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European Chapter of the IPMI "8 Precious Metals" Seminar

Pd demand - focused on use in catalysts

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Overview

- Gross global palladium demand
- Autocatalyst demand
  - Emissions legislation
  - Use of Pd in aftertreatment
  - Three way catalyst
  - Gasoline particulate filter
  - Potential for substitution in gasoline
- Potential for substitution in non-auto areas
- Process catalyst demand
  - Key applications and end uses
  - China’s drive for petrochemical self sufficiency- PET and MEG
- Palladium demand conclusions

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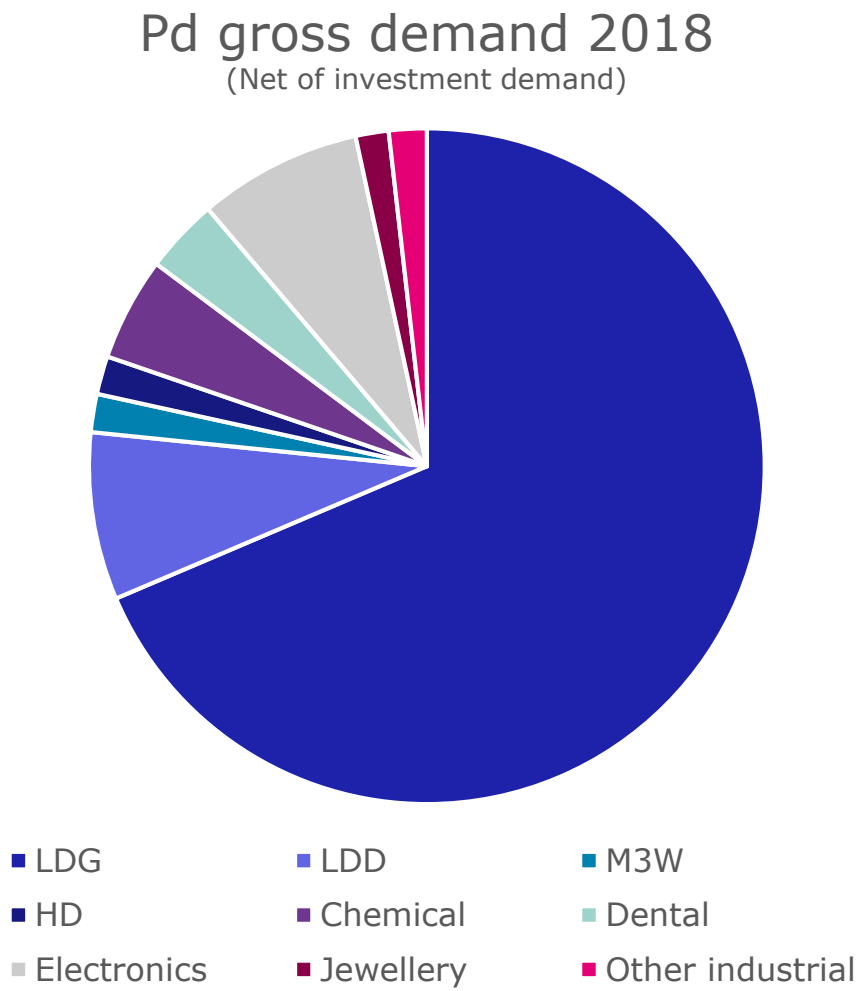
Palladium demand: gross global



- Dominated by automotive use
- (Net of physical investment) automotive demand represents 80% of total demand for palladium in 2018
- Auto demand split as follows:
  - LDG: Light duty gasoline 85%
  - LDD: Light duty diesel 10%
  - HD: Heavy duty 2.5%
  - M3W: Motorcycles & 3-wheelers 2.5%

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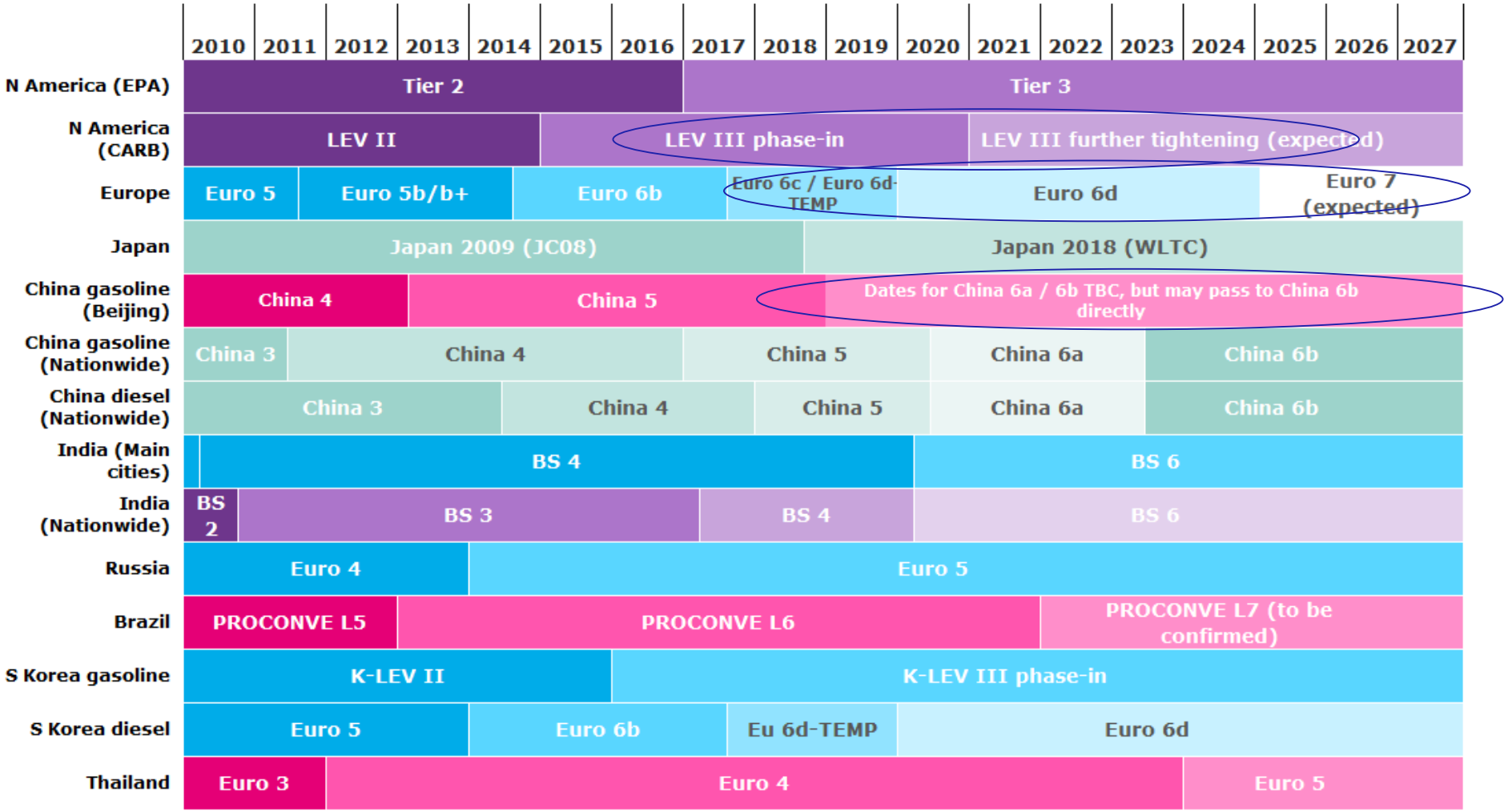
Palladium demand: gross autocatalyst

