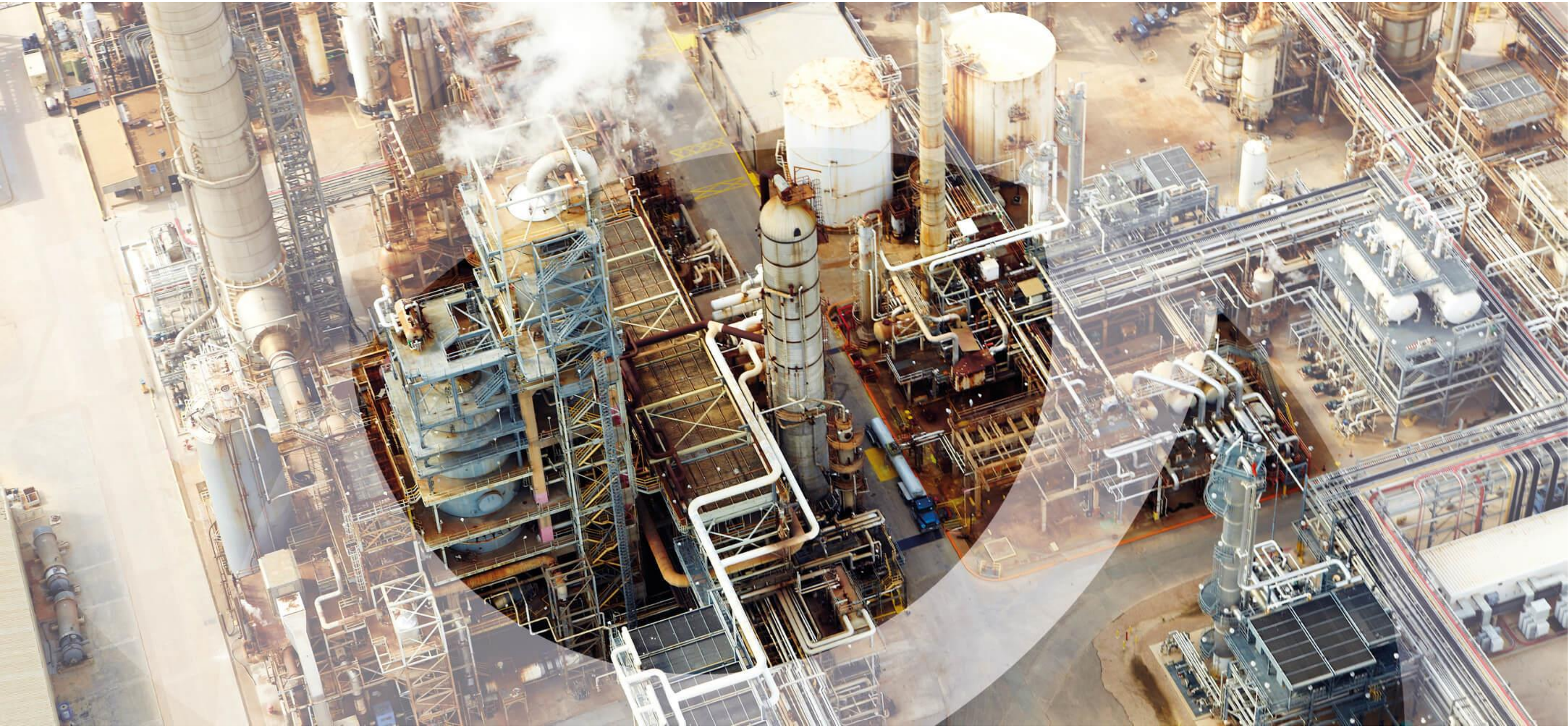
Refinery-Petrochemical Integration

Downstream SME Knowledge Share

SME programme – Term 1 deliverable



Drivers of integration

Market trends impacting fuels and chemical values

Value uplift in integrated sites

Maximising margins and improving competitiveness are the primary drivers of integration

New technologies and catalysts will continue to create opportunities for integration such as H-Oil, LC Max, HS-FCC, DCC etc.

Maximize Margins

Cost reduction

- Reduced transportation costs
- Reduced OPEX
- Working capital/inventory
- Resourcing synergies

Feed flexibility and security

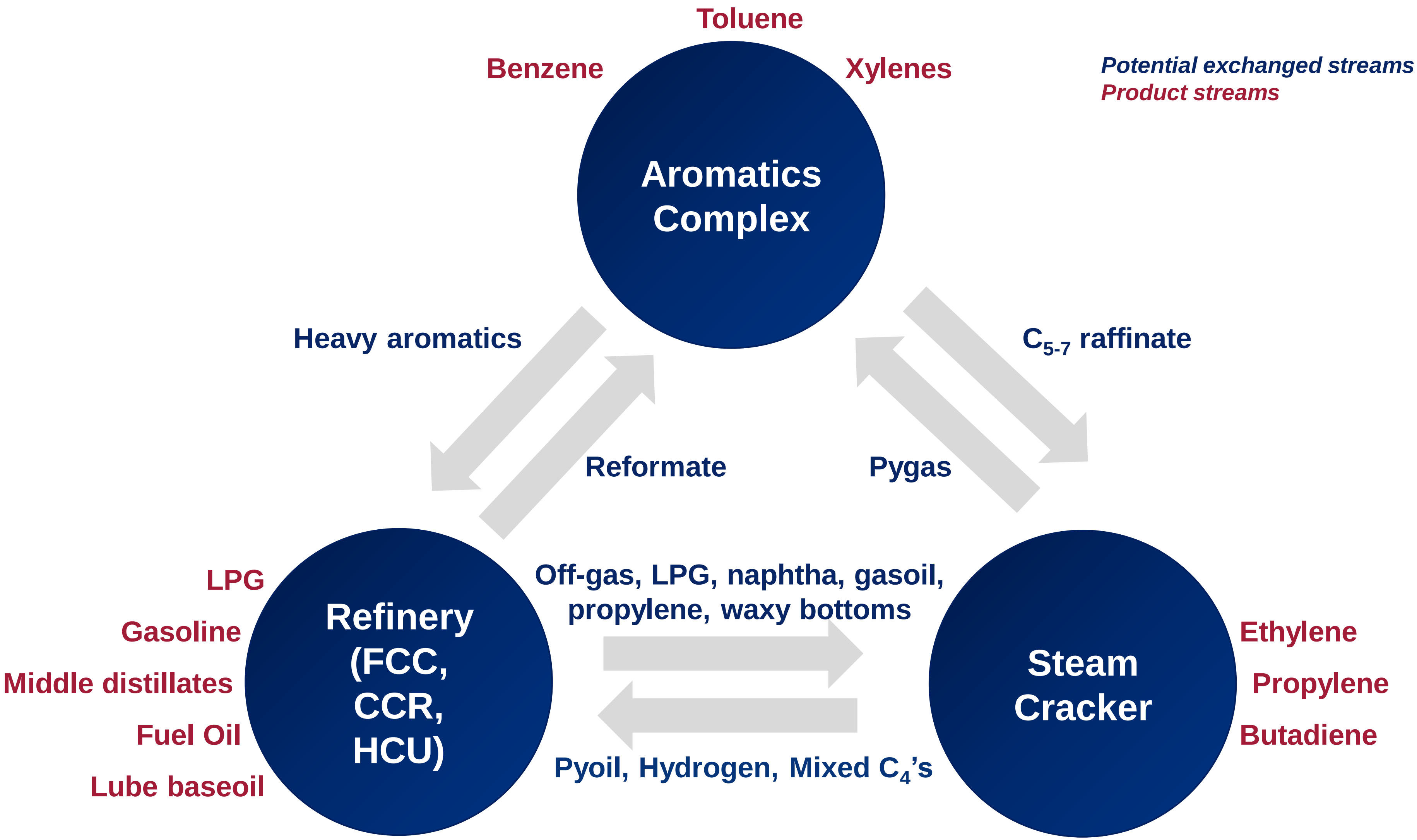
- Feedstock optimization to meet both refinery and petrochemical needs – crude vs condensate vs naphtha
- Choice of feed streams to petrochemical

Product revenues maximisation

- LPG and naphtha as chemical feedstocks
- Aromatics rich stream to BTX extraction
- Pygas, pyoil to refinery as product blend stocks
- Surplus hydrogen to refinery

Source: Wood Mackenzie

But integration increases complexity, capital requirement and interdependency, which needs to be understood and managed



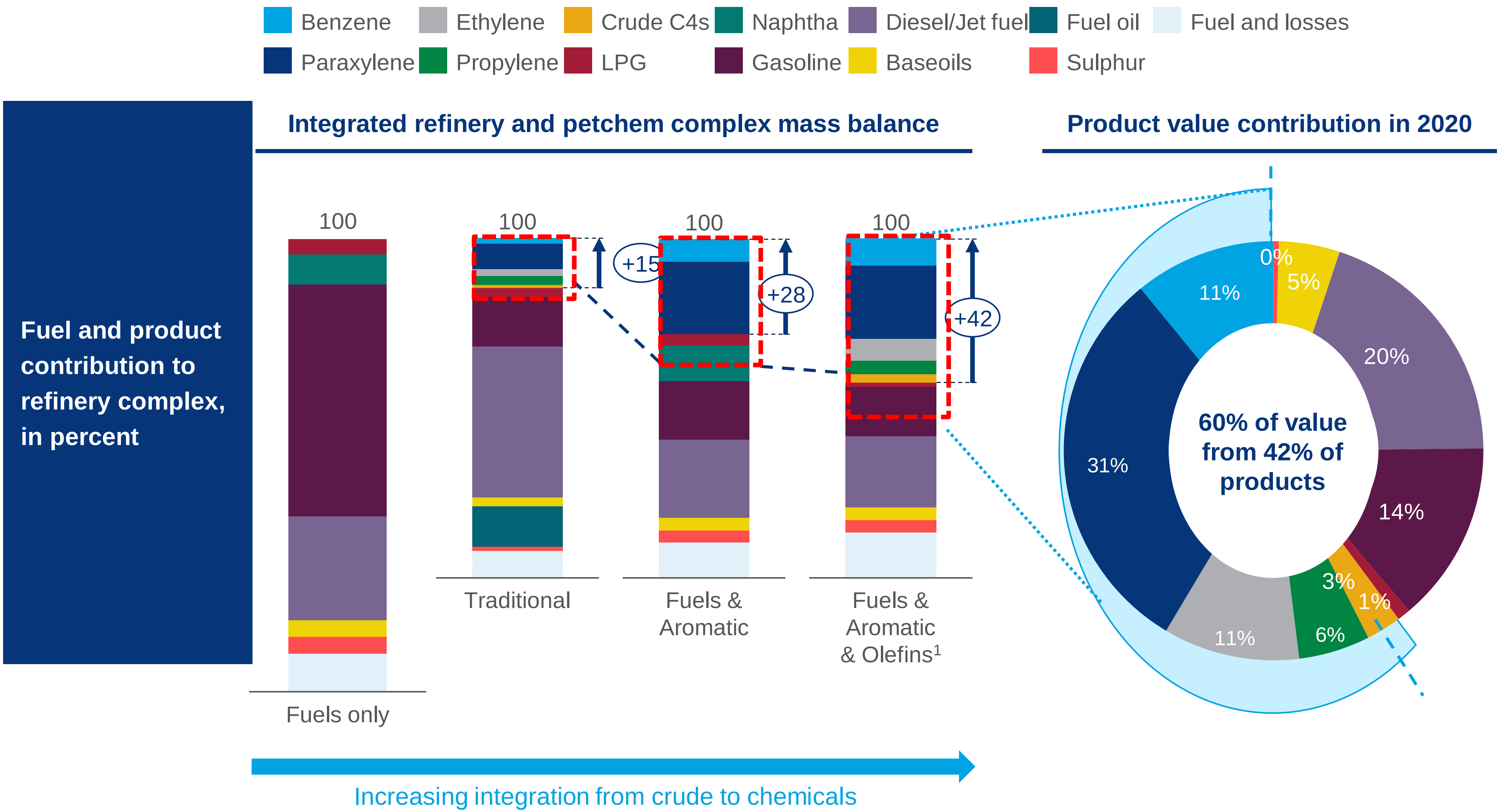
Source: Wood Mackenzie

Crude oil-to-chemicals – varying degrees of integration

	First generation	Second Generation	Third Generation
Simple description and yield / conversion levels	Existing refinery-chemical integration sites, which could be up to **15-20% chemicals** production maximum. Typically many refineries that are fuel oriented (<10%) and highly integrated existing sites would be towards the higher end of the range (15-20%)	The overall crude oil-to-chemicals configuration is at this generation geared towards chemicals optimisation or maximisation. Yield expectations could be up to **40% chemicals**.	The overall crude oil-to-chemicals configuration is at this generation even further geared towards chemicals optimisation or maximisation. Minimisation of fuels production is almost a criteria in this generation. This is a theoretical configuration currently as no existing assets or assets under construction can achieve this level.
Real world examples of generation type	Real world examples of highly integrated sites would be: TOTAL Antwerp BP Gelsenkirchen	Real world examples would be Exxon Mobil, Singapore New complexes under construction in China (e.g Heng Li)	Planned Saudi Aramco/SABIC asset in Saudi Arabia

Source: Wood Mackenzie

Chemical value upgrade is the main driver for close integration and optimisation of refining and petrochemicals



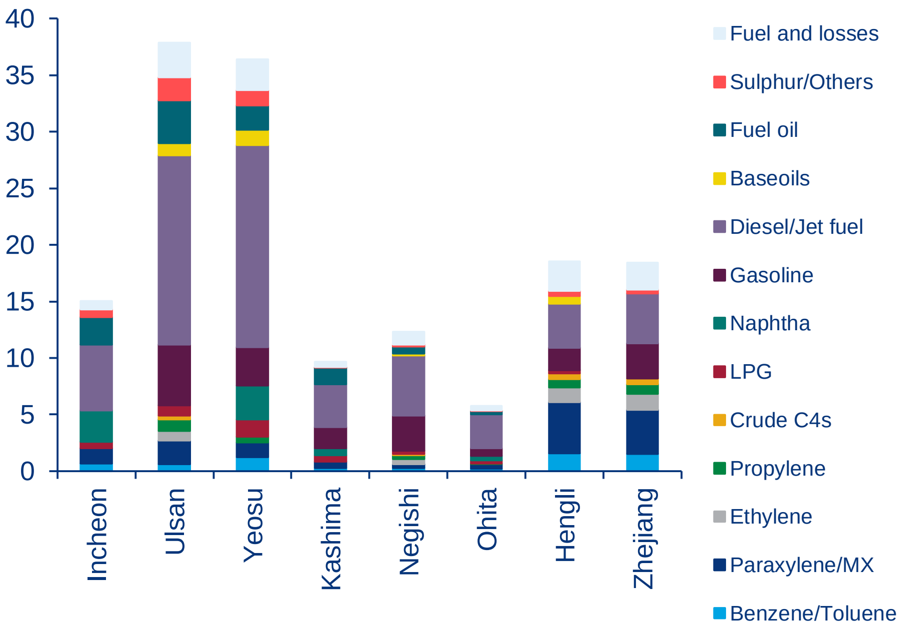
Source: Wood Mackenzie Product Markets Service, PetroPlan

