come to an end due to increasing domestic consumption, increasing exports, and rising production costs. The price of ethane is predicted to rapidly increase over the next five to fifteen years, essentially tripling in the next 5-7 years.

As supply comes more into balance with demand, we will see an increase in ethane costs over the next five to ten years to the point that ethane and naphtha will again return to parity as they were about 20 years ago. If these forecasts are accurate, this will put tremendous pressure on the cost of production for customers that are dependent on importing their ethane from the U.S., which is a significant business risk for those firms.



FUTURE GROWTH OF ETHYLENE PRODUCTION

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GROWTH AND DISADVANTAGES OF C2C COMPLEXES

> **Most consultancies are predicting the future growth in ethylene production will come from crude-to-chemicals (C2C) complexes in which mixed-feed crackers are integrated with oil refineries.**

This perception acknowledges that there is a fundamental dislocation between where ethane exists and where ethylene will be consumed. China, India, and Southeast Asia are fundamental growth areas for ethylene. The Middle East and other National Oil Companies (NOCs) throughout Asia are driven to develop beyond a crude-based economy with large investments in petrochemicals. All these areas are driving regional development with the feedstock that they either already own, or which has the greatest availability and lowest supply risk, crude oil.

Advancements in C2C really started to take off due to para-Xylene (pX) growth—think beverage bottles and performance clothing manufactured from textured polyester yarns—a key component in the production of polyester. Amidst growing demand for polyester, Korea led a build-out of pX complexes between 2011 and 2014 that exhausted the world's supply of merchant heavy naphtha. Facing a lack of feedstock to support polyester demand growth, China drove the growth in C2C projects with a focus on the production of pX.

C2C has slowed in recent years with a significant over-build in pX production, particularly in China. That said, growth in ethylene demand is outpacing pX production by a factor of 4-to-1. Given the supply chain risk, infrastructure costs, geopolitical risks, and national policies associated with investing in what is effectively a single-source merchant ethane market, many high-growth regions are shifting their perception of C2C away from pX and towards light olefins. Ethylene is essentially the new pX. However, this has effectively relegated project developers to higher cost, less efficient, more carbon intensive liquid crackers.

DEMAND FOR SUSTAINABILITY IS IMPACTING ETHYLENE PRODUCTION

Steam crackers, the workhorses for ethylene production, are the largest emitters of CO_2 in the chemical process industry due to their high operating temperatures (~850ºC). Their high-temp, high-steam process requires a lot of capital and energy. Additionally, the methane produced in the process carries a 20% higher CO_2 footprint over the burning of natural gas.

Secondary to ethylene, propylene is a valued byproduct of a steam cracker, as are pygas and pyoil. However, propylene is much more efficiently made in a propane dehydrogenation unit and delivers a 10X lower CO_2 footprint than a steam cracker.

Aromatics produced in steam cracker pygas are 7X higher than those from a reforming unit. Plus, with much of the shipping fleet converting to lower CI fuels such as methanol, hydrogen, ammonia, and LNG, there are increasing concerns in the long-term, off-take risk for pyoil into marine bunker fuel. The bottom line here is that steam crackers are not environmentally sustainable nor cost efficient.