- Demand to reach 8.53 million oz in 2018
- Growth largely in line with global light duty vehicle production
- No end in sight to continued growth in demand with tightening legislation

Light duty global emissions legislation



Note for bottom: Dates shown are for New Vehicle Type Approvals for passenger cars
China dates subject to frequent change; dates shown represent best available current view

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Use of palladium in aftertreatment technologies

Gasoline

- Three way catalyst (TWC)
- Gasoline particulate filter (GPF)

Diesel

- Diesel oxidation catalyst (DOC)
- Diesel Particulate Filter (DPF)
- NOx storage catalyst (NSC) / Lean NOx trap (LNT)
- Passive NOx adsorber (PNA)
- Selective catalytic reduction (SCR / with ammonia slip catalyst SCR/ASC)
- Selective catalytic reduction filter (SCRF)

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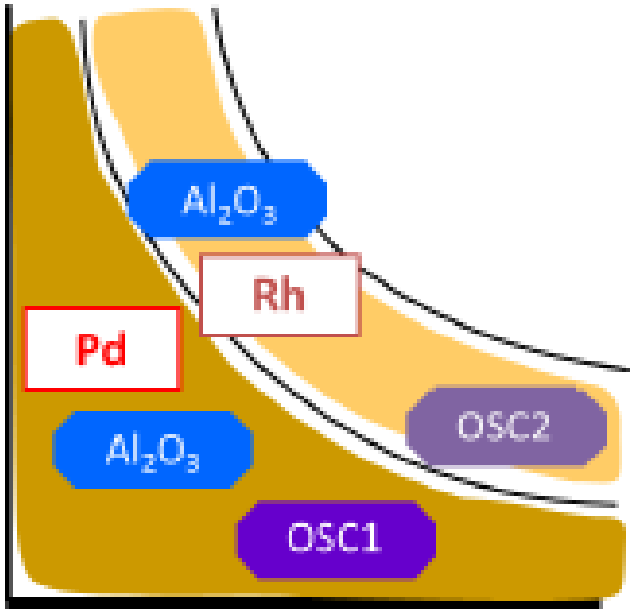
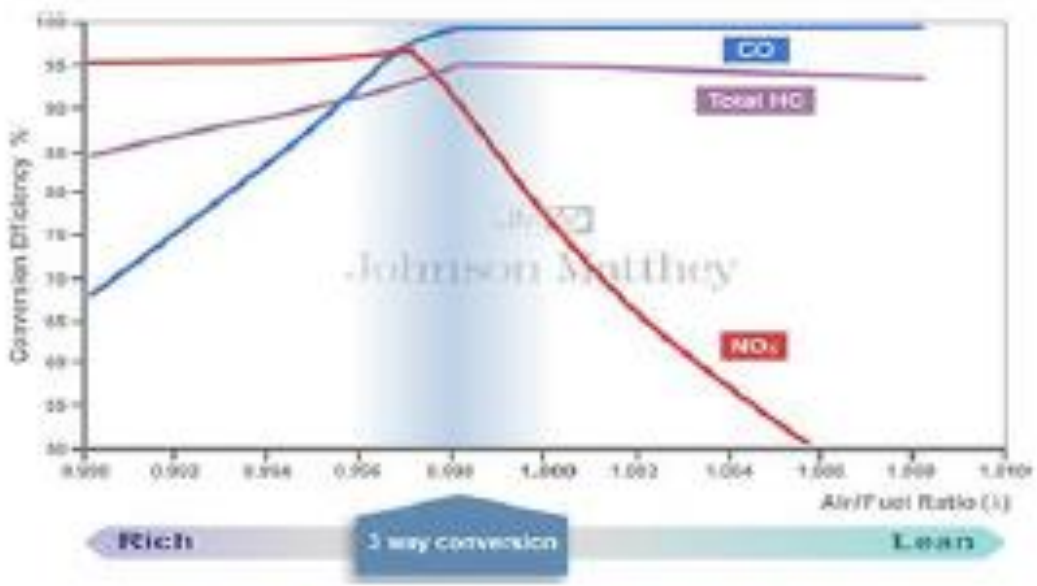
Three way catalyst (TWC)

Pt/Rh, **Pd/Rh** or Pt/Pd/Rh





The ideal air to fuel ratio to achieve maximum conversion is 14.7 parts air to one part fuel – this is known as Lambda = 1