1. Simulated using Petroplan basis of our WM understanding of Hengli's configuration

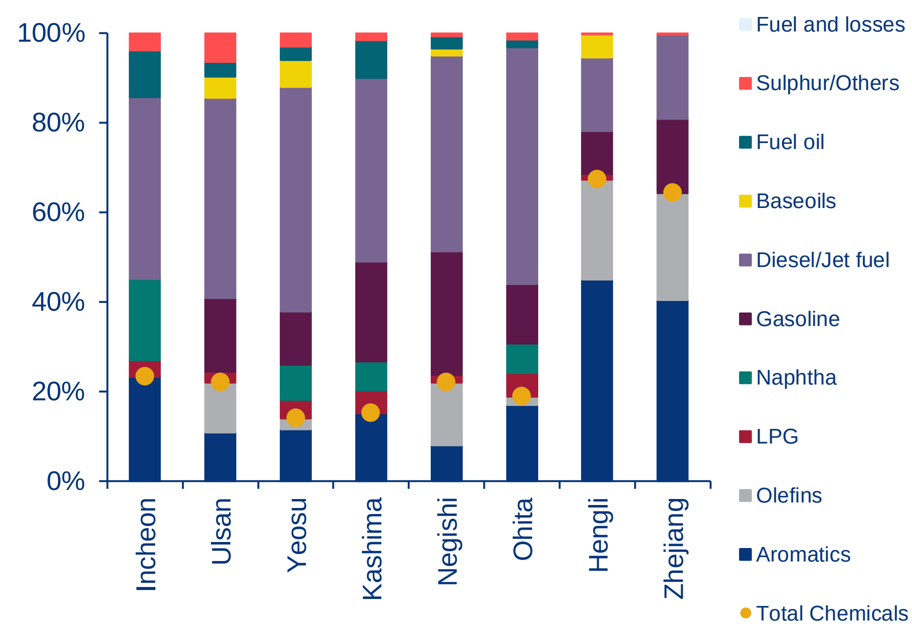
Product yield comparison of integrated sites

Hengli and Zhejiang refinery fuel and loss are high due to high complexity and high capacity for steam cracker

Site product output comparison, Mtpa



Site product yield, wt% comparison



- New Chinese refining sites generate a lot more fuel gas versus traditional refining sites as they employ more technologies to crack heavier middle and heavy distillates into petrochemical feedstock, mainly targeted at maximising heavy naphtha production

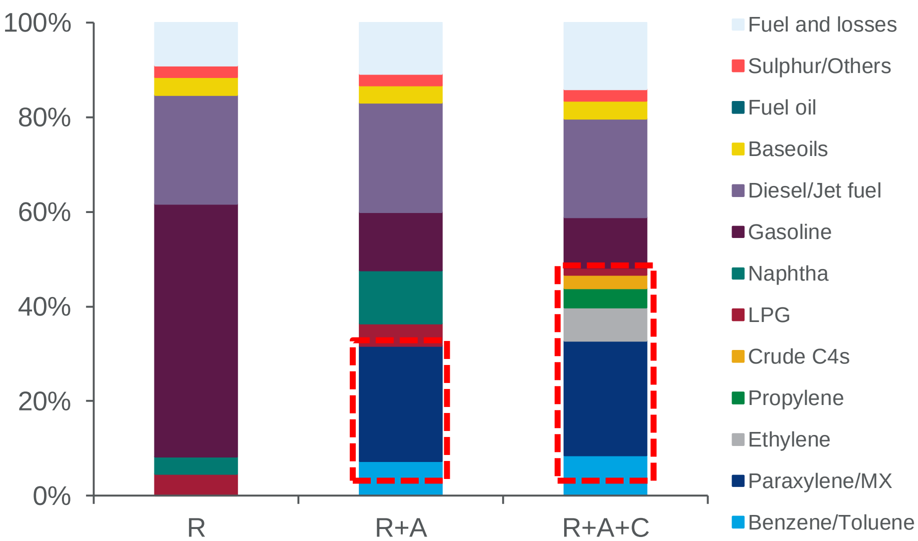
- The Chinese integrated sites are able to overcome the higher amount of fuel and losses by achieving petrochemical yields in excess of 50 wt%
- The combination of a heavier crude diet and much higher petrochemical yields enables these sites to be very competitive

Source: Wood Mackenzie Product Markets Service, PetroPlan

Site mass balance – product output

High conversion of distillate to naphtha leads to highest chemical yield of ~42 wt%

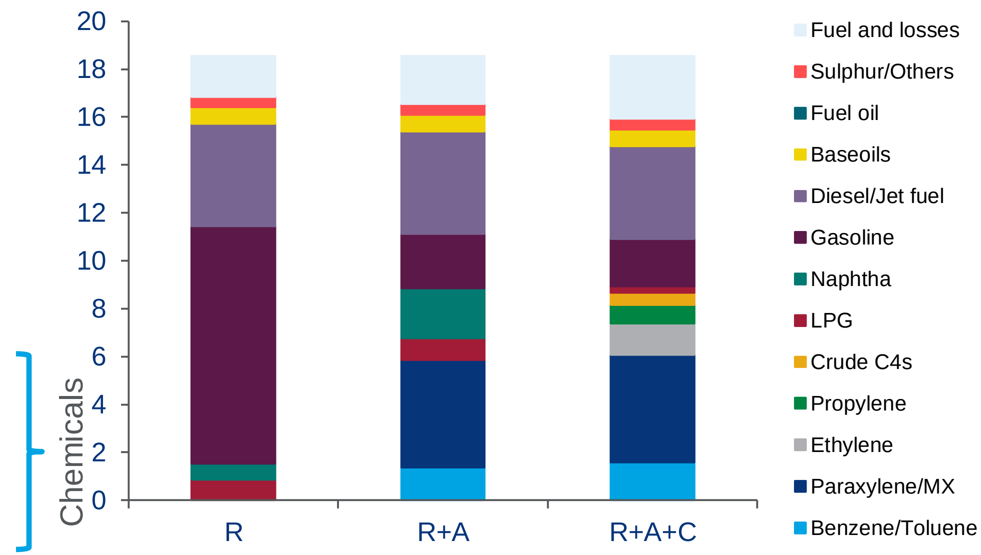
Hengli site product quantity, wt% yields



R = Refining alone
R+A = Refining plus aromatics
R+A+C = Refining plus aromatics plus cracker

- About 46 wt% of the output quantity will be chemicals, compared to only about 15% in traditional integrated site
- Residue/AGO/VGO converted to naphtha in hydrocrackers with high naphtha yield selectivity
- Even with deep integration about 32% quantity will be transport fuels products mainly gasoline and middle-distillates

Hengli site product quantity, Mtpa



- For a full integrated site (R+A+C), value from chemicals could account for up to 65% of the revenues, providing strong uplift
- Diversified product slate provides flexibility to switch yields between fuels and chemicals
- Feedstock flexibility for chemical units, e.g. ethylene cracker

Source: Wood Mackenzie Product Markets Service, PetroPlan

Drivers of integration

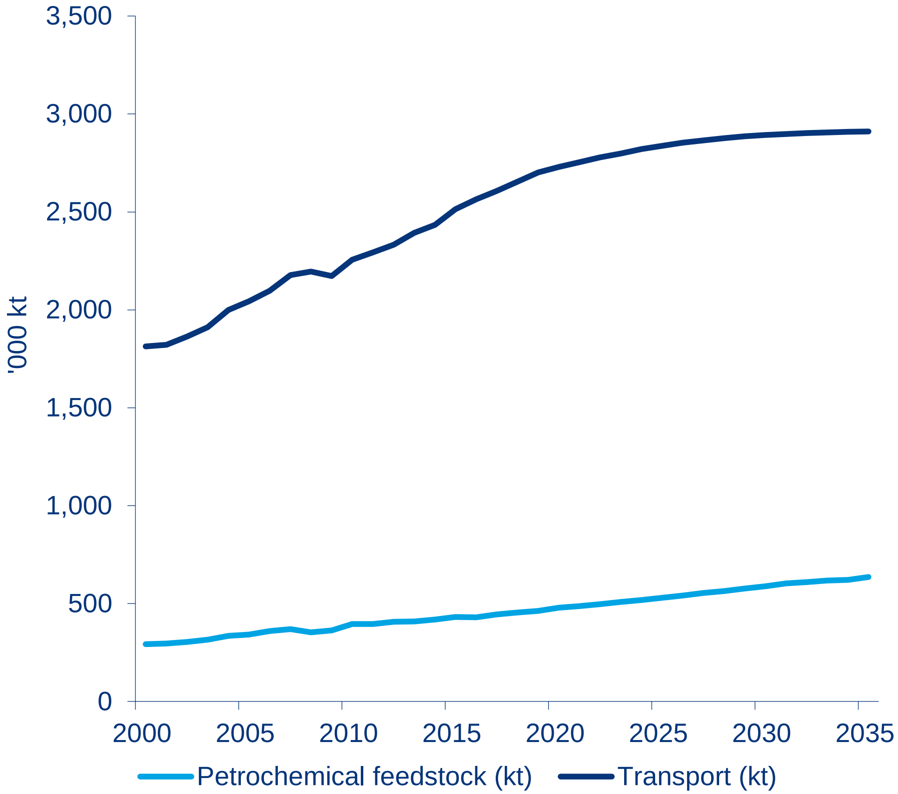
Market trends impacting fuels and chemical values

Value uplift in integrated sites

Demand for transport fuels eclipses petrochemical feedstock 5x over

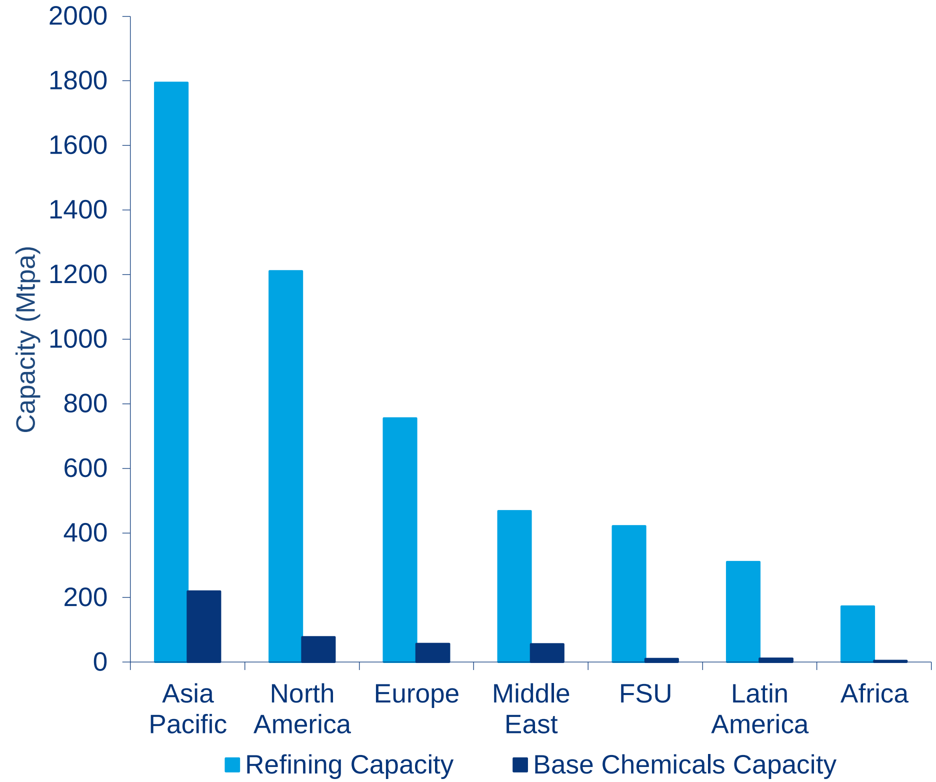
The scale difference in refinery capacity versus chemicals reflects this fact

Petchem feedstock vs. Transport demand, kt



Source: Wood Mackenzie

Refinery vs. chemicals capacity, Mtpa



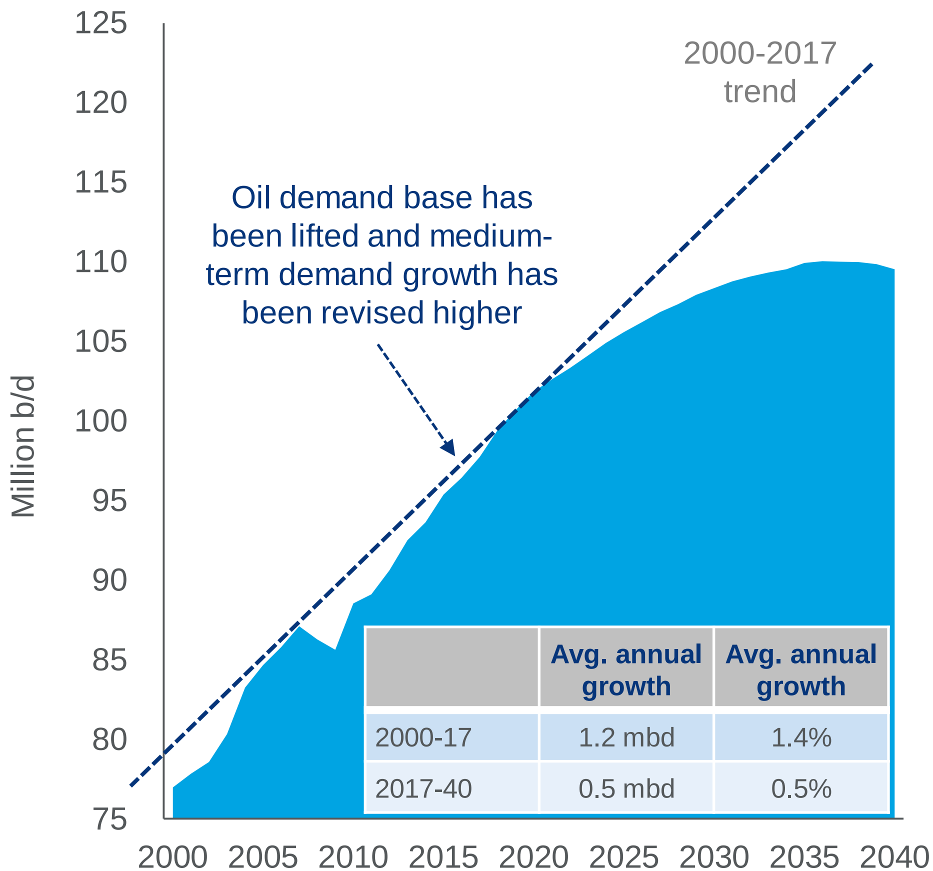
Source: Wood Mackenzie

Source: Wood Mackenzie

Demand growth for base petrochemicals is to outpace that of transport fuels, so many refiners are seeking forward integration