DRIVING TO OPERATIONAL EXCELLENCE

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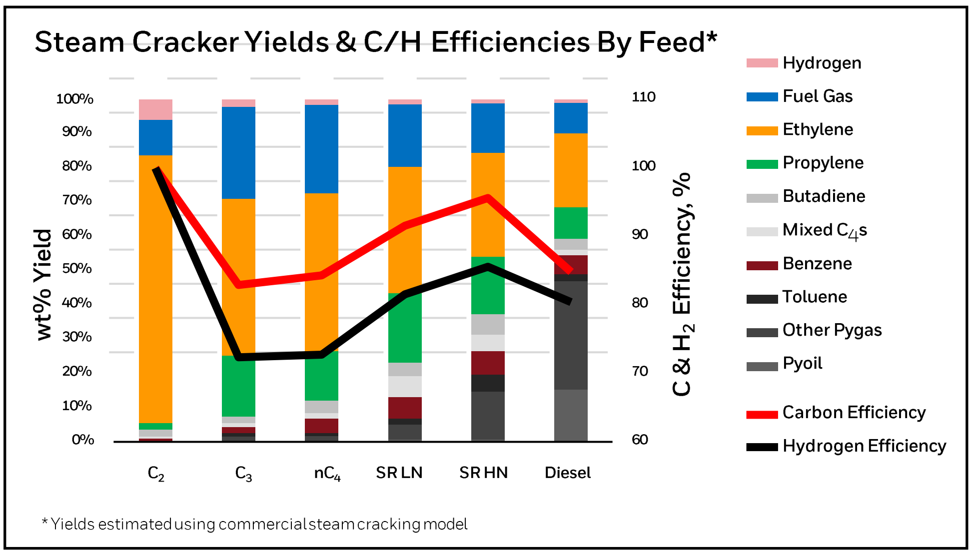
The challenges outlined above demand that producers double down on operational excellence.

And operational excellence begins with "molecule management", putting the right molecules in the right process unit to make the desired products with the least amount of CapEx, OpEx, and lowest carbon footprint.

EFFICIENT PRODUCTION OF ETHYLENE

About 96% of the world's ethylene is made through the process of steam cracking. While a variety of feedstocks can be processed into ethylene via steam cracking, each feedstock (as shown in the graph below) produces a variety of yields.



The most efficient production of ethylene in a steam cracker is achieved by using ethane feed. The first bar in the above chart shows that ethane (C_2H_6) delivers a superior ethylene yield versus any other feedstock. About 80% of the carbon in the ethane ends up being ethylene. That's a very high yield. The amount of fuel gas, or methane produced (shown in blue) is low, while the amount of hydrogen (shown in pink), a valuable co-product especially in regions like Asia, is very high.

Note that the amount of ethylene produced declines with heavier feedstocks; there's also a significant increase in the production of heavier byproducts, such as butadiene, mixed C_4s, aromatic byproducts like benzene and toluene, and pyoil.

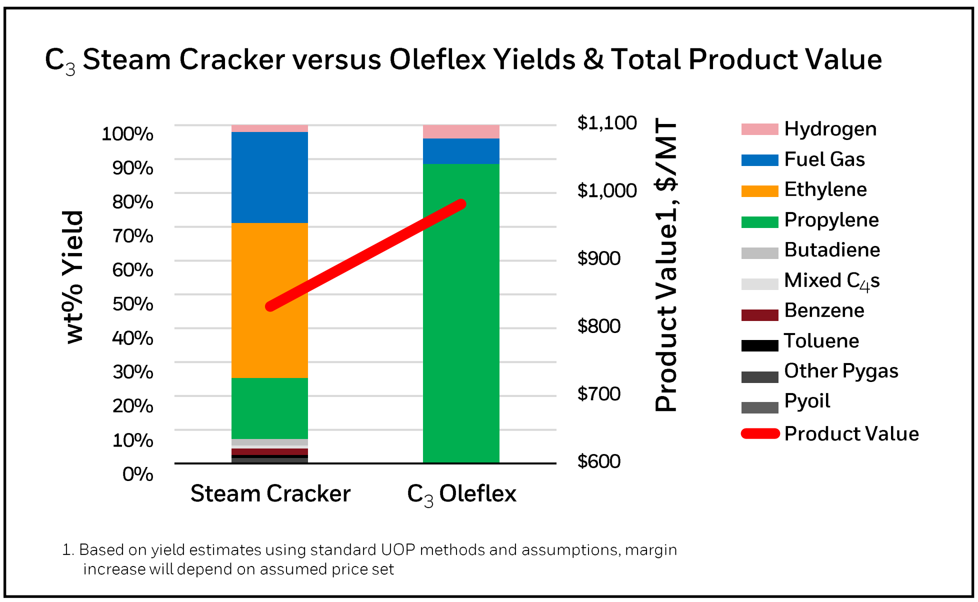
The most undesirable byproduct in the process is methane. Not only does methane decrease carbon efficiency, but for every carbon atom lost to methane, four valuable hydrogen atoms are lost along with it. The best way to eliminate carbon intensive methane from a steam cracker is not to make it in the first place.