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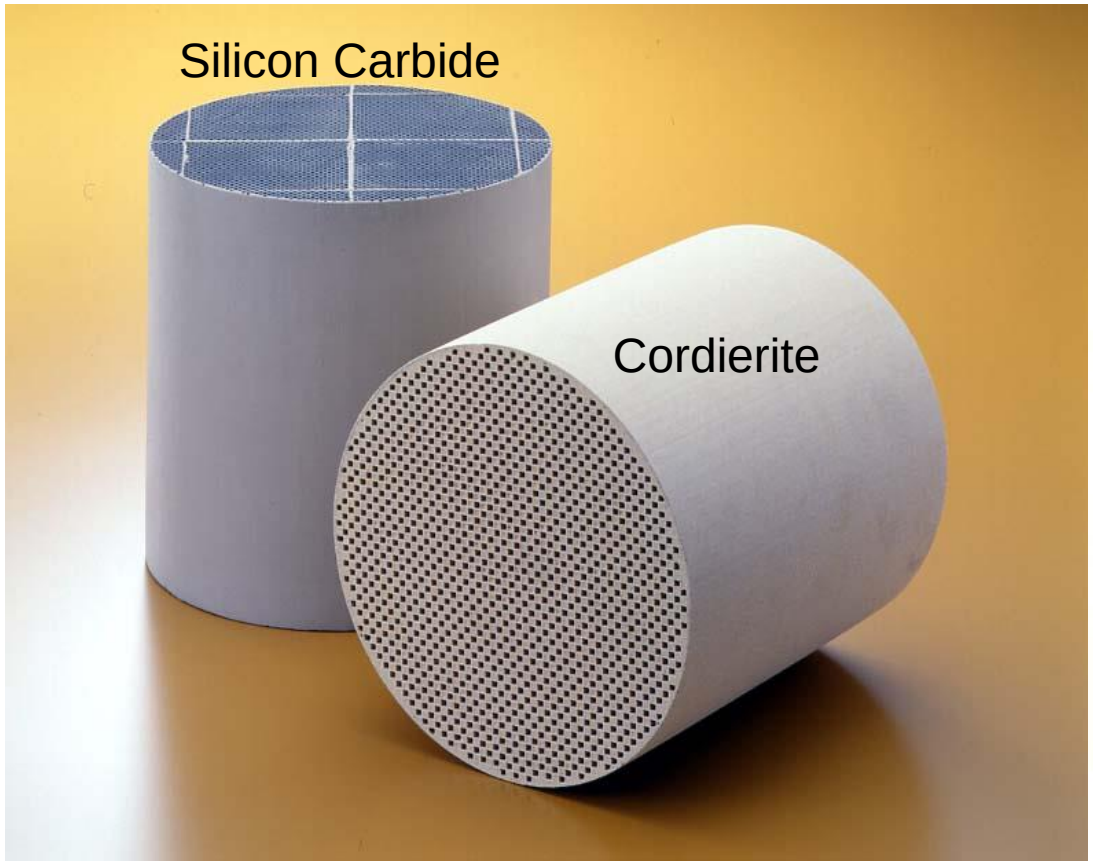
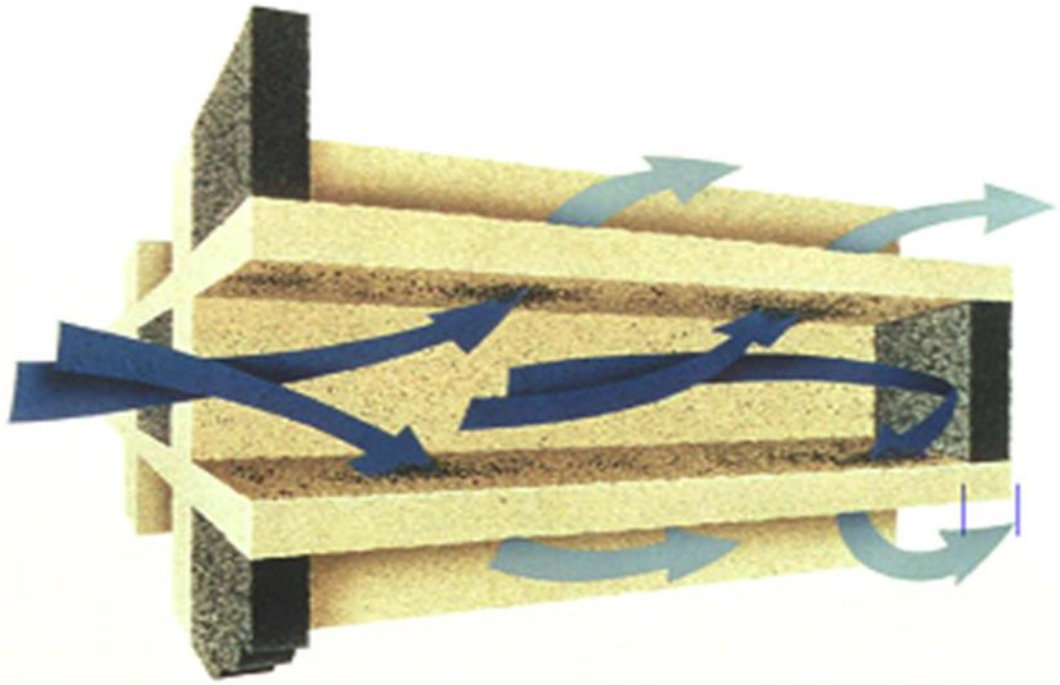
Gasoline particulate filter (GPF)





Alternate channels blocked – gas flows through wall, soot trapped

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Potential for platinum substitution in gasoline

No readily available PtRh or PtPdRh solution to OEMs to meet current legislation – further work needed

"It's not a flick of a switch for us," Rahul Mital, global technical specialist, diesel aftertreatment at General Motors Co., said in a panel discussion at a London Bullion Market Association meeting in Boston Monday. "Any time you want to make a substitution like that, it is at least 18 months to a two-year cycle if we're going to switch. We have to be careful that by the time we do all that," price changes don't negate the benefits, he said.

