Crude oil to chemicals

- Industry development and strategic implications

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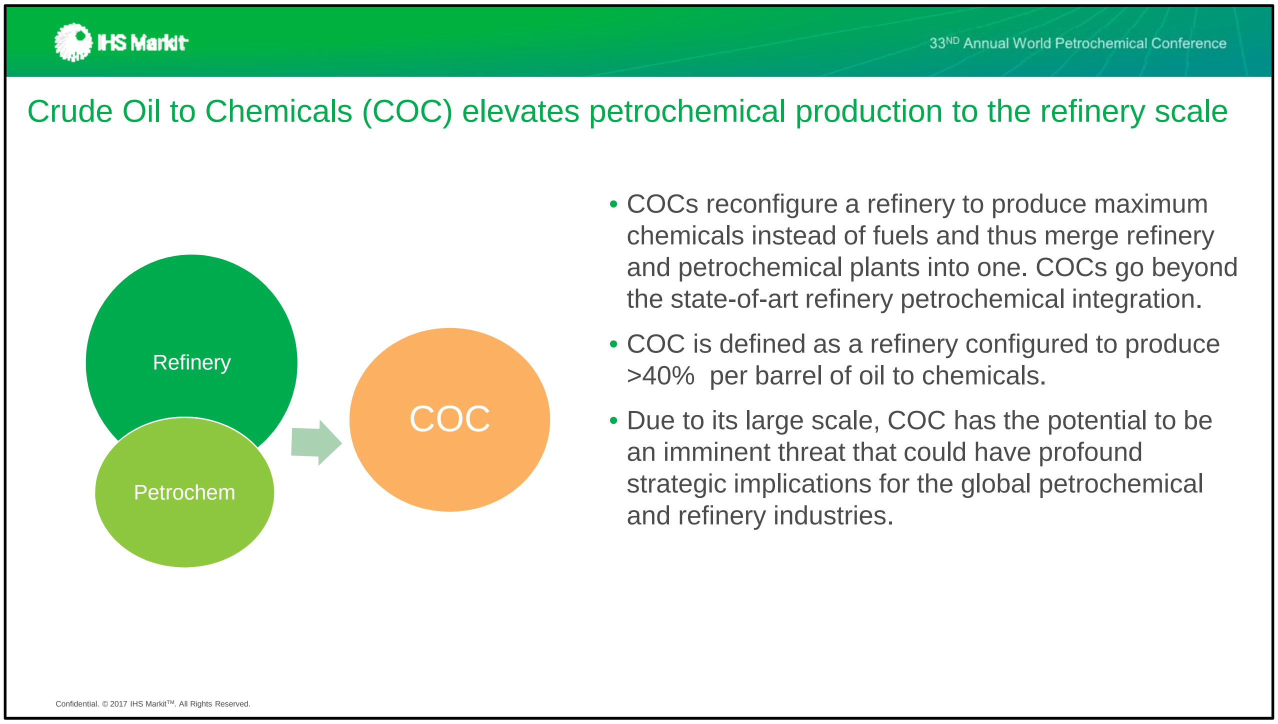


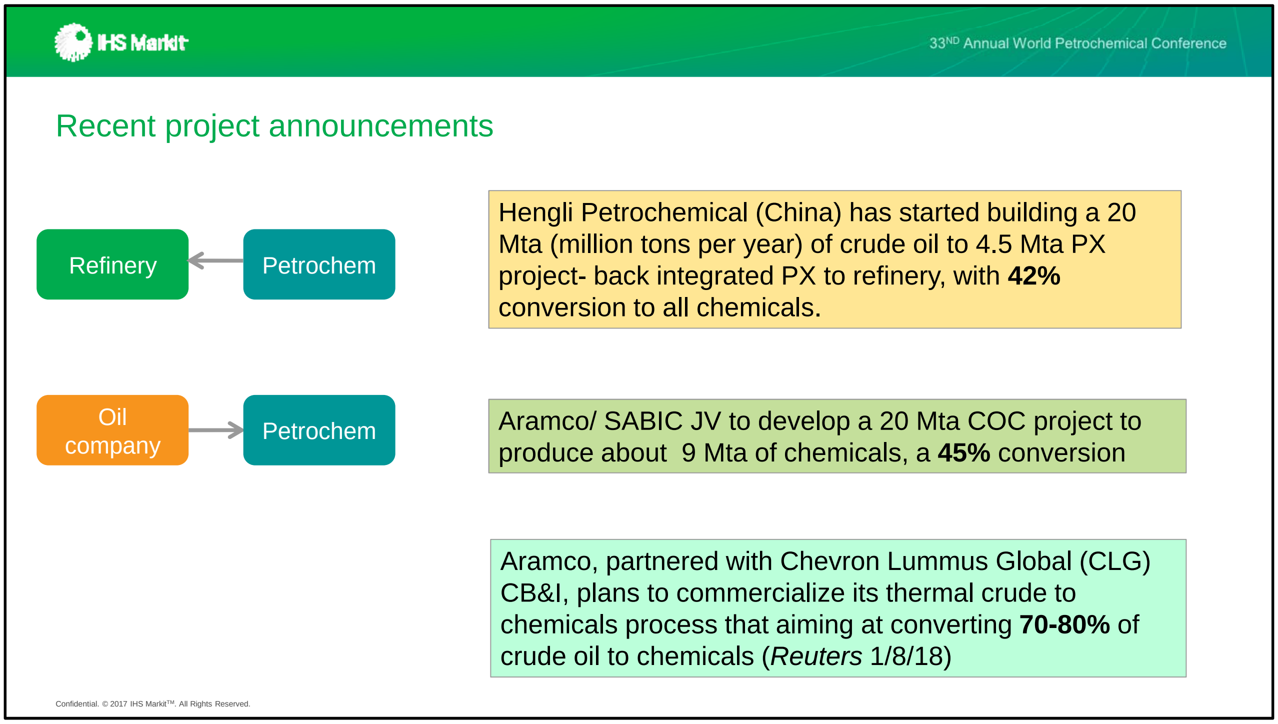
Recently, there have been several large crude oil to chemicals (COC) projects announced or started which involve with reconfiguring a refinery to produce maximum chemicals, instead of transportation fuels as in a conventional refinery. These projects in effect merge a refinery and petrochemical plants into one, and thus go well beyond the state-of-art refinery petrochemical integration. For the purpose of this discussion, I define COC as a refinery configured to produce >40% per barrel of oil to chemicals, and I shall explain the difference between COC as defined and other crude oil to chemicals routes.

COC also elevates petrochemical production to the refinery scale, a roughly 4X increase from the current world scale petrochemical plants. Due to its large scale, COC is the most important imminent development that could have profound strategic implications and dramatic impacts on the future of global petrochemical industry.