It is also worth noting what happens when propane (C_3H_6) is introduced into the steam cracker (second bar from the left). The amount of ethylene produced decreases but production of propylene increases, which for many producers is desirable. However, propane to a steam cracker produces nearly 3X the amount of fuel gas compared to ethane. The amount of hydrogen produced is also lower, and you start to see a little uptick in the heavier byproducts.

Because operational excellence begins with putting the right molecules in the right process unit, the best option to make propylene is an on-purpose propane hydrogenation (PDH) unit, such as the Honeywell UOP Oleflex™ technology.

STEAM CRACKING VS UOP OLEFLEX™ TECHNOLOGY

This chart below compares C_3 Steam Cracker yield and production value to Oleflex Technology. The left bar in this chart again shows the yield breakdown using propane in a steam cracker. The right bar shows the yield breakdown when putting that same propane molecule into Oleflex.



In the Oleflex unit, nearly 90% of the propane becomes propylene. Also, there is a very low yield of fuel gas and a high yield of valuable hydrogen.

LIQUID CRACKERS VS STEAM CRACKERS

In addition to steam crackers, liquid crackers (predominantly in Asia and the EU) are used to produce both ethylene and propylene. Liquid crackers are expensive to build, use naphtha with a higher feed cost, and deliver inferior results. In North America and the Middle East, steam crackers are typically fed ethane (which today is inexpensive), delivering higher yields with lower CapEx and OpEx.

The most efficient feedstocks to produce light olefins are ethane to a steam cracker for ethylene, and propane to a PDH unit for propylene. To achieve sustainable operational excellence, producers will need to address volatilities in the supply and demand of feedstocks and use technology that allows them to spend less and do more. Petrochemical producers need an optimized, flexible, and more efficient way to produce on-purpose ethane and propane, and that is why Honeywell UOP developed the NEP (Naphtha to Ethane / Propane) process. NEP takes LPG or naphtha and converts it to ethane and propane.

THE ADVANTAGES OF NEP TECHNOLOGY

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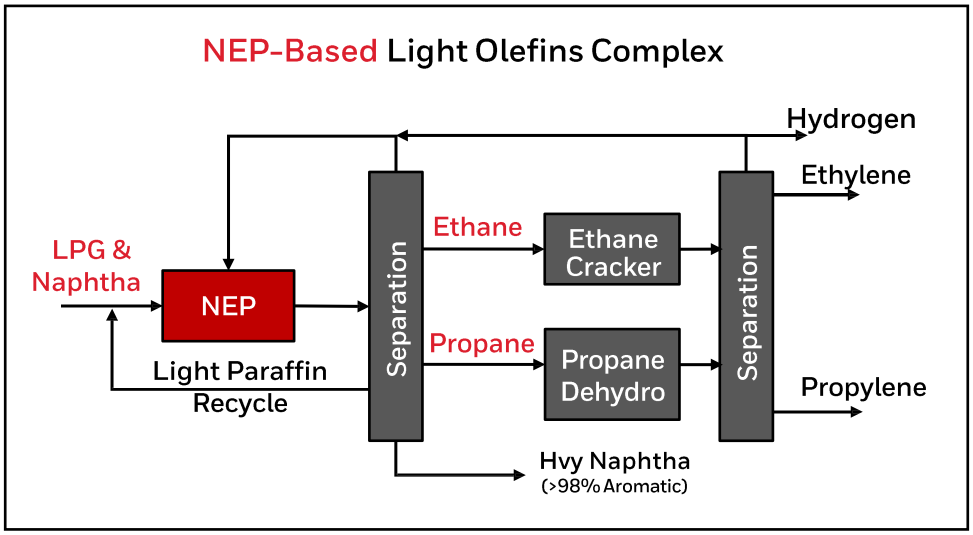
WHAT IS NEP?