"If palladium pressure continues, you will see those results," Mital said.

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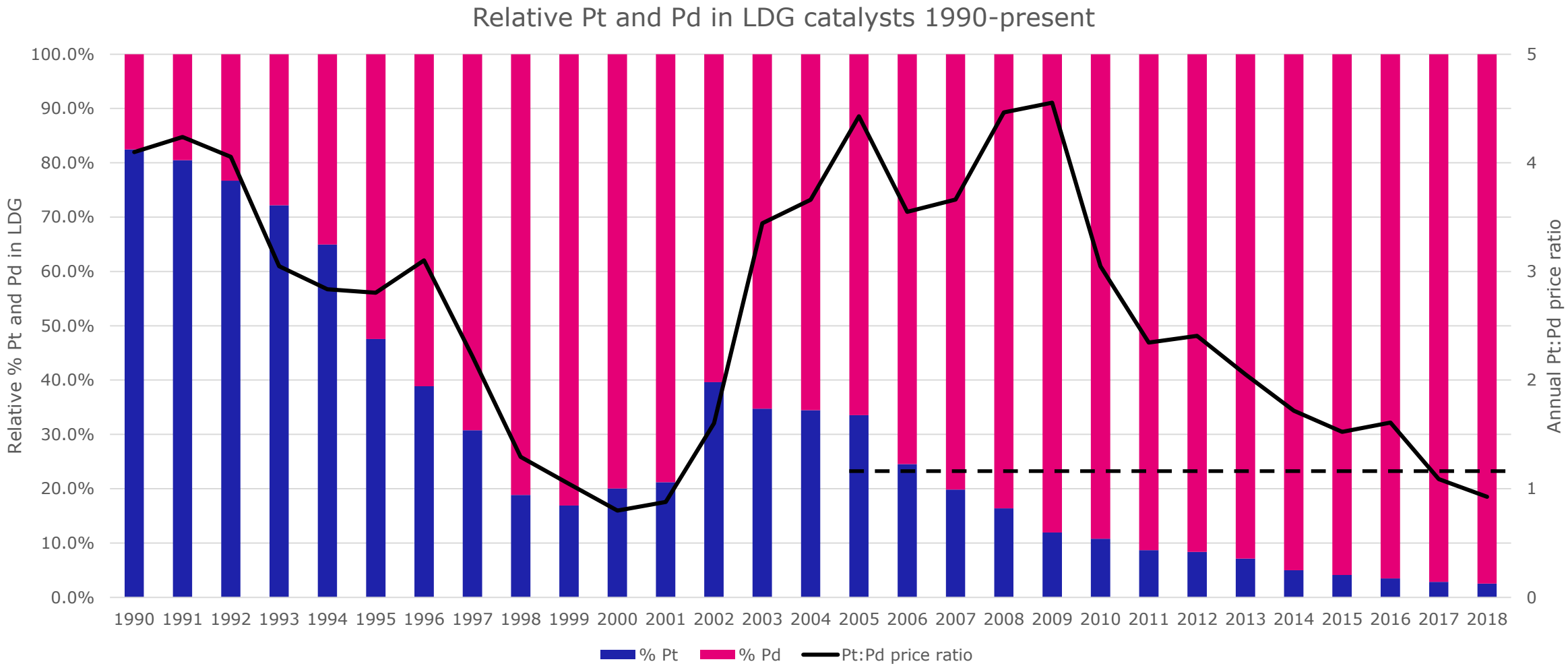
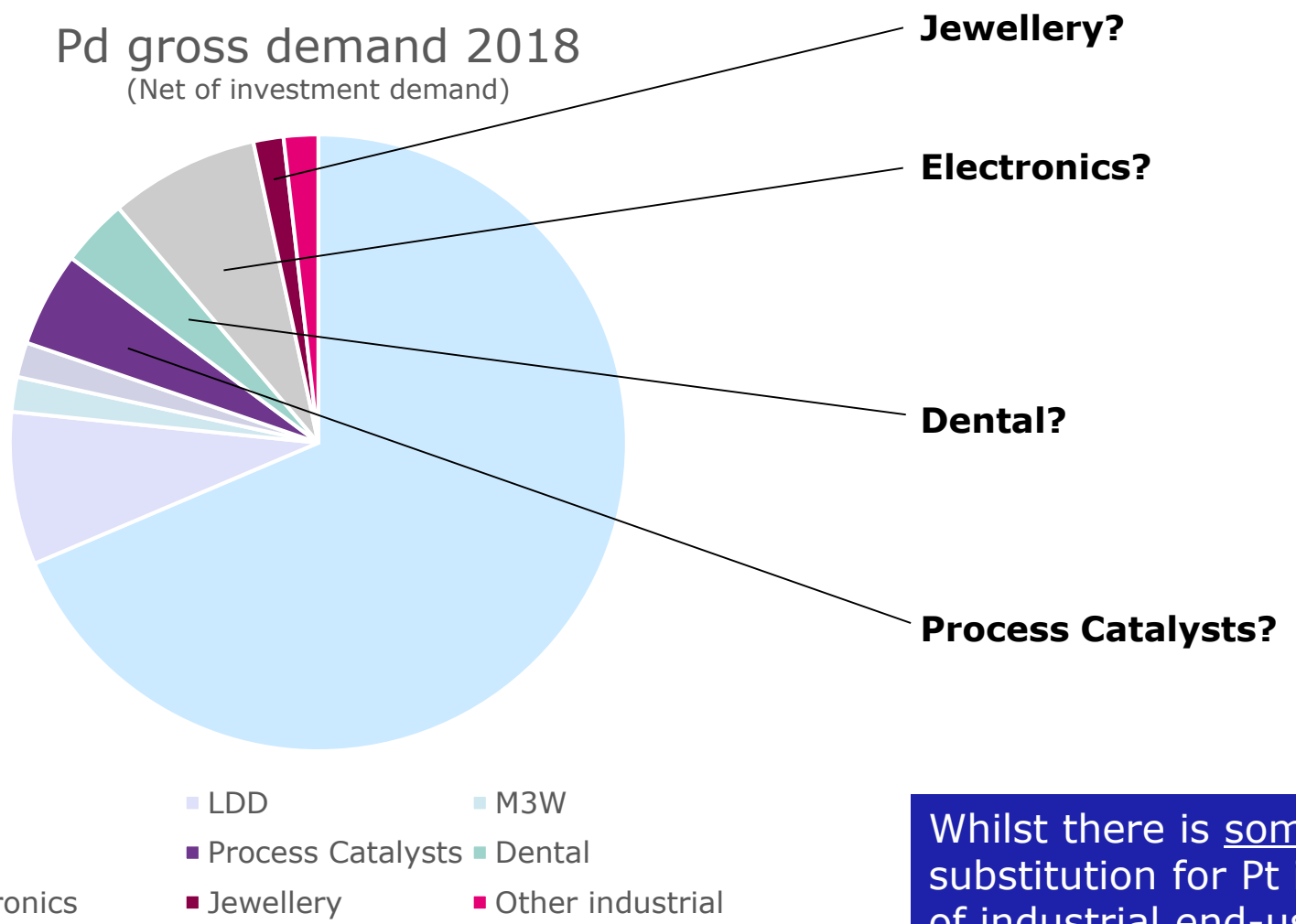
History shows that the industry is slow to change