Agenda

- Recent COC projects and driving forces
- COC vs. traditional refinery-petrochemical integration
- COC configurations & technologies
- Strategic implications
  - Supply / demand of petrochemicals
  - Technology/Process trend
  - Global competition
- Summary

In this presentation, I will introduce several recent project announcements and explain the driving forces behind these COCs. I will explain the major differences between COC and the state-of-art well-integrated refinery-petrochemical complexes. Next, I will discuss COC configurations and technologies required for achieving maximum chemical production. Then I will present some of the strategic implications on supply / demand of petrochemicals, technology trend, and regional competition. At the end, I will summarize my presentation in a few key messages.

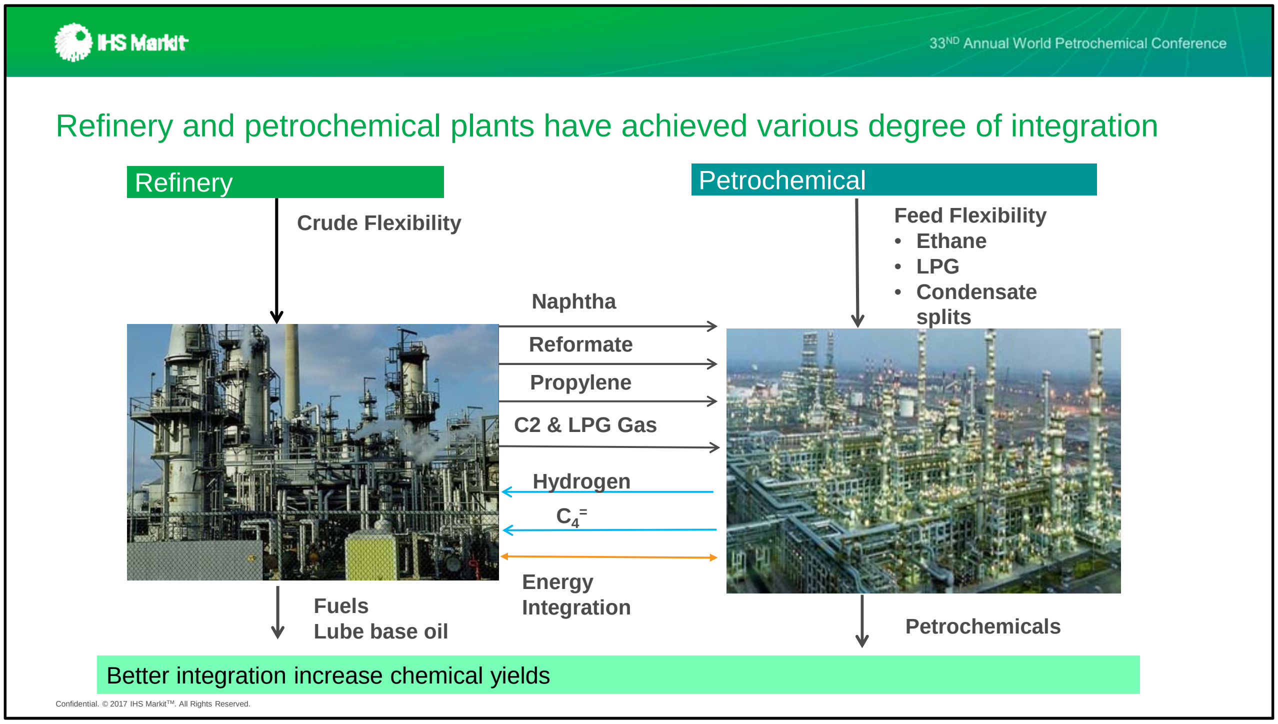


Recently several crude oil to chemicals (COC) projects have been announced in China and Saudi aiming at producing maximum (>40% per barrel of oil) to targeted chemicals.

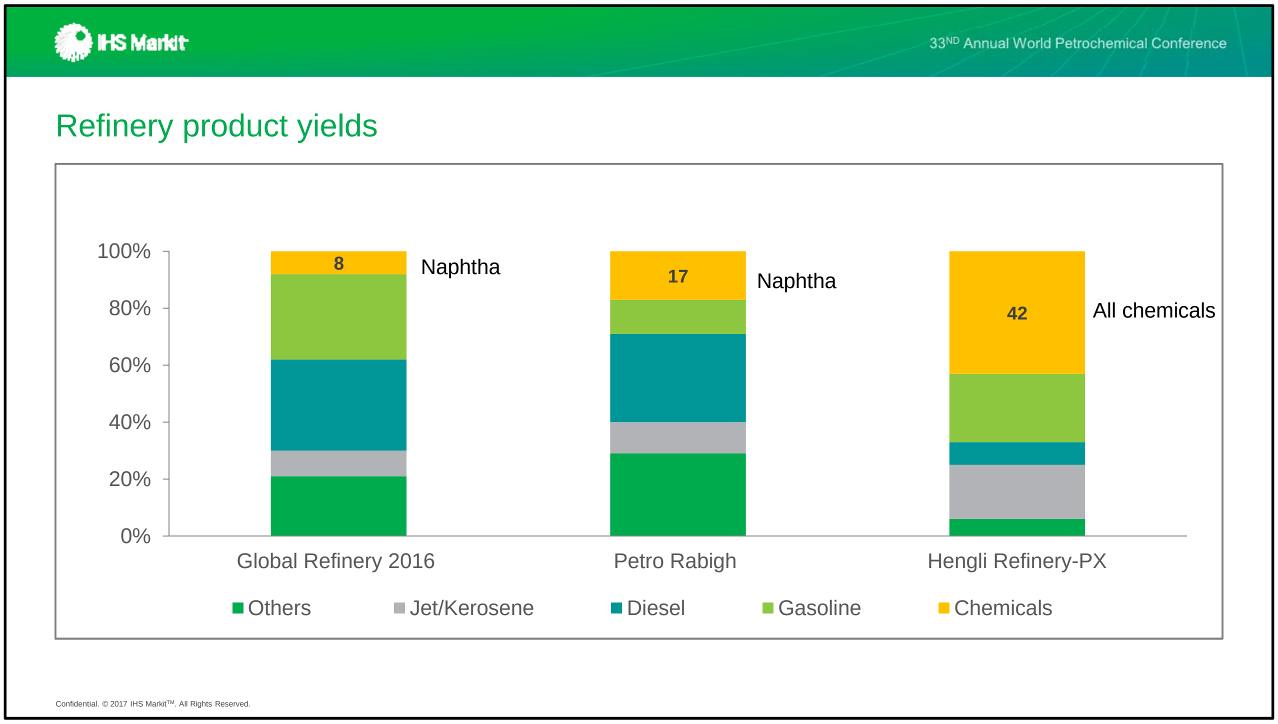
Three refinery-PX projects in China were driven by three PET producers, Hengli, Zhejiang, and Shenghong, to back integrated its PX supply starting from crude oil (refinery). Hengli project has started the construction, and it will start from a 400,000 barrels per day of crude oils (or 20 million tons of crude oil per year to produce 4.5 million tons per year or PX and other chemicals. The conversion from crude oils to total chemicals is about 42%. These refinery-PX complexes represent a downstream company to back integrate its petrochemical production to refinery.