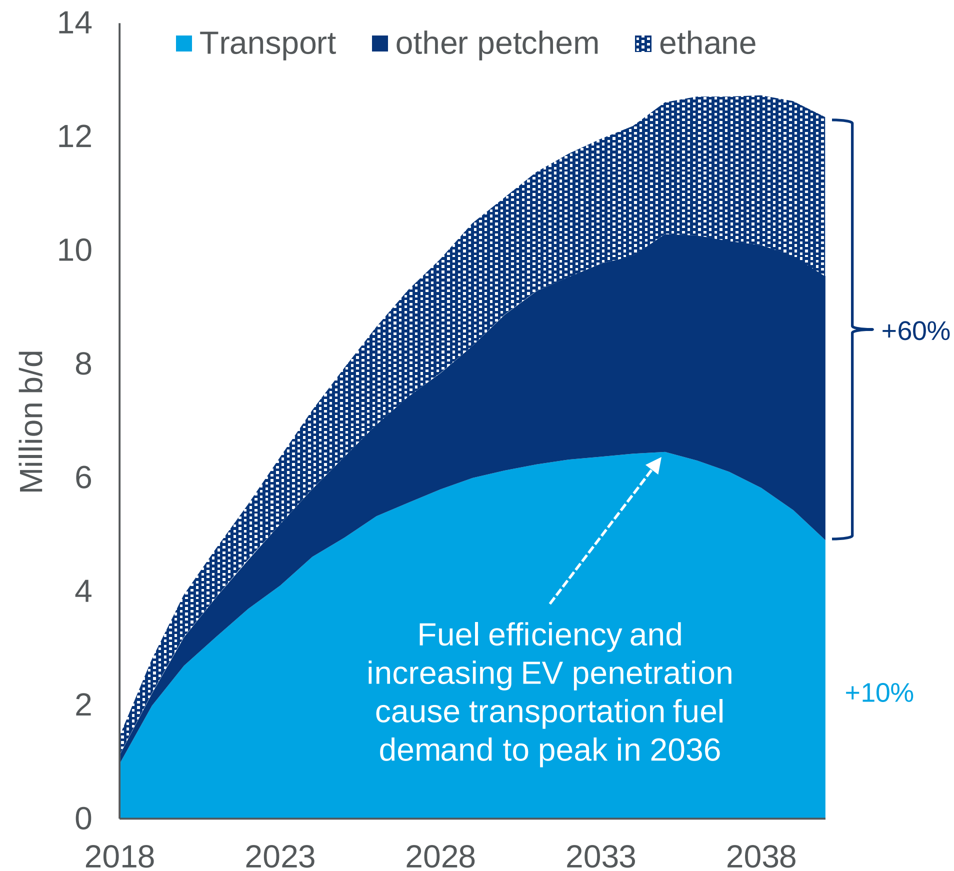
Of the 12 million b/d of growth to 2040, petrochemical feedstocks account for over half

Global oil demand



	Avg. annual growth	Avg. annual growth
2000-17	1.2 mbd	1.4%
2017-40	0.5 mbd	0.5%

Change in oil demand from 2017



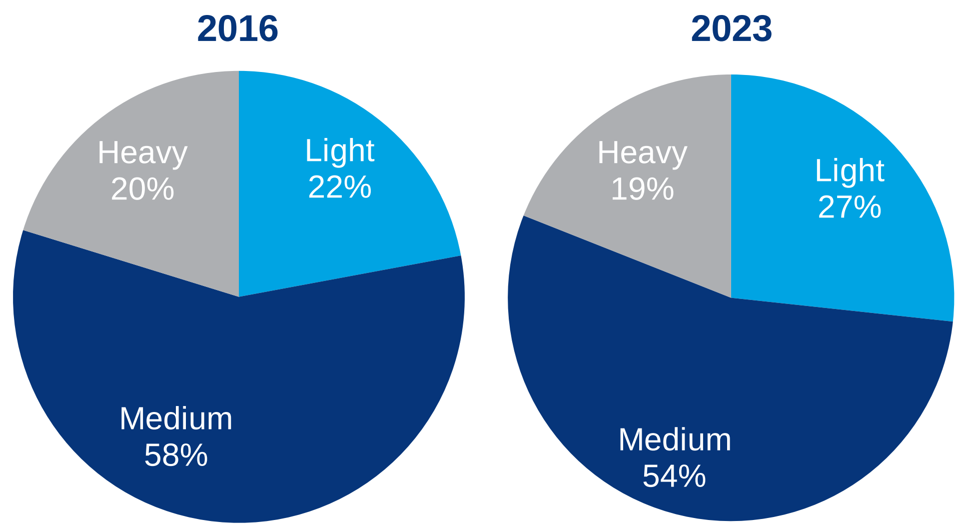
Source: Wood Mackenzie

Global crude slate lightens by about 5%, which leads to higher lighter products relevant for chemical integration

Crude choices should be based on integrated site economics

Global crude processing by quality vs 2016, Million b/d

Global crude slate by quality (%)

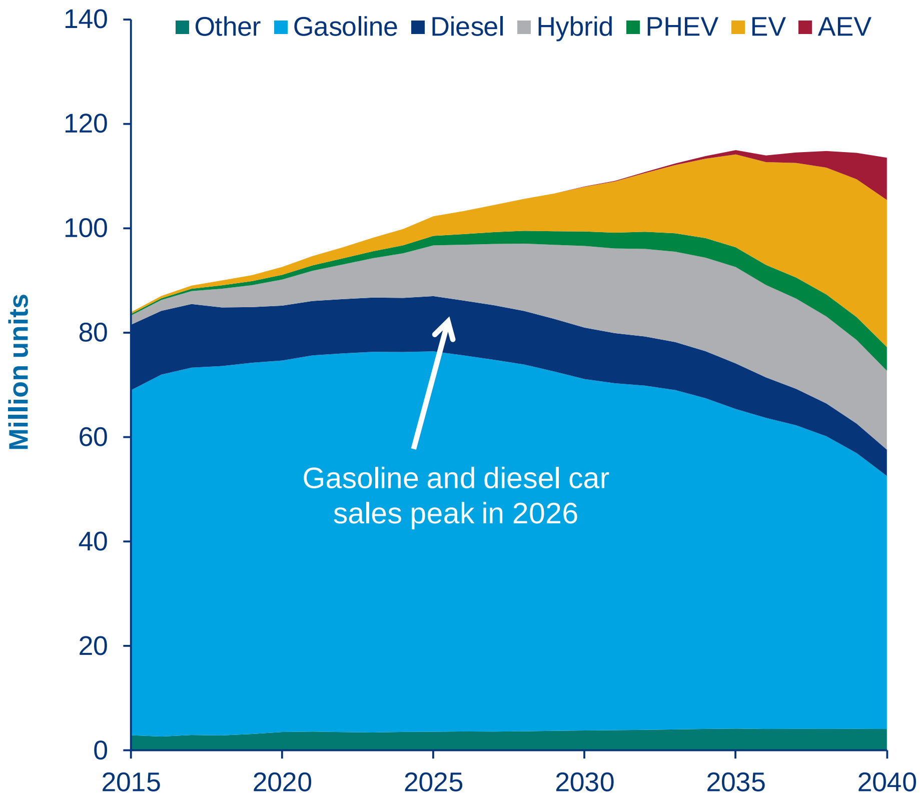


Source: Wood Mackenzie Product Market Service, Crude trade

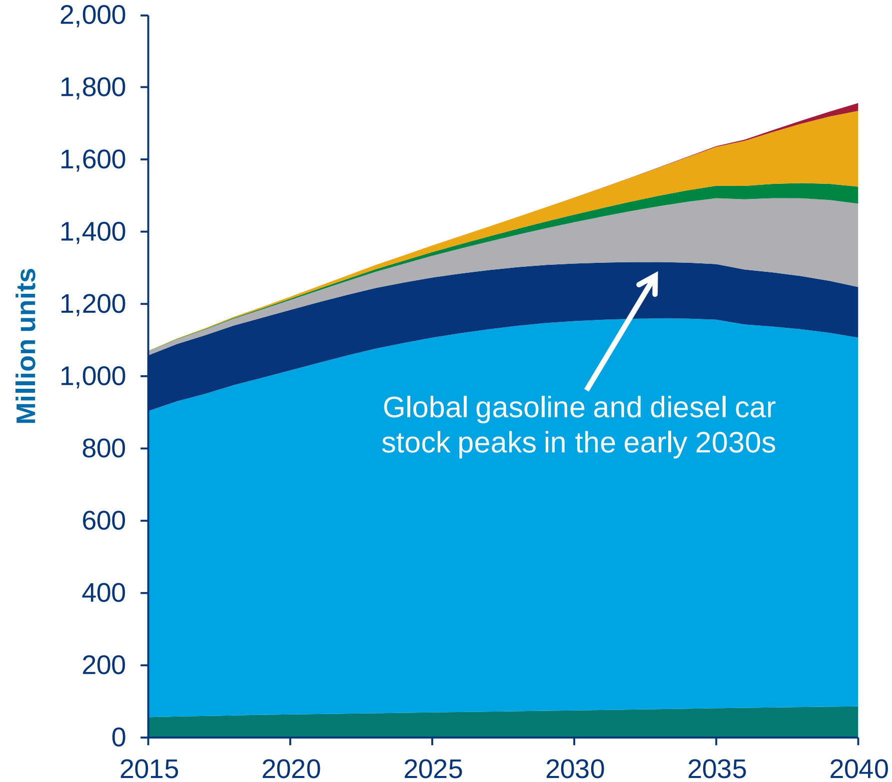
Global EV sales accelerate in the 2030s as battery costs fall, but it takes time to impact the global vehicle fleet

Even with the shift to EVs in the developed world, the global ICE vehicle stock does not peak until the early 2030s. However, EV's dampen demand growth rates

Global passenger car sales by type



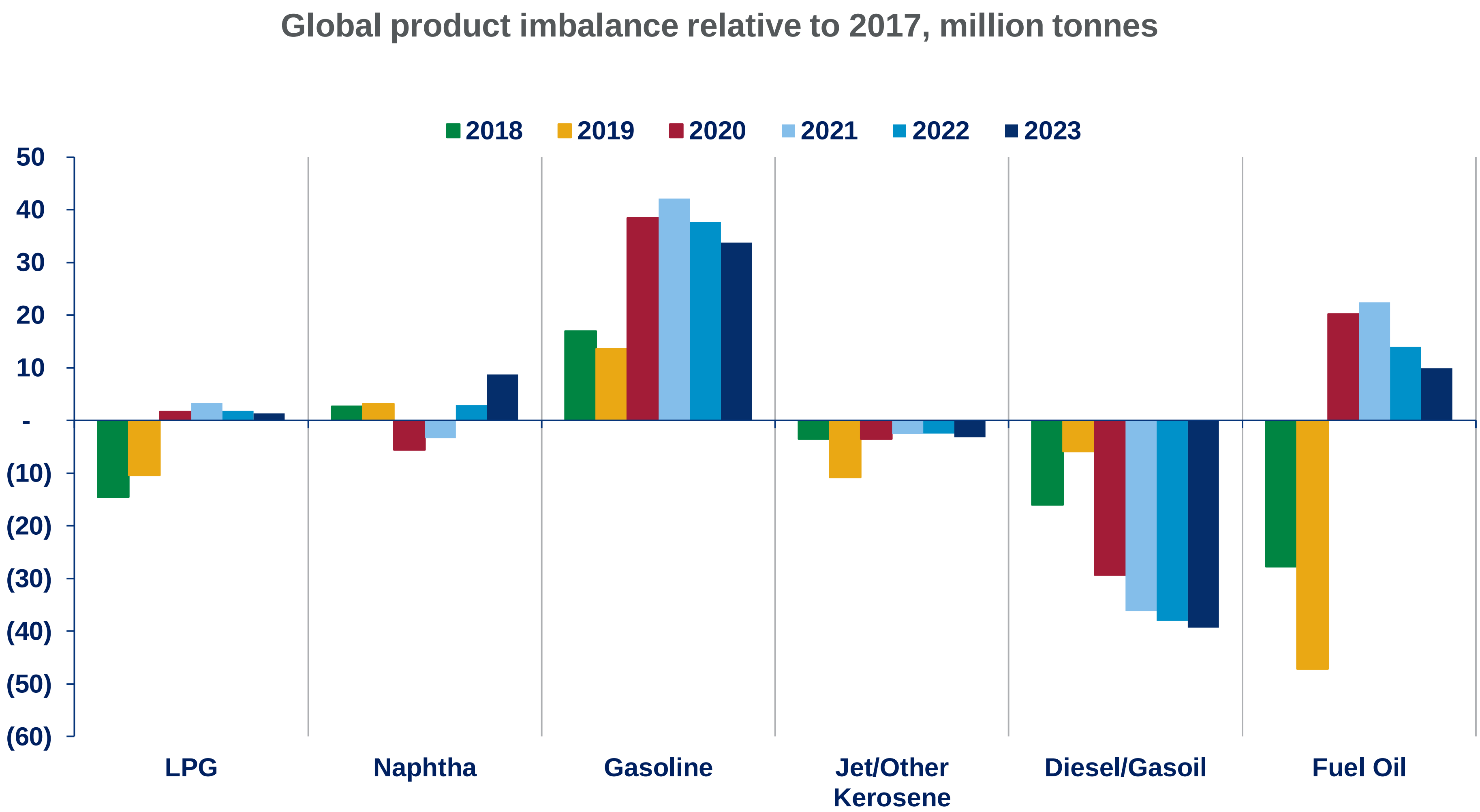
Global passenger car stock by type



Source: Wood Mackenzie

Globally, gasoline is long to 2023, suggesting weak crack spreads

IMO and slowing gasoline demand growth leads to refining returning to being distillate led