Switching from Pt to Pd in the light duty gasoline sector



Substitution threats in non-auto demand areas



Whilst there is some price elasticity, Pd substitution for Pt is unlikely in vast majority of industrial end-uses

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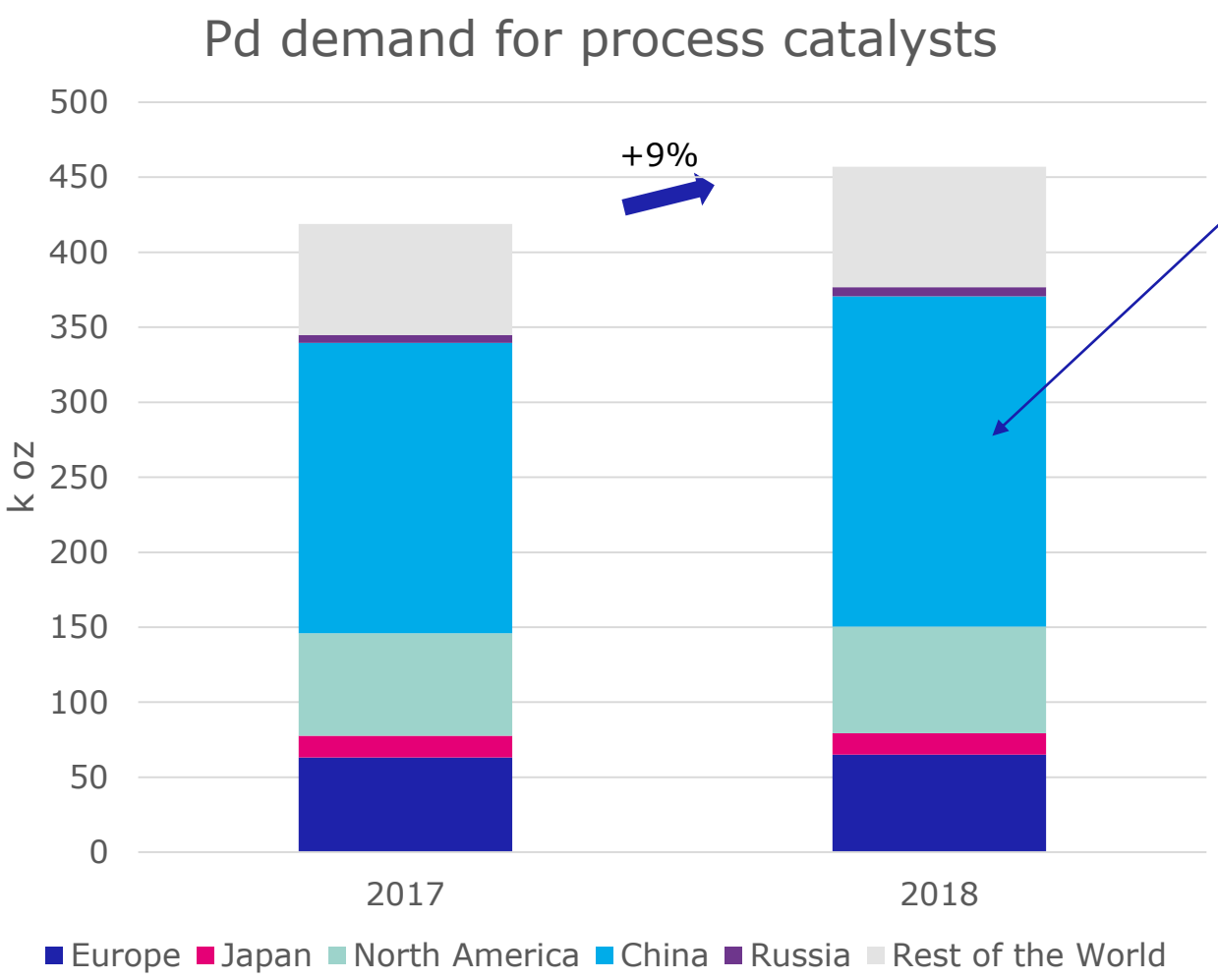
Palladium demand: process catalysts



48% of global process catalysts demand came from China in 2018

- Increase in palladium purchasing
- China government policy to improve self sufficiency in key chemical feedstocks
- New CTMEG capacity
- Soft demand for PTA- now signs of recovery
- Strong hydrogen peroxide and caprolactam demand