Below is a flow chart that illustrates how LNG or naphtha can be processed through a naphtha to ethane / propane process in a light olefins complex:



The NEP process converts LPG and/or naphtha into ethane and propane. The ratio of ethane to propane is tunable, meaning one can choose to make a larger amount of ethane or a larger amount of propane, or even no propane at all, which eliminates the need for a PDH unit if propylene is not a desired product.

Excess hydrogen, light paraffins, and naphthenes from any unit in the C2C complex, or merchant feedstocks, can be fed to the NEP unit. While aromatics are not converted in NEP, they are acceptable in the feed. Their removal is simply an economic optimization between the cost of separation versus the hydraulic load in the unit.

NEP reduces the amount of feedstock required to make the target product. That lowers supply costs, energy usage, operating expenses—it reduces the size of everything involved in the project.

COMPARE NEP TO NAPHTHA CRACKING

Using the NEP unit, we can increase the yield of light olefins—ethylene and propylene—from about 50% in a naphtha cracker to over 70%. This means we are creating more of the target, high-value products from the same quantity of feed stock. Also, remember that the primary product from a steam cracker should be ethylene. With the low relative yield of ethylene from a mixed-feed steam cracker, the entire unit needs to be increased in size to produce the target tonnes of ethylene. In the example below, the MFSC is nearly double the size compared to that of the NEP based complex.

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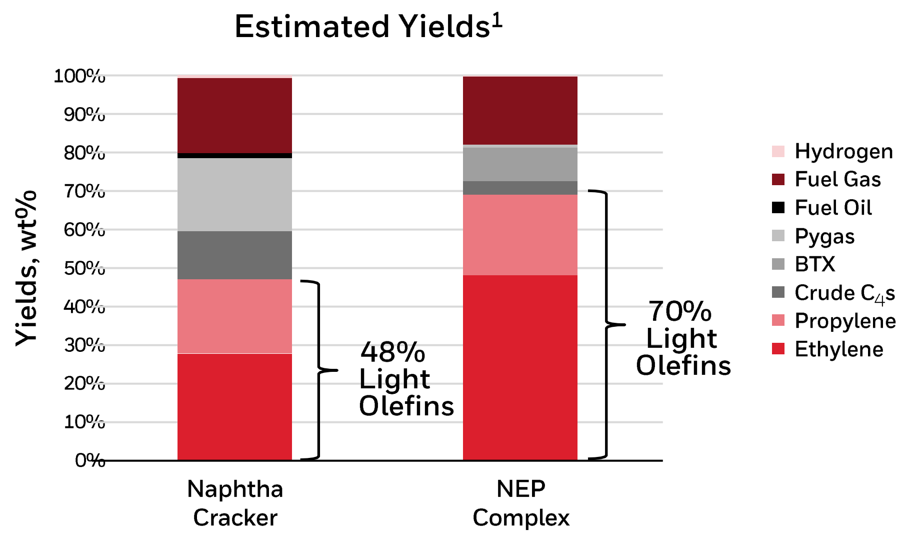


Both cases processing 3600 kMTA of HC LN
NEP complex tuned to E:P=2.4

1. Yields based on commercial steam cracking model for naphtha cracker and UOP proprietary models and commercial steam cracking model for NEP complex