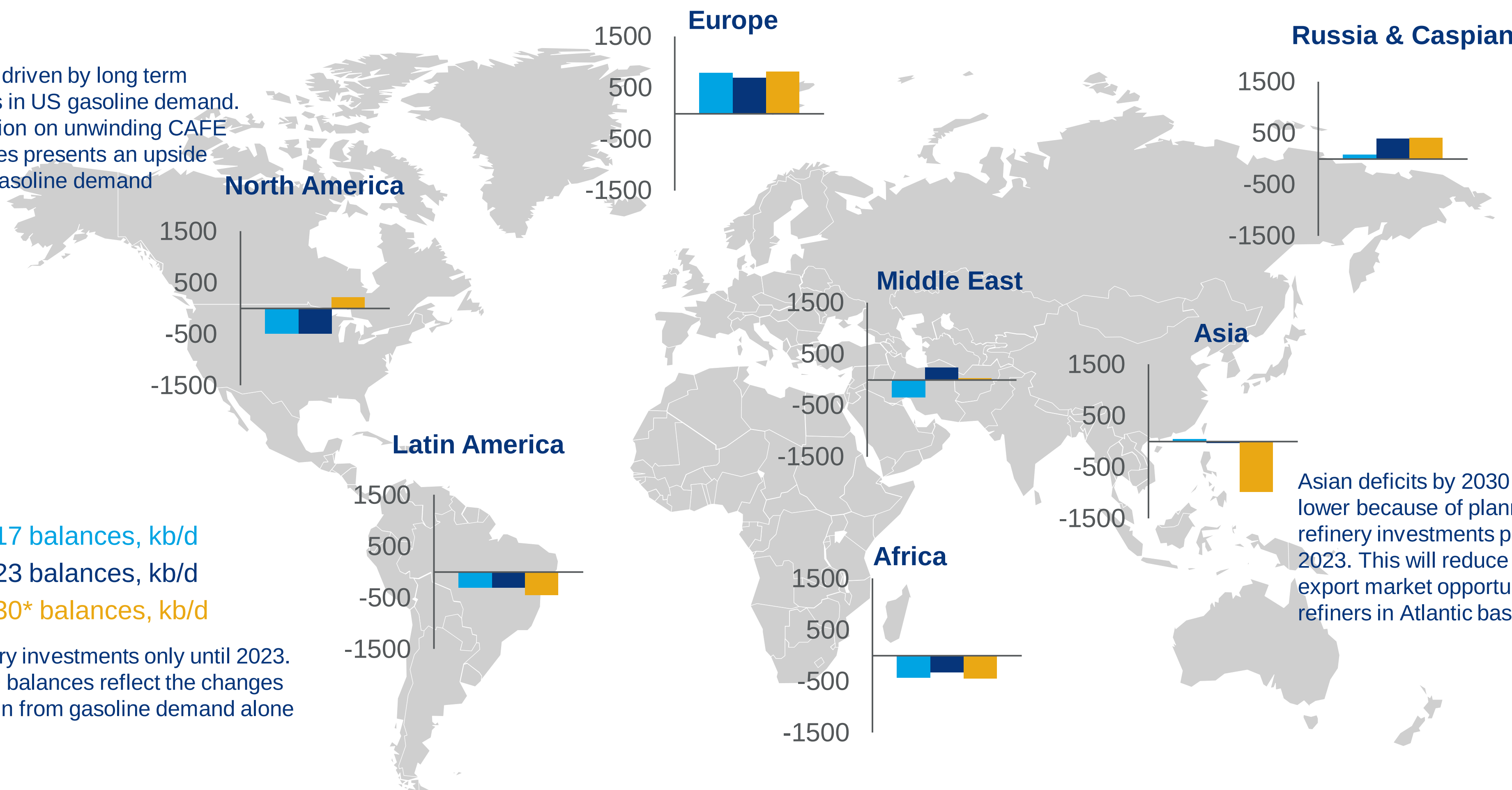


Gasoline surplus in some markets could lead to more availability of chemical feedstocks for integration opportunities

Question for markets with gasoline surplus: Export gasoline or transform it into chemicals?

Gasoline balances, 2017 to 2030

Surplus driven by long term declines in US gasoline demand. Discussion on unwinding CAFE mandates presents an upside risk to gasoline demand



Asian deficits by 2030 will be lower because of planned refinery investments post 2023. This will reduce the export market opportunity for refiners in Atlantic basin

2017 balances, kb/d
2023 balances, kb/d
2030* balances, kb/d

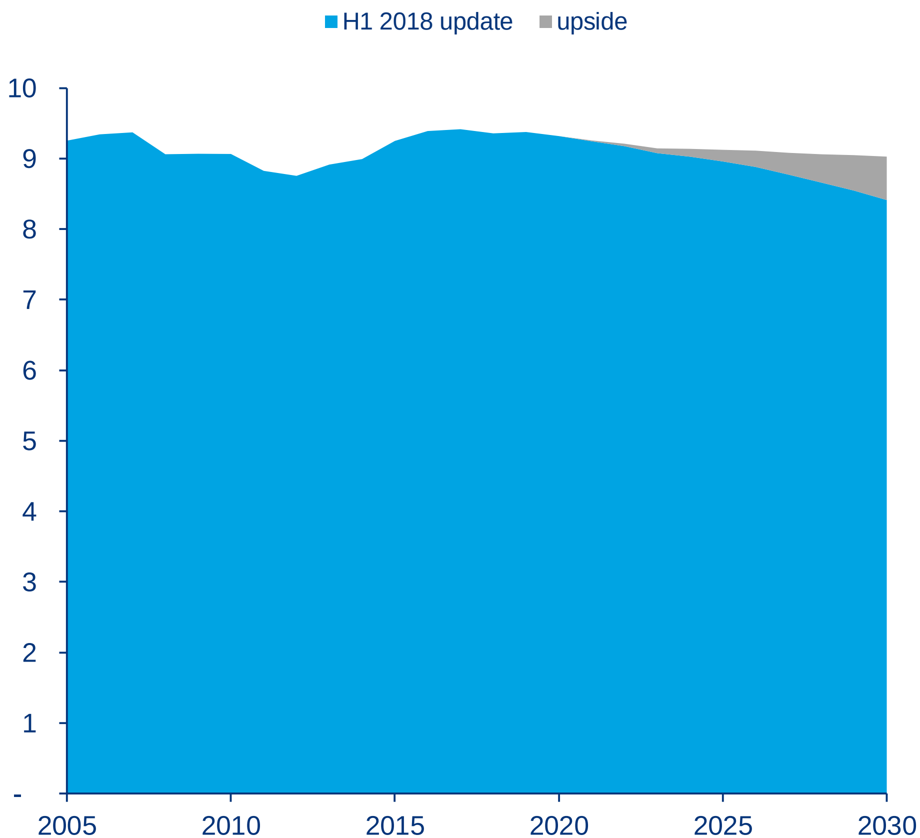
* Refinery investments only until 2023. So 2030 balances reflect the changes coming in from gasoline demand alone

Source: Wood Mackenzie Product Markets Service

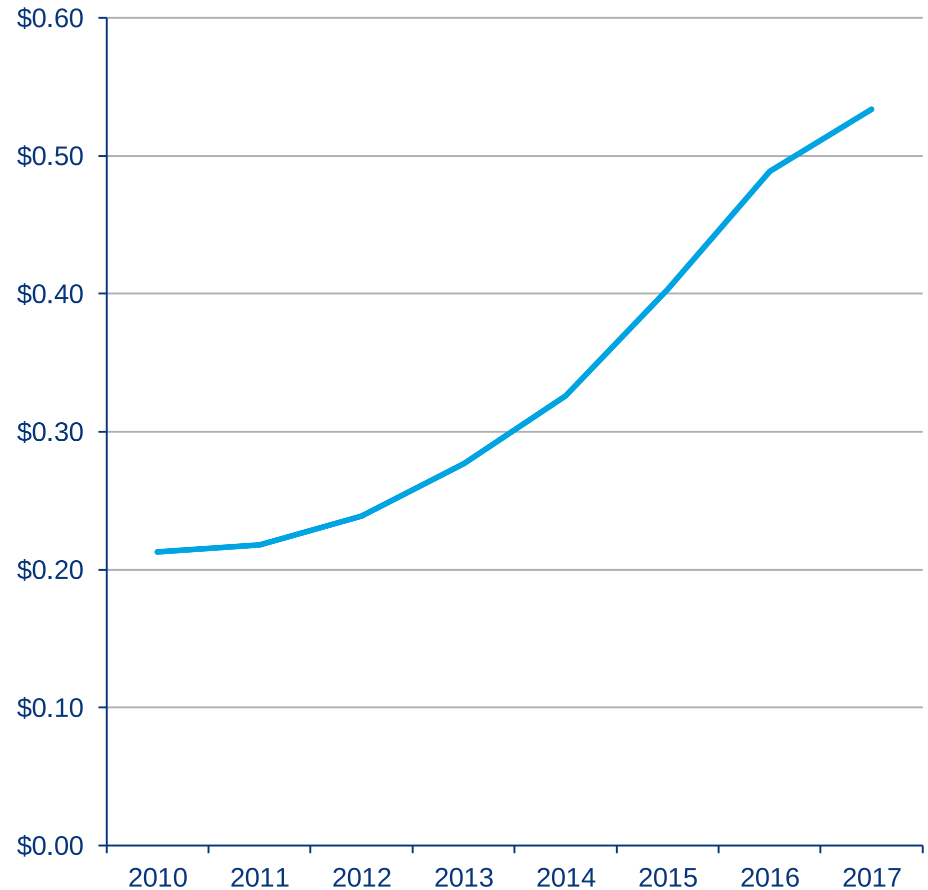
Trump Administration's review of CAFE standards poses slight downside risk to octane

However, natural turnover of vehicle fleet should continue to pull more premium gasoline into the fuel pool

US Gasoline CAFE standard upside risk (million b/d)



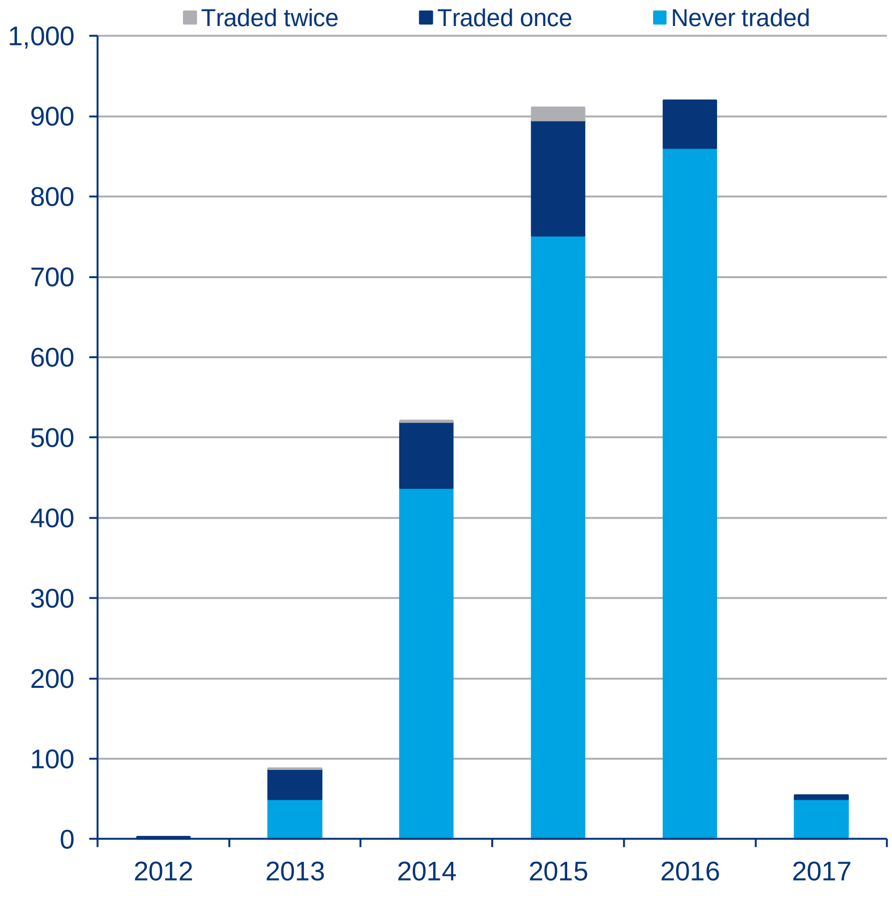
PADD II Street Octane Spread ($/USG) – conventional areas