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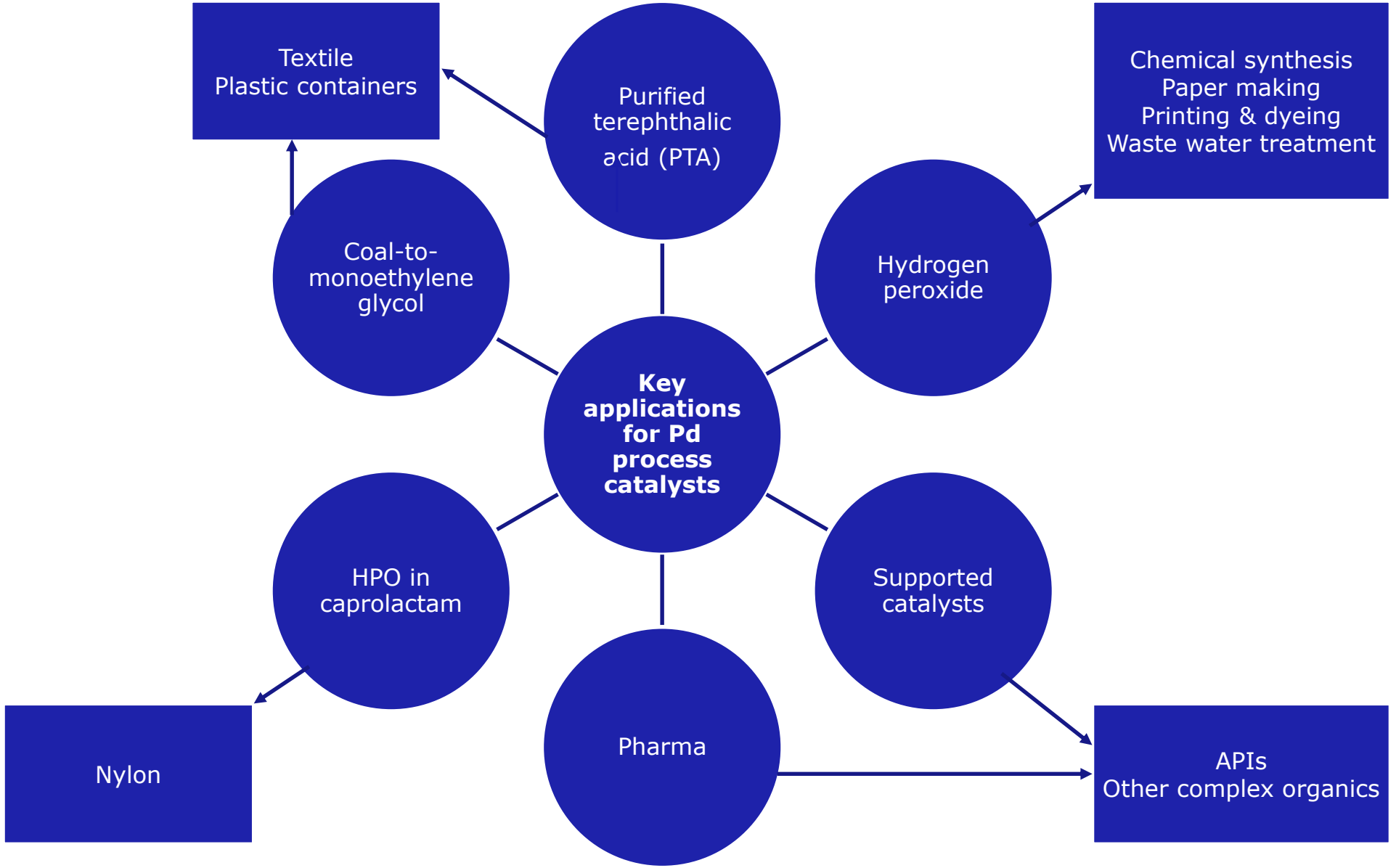
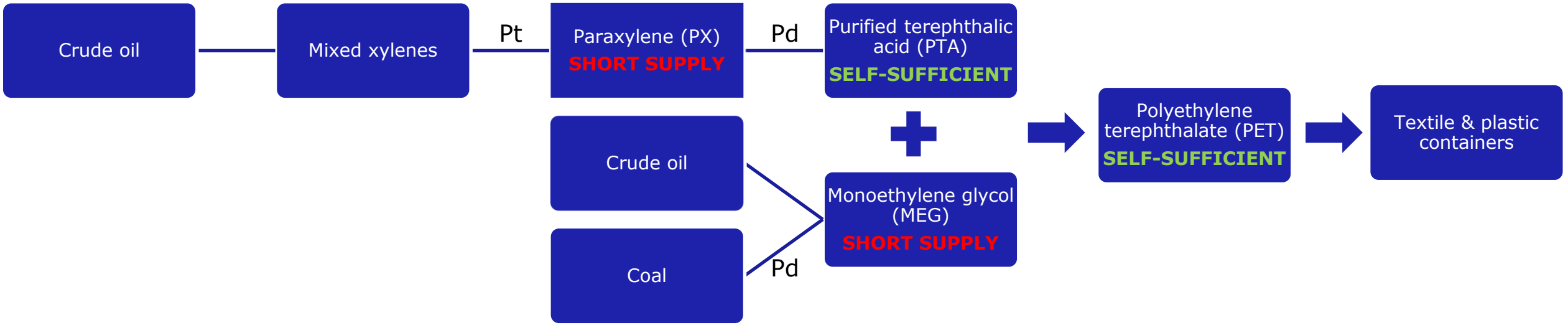
Palladium demand: process catalysts- key applications & end uses