Saudi Aramco and SABIC also recently announced to form a JV to convert 20 million tons per year of oil to produce about 9 million tons of chemicals, or about 45% conversion of oil to chemicals. The project was driven by Saudi's goal to better monetize its oil assets to produce higher value chemicals (instead of fuels) and to diversify it chemical feedstock away from its decreasing NGL supply. This project represents a big oil company moving downstream to become a big petrochemical company.

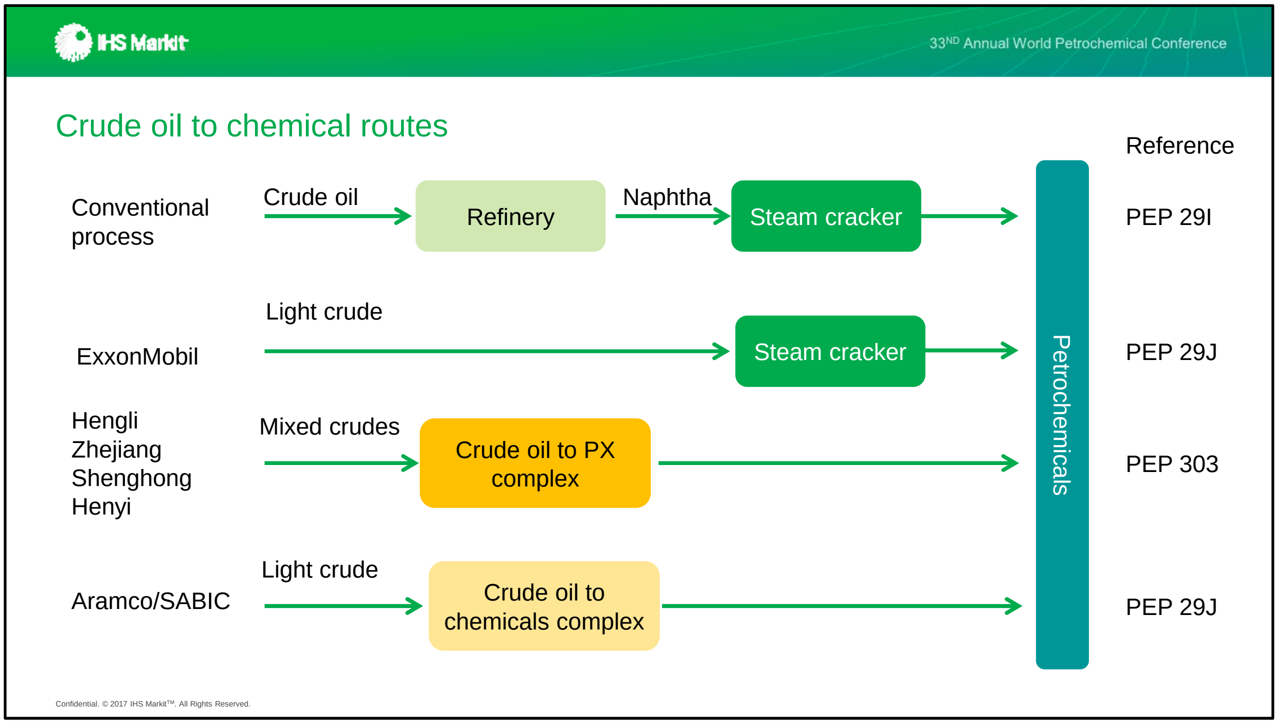
Furthermore, Saudi Aramco recently signed an technology development agreement with Chevron Lummus Global (CLG), and CB&I to commercialize its thermal crude oil to chemicals technology aiming at converting 70-80% per barrel of oil to chemicals. If also starts from 20 million tons of oil, it could produce 14+ million tons of chemicals per year. Put it in perspective, the first wave of all ethane crackers are expected to add around 11 million tons of ethylene from 2016-2022.



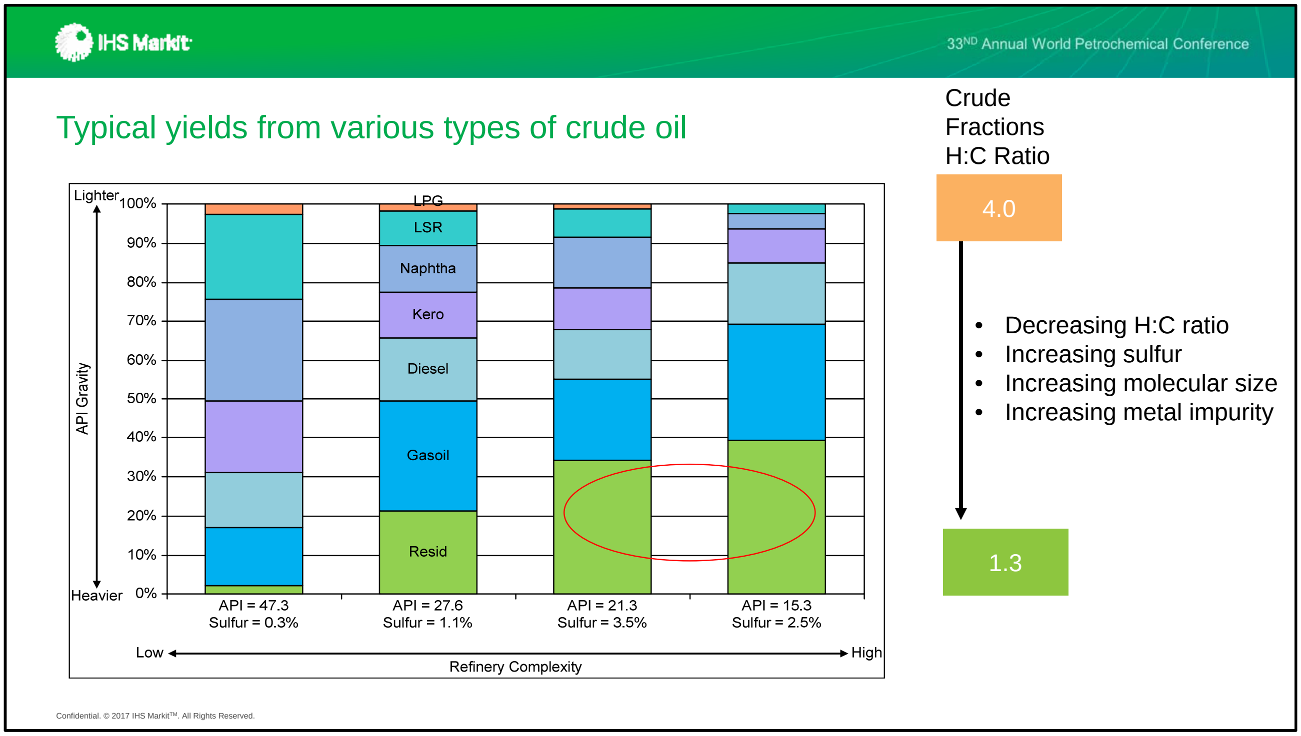
1. A conventional refinery is set up to produce fuels and a petrochemical plant is to produce petrochemicals. The key to refinery profitability is crude flexibility, while the key to petrochem complex is feed flexibility,
2. In a well refinery-petrochemical complex, the materials are coordinated to maximize the chemical production and the utilization and energy is integrated to increase energy efficiency.
3. However, even when integrated, refinery is still aiming at producing fuels while the petrochem complex focuses on chemical production.
4. In a crude oil to chemicals unit, as described earlier, the two merge into one, and the primary goal is to produce maximum chemicals.