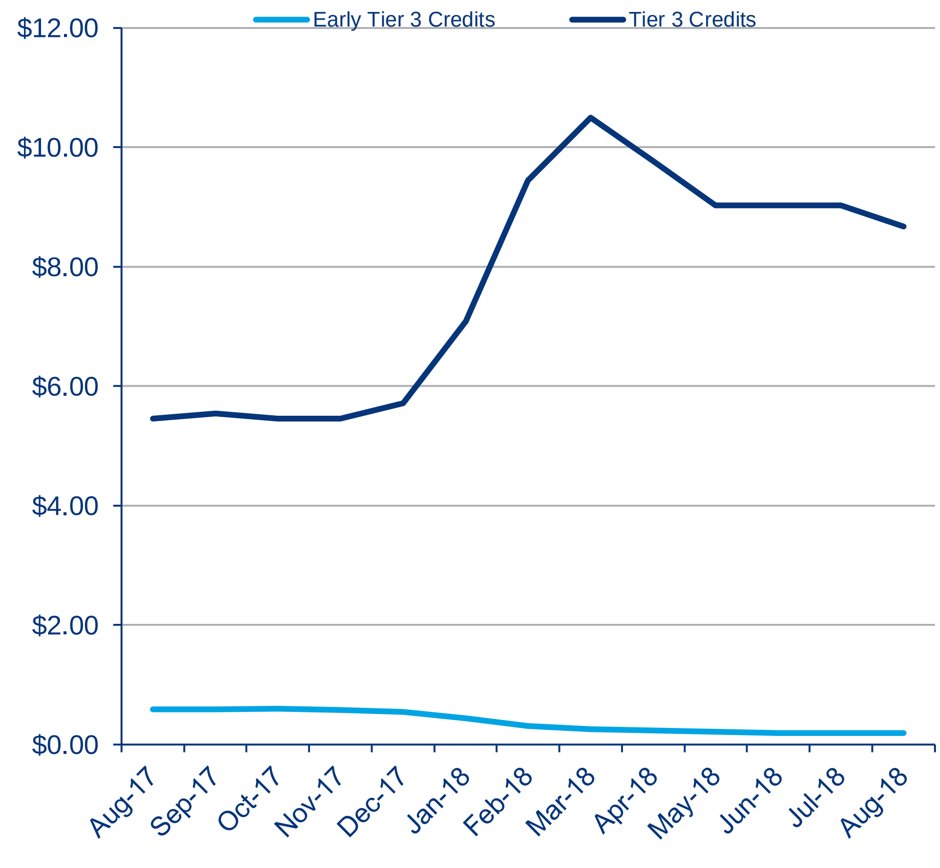
US gasoline sulfur credits demonstrating high cost of additional hydtrotreating

Increased severity is adversely affecting aromatic content of gasoline blend pool, boosting octane

Supply of Tier III sulfur credits (billions)



Price of Tier 3 credits ($/bbl gasoline)

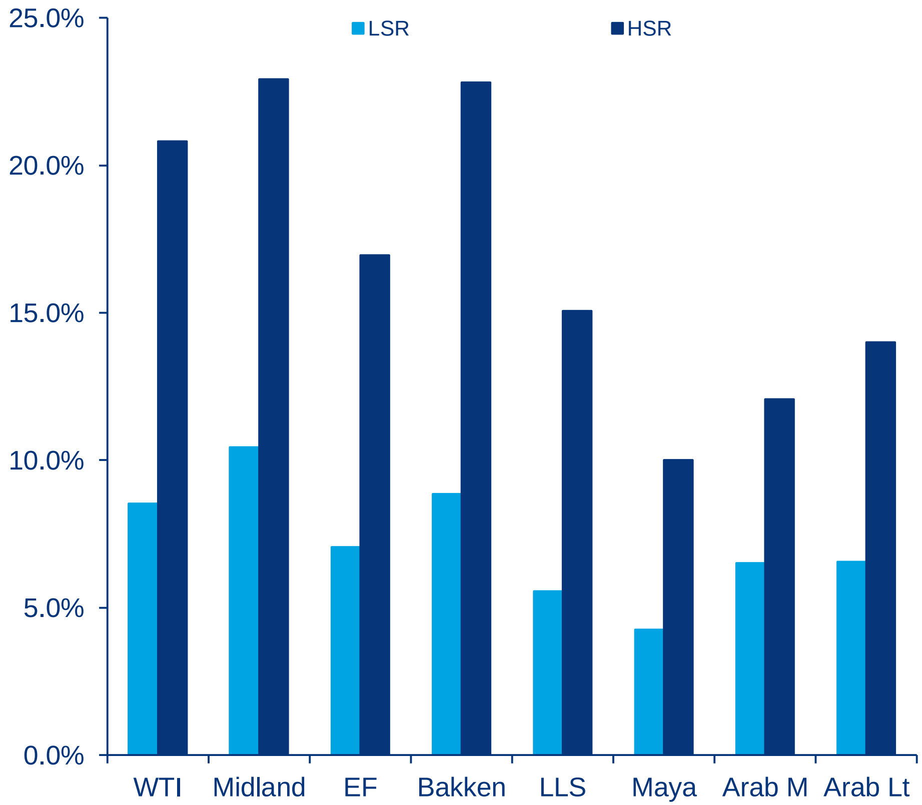


Source: Argus, EIA

Increased paraffinic naphtha, hydrotreating severity, and production of turbo-charged engines all point to a strong future for octane

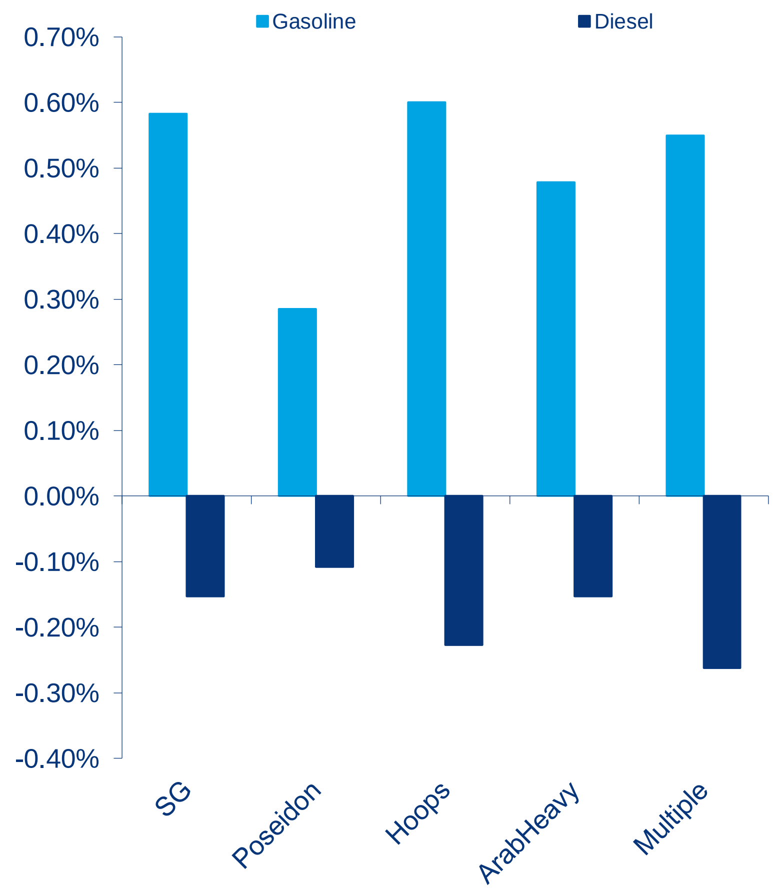
Main US light crudes have ~10% higher average gasoline-range yields than traditional foreign crudes

Light ends yields of various crudes



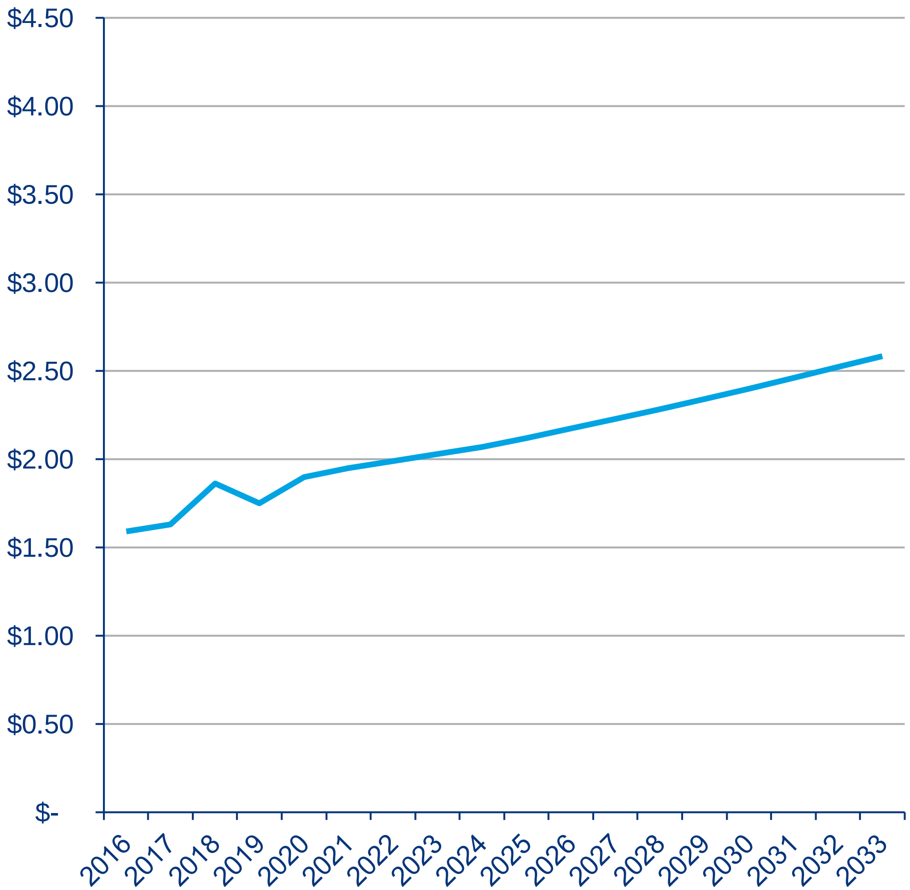
Source: Wood Mackenzie

Shift in yields by switching to WTI

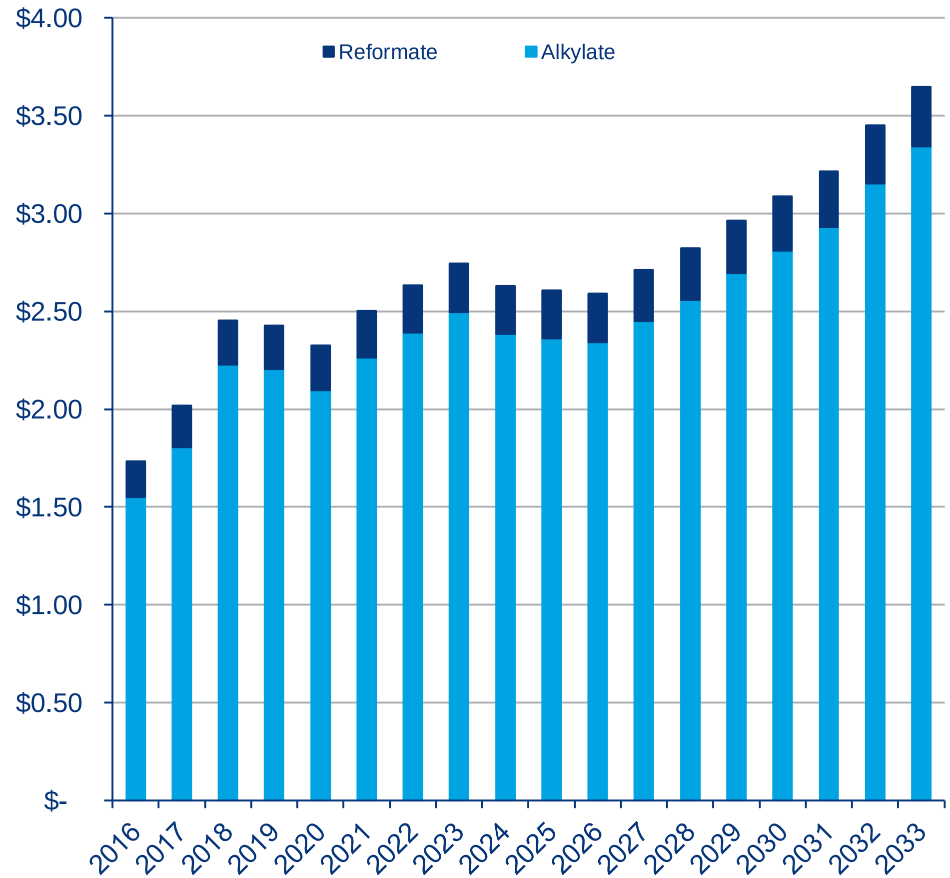


Reformate and alkylate likely to see upward pressure over forecast

US Gulf Coast Octane forecast ($/gallon)



US secondary unit gross margins ($/gallon)



A steam cracker integrated with a refinery allows the flexibility to vary its feedstock and to optimize its production

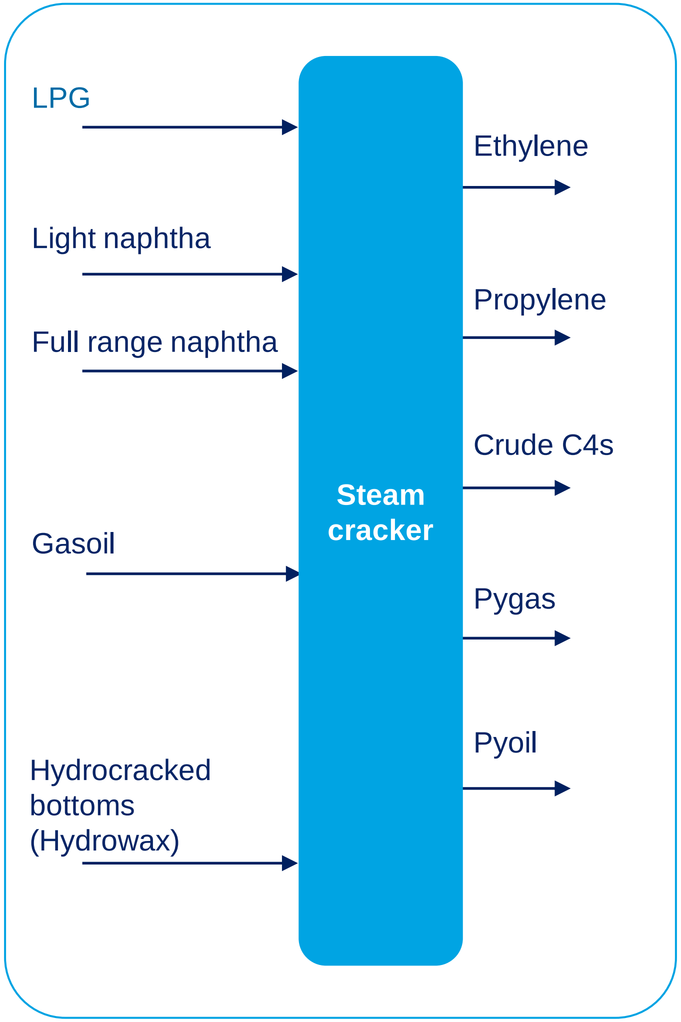
Security of feedstock supply to a steam cracker is also a key advantage of integration

Optimisation - feedstock

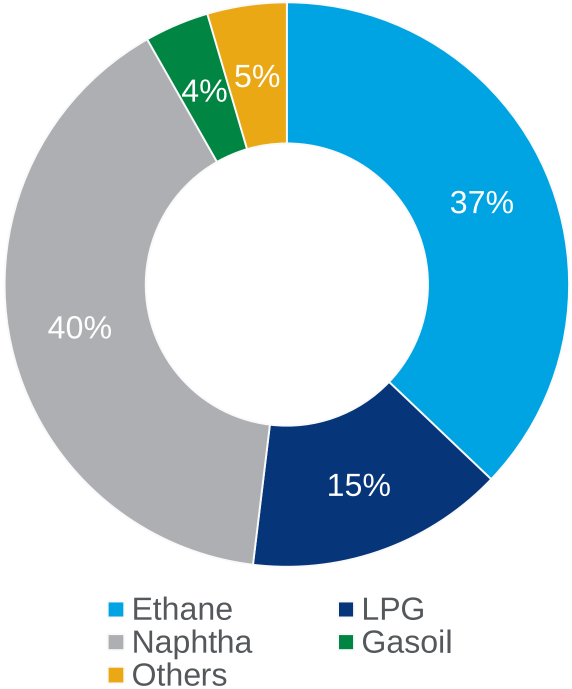
- LPG vs naphtha feed
- Cracker feed vs fuel sales vs refinery fuel optimization
- Naphtha imports vs condensate/ crude processing
- Hydrocracker conversion optimization
- HCU bottoms to FCCU or steam cracker?