China’s drive for petrochemical self-sufficiency- PET value chain



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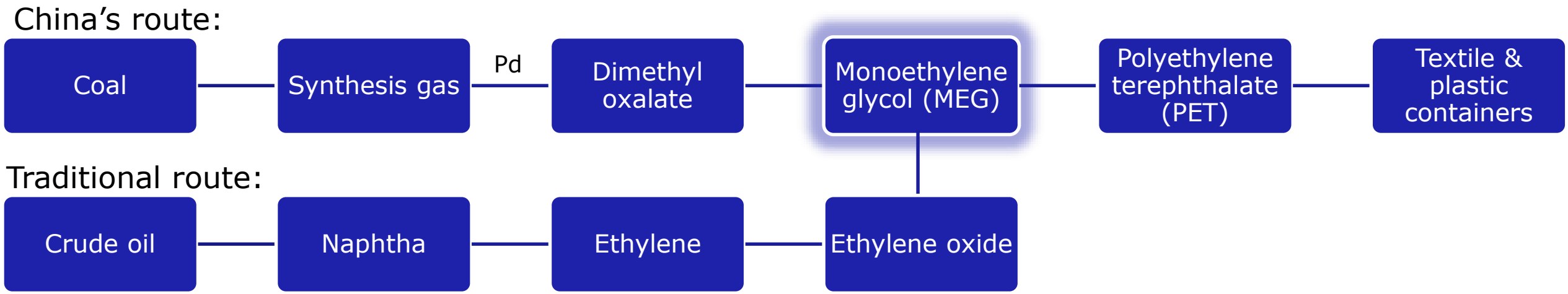
China’s drive for petrochemical self-sufficiency- MEG



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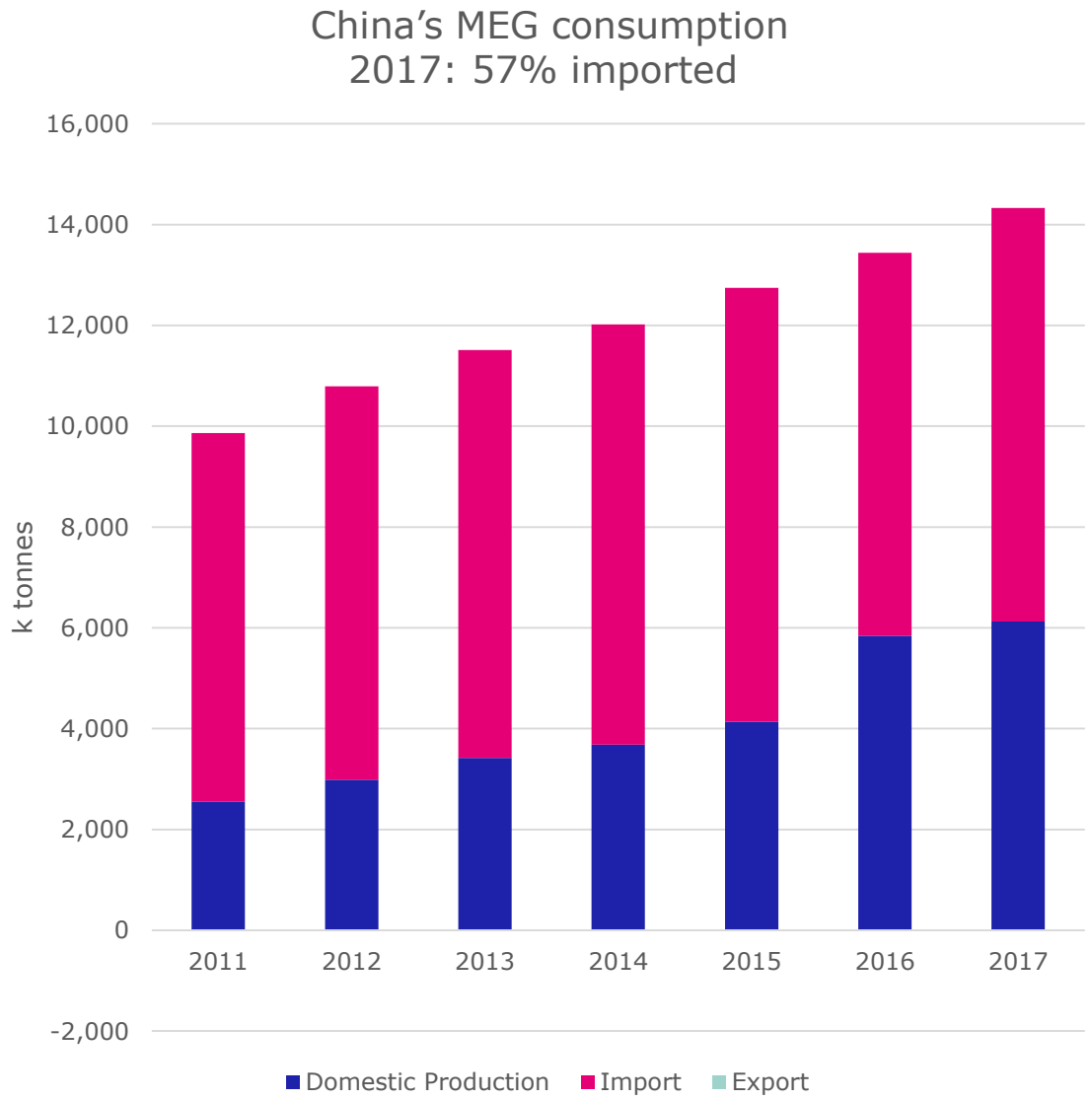
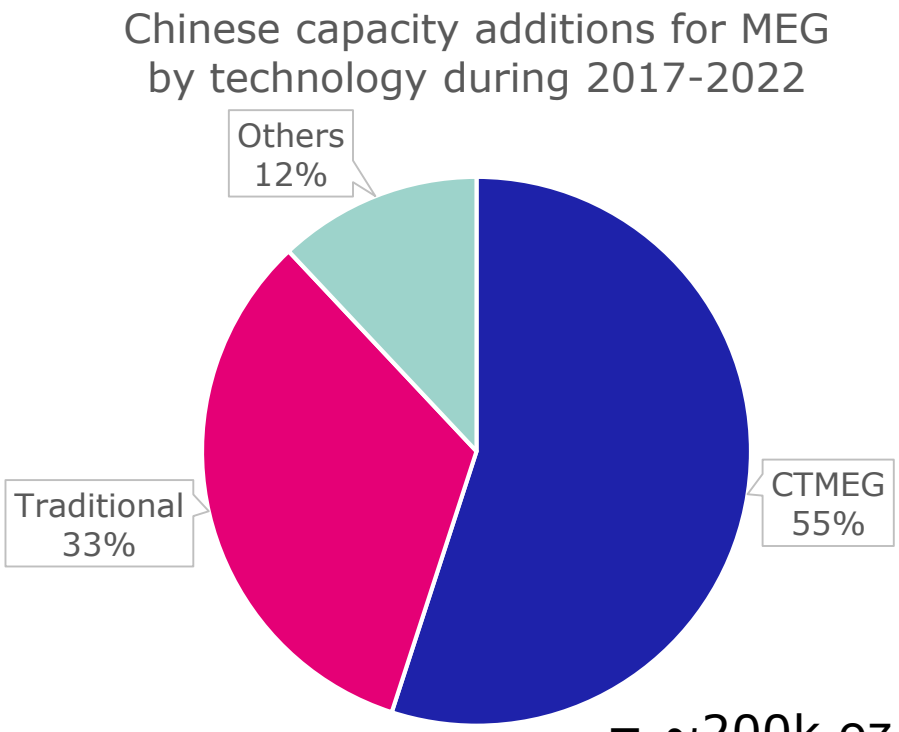
China’s drive for petrochemical self-sufficiency- MEG