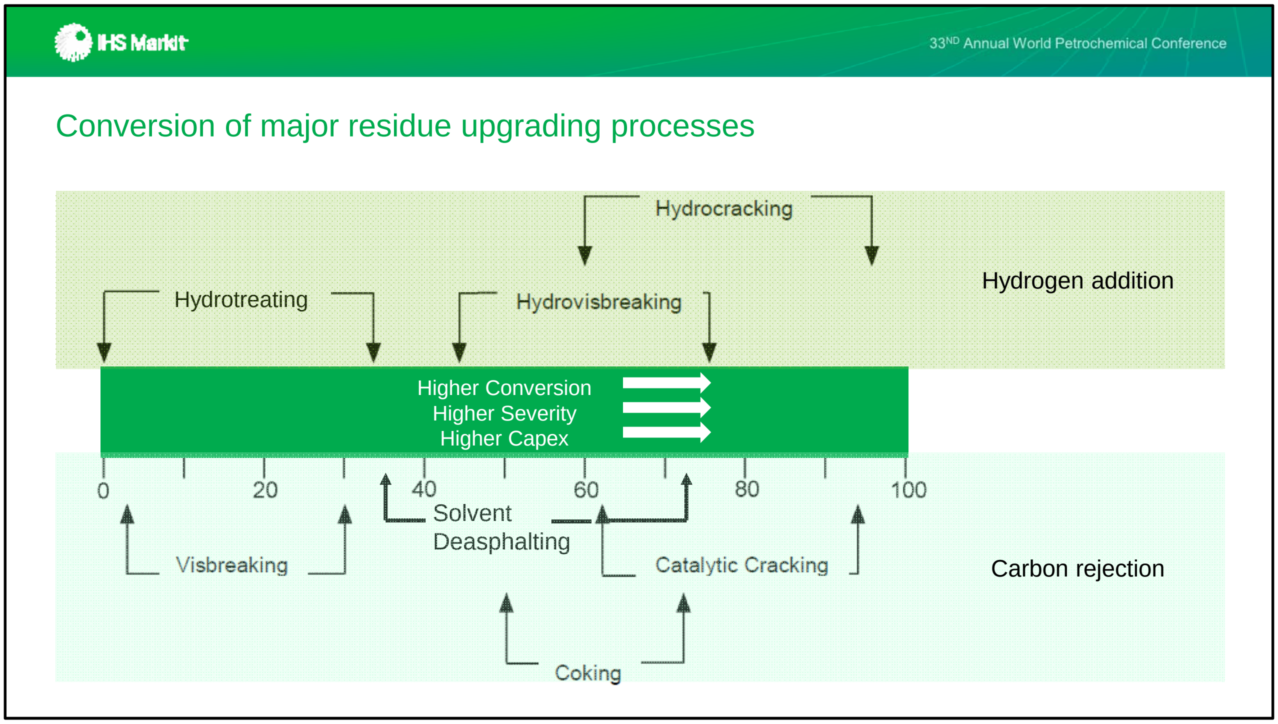
1. With an increasing degree of integration, a refinery-petrochemical complex can achieve a greater % of chemical production.
2. As a global average, a refinery produces about 8% naphtha per barrel of oil available for chemical production.
3. A state-of-art well integrated refinery-petrochem complex such as Petro Rabigh (Aramco/Sumitomo) and Sadara (Aramco/Dow), produce about 17-20% naphtha for chemicals per barrel of oil.
4. Hengli's refinery-PX COC project will convert about 42% per barrel of oil to chemicals, truly a quantum jump from an state-of-art well integrated refinery-petrochemical complex.