Optimisation - products

- Crude C4s: Butadiene vs gasoline
- Pygas: Aromatics extraction vs gasoline
- Pyoil: Upgrade, fuel oil blending or ULSFO (IMO)



Global ethylene production by feedstock (2017)

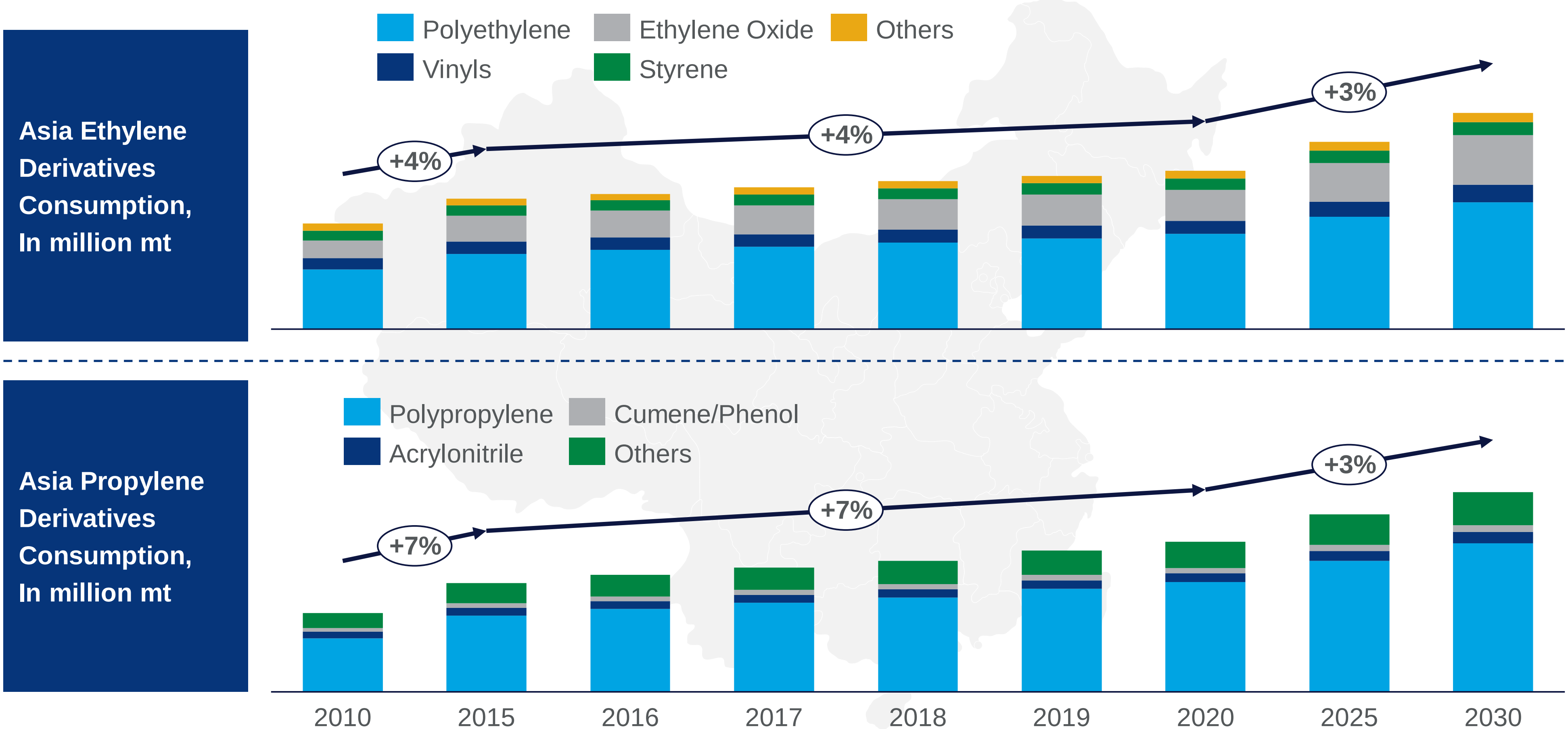


~60 % of the global ethylene production is based on liquid feedstocks (LPG, naphtha, gasoil), which are derived mostly from refinery streams.

Source: Wood Mackenzie

Petrochemical feedstock demand growth fundamentally driven by olefins derivative demand growth…

Asia's olefin derivative demand is growing (ethylene) and growing rapidly (propylene)

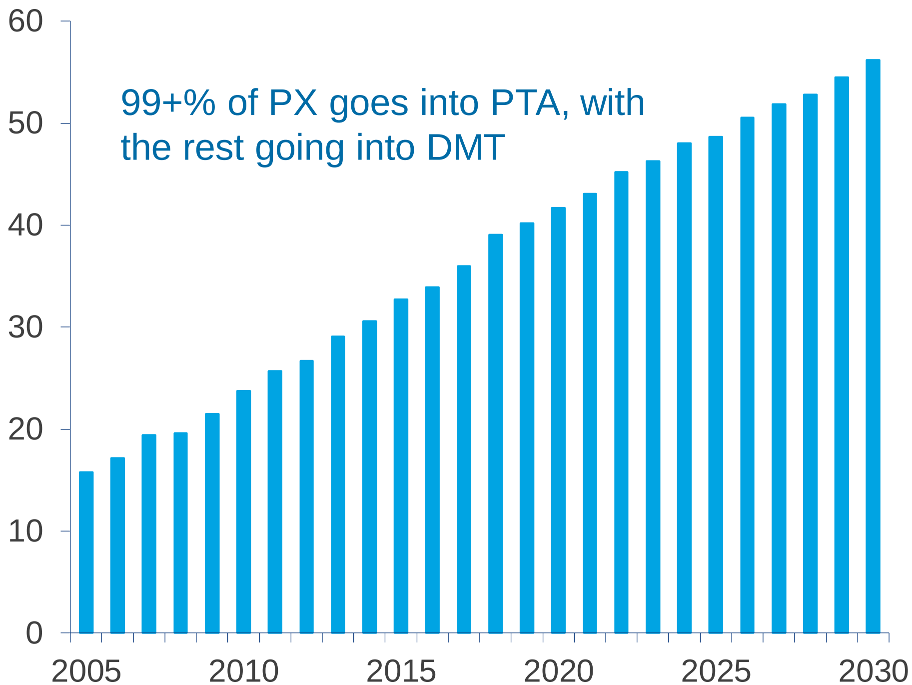


Source: Wood Mackenzie Chemical Ethylene and Propylene Global Supply and Demand Analytics Service

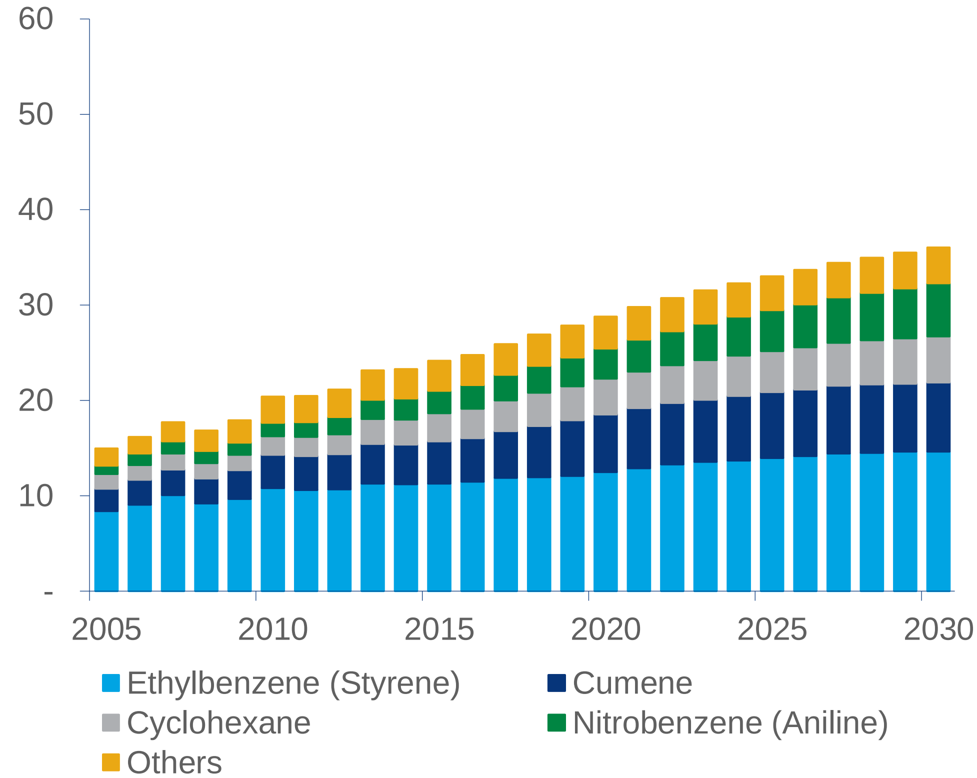
…and aromatics derivative demand growth

Asia aromatics derivatives: Growth in Polyester chain continues to drive PX demand

Asia PX consumption into PTA/DMT (Mtpa)



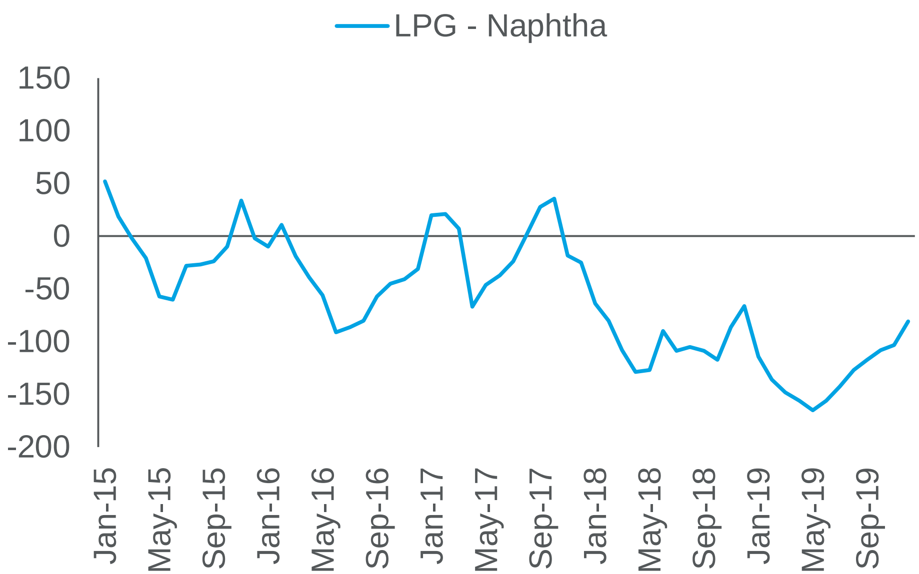
Asia Benzene Direct Consumption (Mtpa)



Source: PCI Wood Mackenzie

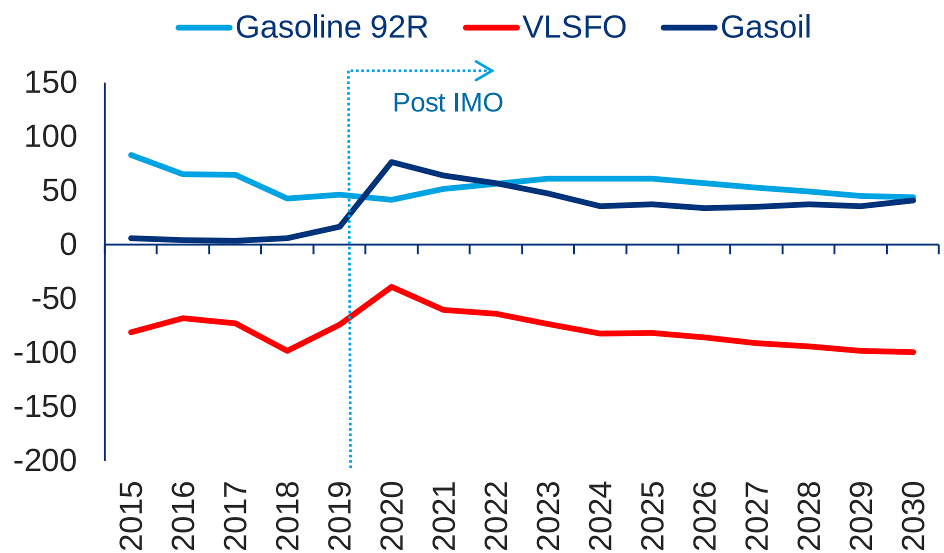
Oil price volatility and refining markets will influence steam cracker feedstock prices, choices and economics

