S&P Global Energy

MEG in Flux

Joyce Lee
Director, Asia Olefins
S&P Global Energy, CERA

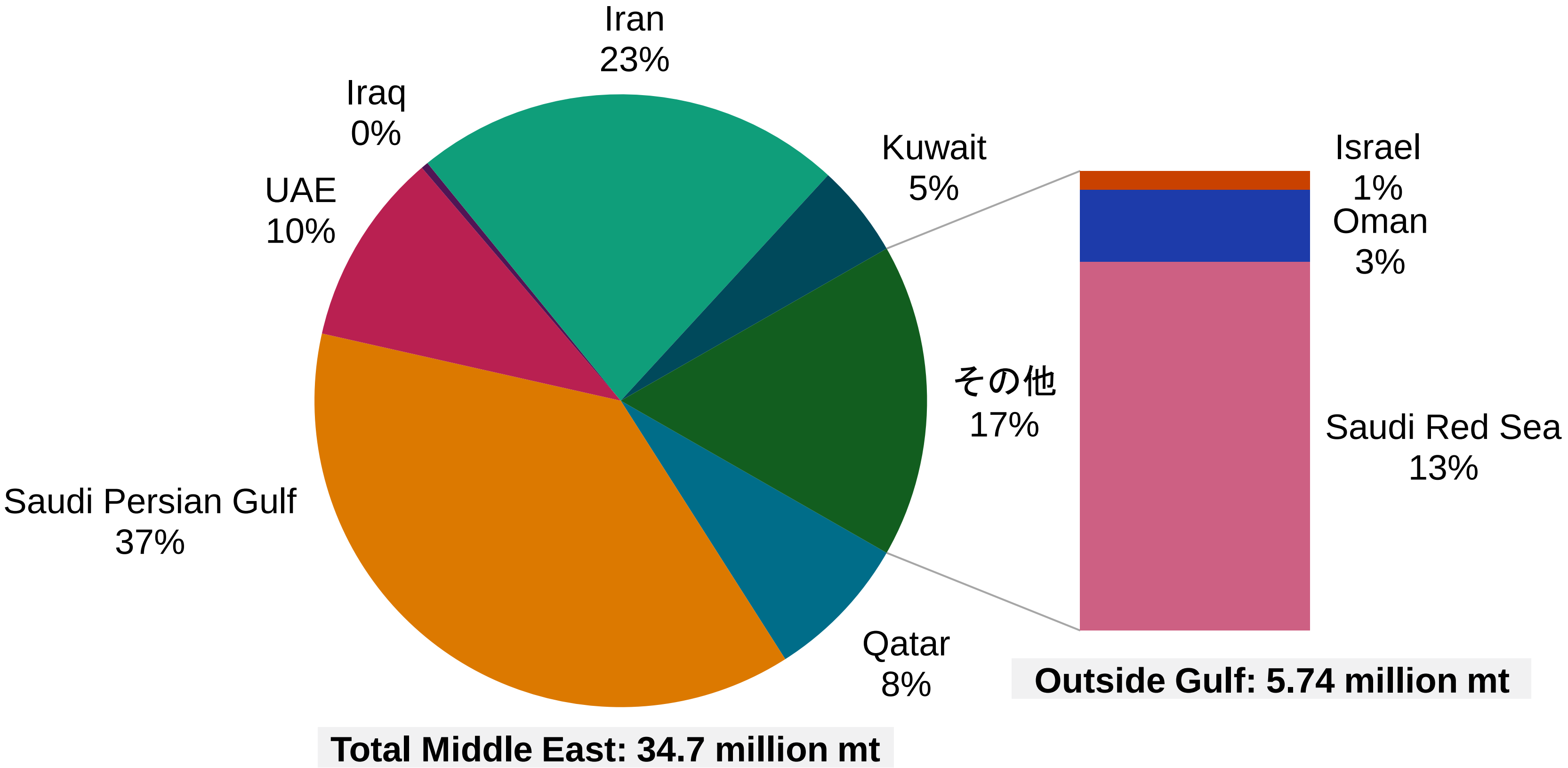
May 29th, 2026

Agenda

S&P Global Energy

War in the Middle East isolated 29 MMT of ethylene capacity in the Persian Gulf; Asian crackers' operating rates mostly constrained by feedstock shortages

Middle East cracker capacity outside the Persian Gulf



Source: S&P Global Energy.

Global ethylene capacity, 2025 (232 MMT)

Persian Gulf
29 MMT:12.5%

Eastern Asia
81.5 MMT: 35%

SE Asia
14.9 MMT: ~6%

South Asia
8.8 MMT: ~4%

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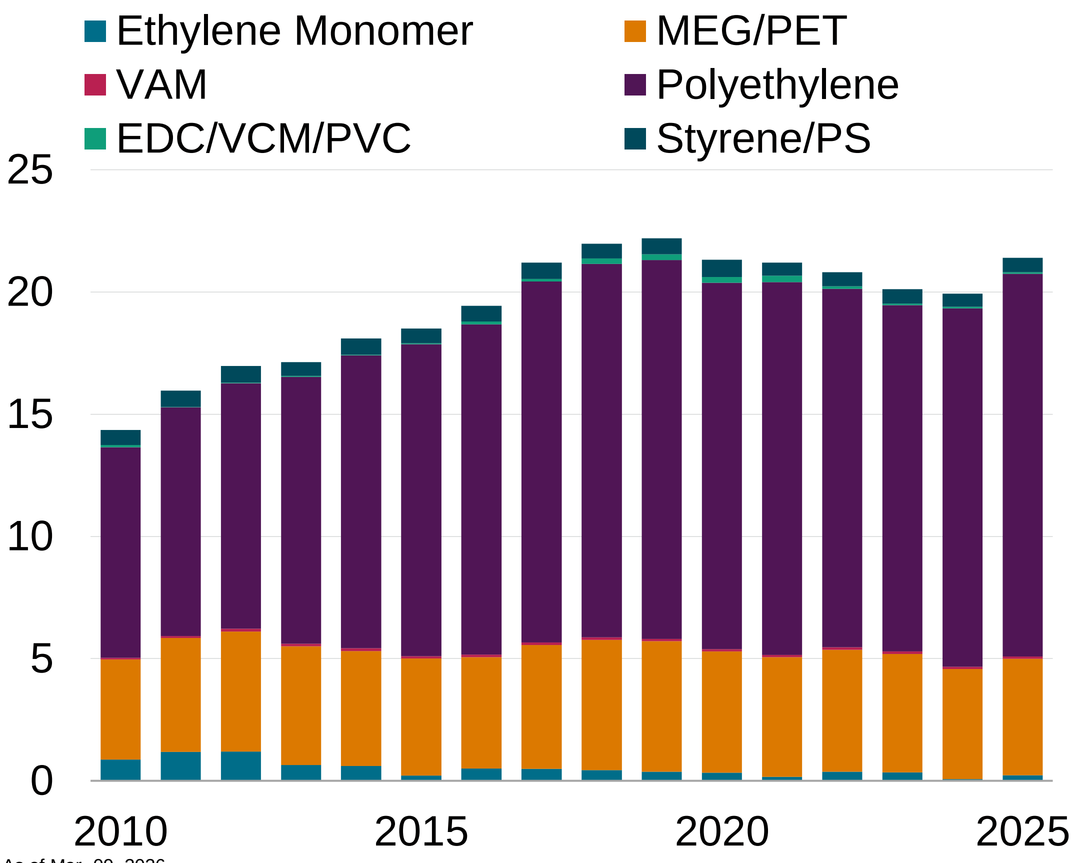
Middle East war impact across ethylene value chain : Bigger supply disruptions of derivatives, notably, PE and MEG, rather than monomer supply

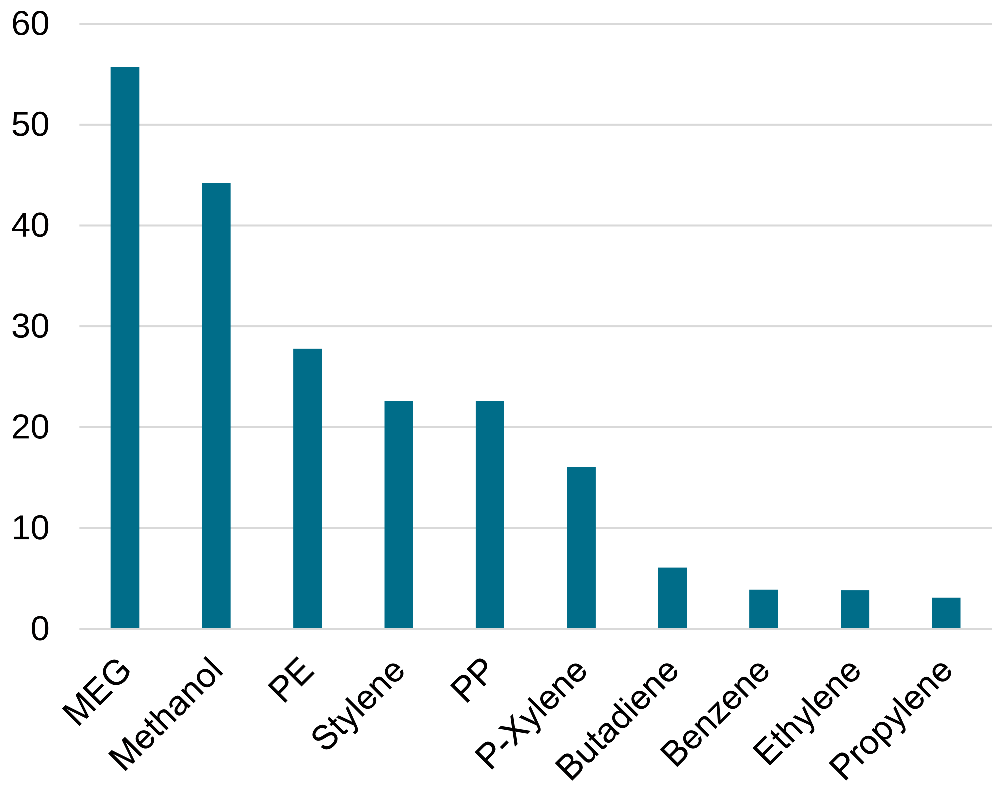
Middle East Ethylene Net Equivalent Trade, MMT



As of Mar. 09, 2026.

Source: S&P Global Energy

Middle East exports % of total global exports (2025)



Source: S&P Global Energy.

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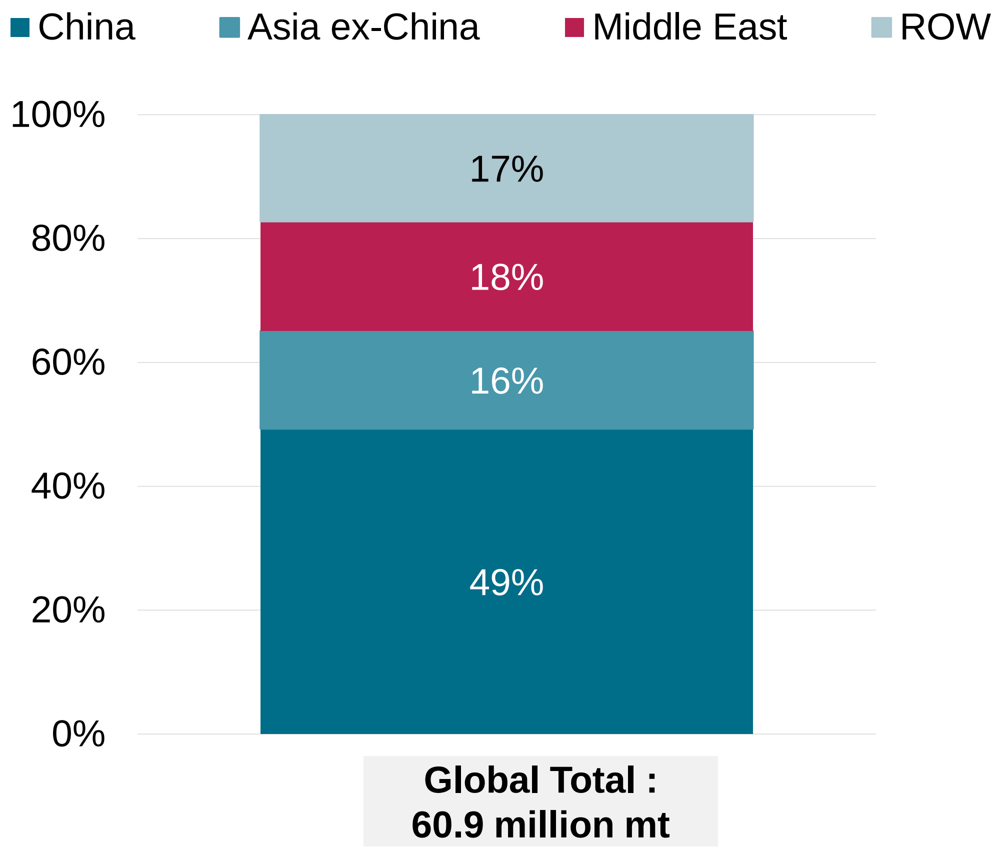
Middle East MEG operations largely shut by logistics disruptions and war damage

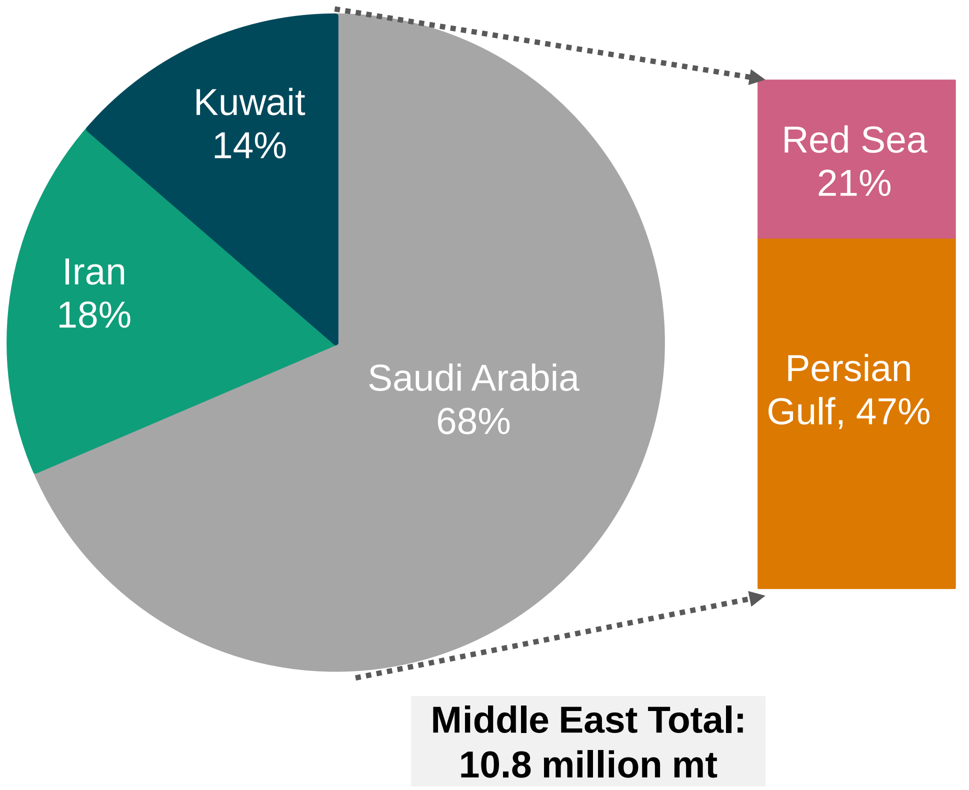
~80% of Middle East MEG capacity is concentrated in the Persian Gulf