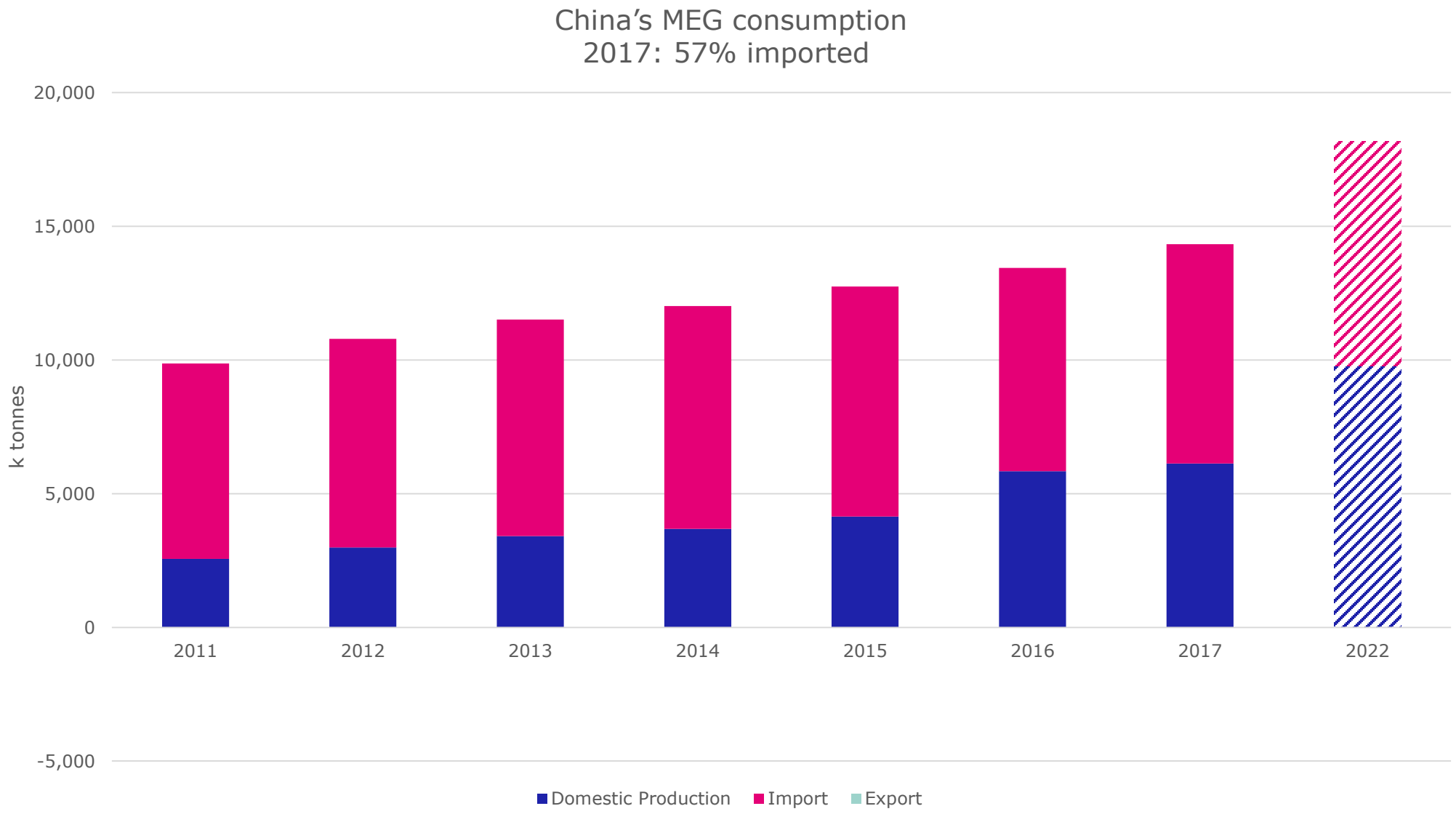




= ~200k oz Pd demand 2017-22

Source: IHS

China’s drive for petrochemical self-sufficiency- MEG



Source: IHS

Palladium demand: conclusions

- Dominated by autocatalysts
- 2018 growth in demand largely in line with global light duty vehicle production
- Future growth driven by emission legislation- Europe, China, North America, India
- There is the potential for platinum substitution in gasoline- but not simple
- Whilst there is some price sensitivity, Pd substitution for Pt is unlikely in vast majority of industrial end-uses
- Surge in palladium purchasing in the chemical industry, led by China
- China’s drive for petrochemical self sufficiency adding Pd demand- new CTMEG capacity
- Palladium consumption also boosted by the addition of new PTA and hydrogen peroxide capacity, and investment in production of caprolactam using the hydroxylamine phosphate process

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