LEVERAGE HIGH YIELD TO REDUCE COST

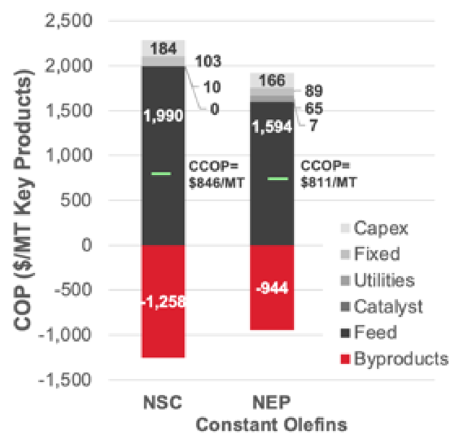
The comparison in the chart below shows how it is possible to leverage the high yield produced in the NEP unit by reducing the feed consumption and reducing feedstock purchases by up to 50%. Typically, because of the better feed utilization and reduction of lower-value byproducts, a producer can reduce the cash cost of production by about $30 to $70/metric tonne. This translates to an increase in operating profit of up to 35%, which makes the NEP-based olefins complex much more competitive and bankable.

	Naphtha Steam Cracker[1]	NEP[2] (Fixed Olefins)	NEP[2] (Fixed Feed)
Feed (MMTA)	4.3	3.4	4.3
Ethylene (MMTA)	1.50	1.50	1.87
Propylene (MMTA)	0.75	0.83	1.04
E:P Ratio (MT/MT)	2.0	1.8 (tunable)	1.8 (tunable)
Northeast Asia			
TPI ($M)	Base	-260	+27
COP ($/MT $C_{2=}$)	Base	-35	-41
IRR, 20 yr (%)	**Base**	**+3.0%**	**+5.0%**
NPV$_{12}$, 20 yr ($M)	Base	+390	+740

1. Based on commercial steam cracking model and published sources
2. Estimates based on UOP pilot plant information and proprietary UOP models

MMTA = Million Metric Tons per Annum
E:P = Ethane to Propane Ratio
TPI = Total Plant Investment
COP = Cost of Production

IRR = Internal Rate of Return
NPV = Net Present Value



Also, because the capital cost for an ethane (steam) cracker is about half that of a liquid or naphtha cracker, this reduces the overall capital investment and allows for the addition of an NEP unit and a PDH (propane dehydrogenation unit).

TUNABLE PRODUCTION

The NEP separation into ethane and propane is tunable from no propane production all the way to an ethane-propane ratio of 0.25 (4-to-1). The NEP process is also flexible in terms of feedstock as the yield pattern is not highly dependent on the carbon range (butane, hexane, naphtha, etc.). What's more, it is very tolerant to iso-paraffins, which can be problematic if fed to a traditional steam cracker. The negative impact that iso-paraffins have on steam cracker performance leave traditional C2C complexes limited to mid-70s level of conversion based on the economics of the MFSC. The iso-tolerant performance of NEP allows for feed conversion >95% in the C2C complex, enabling lower feedstock consumption per tonne of ethylene and ~80% conversion of crude oil to net olefins.

MULTIPLE BENEFITS DELIVER COST EFFICIENCY AND SUSTAINABILITY

NEP not only allows for much higher ethylene yield/tonne of feedstock to the steam cracker on a standalone basis, but also reduces the tonnage of crude oil that needs to be processed in an integrated C2C complex.

By switching from a naphtha to an ethane cracker, producers can support much larger single-train capacities and gain greater capital efficiency. Yields improve from about 1.8 million metric tonnes per year for a naphtha cracker to 2.2 million metric tonnes per year for an ethane cracker in the NEP complex. This limit is driven by the steam cracker, not the NEP unit itself.

As the industry looks to electrify the heating sources used in cracking in the future, the electrification of ethane crackers is more straightforward and delivers more benefits compared to liquid crackers.

CO_2 emissions from a naphtha cracker versus an NEP-based complex can be reduced up to 50% per metric tonne of light olefin. Additionally, if a customer is interested in a low-carbon solution without C_4 or aromatic byproducts, UOP has options that can reduce CO_2 and deliver up to 75% greater olefin yields.