Middle East and Asia MEG % of 2025 Global MEG capacity



Source: S&P Global Energy

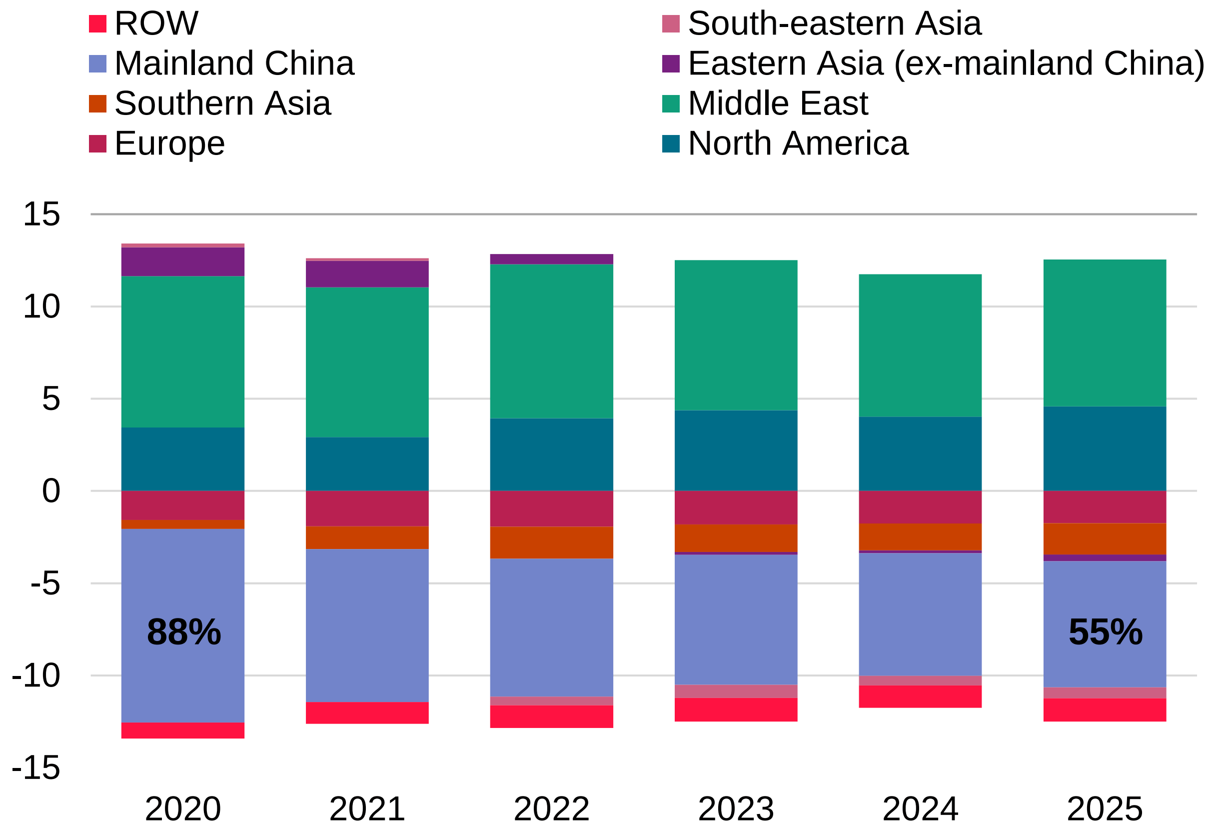
Middle East MEG capacity per country, 2025



Source: S&P Global Energy

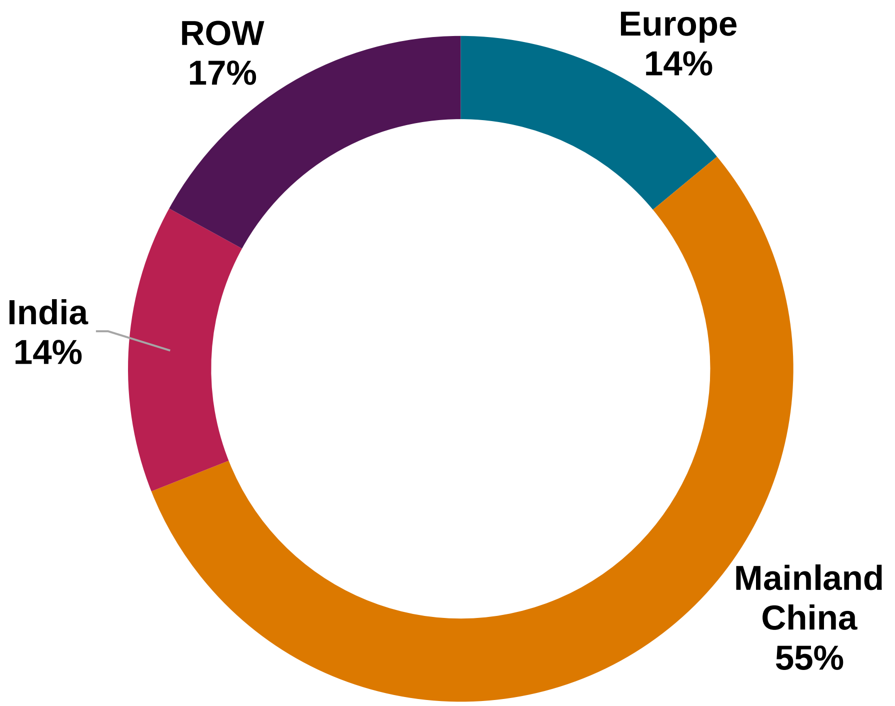
Global MEG trade flow has been largely dominated by Middle East and China

MEG regional net trade trend, MMT



As of Q1, 2026.
Source: S&P Global Energy

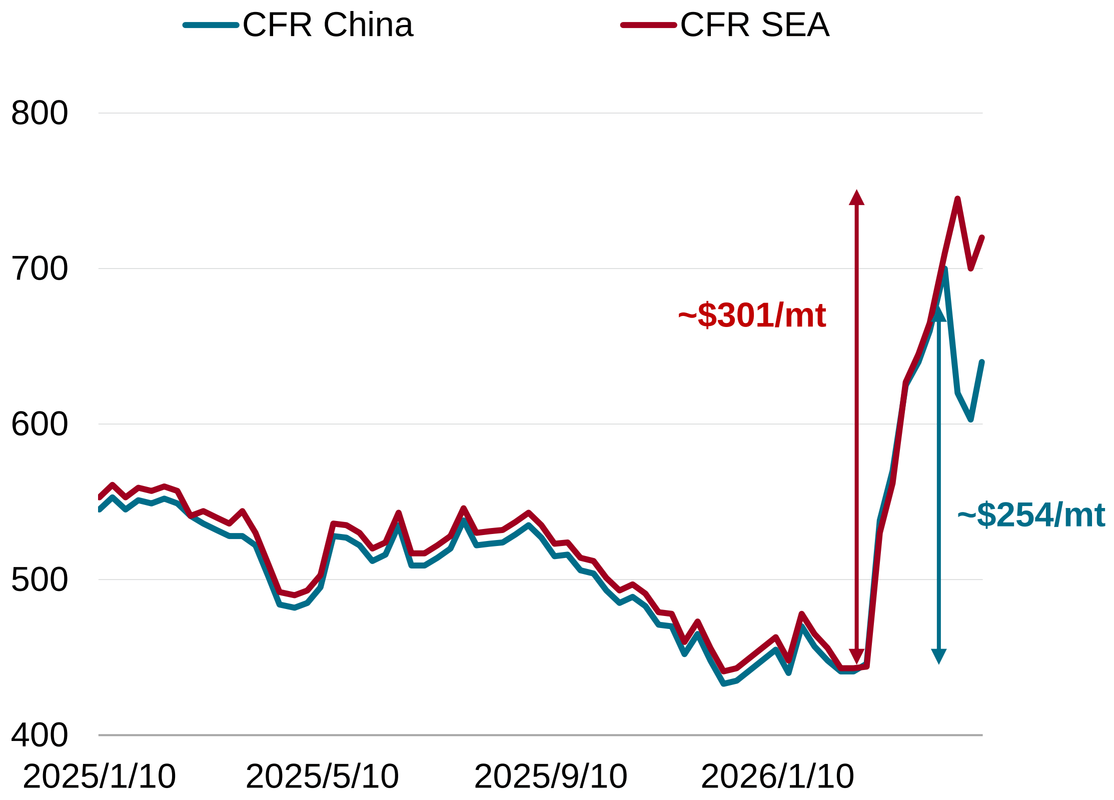
Global MEG net import regions, %, 2025



Source: S&P Global Energy

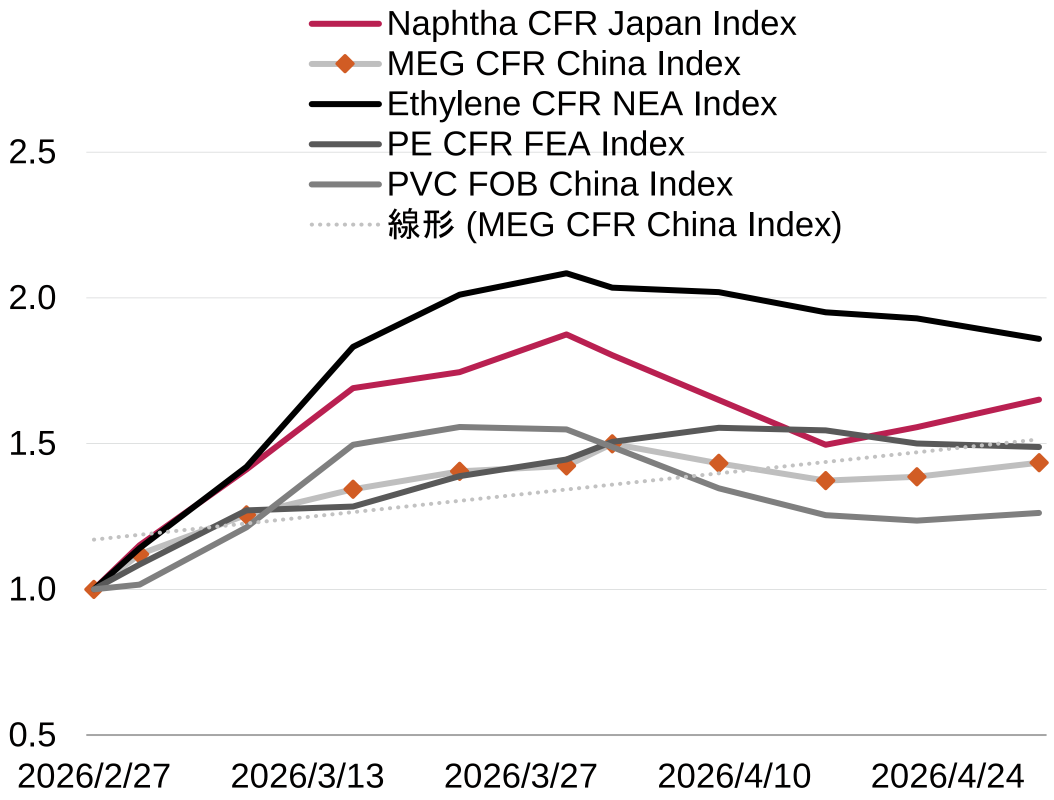
MEG prices rose, but lagged feedstock and other ethylene derivatives

Asia MEG price movement, $/mt



Data compiled May 4th 2026
Source: S&P Global Energy

Feedstock & MEG price index (1= Feb 27th, 2026)



Data compiled May 4th 2026
Source: S&P Global Energy

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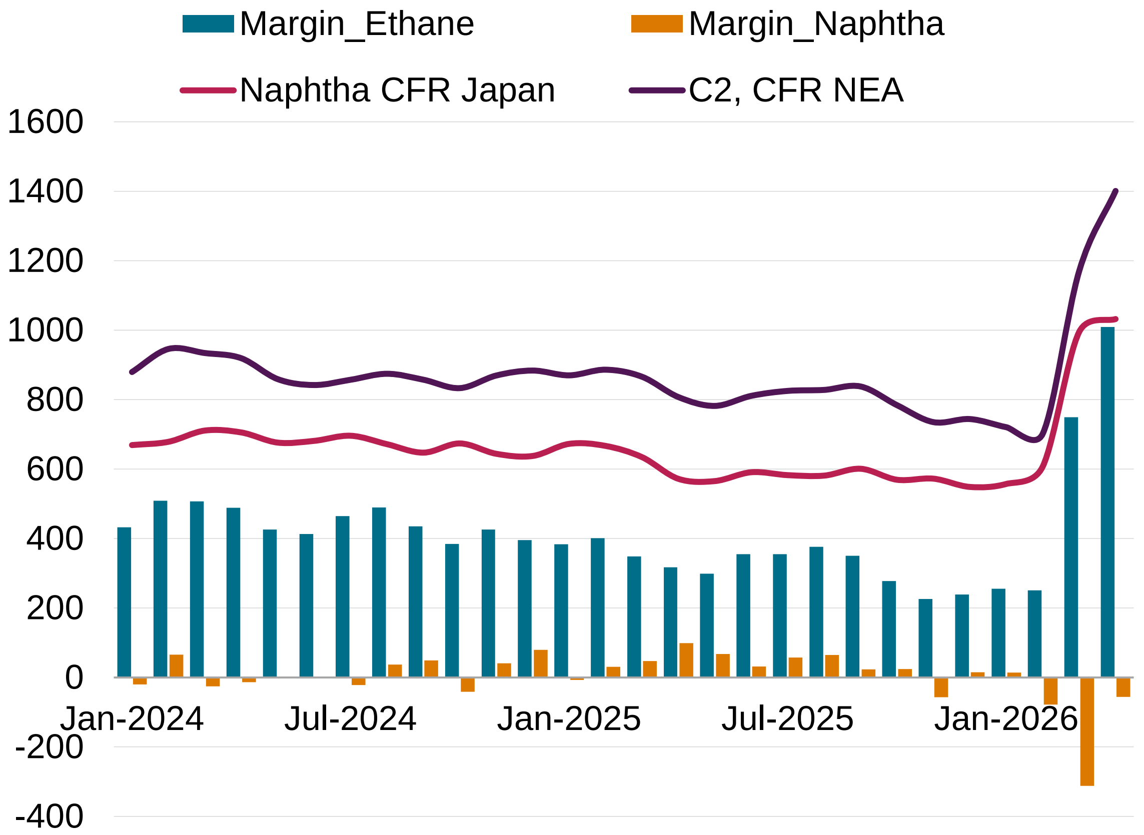
Weak demand caps olefin and derivatives price upside, pressuring Asian naphtha-based producers

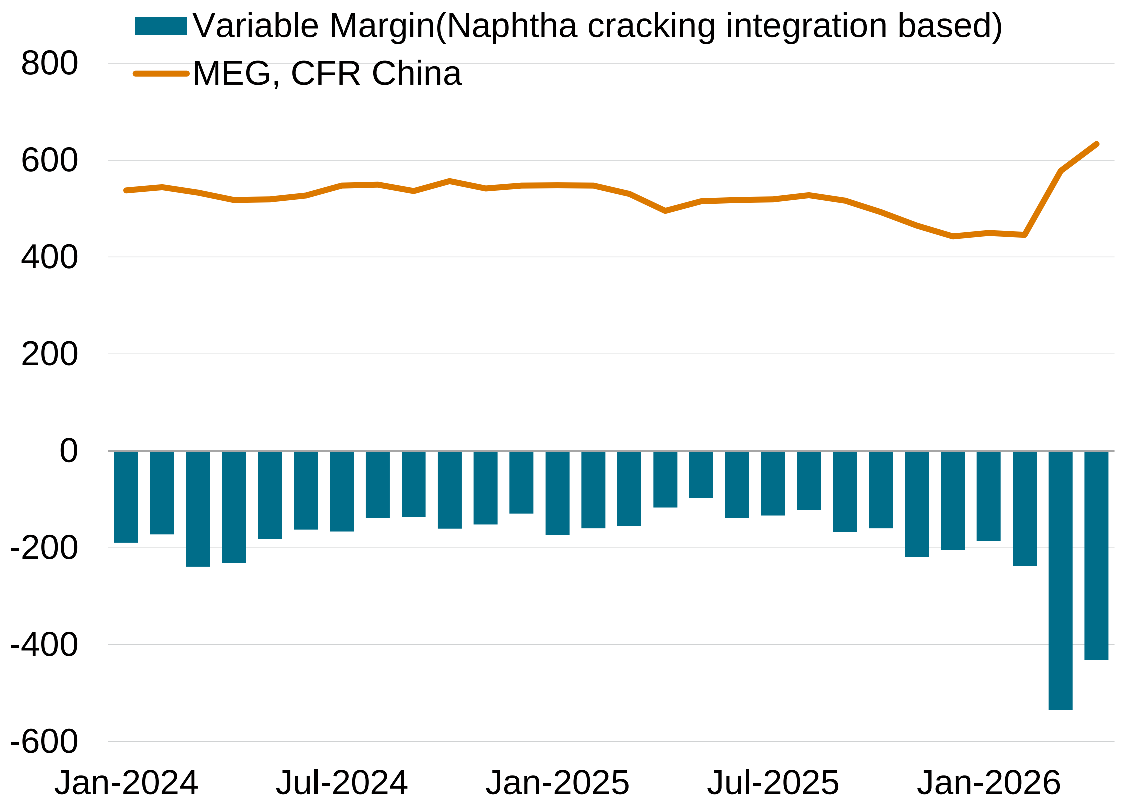
Asia ethylene feedstock and variable margin, $/mt



Dat compiled May 4th, 2026.

Source: S&P Global [Division].