Singapore product spreads (short term), $/t



- Both LPG and naphtha prices rises with oil price recovery, but LPG prices lag behind in the longer term to remain attractive as steam cracker feedstock
- Increasing flexibility to crack LPG an option – also enables to capture short term fluctuations

Singapore product spreads vs naphtha, $/t



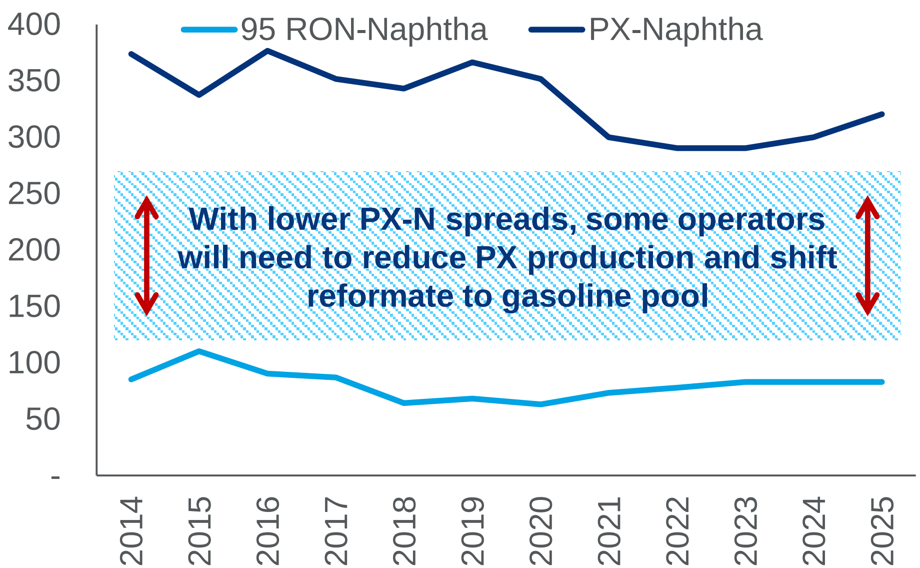
- Naphtha values linked to gasoline market. Weaker gasoline and stronger naphtha narrows gasoline and naphtha spread
- Cracker feedstock gasoil and hydrowax expected to become more valuable post IMO as they could be used as VLSFO (very low sulphur fuel oil, S < 0.5 wt%) blending component for bunker market if segregation allows
- Economics of gasoil cracking expected to diminish. Potential to switch to naphtha if flexibility allows

Source: Wood Mackenzie Product Markets Service

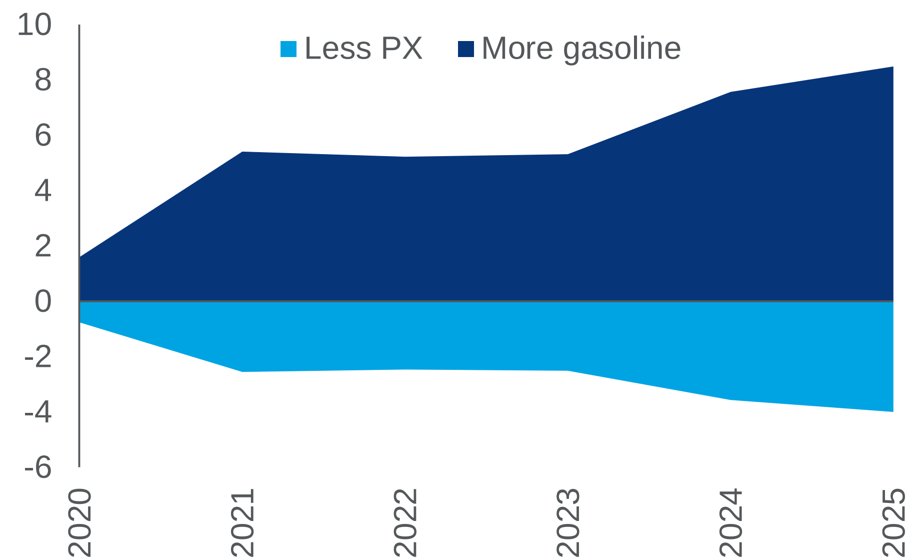
Medium term PX markets add more pressure to gasoline

Additional gasoline from South Korea and Japan could range from 150-200 kb/d by 2025

Asia spreads versus naphtha, US$/t



South Korea and Japan PX and gasoline production vs. 2017, Mt



Shift towards gasoline would depend upon

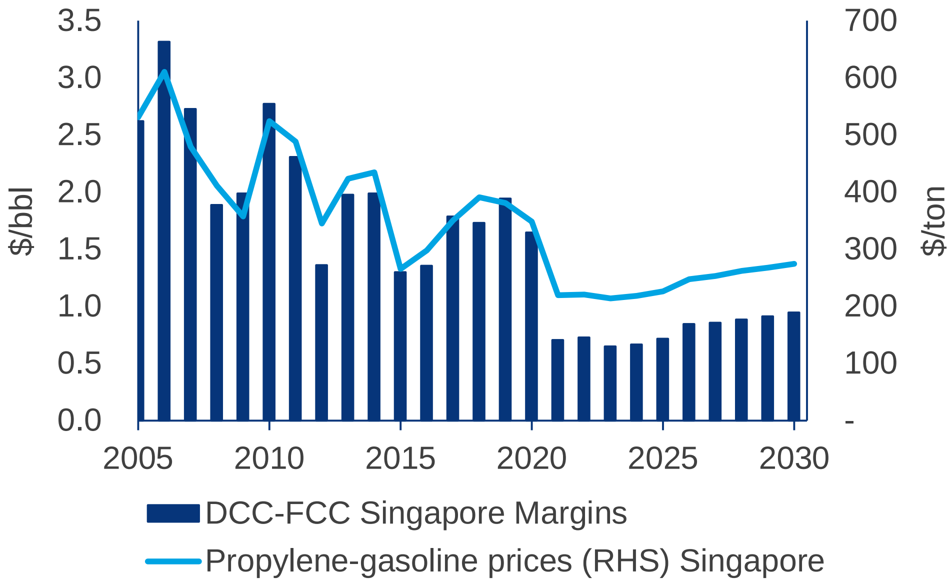
- Where does the site lie on the PX cost curve?
- Relative export competitiveness in PX and gasoline markets
- Will the additional volumes be made available as reformate for blending, as finished gasoline or as naphtha?

- Higher supply of PX from Chinese projects leads to lower utilisation of PX exporters in South Korea and Japan
- More gasoline supply, as a result, could be absorbed in Asian deficit markets, mainly South east Asia.
- But this reduces the opportunity for gasoline exporters and adds to a global gasoline weakness that we are expecting

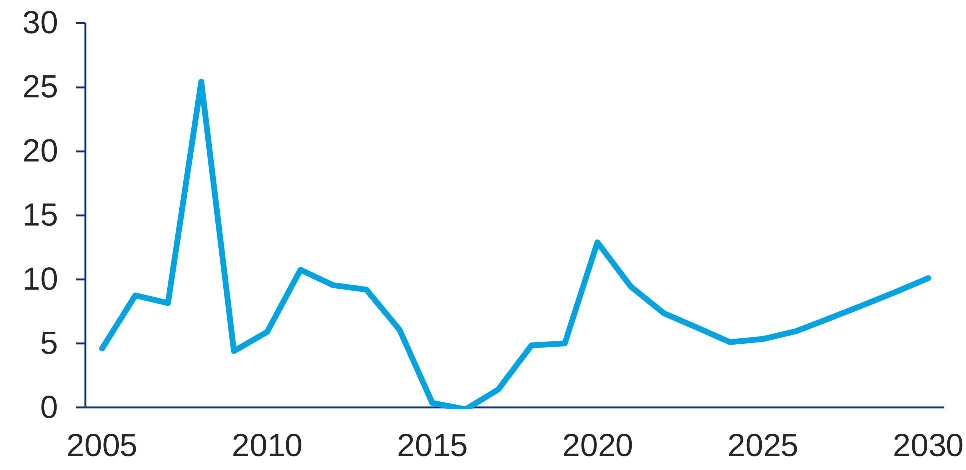
Source: Wood Mackenzie Product Markets Service, Chemical Market Service

FCC refiners dilemma – gasoline, propylene or diesel?

FCC propylene vs gasoline dynamics



Diesel vs gasoline prices (Singapore), $/bbl



- Technologies now available to increase FCC propylene to more than 20 wt% at FCC outlet
- With DCC (deep catalytic cracking) a refiner increases propylene yield by ~5 wt% at refinery gate
- Higher CAPEX/OPEX for propylene mode - What is the optimal propylene production? Is there sufficient scale to integrate with downstream PP facilities?

- Forecast diesel cracks are much higher than gasoline cracks
- Standalone gasoline focused FCC margins expected to be weak Higher LCO in FCC – by changing catalyst or new technologies
- Higher processing cost for LCO
- Bypass VGO feed to FCC towards diesel pool (IMO regulation)

Source: Wood Mackenzie Product Markets Service, Chemical Market Service

Drivers of integration

Market trends impacting fuels and chemical values

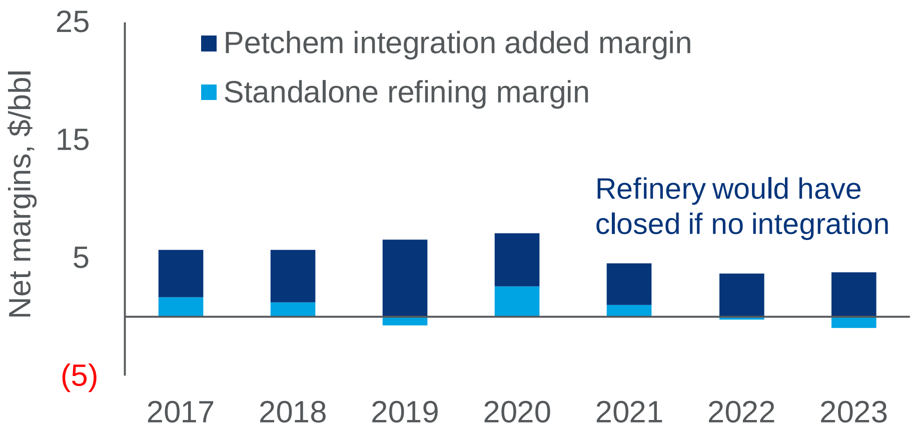
Value* uplift in integrated sites

*

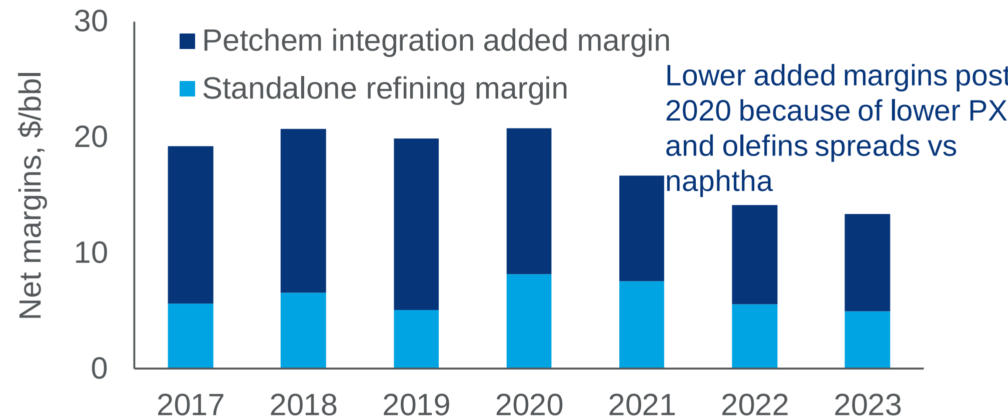
- Economics are very site-specific, depending on market pricing, technologies and configurations used and location.
- The economics discussed only include base chemicals PX, benzene, ethylene, propylene and crude C4s values and not for further derivative chemicals.

Petrochemicals add value in all configurations. But benefits vary by site, relative values of fuels/chemical and over time

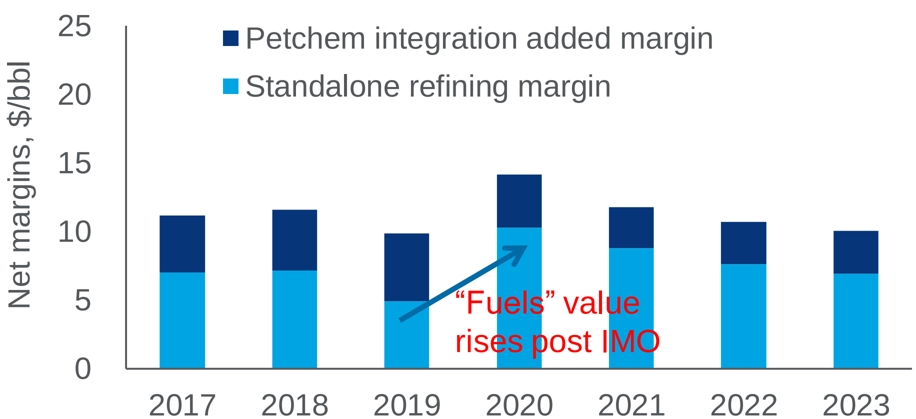
Site 4 – HSKIM refinery + Aromatics (A)



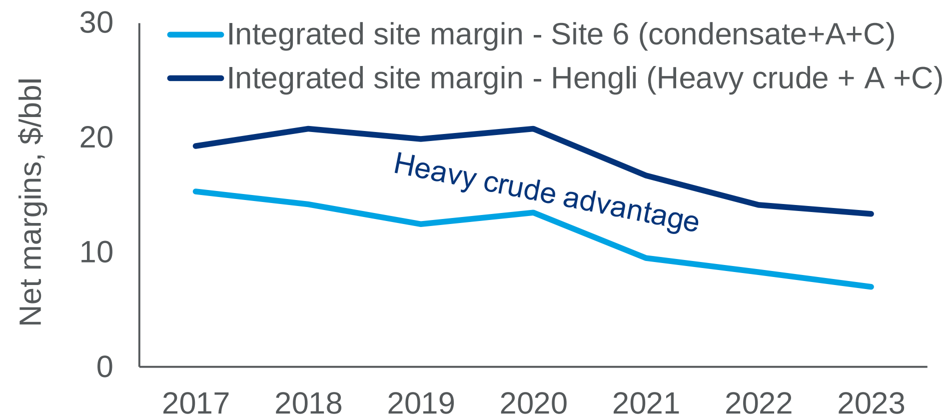
Site 7 Hengli – H-Oil/HCU + Aromatics + Cracker