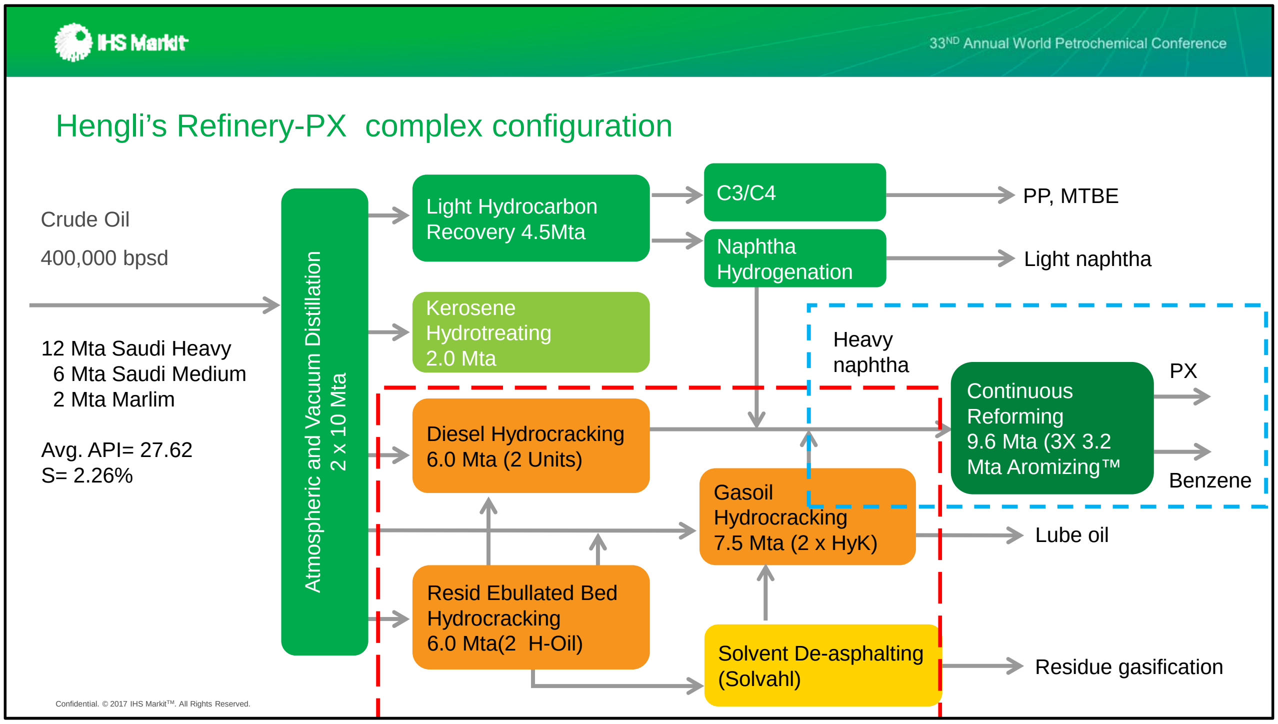
1. This slide shows the different routes of converting crude oil to chemicals
2. In a refinery- steam cracker arrangement naphtha is sent from a traditional refinery to steam cracker to produce petrochemicals. Crude oil can be considered as an indirect feed for the petrochemical industry.
3. In recent years, there have been several “crude to chemicals” announcements including ExxonMobil, Aramco, SABIC. Hengli, Zhejiang Petrochem, Shenghong, and Hengyi. Let’s look at how some of the processes are configured.



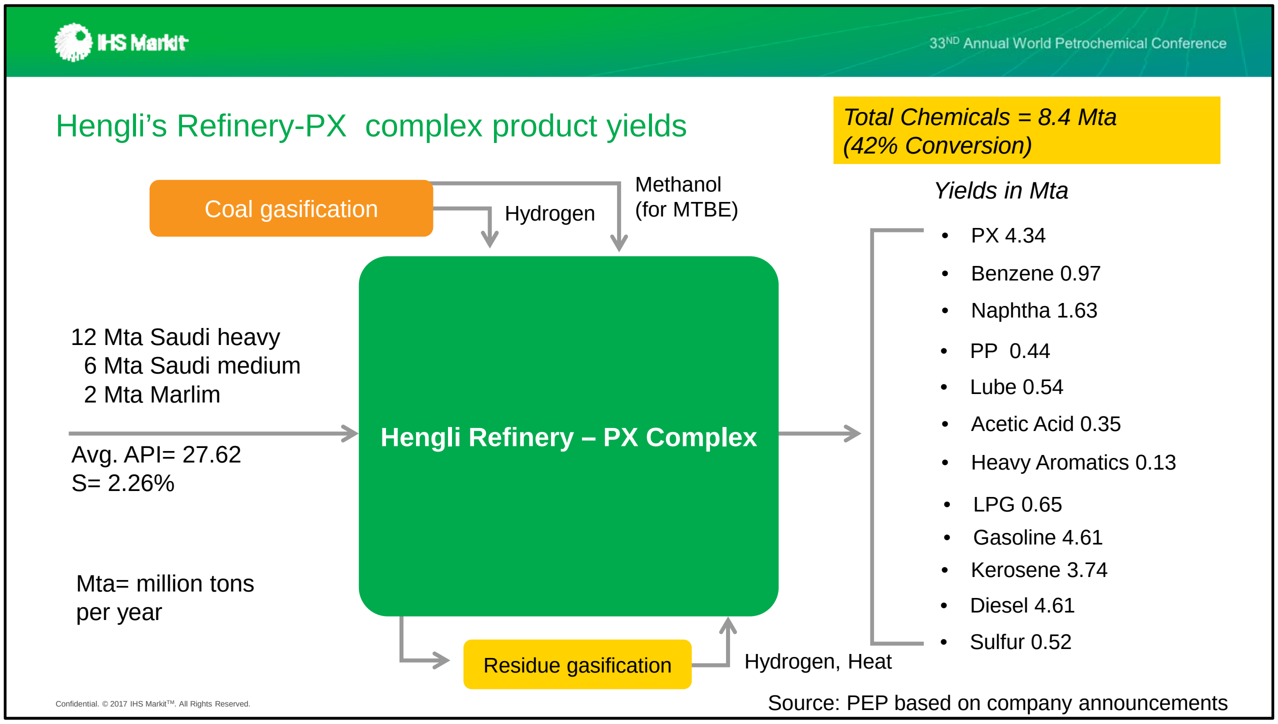
1. This graph shows typical assay of four types of crude oils with a light crude on the left and increasingly heavier crudes to the right.
2. Heavier oil will have higher amount of heavy residue
3. For each type of oil, from light to heavier fractions from the top to the bottom, molecular size increases, H:C ratio decreases, and sulfur and metal impurities (Ni +V) increase.
4. Thus, any process to produce more chemicals from crude oil requires to:
    1. Reduce heavy residue to lower molecules
    2. Raise H:C ratio around 2 for all chemicals
    3. Reduce sulfur and metal impurities