Asia MEG price and variable margin trend, $/mt



Data compiled May 4th 2026

Source: S&P Global Energy

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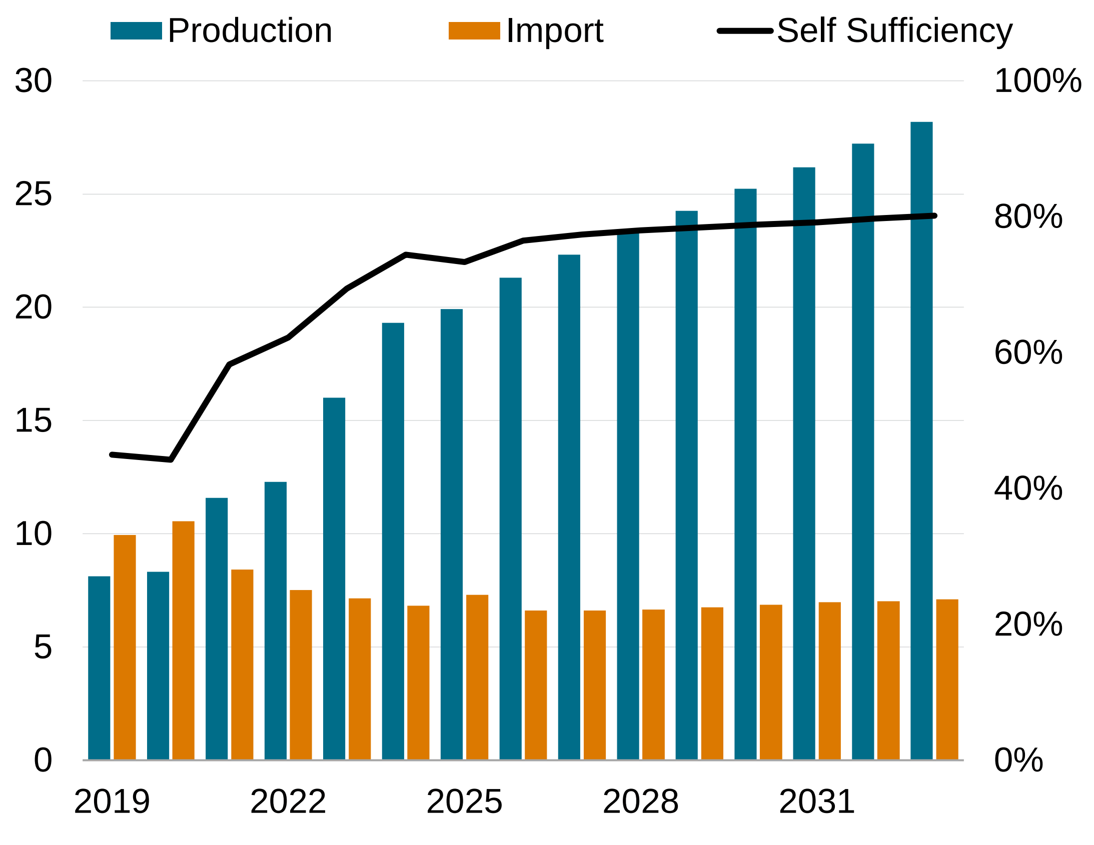
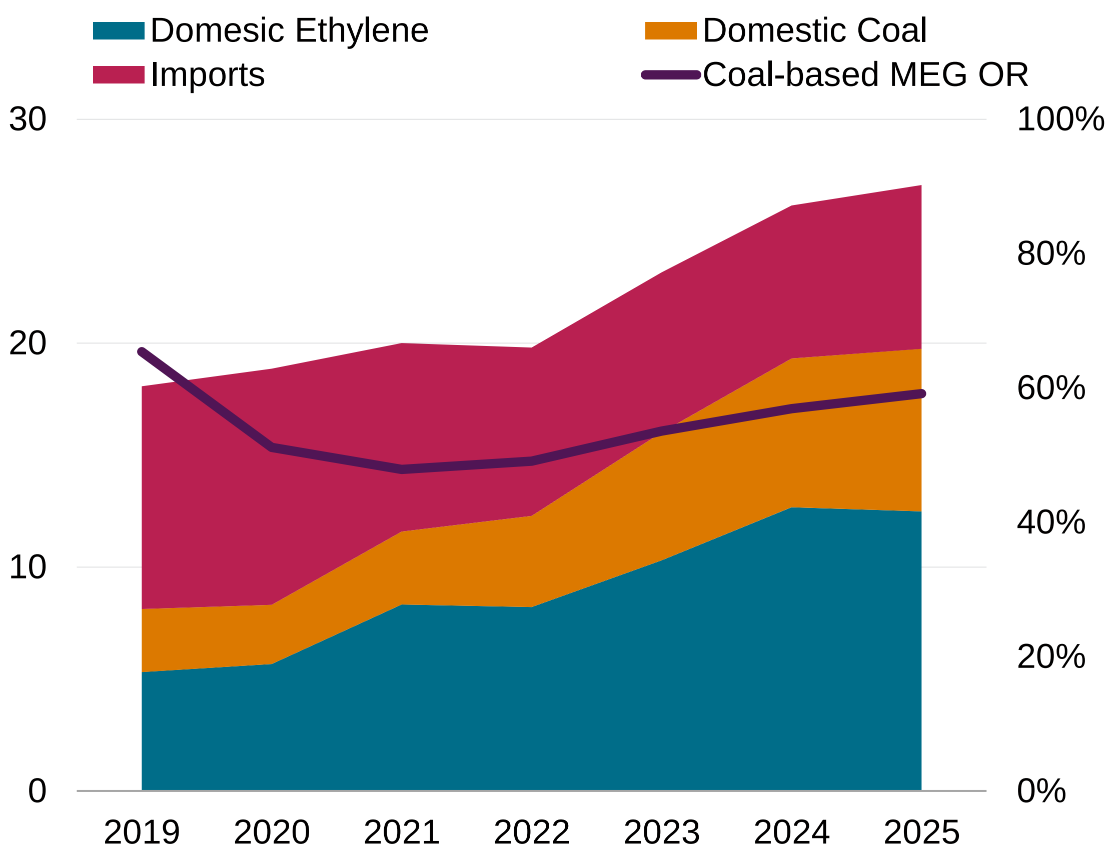
China's increased MEG self-sufficiency (~75%) and large idle coal-based MEG capacity help mitigate Hormuz supply disruption

China MEG production and self-sufficiency, mmt,



Source: S&P Global Energy

China MEG demand fulfilled by sources, mmt, %

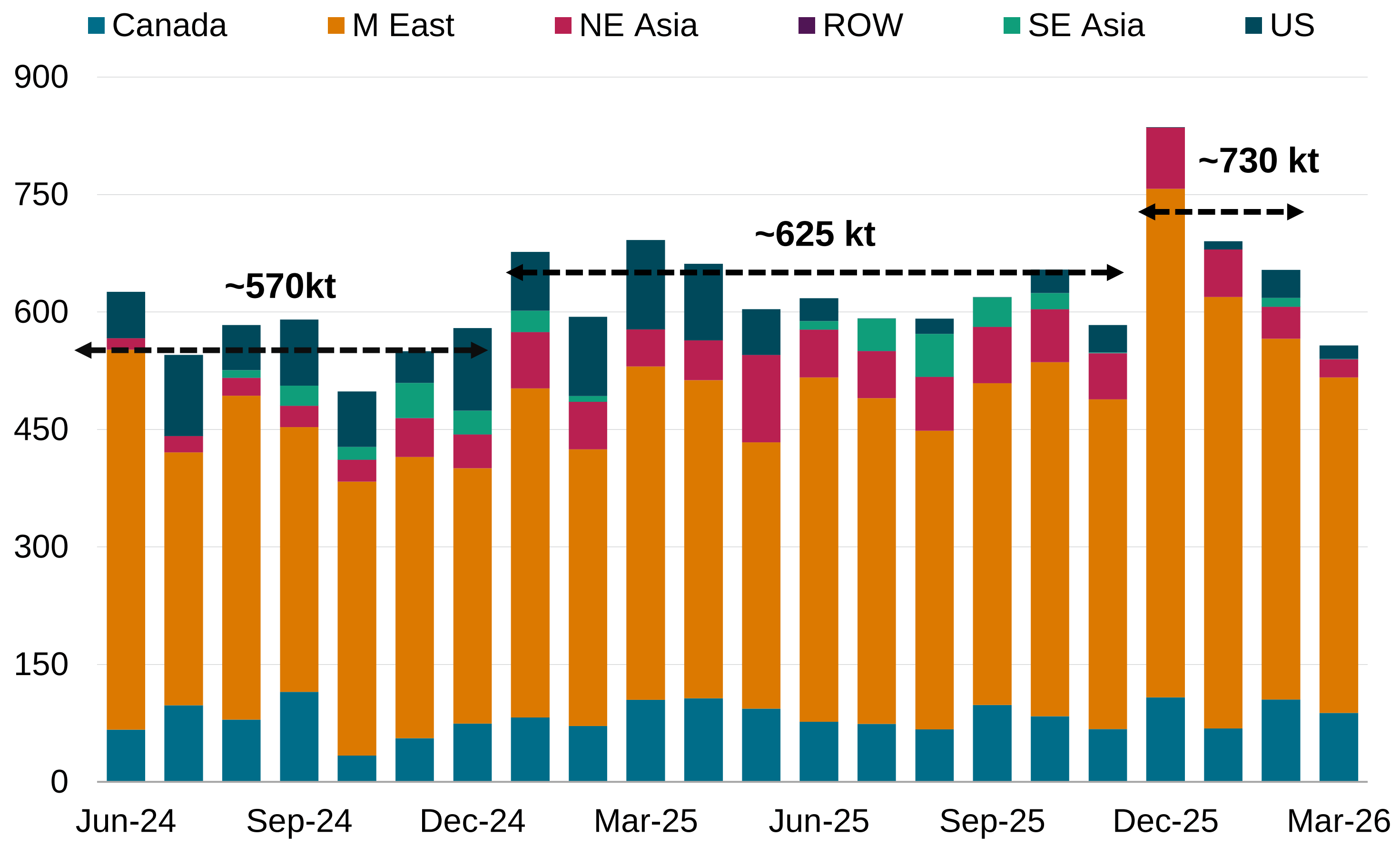


Source: S&P Global Energy

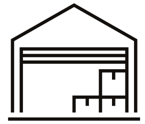
S&P Global Energy

High port inventories in China from Q1 2026 Middle East imports help cushion supply shocks amid slower demand

China's MEG monthly imports by regions (thousand mt)

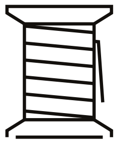


Data compiled May 4th 2026
Source: GTA, S&P Global Market Intelligence



- **Imports since end-2025 rose 16% vs 2025 monthly average (Jan-Nov) and 18% YoY**

- **Seasonal demand weakness during early-2026 Lunar New Year**



- **Q1 2026 polyester demand declined YoY amid maintenance and project delayes**

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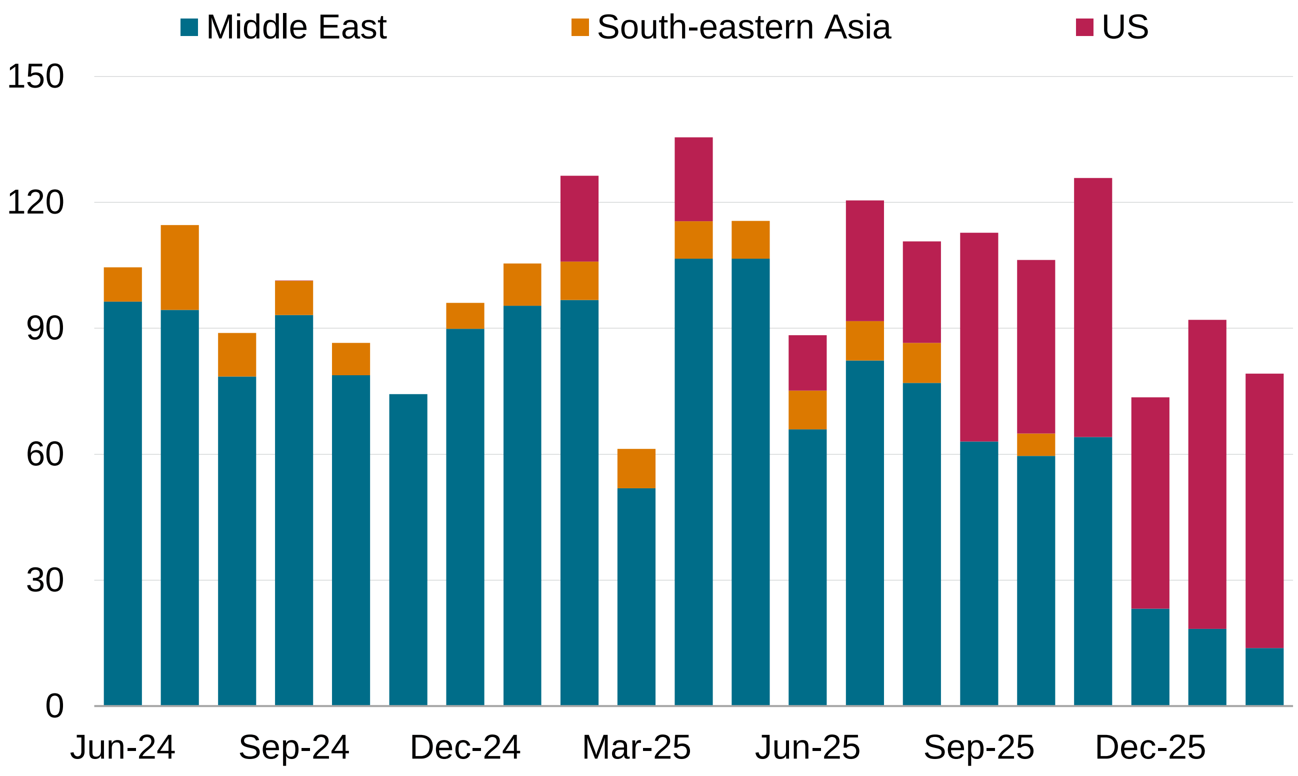
Anti-dumping risks shift MEG trade flows toward India, lifting US imports to record highs since 2025 and softening Hormuz-related supply disruptions

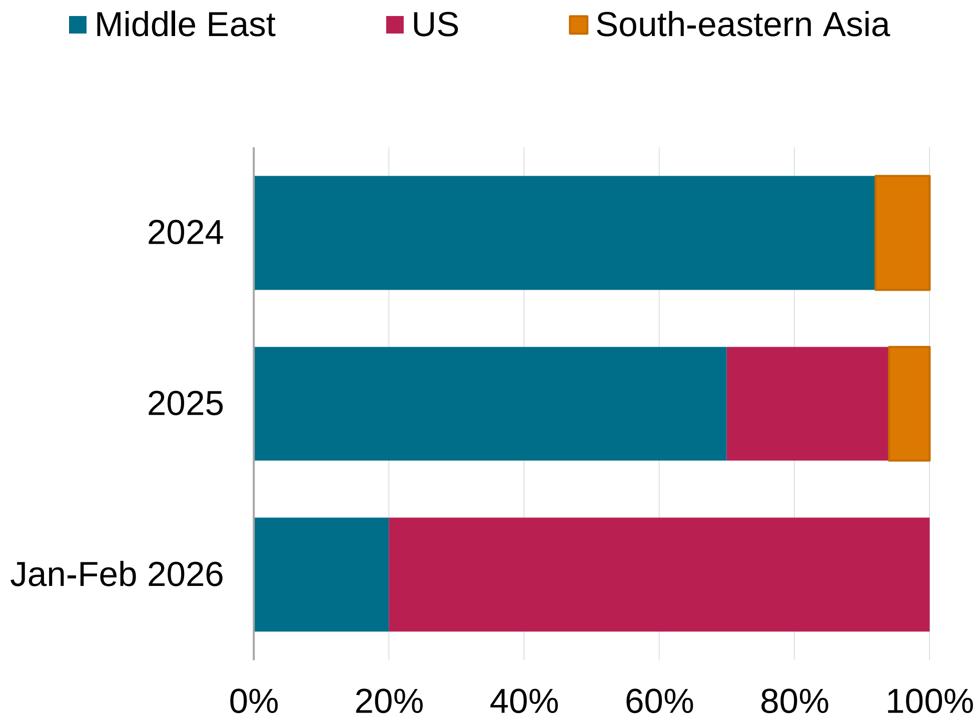
India MEG imports by country (thousand mt)