A final advantage of NEP technology is that it allows for a more efficient use of a plant's footprint. In both brand-new and existing plots, NEP technology is amenable to a stacked layout. Additionally, the NEP unit does not have to be close-coupled to the rest of the plant. If a customer has additional space, even miles away from their existing facility, a small pipeline can be used to connect the NEP unit to the steam cracker. Plot space can be cut by up to 10% from a conventional C2C application by using the NEP system.

CASE STUDY: NEW LIGHT-CRUDE-TO-POLYOLEFINS COMPLEX

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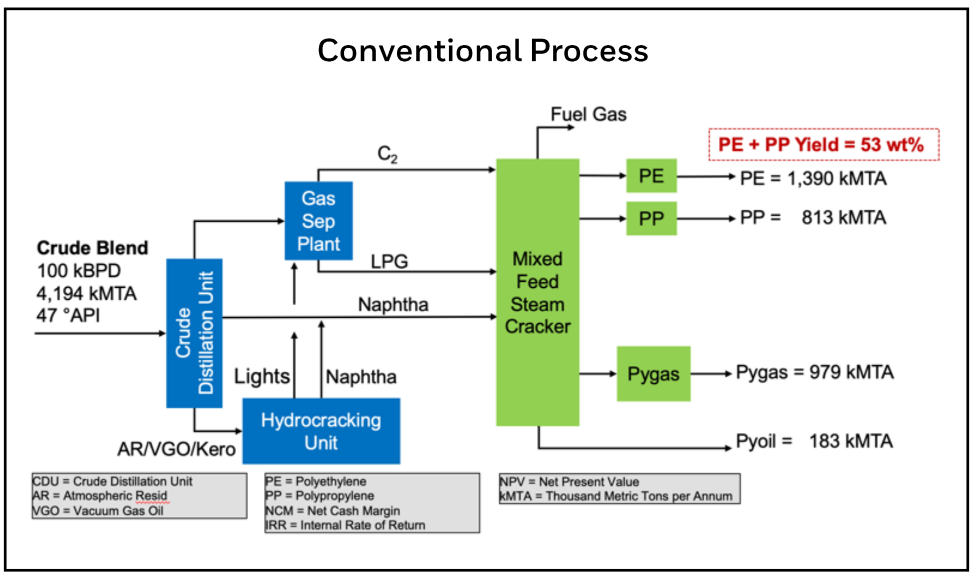
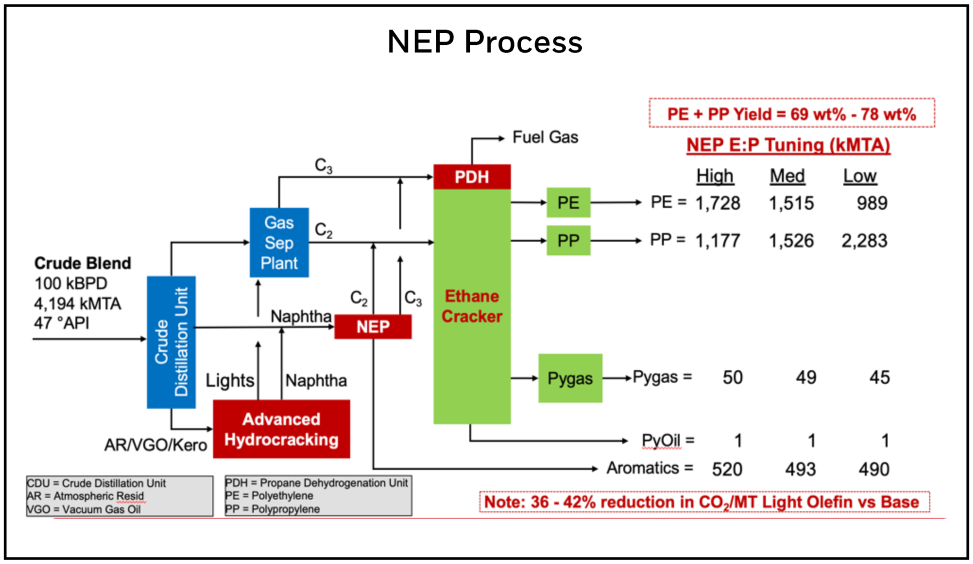
The customer in this case study approached UOP with a brand-new greenfield light-crude-to-polyolefins complex.