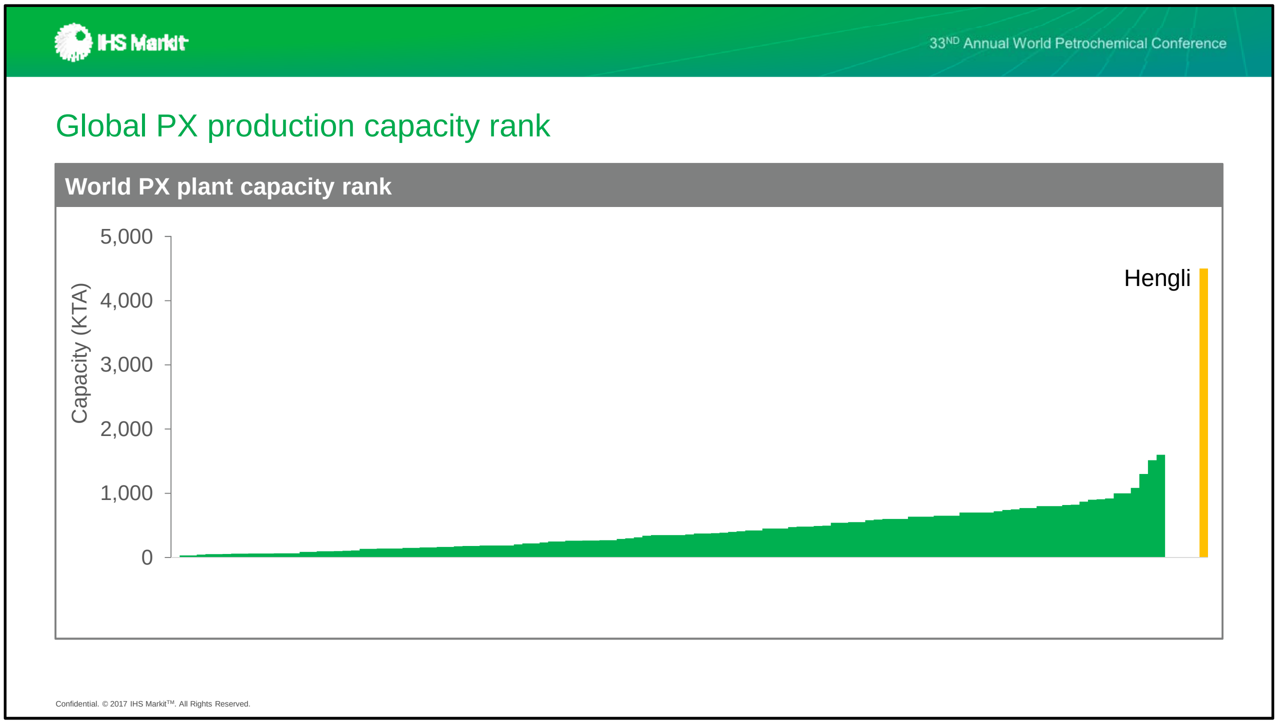
1. This slide shows major available processes for upgrading heavy fractions to lighter molecules with increasing % of conversion from the left to the right.
2. A process capable of higher conversion generally operates at higher severity and thus has a higher capex.
3. H:C ratio can be raised either by carbon rejection or by hydrogen addition, the former includes coking, catalytic cracking, etc., while the latter including hydrocracking.
4. To produce more chemicals from crude oil, hydrogen addition is preferred since carbon shouldn't be wasted. Hydrocracking can add hydrogen, remove Ni and V metal impurities (which are catalyst poisons for downstream processes), reduce the size of heavy molecules, reduce % sulfur, and has the highest conversion, making it a preferred choice for COC. Other choice includes Flexicoking ™.



1. This graph shows our understanding of the configuration of Hengli's refinery-PX complex being under construction.
2. It process a mix of Arabian Heavy, Arabian Light, and Marlim crudes in a ratio of 60%/30%/10%.
3. It employs Axens's H-Oil RC ebullated bed hydrocracking for vacuum resid, HyK hydrocracking for gasoil, and diesel hydrocracking as well as Solvahl deasphalting processes to produce maximum heavy naphtha for aromatics unit.
4. It also produce significant other chemical feedstocks such as light naphtha and propylene.
5. Other licensors who can provide competing technologies include CB&I, UOP, KBR, etc.



1. This graph shows our understanding of product yields, the total chemical yield is estimated at 43% including lube oil.
2. The aromatics production alone includes 4.3 million tons of PX and 0.97 million tons of benzene per year.



1. The potential impact of COC lies in its huge scale. For PX, Hengli refinery – PX complex plans to produce 4.3 Mta of PX, about four times that of an average world scale PX plant. It will take only a few of the similar refinery-PX complexes to significantly alter the local and global supply and demand balance.

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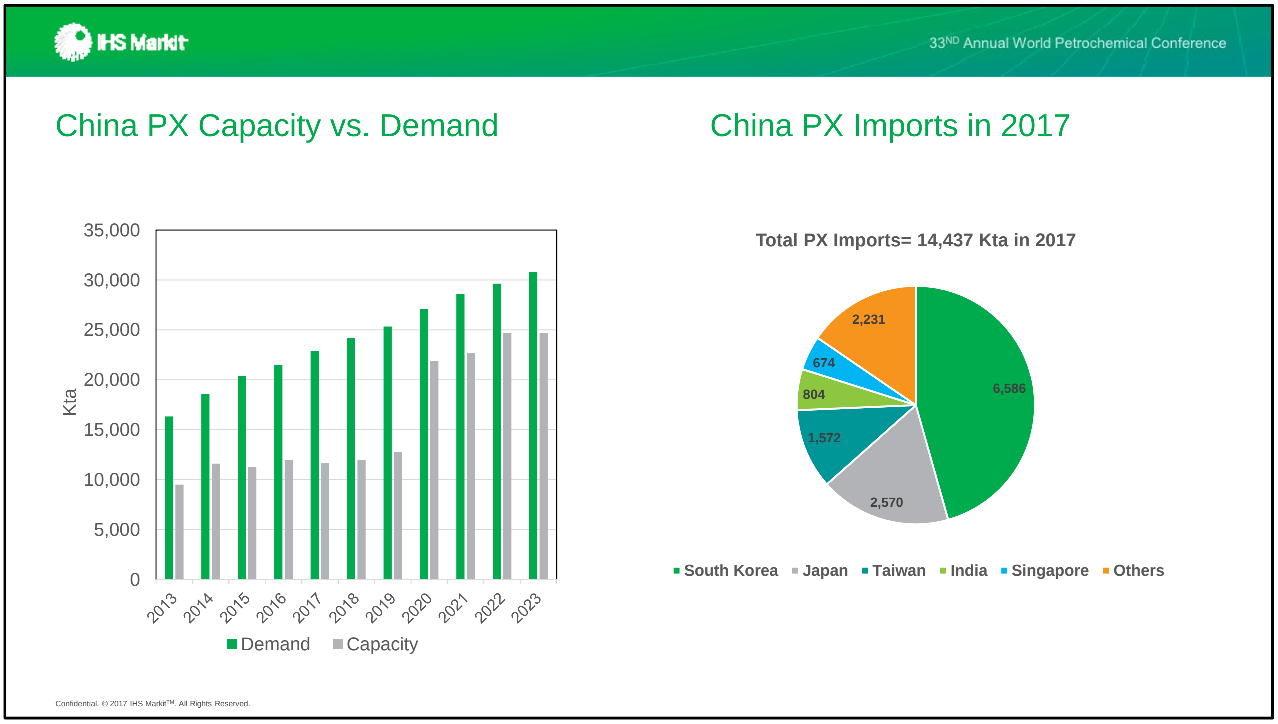
Crude to Chemical Projects

Project	Refinery Capacity (Mta)	P-Xylene Capacity (Mta)	Olefin Capacity (Mta)	Investment ($bn)	Expected Operation
Hengli	20	4.3	1.5	11.4	Mid 2018
Zhejiang Petrochem[a]	40	10.4	2.8	26.6	Dec 2018 (1st phase) 2nd Phase 2026?
Shenghong refinery and Integrated Petrochem	16	2.8	1.1	11.0	2019
Hengyi (Brunei) PMB Refinery-Petrochem [b]	8	1.5	0.5	3.45	2018
Aramco SABIC JV	20	--	9 (total chemicals)	20	2025

This table gives a list of COC projects with three refinery-PX complexes in china, one refinery-PX complex Brunei, and Aramco/SABIC JV in Saudi Arabia, each with announced investment cost and expected date of completion.