Data compiled May 4th 2026

Source: GTA, S&P Global Market Intelligence

India MEG imports by regions, %



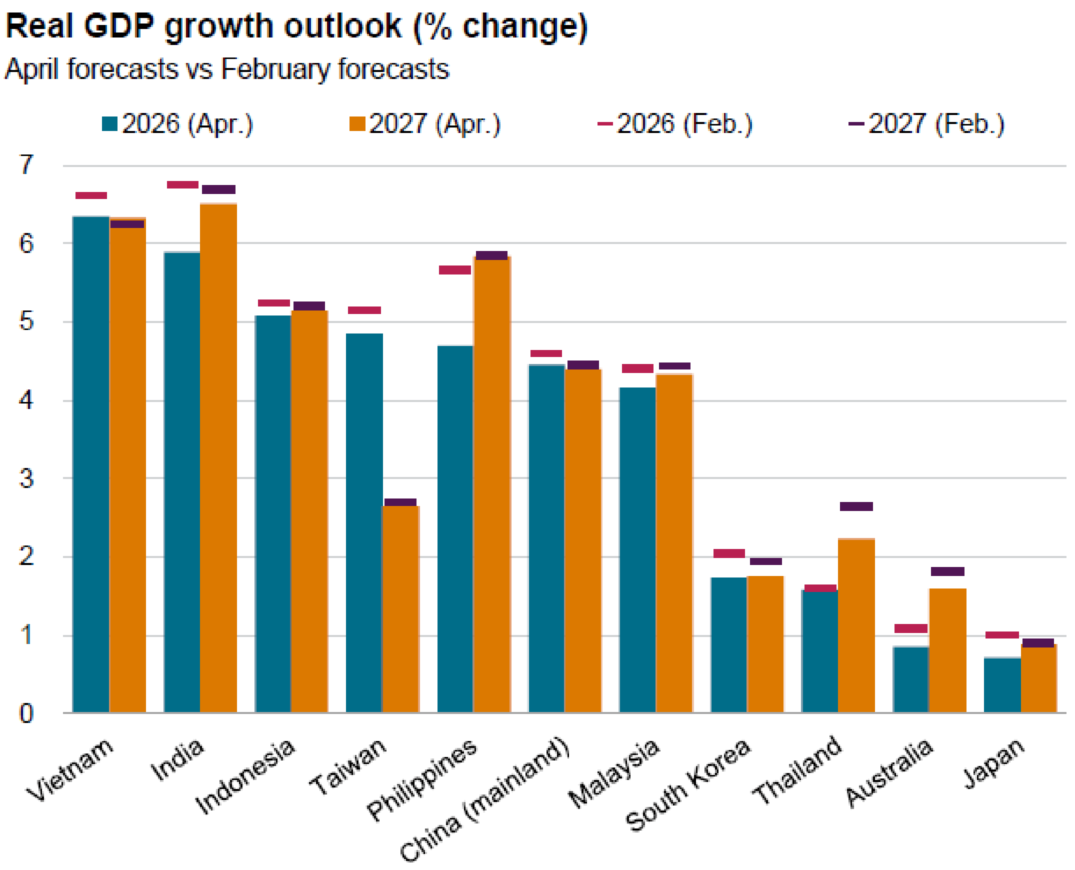
Data compiled May 4th 2026

Source: GTA, S&P Global Market Intelligence

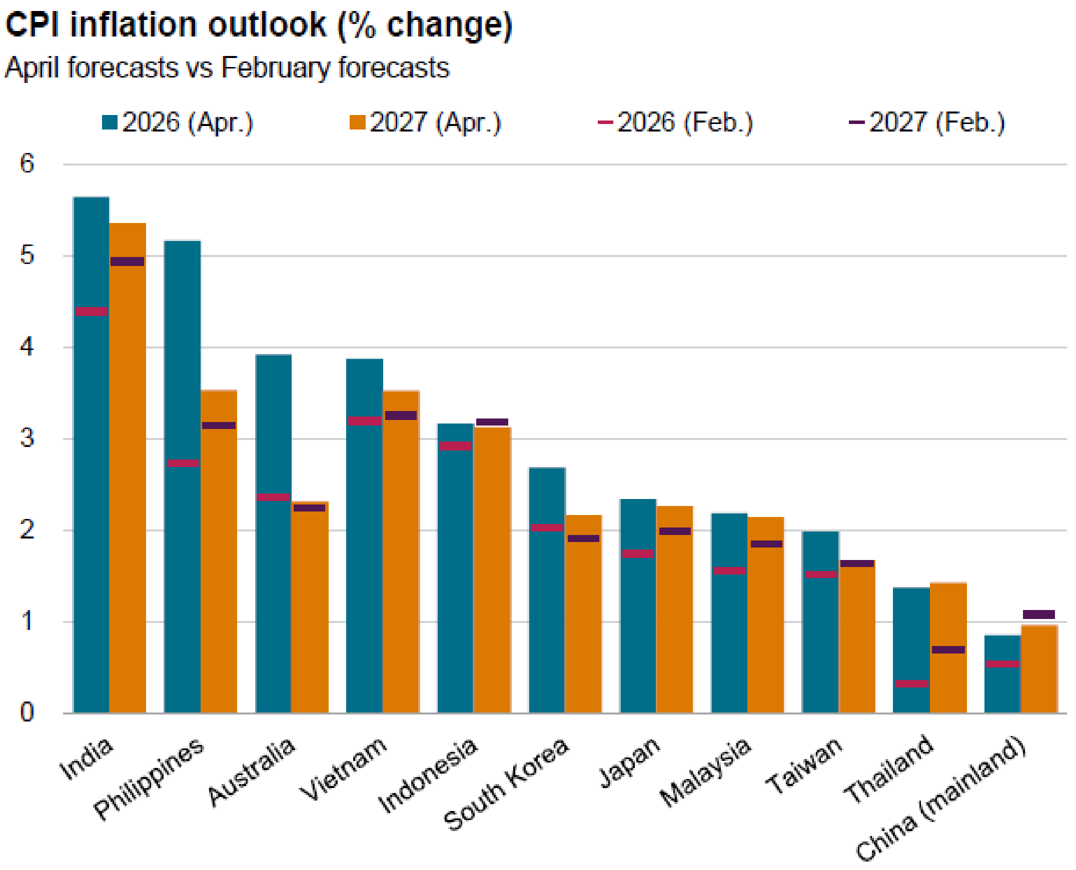
S&P Global Energy

Rising geopolitical risks and energy costs weigh on consumer sentiment, dampening downstream demand and GDP growth

Growth and inflation outlooks have worsened across APAC



As of of April 15, 2026.
Source: S&P Global Market Intelligence.



As of of April 15, 2026.
Source: S&P Global Market Intelligence.

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Energy

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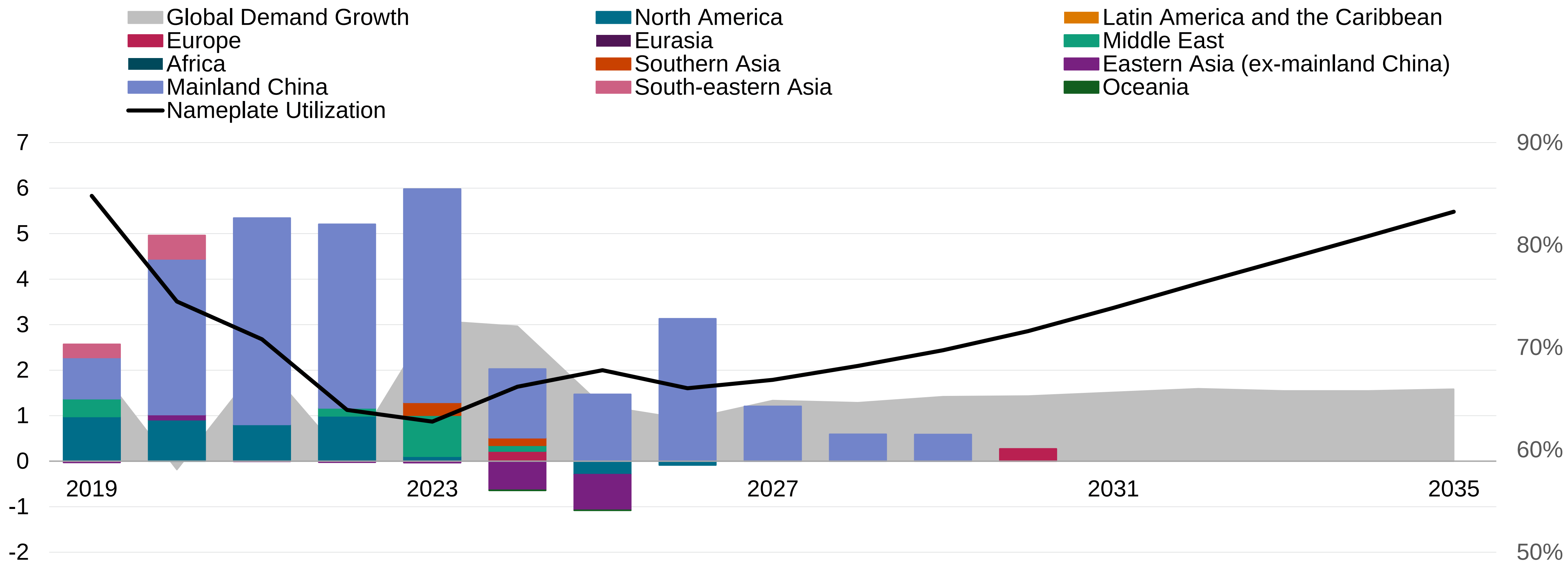
China’s capacity additions peak in 2026, but the rapid growth phase ends, allowing demand to catch up from 2027 onwards

Global MEG capacity changes vs demand growth (million mt)



Source: S&P Global Energy

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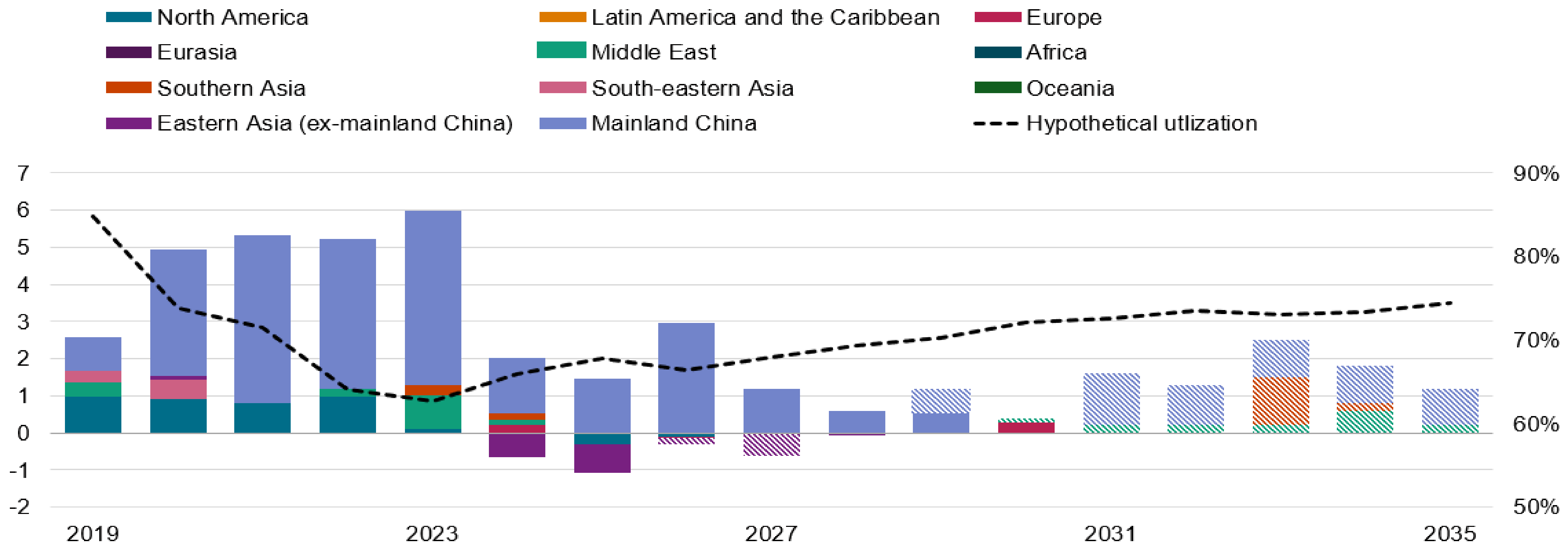
Possible closures in NE Asia may speed up near term recovery – but hypothetical MEG additions in the 2030 would keep utilization in the mid 70% range

Global MEG hypothetical capacity change vs demand growth (million mt)



Source: S&P Global Energy

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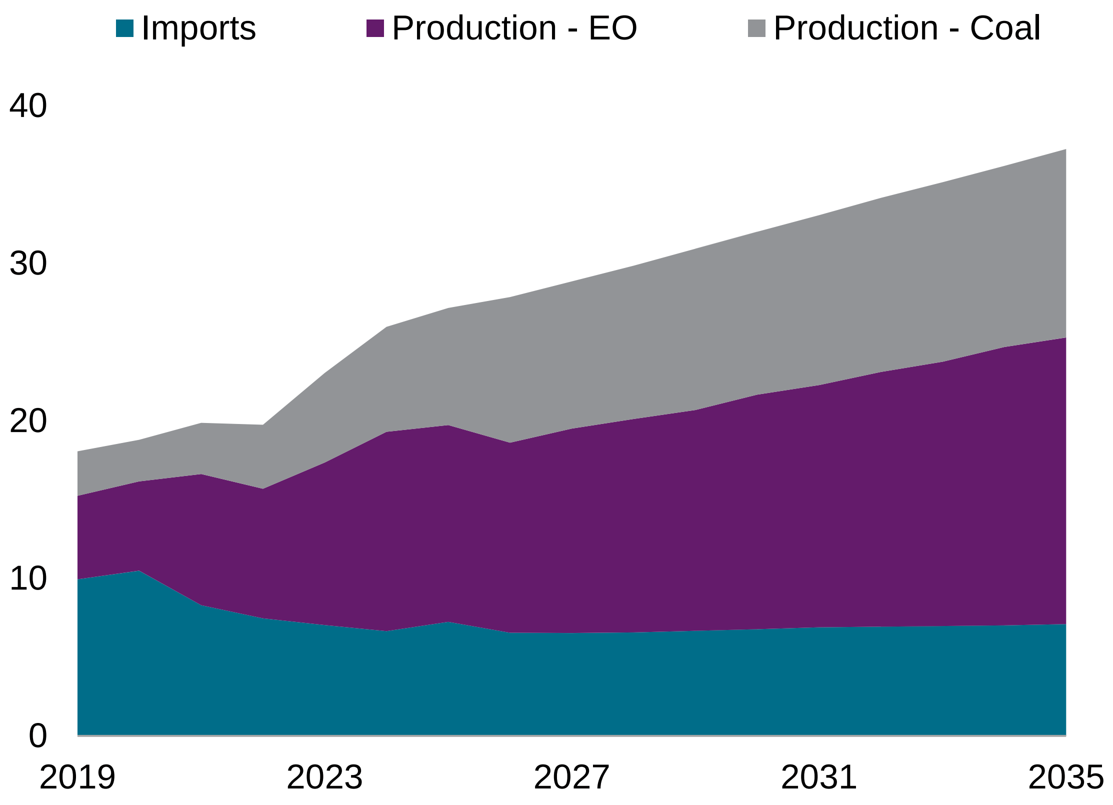
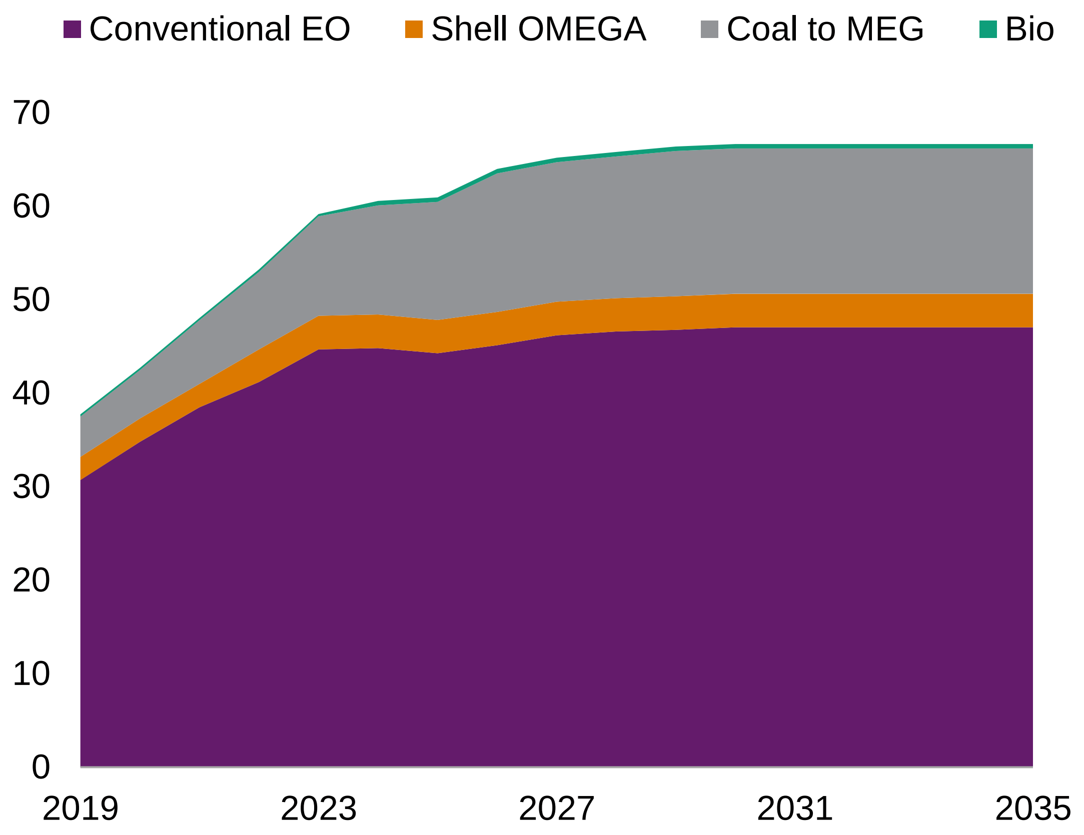
China's rapid coal-to-MEG expansion has diversified production routes, enabling buyers to optimize across imports, coal-based and conventional supply.