Site 5 – HCU/RFCC + Aromatics (A) + Cracker (C)



Site 7 (Hengli) and Site 6 margin comparison

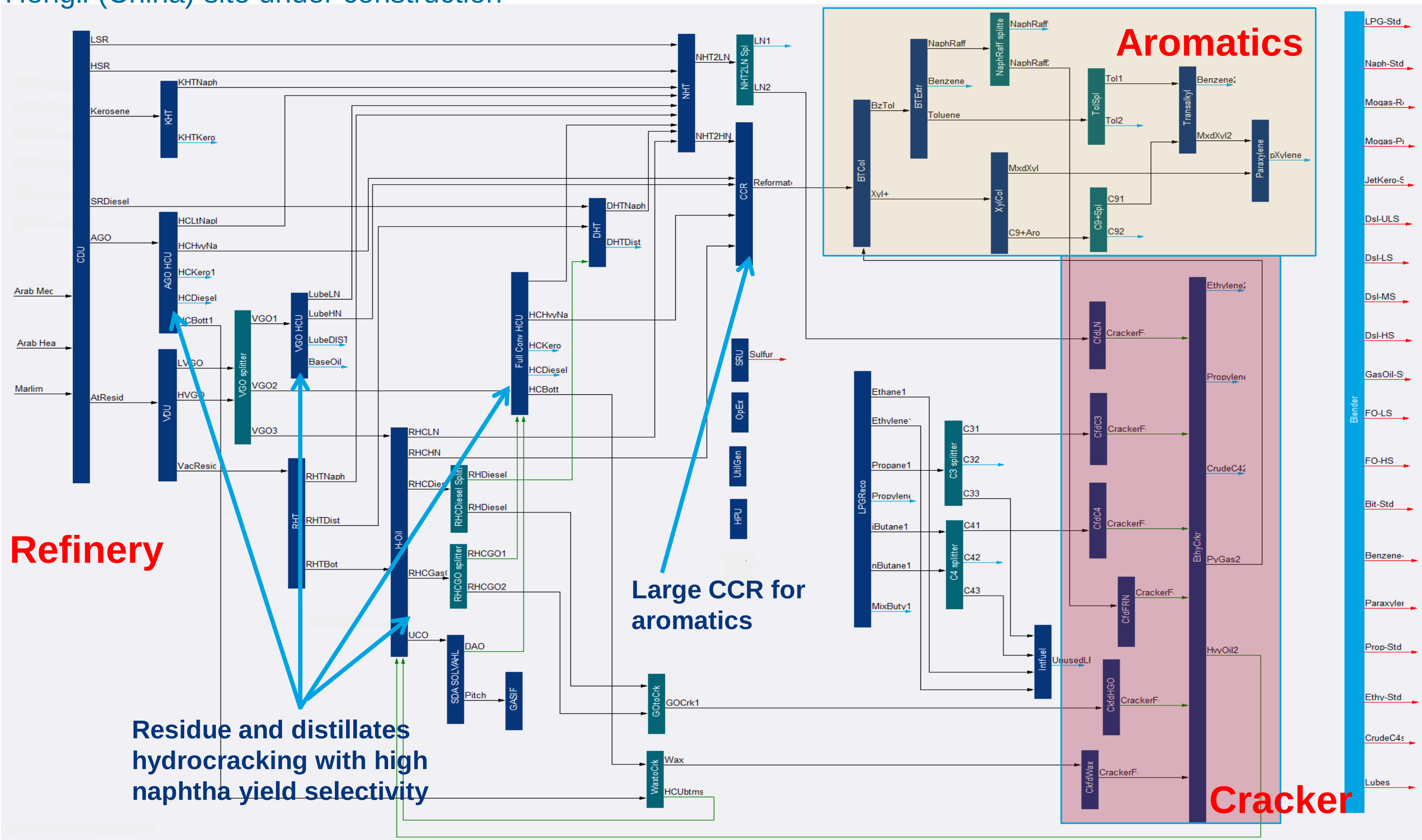


Source: Wood Mackenzie Product Markets Service, Chemical market service, Petro Plan

New mega sites being developed in China are complex with deep integrated with chemicals

High CAPEX for such sites impacts ROI and development timelines.

Hengli (China) site under construction

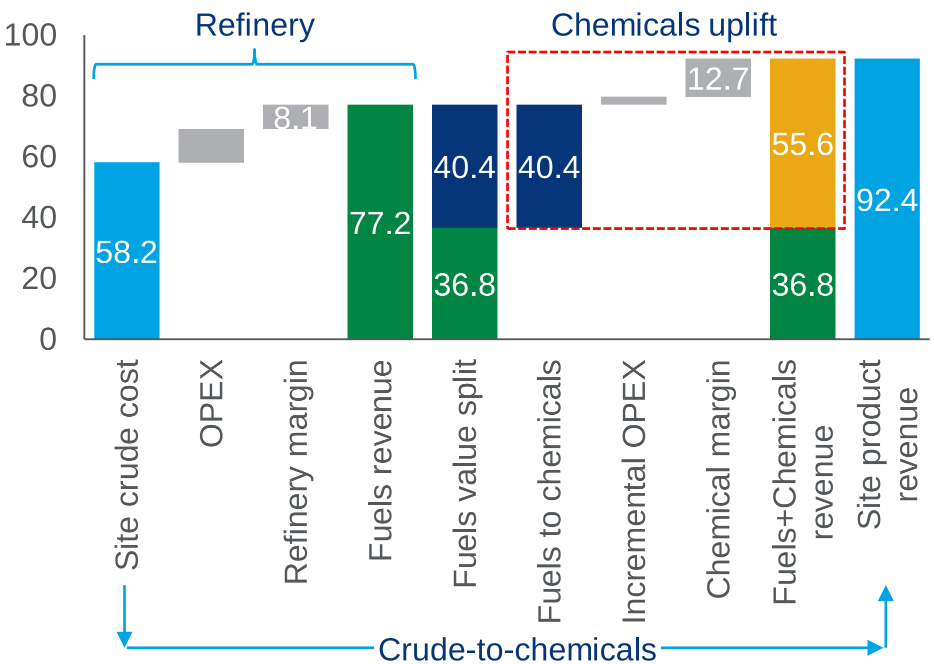


Source: Wood Mackenzie Refinery Evaluation Model, Petro Plan

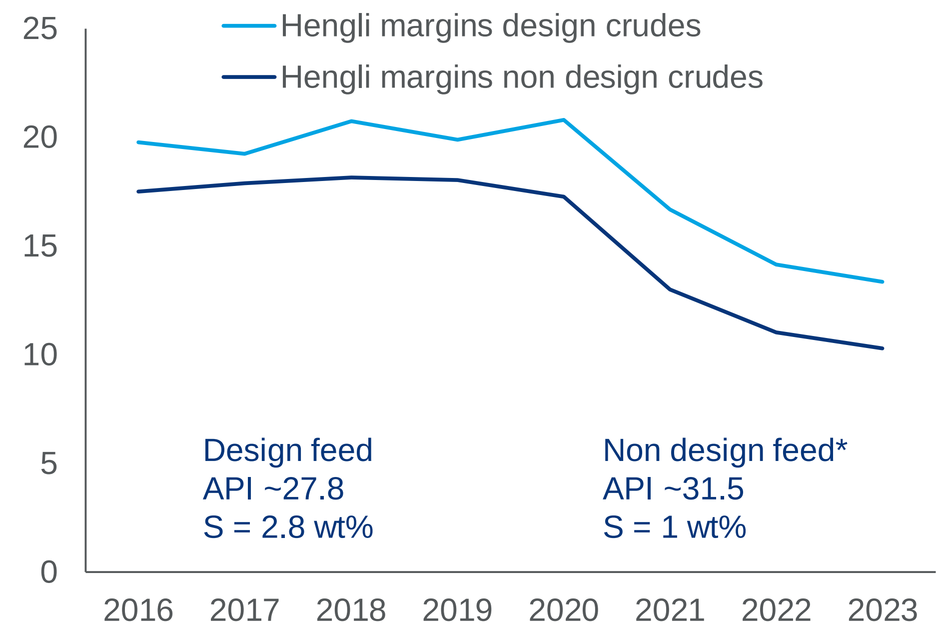
But once built these integrated sites are competitive on cash costs

Some of these sites are being built for long-term feedstock security in heavy naphtha

Hengli margins and value build-up (2020), US$ for every barrel of crude



Hengli integrated site net margins, US$/bbl



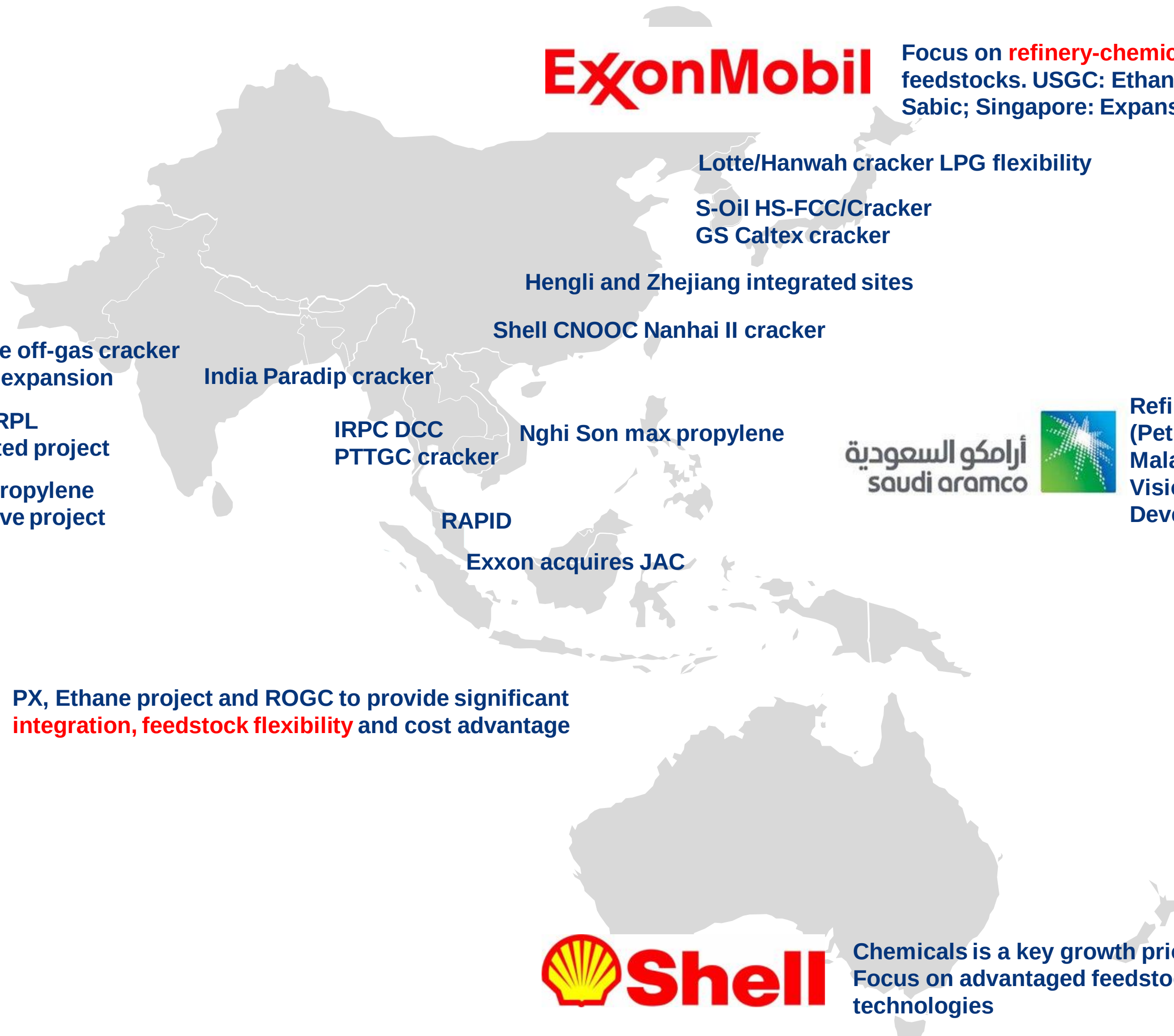
- Location will be a key driver in overall project economics
- Relative fuels/chemicals pricing, utility fuel costs, relative crude freight, will all impact relative project economics in various locations of these mega projects

- Lower PX-naphtha spreads post-2022 reduce the value-add from aromatics
- Margin loss because of sub-optimal feed varies from $2/bbl to $4/bbl, based on market environment

Source: Wood Mackenzie Product Markets Service, PetroPlan

* Non design feed assumed at similar levels to average Sinopec/Petrochina

Integration between refinery and chemicals is an important growth strategy for a number of companies and projects in Asia



ExxonMobil: Focus on refinery-chemical integration or advantaged feedstocks. USGC: Ethane-to-PE Complex & JV plans with Sabic; Singapore: Expansions & Jurong Aromatics acquisition

Saudi Aramco: Refinery-chemicals integrated JVs in Saudi (PetroRabigh / Sadara / SATORP), Korea (S-Oil), Malaysia (RAPID), China (Fujian), Motiva (US) Vision 2030; Oil-to-chemical technology Development

Reliance Industries Limited: PX, Ethane project and ROGC to provide significant integration, feedstock flexibility and cost advantage

Shell: Chemicals is a key growth priority for Shell for 2020+ era. Focus on advantaged feedstock, big integrated sites and new technologies

Conclusions

- Refiners need to explore ways to mitigate the slowing growth in demand from transport and look to align their production in generating feedstock for chemicals.
- Non-integrated refiners and petrochemical producers with less flexibility will be more vulnerable to market risks.
- There are a number of ways and opportunities for refiners and chemical producers to unlock the integration synergies.
- There is no one-size-fit-all option. Right option needs a holistic approach to look at your product opportunities, configurations, technologies and return on capital.

- *What are your sweet spots? Investigate your options and investment decisions:*
  - » Model your refinery in **PetroPlan** with/without chemical units. Assess market risks, competitiveness versus peers and various integration options
  - » Assess downstream competitiveness with **Ethylene Asset Cost Tool** and **Paraxylene Asset Cost Tool**
  - » Explore growth areas with targeted **bespoke studies** with us

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