This customer's objectives are to maximize polyolefins, minimize or eliminate byproducts, and maximize ROI. The exact balance between polyethylene and polypropylene is undecided; they wanted us to look at the ratio of polyethylene to polypropylene as a part of the study. Their available feedstock is 100,000 BPSD of a light crude mix.



A crude distillation unit would separate the feedstock into some key fractions. The light hydrocarbons and some naphtha would go right to the mixed-feed steam cracker. Atmospheric residual oil, vacuum gas oil, and kerosene would go into a hydrocracking unit. The hydrocracking unit, which takes big molecules and makes them smaller, would focus on making naphtha to feed the mixed-feed steam cracker. LPG and naphtha would then typically be fed into separate furnaces in the mixed-feed cracker, which would make the ethylene and propylene that would be converted to their corresponding polymer in a fixed ratio of about 1.7:1 polyethylene to polypropylene.

With this conventional approach, the amount of polyethylene and polypropylene generated would correspond to about a 53% yield. In other words, only 53% of the carbon in the incoming feed would end up as the target products of polyethylene and polypropylene. There would be nearly a million tonnes per year of pygas as a byproduct which would need to be dealt with, as well as around 200 kMTA of pyoil.



Using the conventional approach, the yield to polymer was only about 53%. Using NEP, we're in the range of 69-78% carbon efficiency. The amount of pygas produced is much lower, and the pyoil is nearly zero. There are some aromatics produced by the NEP unit that can either be combined with the pygas and the aromatics back upstream for conversion to fully eliminate those streams, based on the customer's economics and downstream strategy.

The initial rate of return for this NEP-based crude-to-chemicals complex is about 4-5% higher than the base case, which translates into a net present value increase of between $4-5 billion depending on the tuning of the NEP unit. This also delivers a 36-42% reduction in CO_2 (scopes 1, 2 & 3) per tonne of light olefin with the NEP-based complex. The total investment for this case is about 10-20% higher than the base case, a minimal additional investment given the incremental value that is created.

NEP is a carbon improvement, it's decarbonization—
it's a sustainability project with an internal
rate of return that pays for itself. It's just smart.