China MEG supply by source (million mt)



Global MEG capacity by production route (million mt)



Source: S&P Global Energy

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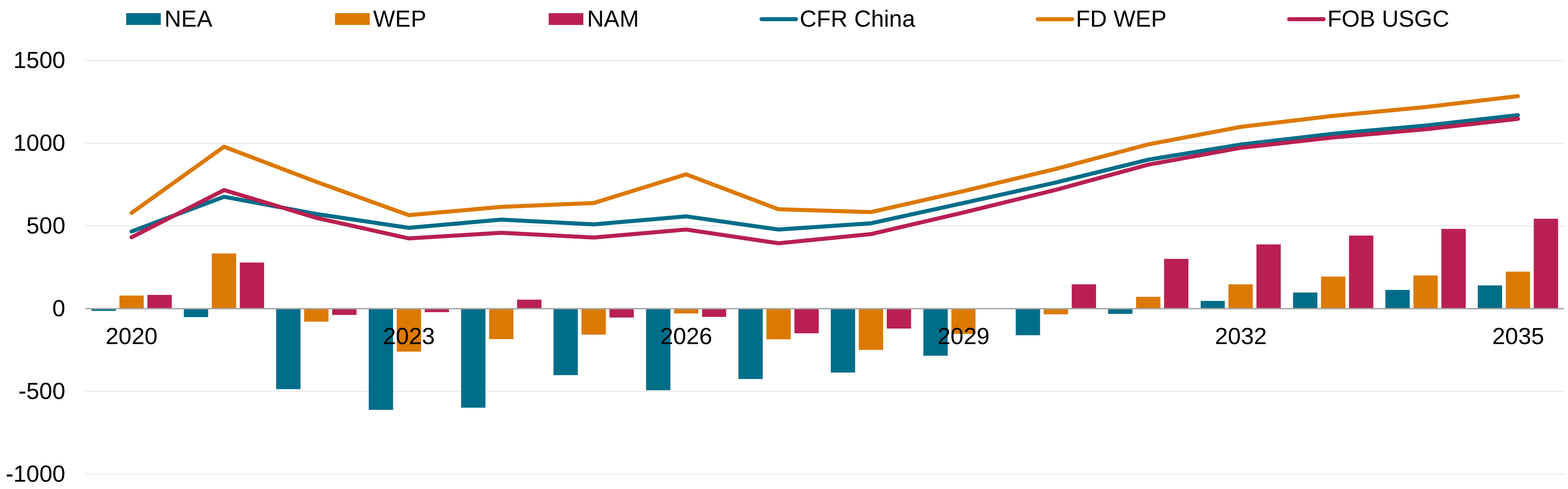
China remains the price-setter, keeping MEG prices low in the near-term, challenging margins even for ethane-based producers

Regional MEG spot price and cash margin trends, Integrated, $/mt



Data compiled April 30th 2026

Source: S&P Global Energy

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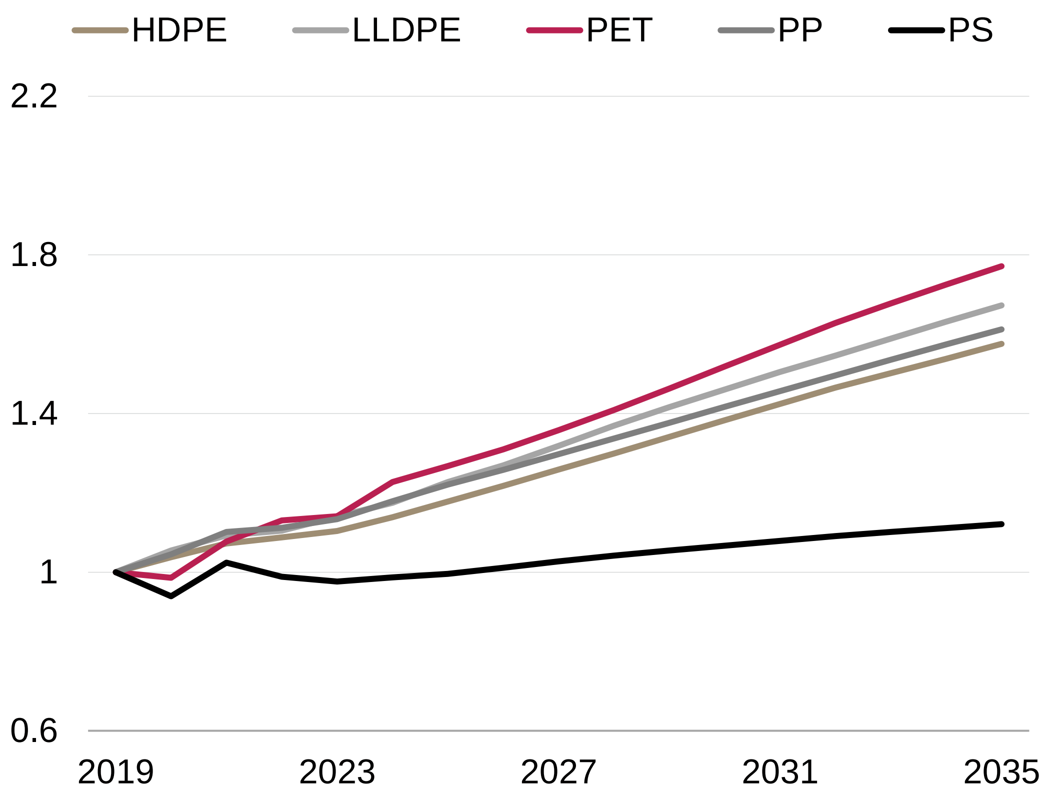
Energy

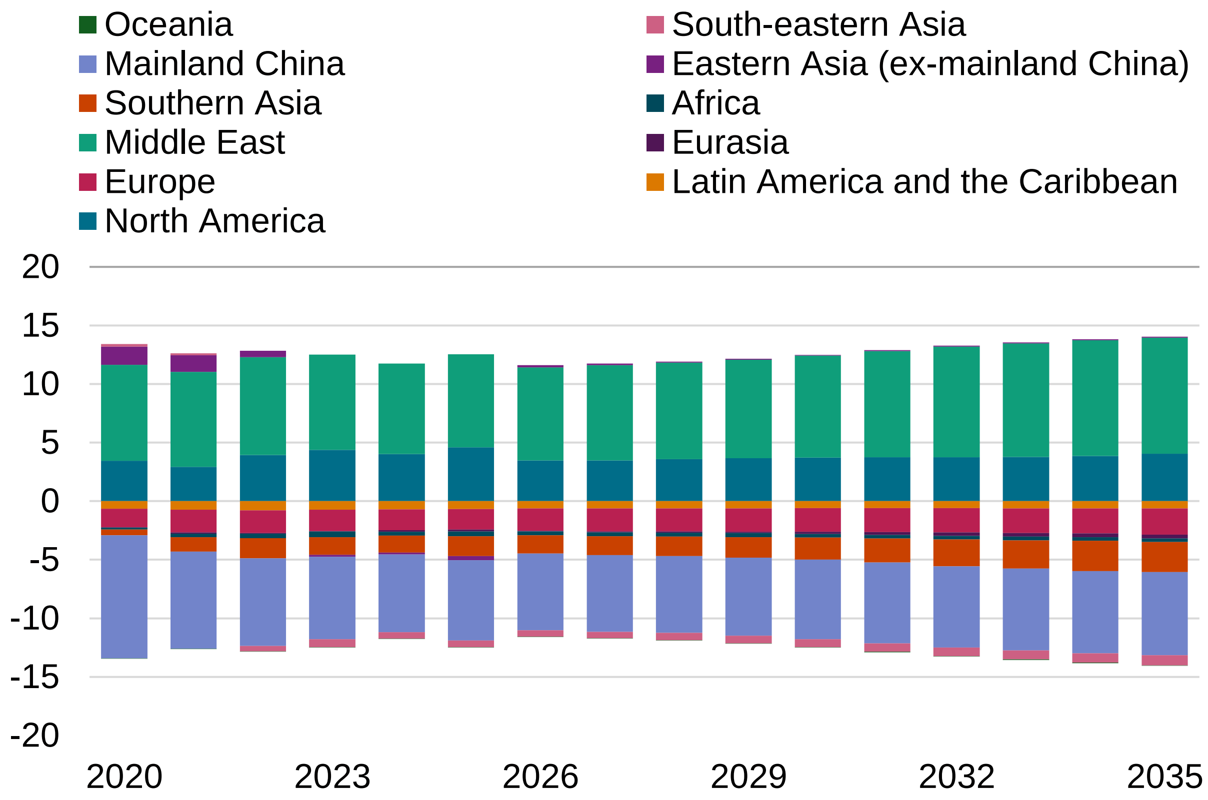
In the longer run, strong and stable demand growth is expected to support continued MEG trade growth

Global polymer demand (index = 2019)



Source: S&P Global Energy

Global MEG net trade, million mt



Source: S&P Global Energy

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Energy

Rebalancing Benzene Value Chain: Tackling Supply Glut, Tariff Turbulence

Eshwar Yennigalla
Sr Principal Analyst,
Asia Aromatics

May 2026

Agenda

Pre-war market expectations for 2026

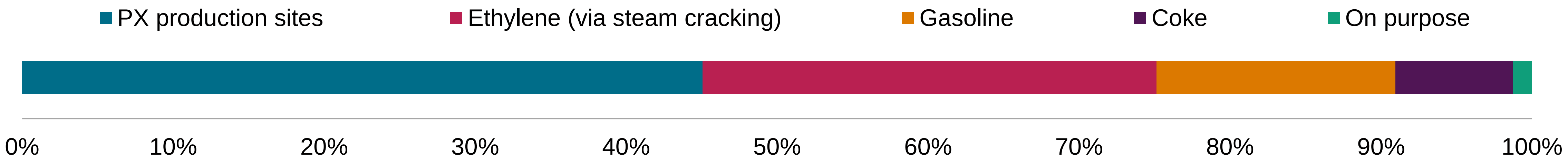
Impact across the Benzene Value Chain

Path Forward and Scenarios for Margin Recovery

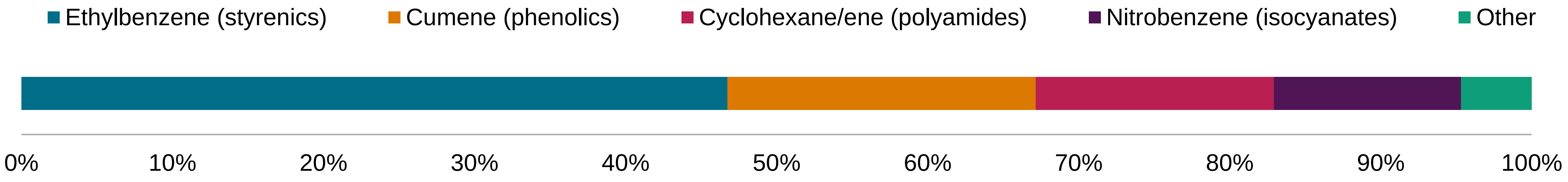
S&P Global
Energy

Benzene is principally a byproduct of p-xylene, gasoline, ethylene and coking coal with 4 major derivatives

Benzene production 2025 by driver



Benzene demand by derivative 2025



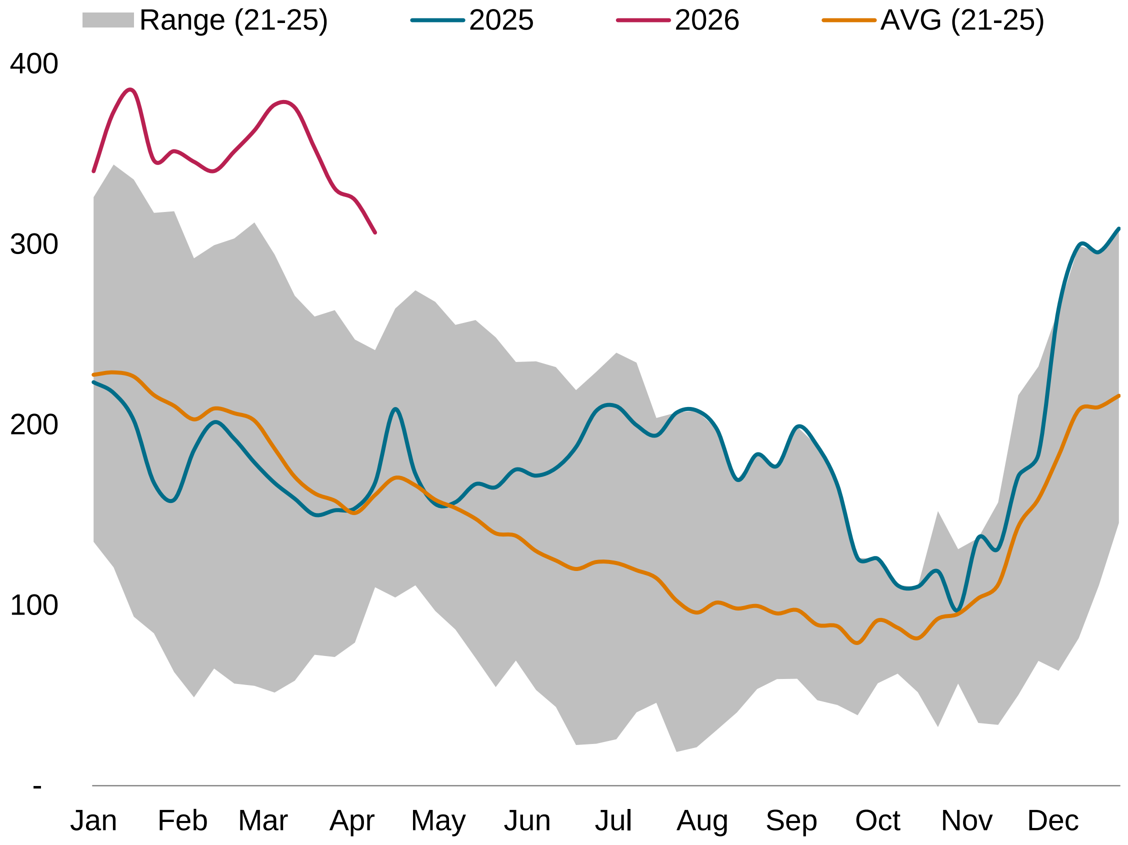
Date compiled, May 2026

Source: S&P Global Energy.

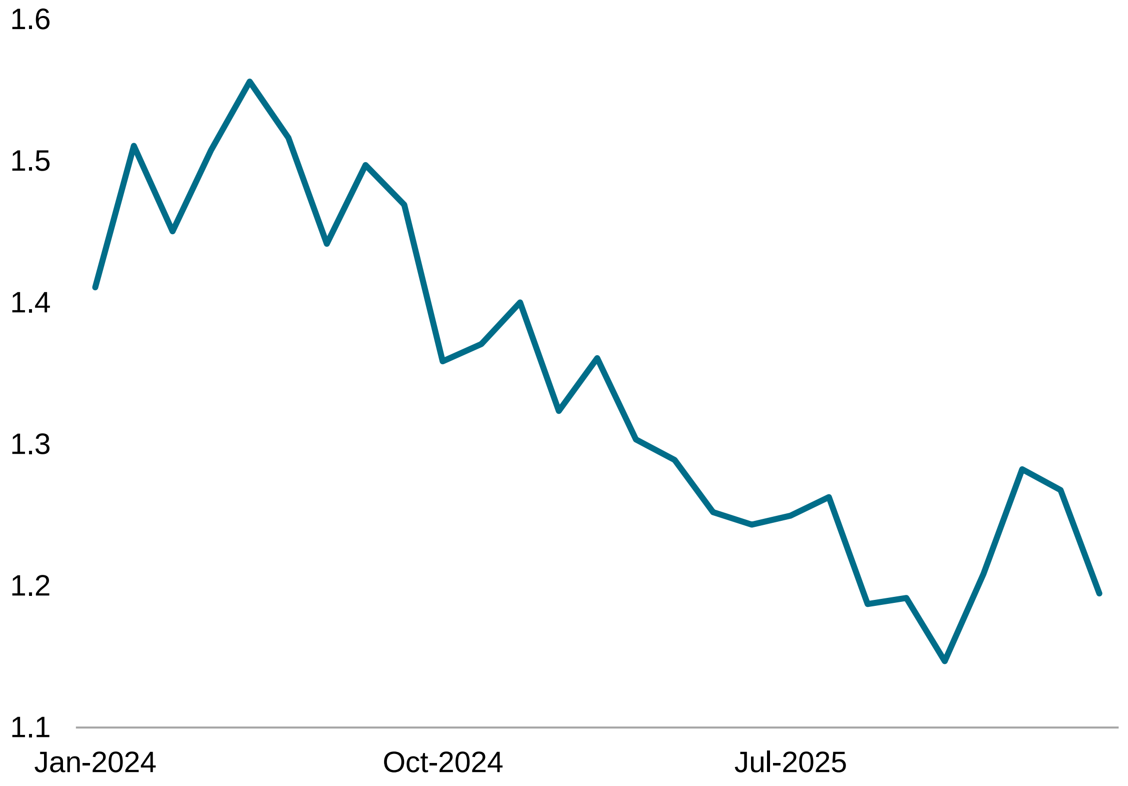
S&P Global Energy

A market in oversupply with high inventory and weak pricing

China Benzene Inventory Tracker (kt)