The investment cost of each project was announced in 2015-2017 time frame, and therefore only indicative. When compare the project cost in Asia vs Saudi Arabia on the indicative cost basis, it is notably that the project cost in Asia is roughly ½ that in Saudi Arabia.



The left graph in this slide shows IHSM's PX capacity vs. demand in China in recent years with projection to 2013. China's PX capacity has lagged its domestic demand for years. With the added capacities in the next few years including our conservative of capacity addition from the new refinery-PX complexed list in the previous slide, by 2020, this supply gap will be closed significantly. And if the second phase projects come on stream, it could further close China's supply gap.

The right graph in this slide shows China's PX imports by origin in 2017. As the domestic PX supply gap closes in 2020, PX imports are expected to reduce substantially, affecting South Korea, Japan, Taiwan, etc., the main PX exporting countries/regions to China.

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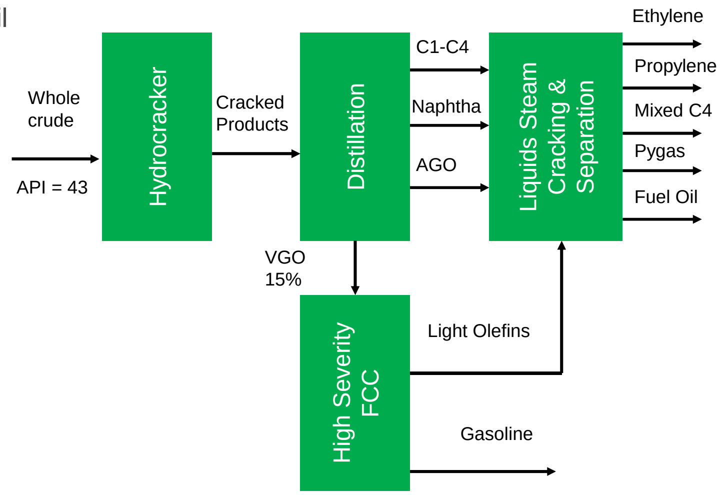
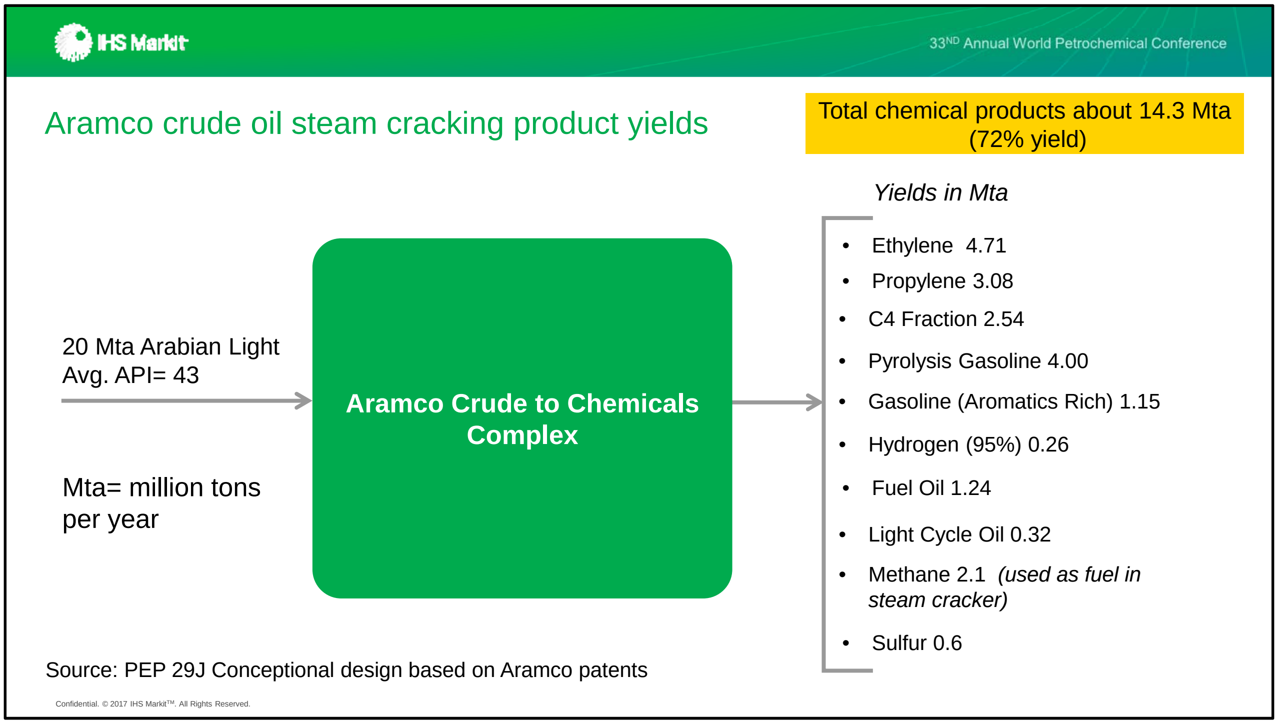
Saudi ARAMCO's approach to steam cracking crude oil