CASE STUDY: NEW STEAM CRACKER TO MINIMIZE PROPYLENE PRODUCTION

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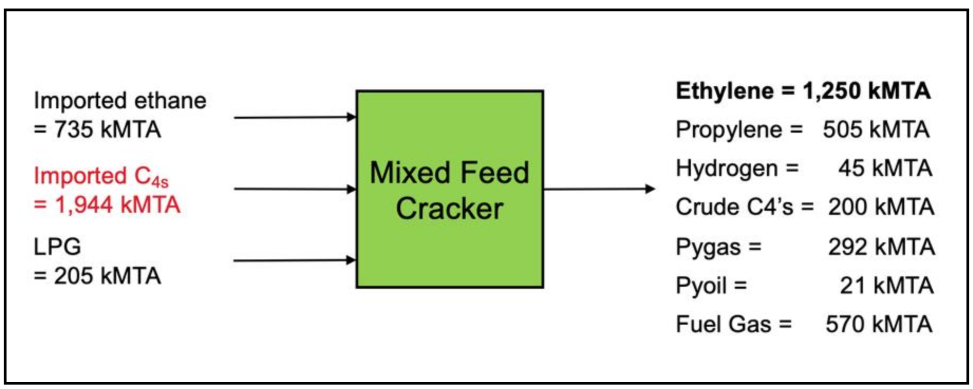
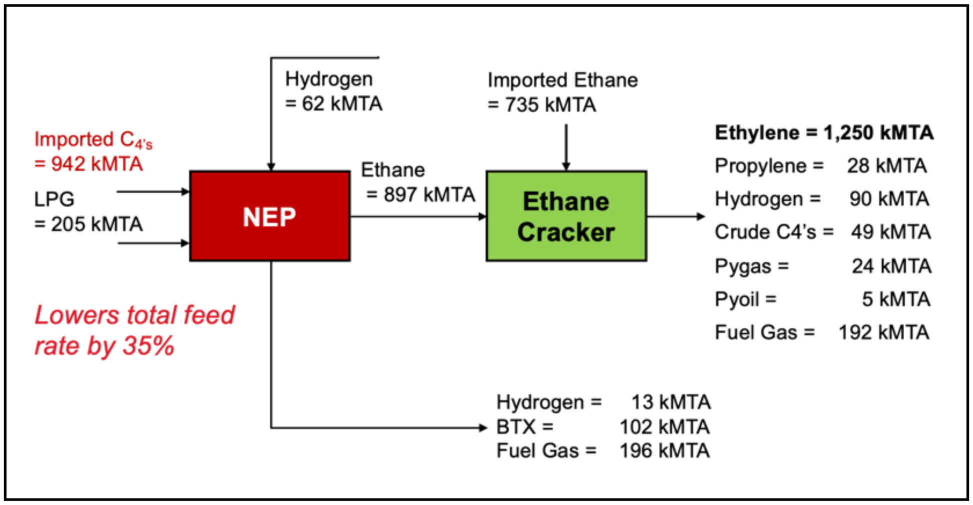
In this application, the customer is planning to make an investment for a new steam cracking unit.

They want to make 1,250 kMTA of ethylene; they don't want propylene or other byproducts. Of course, they want to maximize their return on investment. The feeds they intend to use are about 200 kMTA of in-region LPG and 735 kMTA of imported ethane, plus a balance of imported mixed butanes.



The very simple block-flow diagram above shows the amount of imported ethane, imported C_4s, and LPG required to hit the target of 1.25 million tonnes of ethylene. Note that this conventional process requires 1.94 million tonnes of imported mixed butanes, and generates a large quantity of byproducts, including propylene, crude C_4s, pygas, and pyoil.



The UOP NEP technology uses the imported C_4s and the available LPG through the NEP unit to make ethane, which is then combined with the imported ethane. The customer can now hit the 1.25 million target using less than half of the imported mixed butanes, while also generating far fewer byproducts. The process makes 94% less propylene, less fuel gas, less crude C_4 byproduct, less pygas, and less pyoil. This approach enables ethane cracking and de-risks the feedstock sourcing with an alternative supply chain, thus providing a hedge against volatility and increases in price on imported ethane from North America.

CapEx for this complex is estimated to be 25% lower than the mixed feed cracker, and the internal rate of return is estimated to be about 6% higher.

UOP NEP Technology is rewriting the textbook on how to design a petrochemical complex.

IN CONCLUSION

NEP is a strategic, future-forward technology that will help producers meet industry challenges, deliver operational excellence, and remain competitive.

NEP allows producers to make all their petrochemicals using half the feedstock.

NEP helps to future-proof existing facilities against potential feedstock supply and price risks by making ethane and propane from feedstocks that are readily available, like LPG and naphtha.

NEP allows producers to reduce or eliminate undesirable byproducts.

NEP yields better ROI, significantly better IRR, and a dramatic reduction in CO_2.

The NEP process is flexible in terms of feedstock.

The UOP NEP Technology is ready for license.

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[1] S&P Global Commodity Insights. (2021.) *The Future of Ethane as a Global Commodity.*

For more information

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