Benzene to naphtha ratio, NE Asia

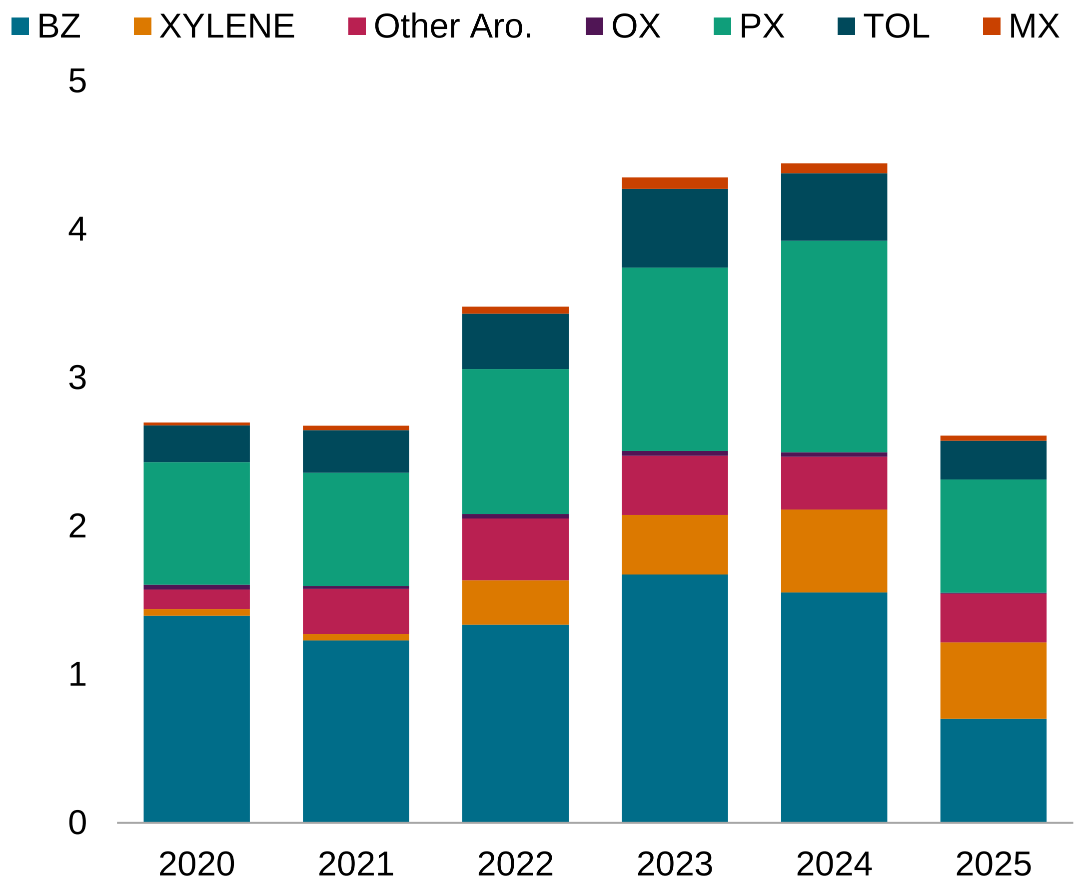


Date compiled, May 2026
Source: S&P Global Energy.

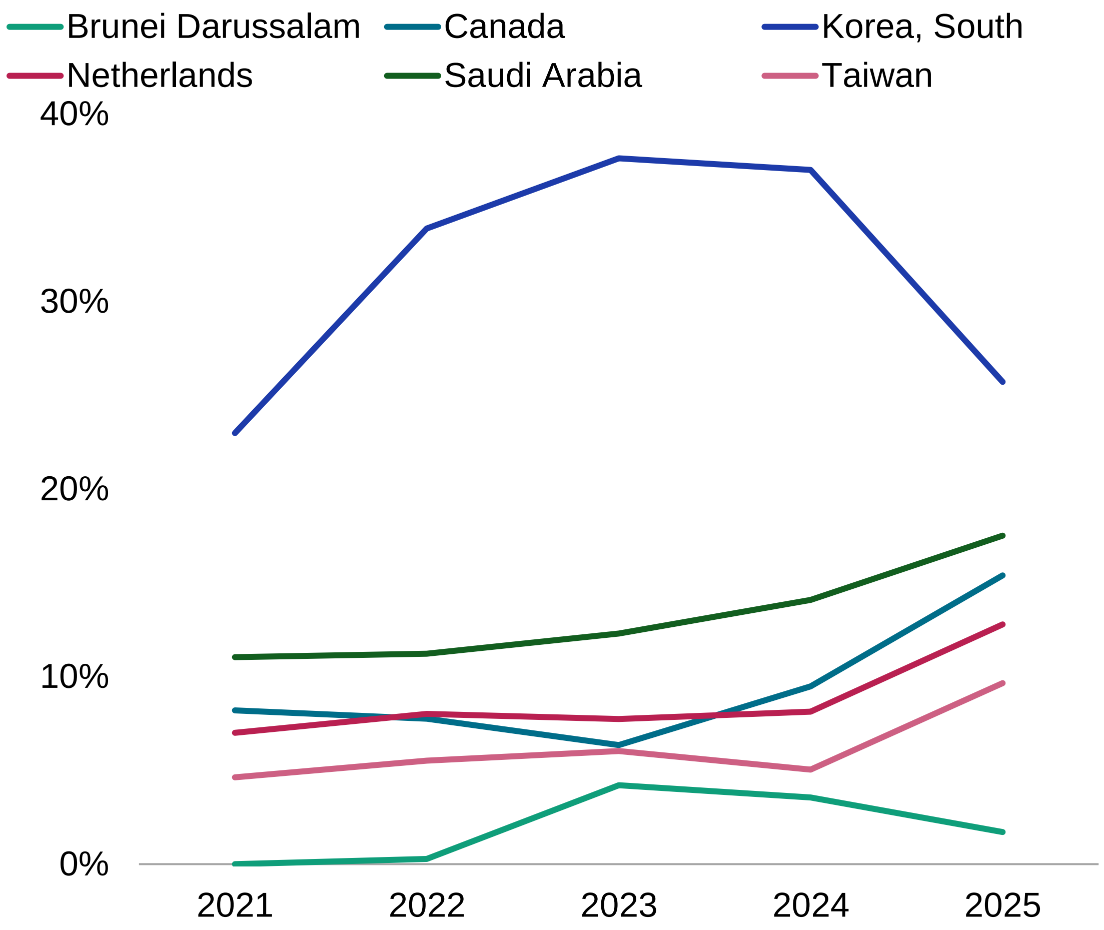
S&P Global
Energy

US imports are expected to revive in 2026 as global trade dynamics shift, along with recent court rulings that overturned tariffs.

US aromatics import by product (MM mt)



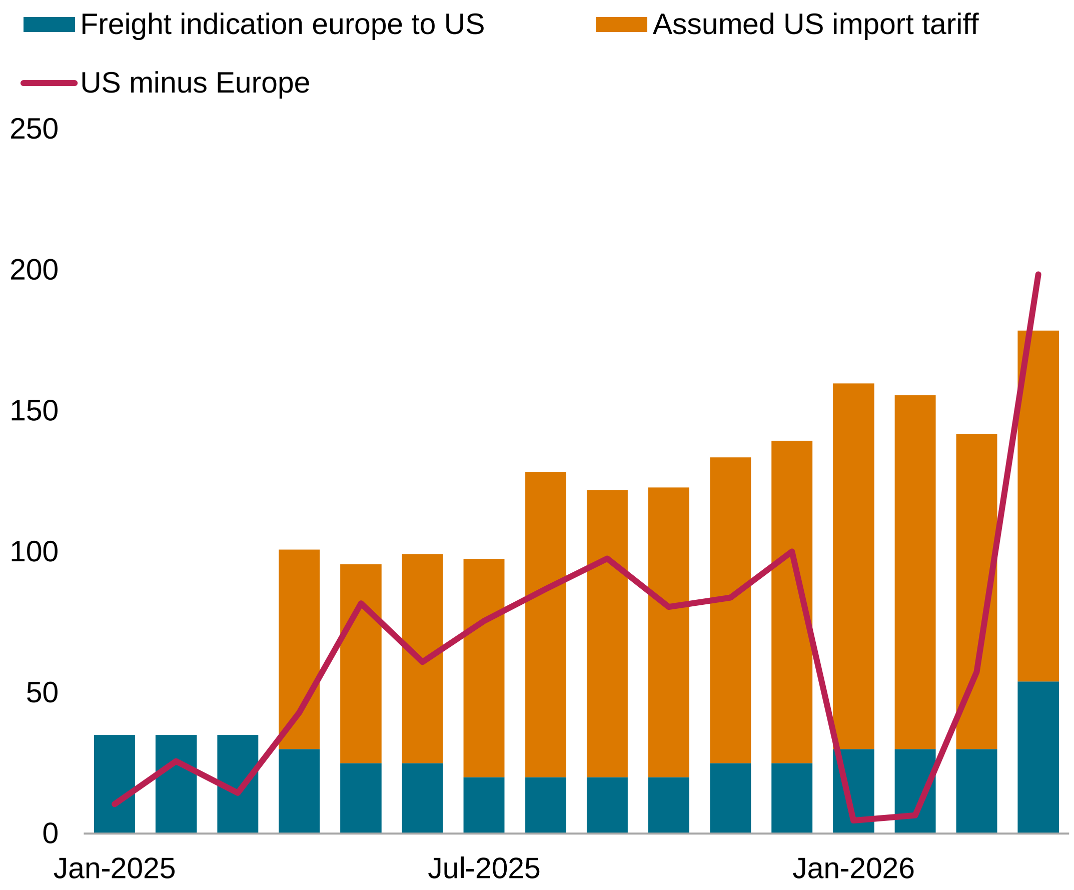
US Aromatics import ratio



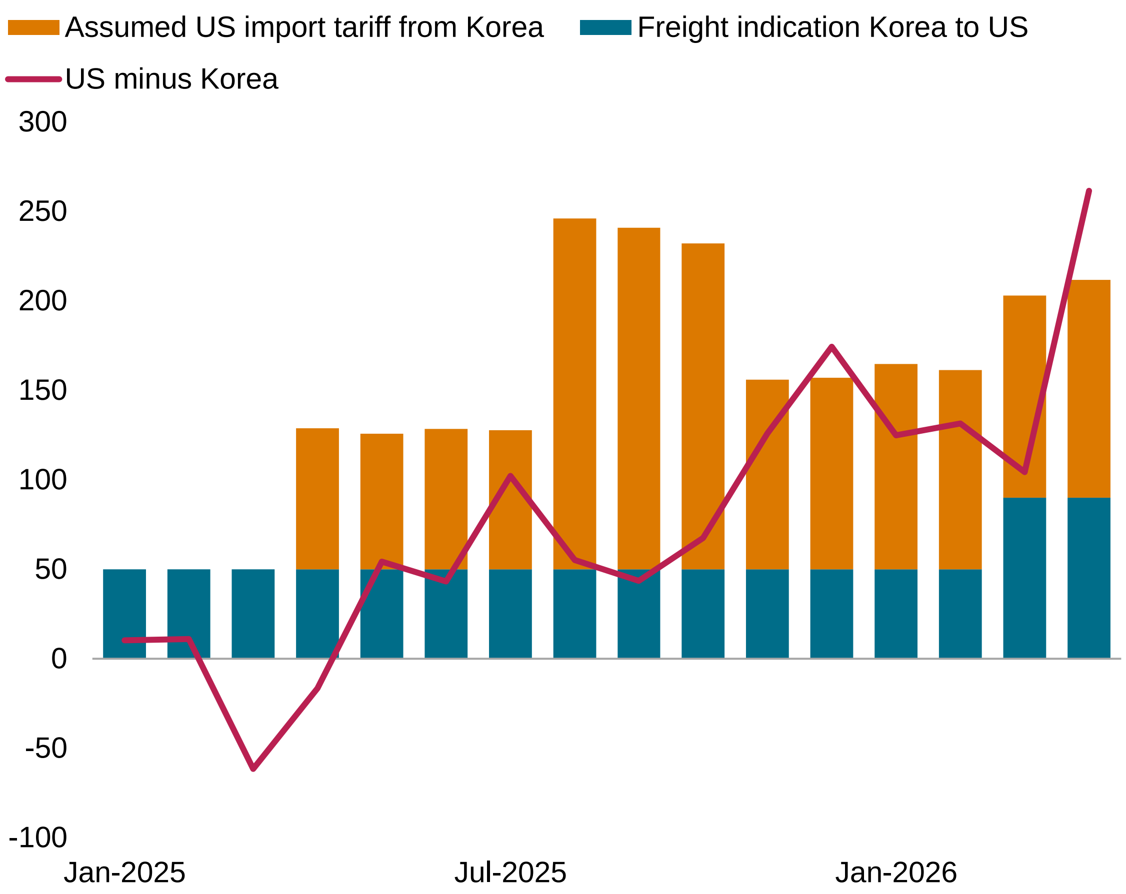
Date compiled, May 2026
Source: S&P Global Energy.

Tariffs dampened US demand and imports, leading to a rethink by major exporters and wide regional price spreads

Benzene arbitrage, Europe to US ($/mt)



Benzene arbitrage, South Korea to US ($/mt)

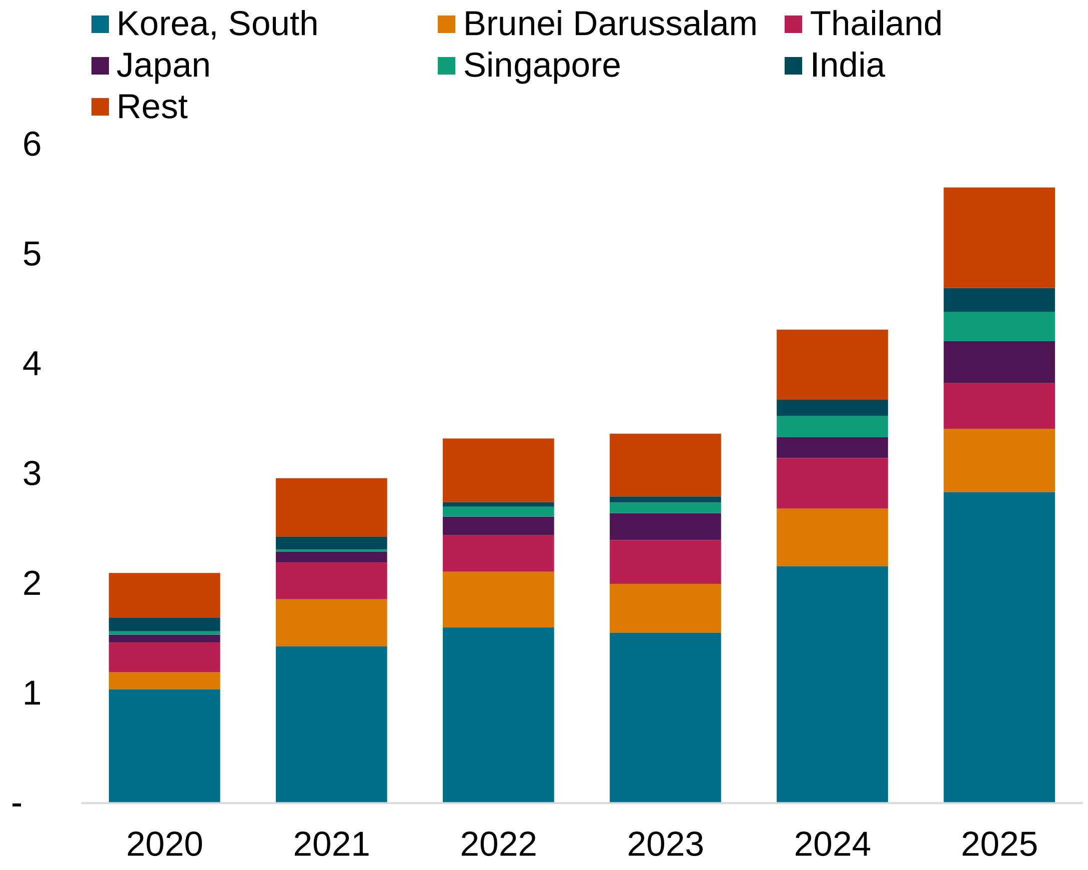


Date compiled May. 2026.