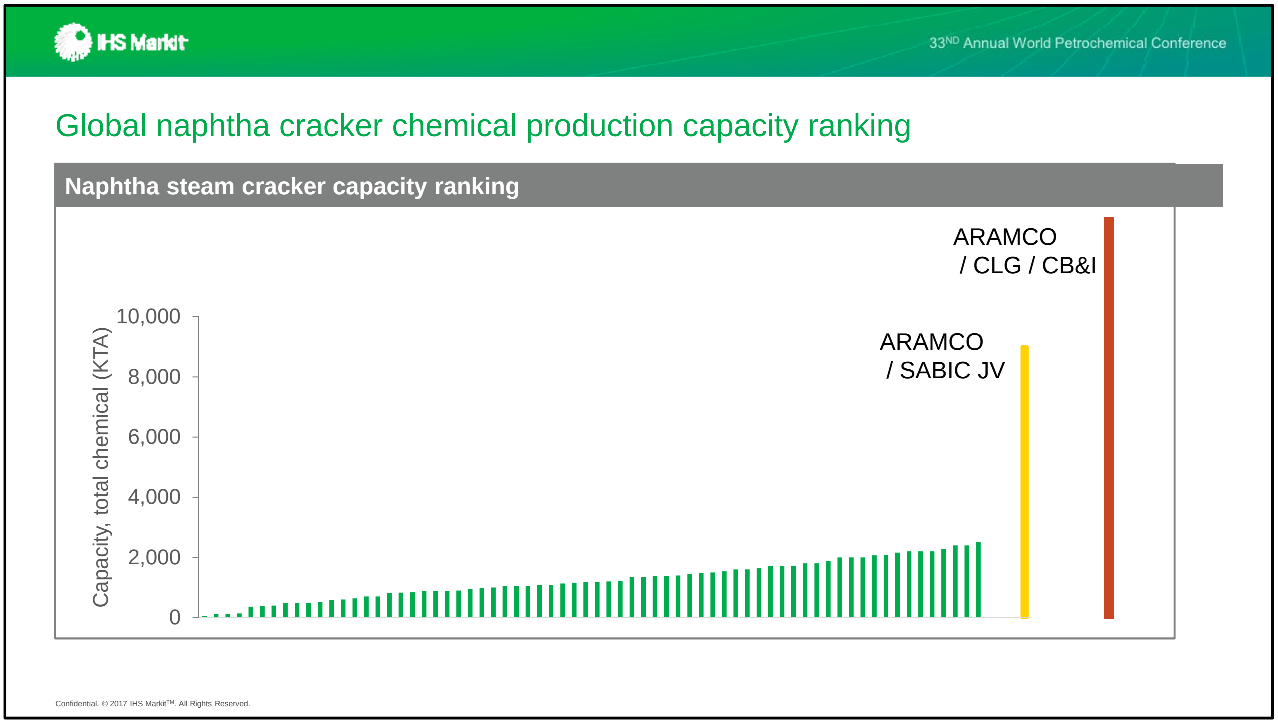
- ARAMCO feeds Arabian Light crude oil to resid hydrocracker (HK)
- Feed rate 80,000 barrels per day to make 935 thousand tons per year of ethylene
- Lightest 85% of HK product conventionally steam cracked
- Heaviest 15% of HK product fed to proprietary high-severity fluid cat cracker (FCC), making cracked naphtha + propylene
- FCC technology developed as joint venture with Nippon JX



1. While Aramco/SABIC only announced that its JV will process a light crude with 20 million tons per year capacity to produce 9 million tons per year of chemicals (45% conversion).
2. Aramco also announced that it will work with Chevron Lummus Global (CLG) to develop hydrocracking technology that's capable of converting 70-80% per barrel of oil to chemicals.
3. Although, we are not aware of Aramco's COC exact process configuration, we developed a conceptual design based on Aramco's COC process patents.
4. Based on patents, we believe that Aramco hydrocrack its light crude (assumed to be Arabian light in our analysis) first. Then it goes into a distillation column, which can be simpler than the regular CDU since the heavy ends of the light crude has been reduced by hydrocracking.
5. The lighter fractions from the distillation column are steam cracked to produce chemicals while the heavy fraction is sent to a high severity FCC to produce additional chemicals and fuels.



1. Our estimate of chemical yields according to our conceptual design turns out to be 72%, amazingly in agreement with what Aramco claims as the yield of 70-80% of its eventual COC process.



The potential impact of Aramco and SABIC projects can be seen in this slide, which compares production capacity of current global steam crackers with COC by Aramco/SABIC JV and the future design by Aramco/CLG/CB&I. Aramco/SABIC JV is expected to produce 9 Mta of petrochemicals, about 4X higher than a current world scale naphtha steam crackers, while the Aramco/CLG/Lummus design, when it's realized, will produce 6.5X chemicals that of a current steam cracker.

Implications to the global refinery and petrochemical industries

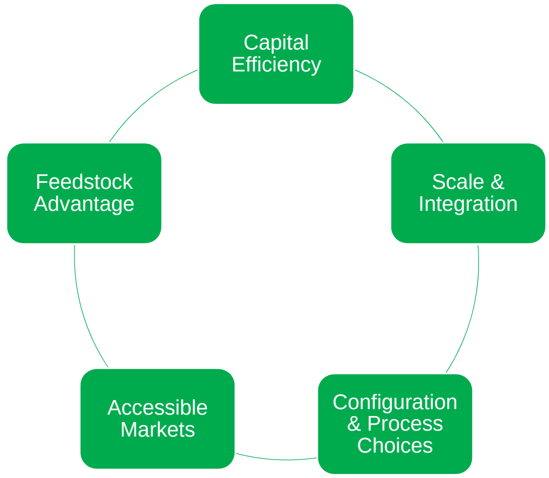
- COC, due to its large scale, is expected to significantly change global supply / demand balance of major petrochemicals in years to come, starting with PX in China
- Aramco/SABIC's COC projects can allow Saudi Arabia to better monetize its oil assets and to diversify its petrochemical feedstocks from NGLs
- COC in China will allow PET producers to increase its PX self-sufficiency substantially.
- The line between refinery and petrochemical will be blurred, with COC companies competing both in fuel and chemical products.

Implications on technology choices

- COC requires significant refinery residue upgrading. Hydrogen addition is favored over carbon rejection.
- Hydrocracking will become one of the most important processes, due to its ability to crack, add hydrogen, remove sulfur, produce naphthas, and achieve high conversion.
- Hydrocracking for COC requires catalysts that can produce more light and heavy naphtha, rather than middle distillates and diesel for fuel production.
- Targeting chemicals changes crude selection and optimum configuration.
- Hydrogen consumption, total utilities consumption, product yield, and capital investment are key performance indicators

Implications on global competition

- COC takes scale and integration of petrochemicals production to a whole different level, and itself becomes a competitive advantage.
- In addition to feedstock advantage and accessible markets, process configuration and technology choice become important competitive factors at such a large scale.
- Capital efficiency also becomes a critical competitive factor.



Key messages

- Crude oil to chemicals (COC) is expected to profoundly impact the global petrochemical industry..
- COC requires a significant reconfiguration of the refinery to upgrade heavy products to chemicals. It goes well beyond the state-of-art refinery-petrochem integration.
- COC's impact lies in its huge scale and high chemical yields, which can overwhelm even the largest conventional petrochemical plants. It wouldn't take more than a few COCs to dramatically alter the world's petrochemical supply / demand balance.
- COC is the most important new development in basic petrochemicals. It deserves our closest attention.

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