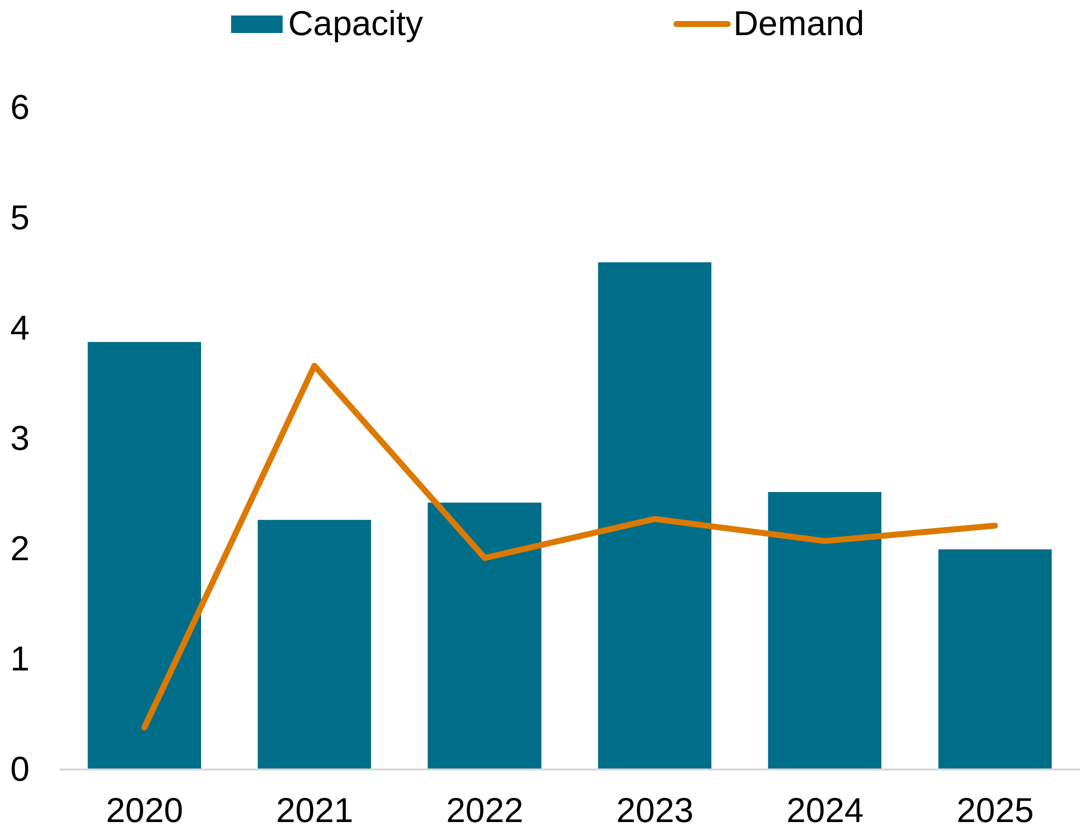
Source: S&P Global Energy.

China imports increasing despite new benzene capacity amid strong investments across derivative markets.

China Benzene import by country (MM mt)



China benzene capacity and demand growth year on year (MM mt)



Date compiled, May 2026
Source: S&P Global Energy.

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Pre-war market expectations for 2026

Impact across the Benzene Value Chain

Path Forward and Scenarios for Margin Recovery

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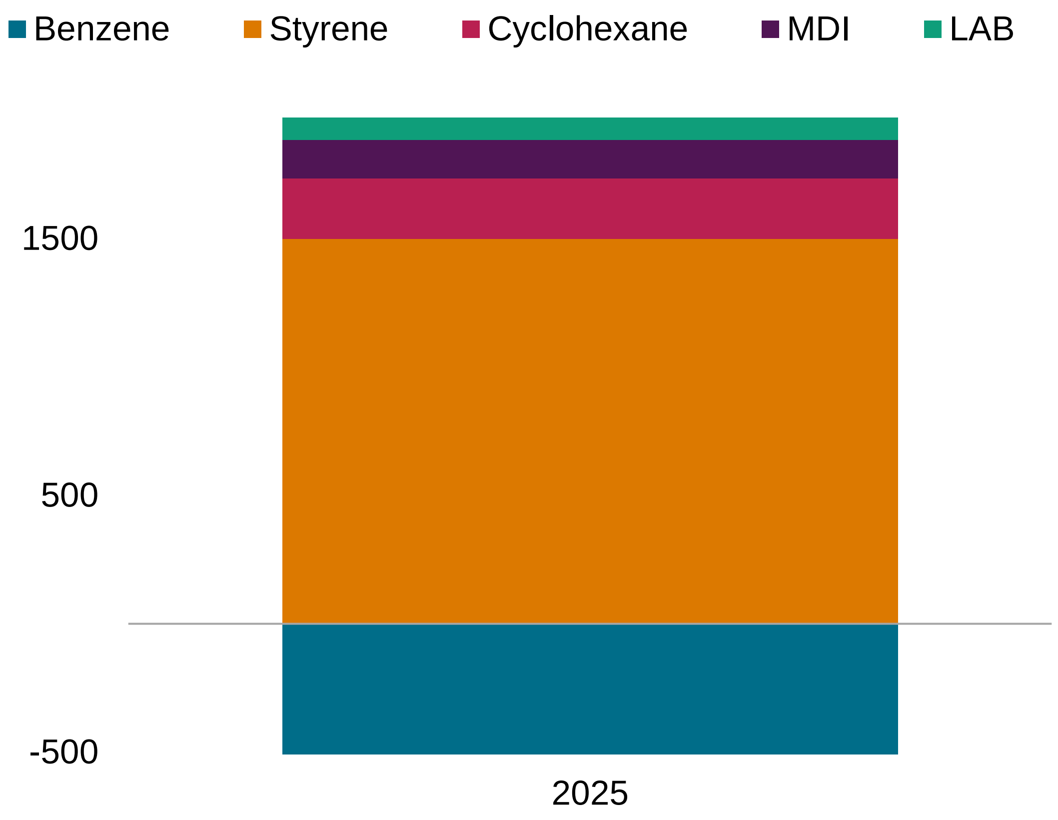
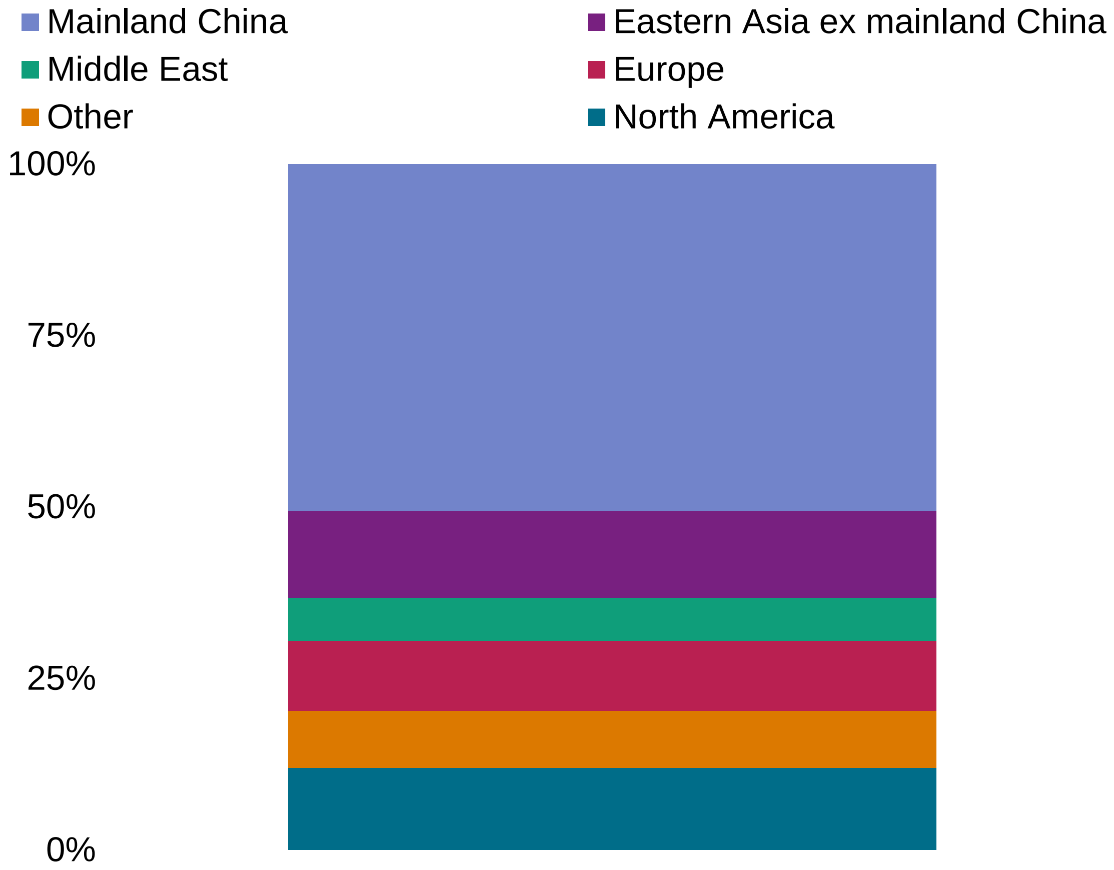
Closure of the Hormuz Straits directly impacts availability of styrene and other derivatives; but reduced operations in Asia have deeper implications

Net trade of benzene through Straits of Hormuz and derivatives (kt bz equivalent)

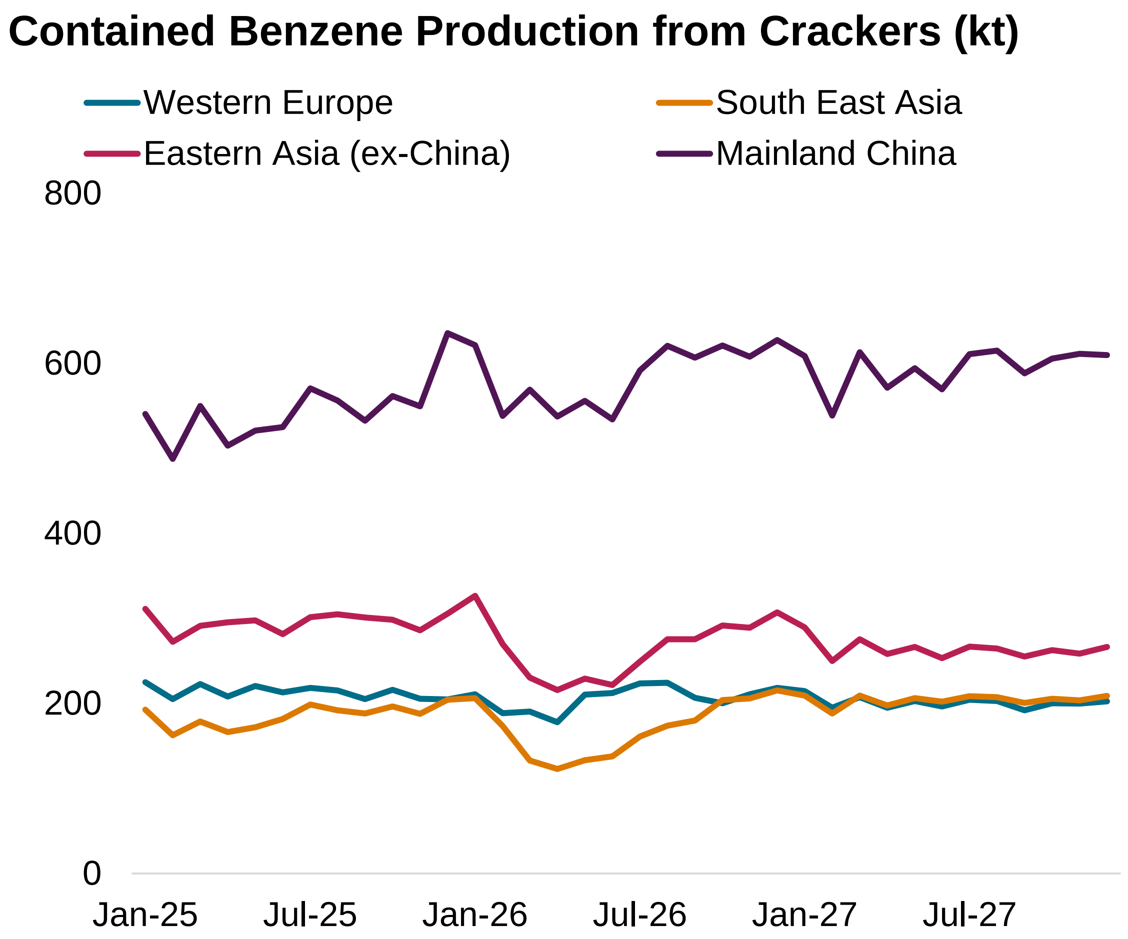


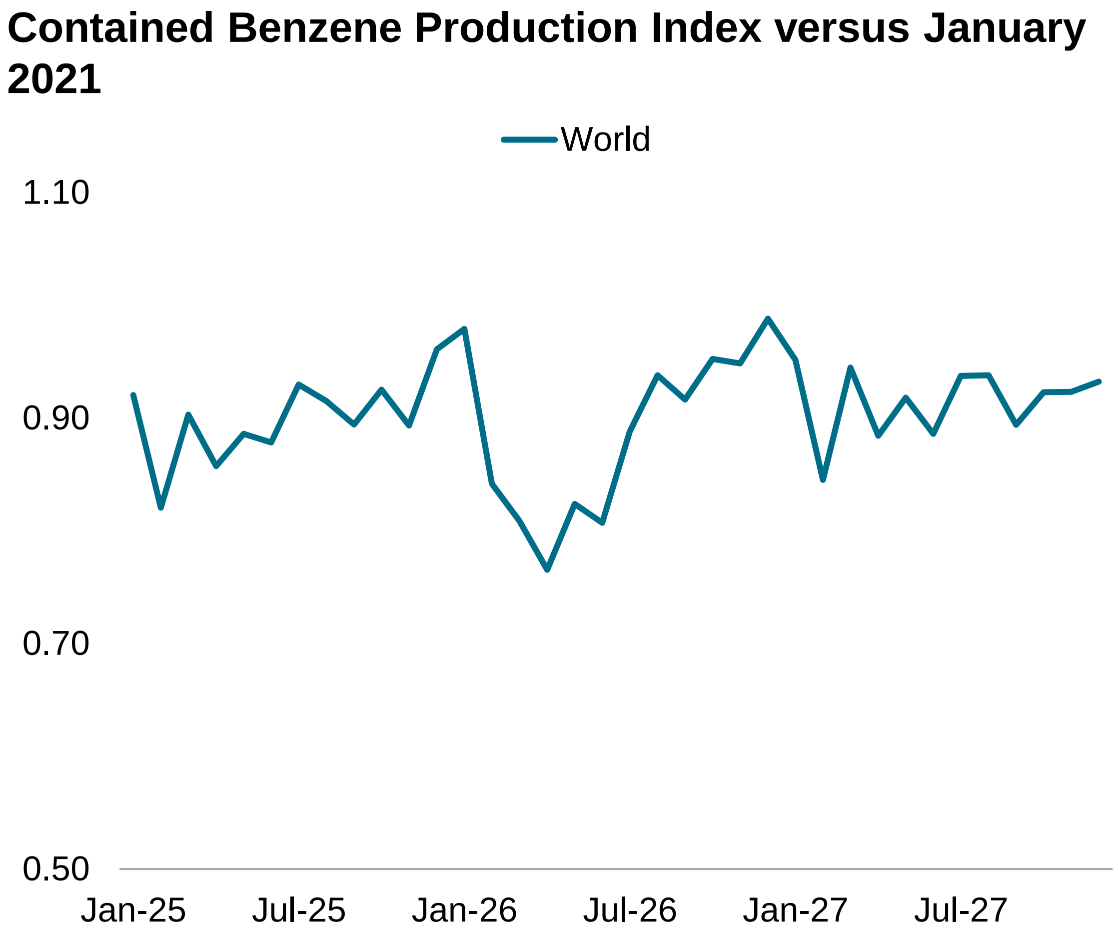
Benzene demand by region



Date compiled, February 2026
Source: S&P Global Energy.

Global drops in pygas production amid expensive naphtha cracking costs have led to tightening aromatics supply.

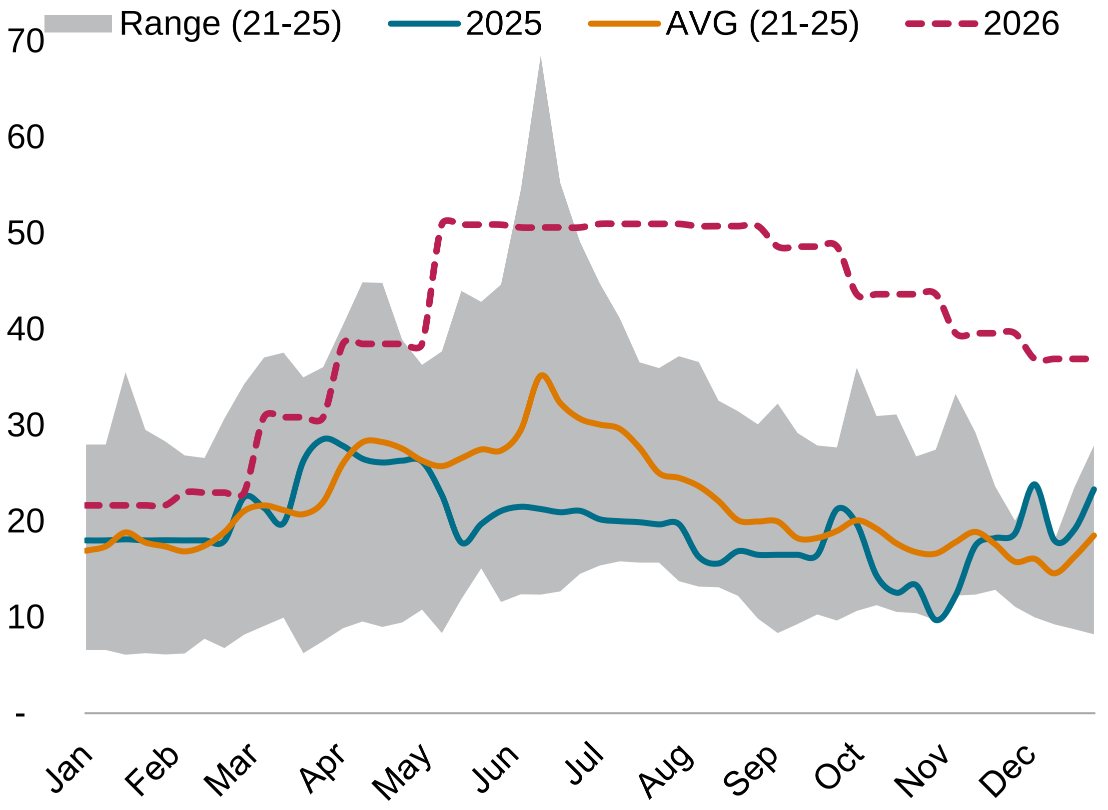




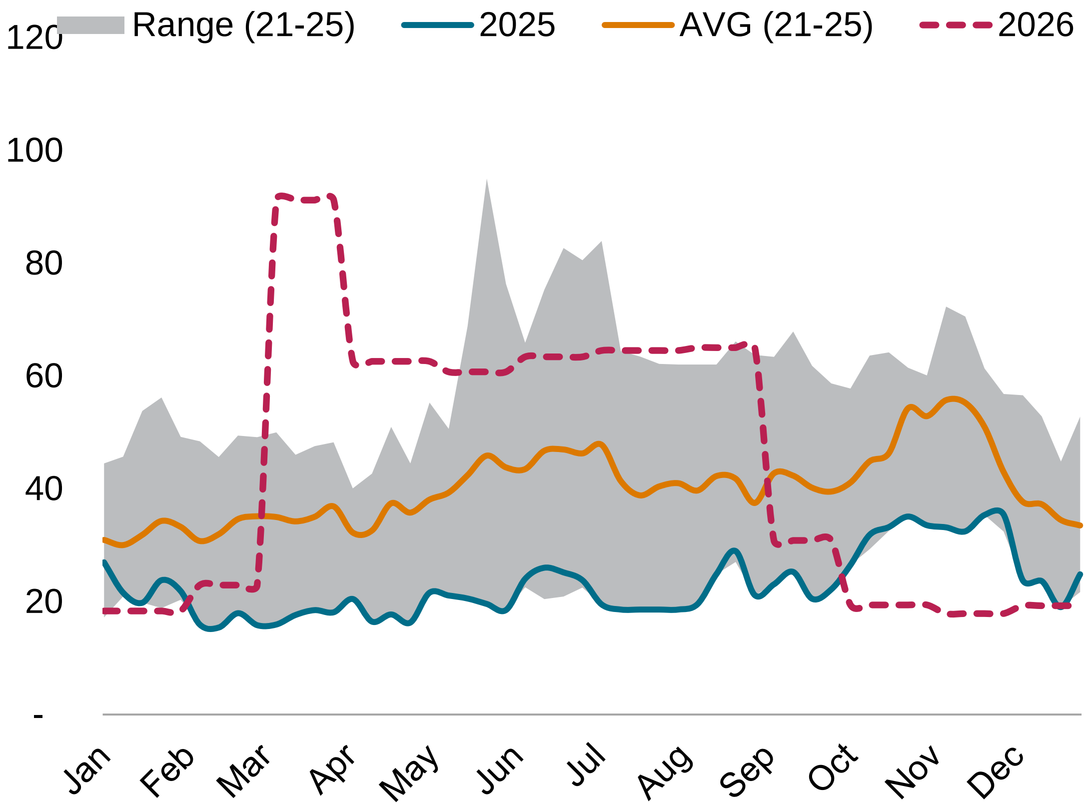
Date compiled, May 2026
Source: S&P Global Energy.

Gasoline cracks are forecast to remain elevated owing to lower refinery runs, with strong octane demands projected for USGC markets in Q2 and Q3

USGC Gasoline Octane Spread (cts/gal)



Singapore Gasoline Octane Spread ($/mt)



Date compiled, May 2026
Source: S&P Global Energy.

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India's reduced gasoline exports and China's export freeze will sharply limit Asia's import options, tightening regional supply balances

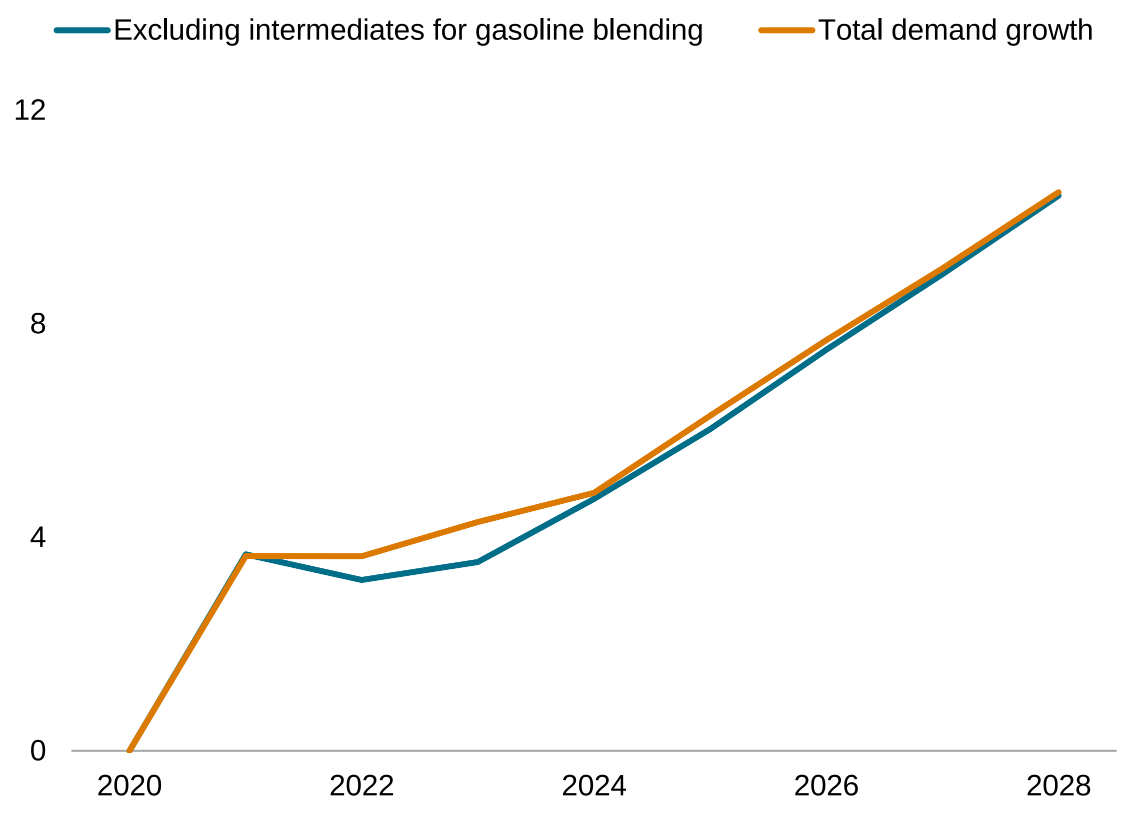
Gasoline trade flow

Data compiled March 27, 2026.

Source: S&P Global Energy: IC-263004-02.

Demand recovery shifts benzene intermediates back to chemical outlets; on hold? - gasoline may start to pull

Benzene cumulative demand growth (MMt)



Date compiled November 2025
Source: S&P Global Energy.

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Pre-war market expectations for 2026

Impact across the Benzene Value Chain

Path Forward and Scenarios for Margin Recovery

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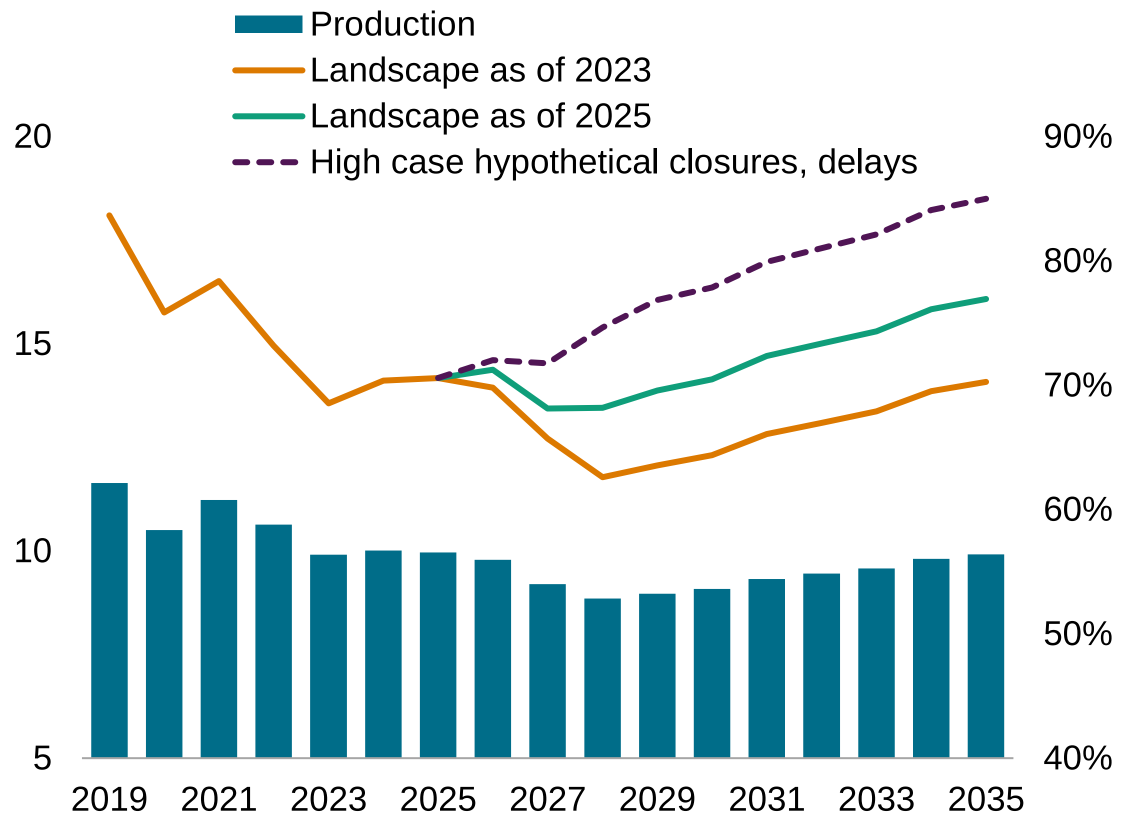
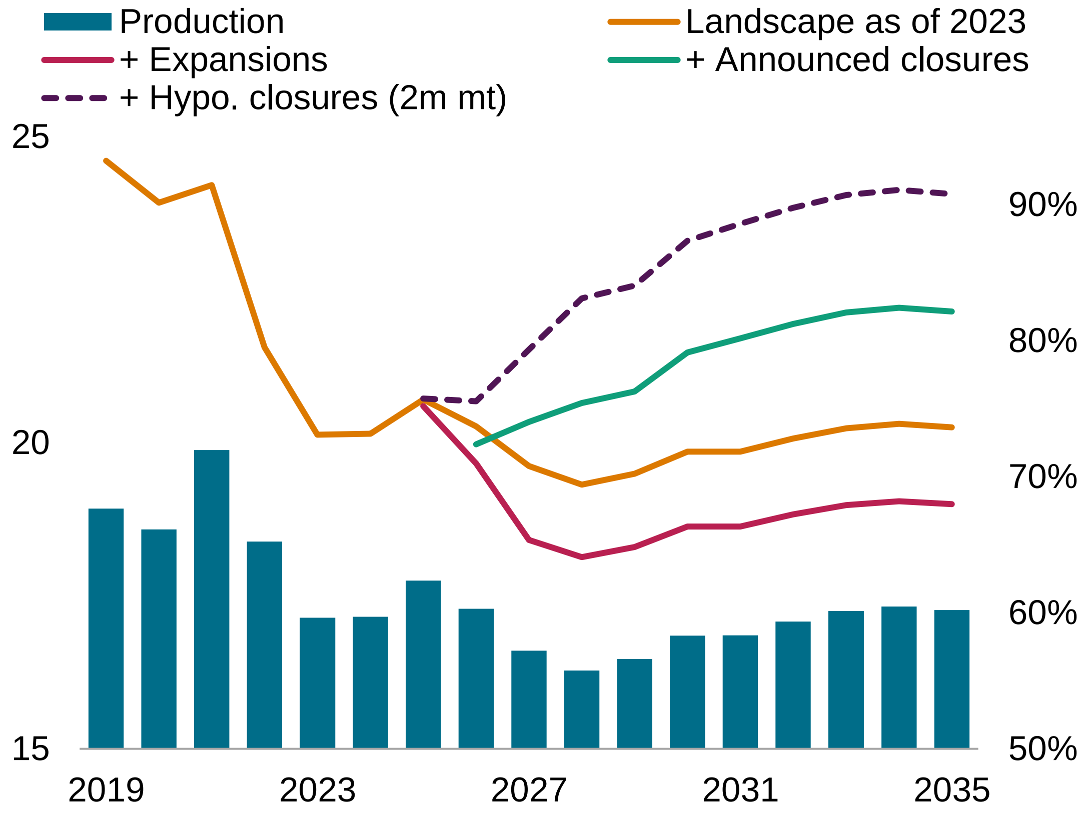
Energy

NE Asian markets lead rationalization in benzene, driven by naphtha fed steam cracker shutdowns.

NE. Asia benzene production (million tons) & operating rate scenarios



NE. Asia ethylene production (million tons) & operating rate scenarios



Date compiled, May 2026
Source: S&P Global Energy.

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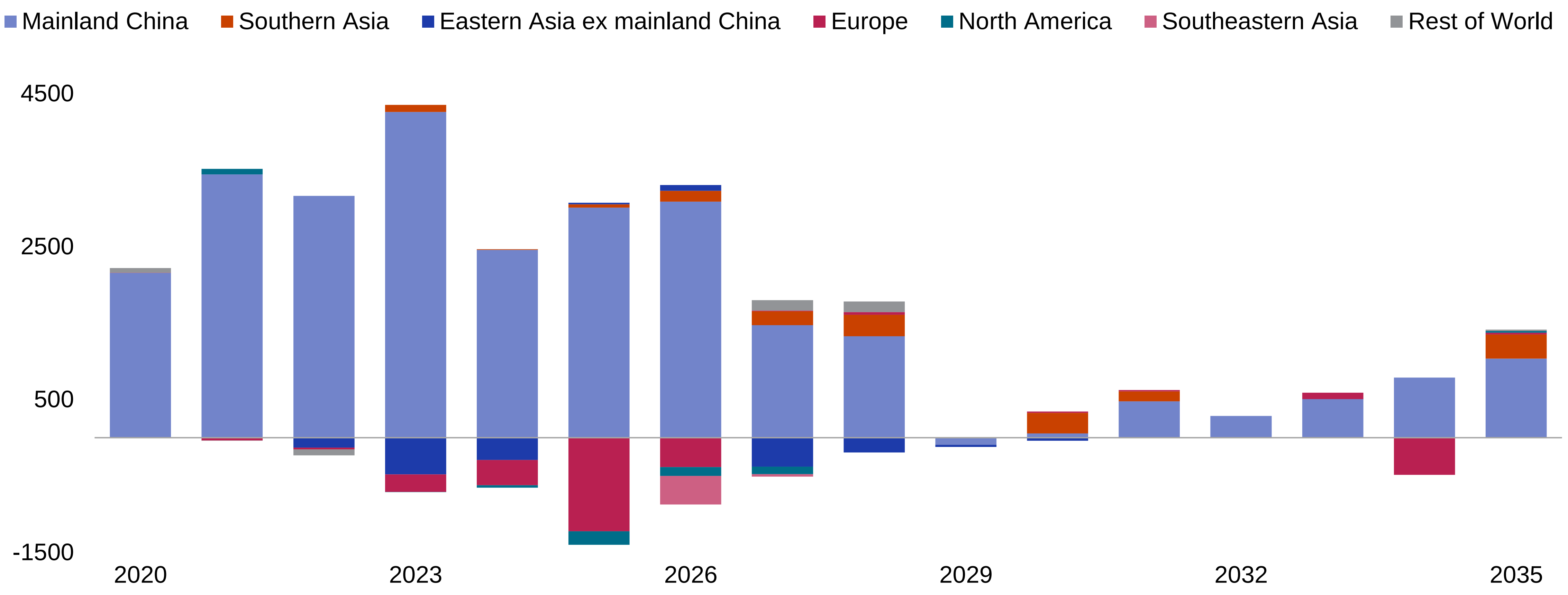
China will continue to build new capacity, albeit at a slower pace

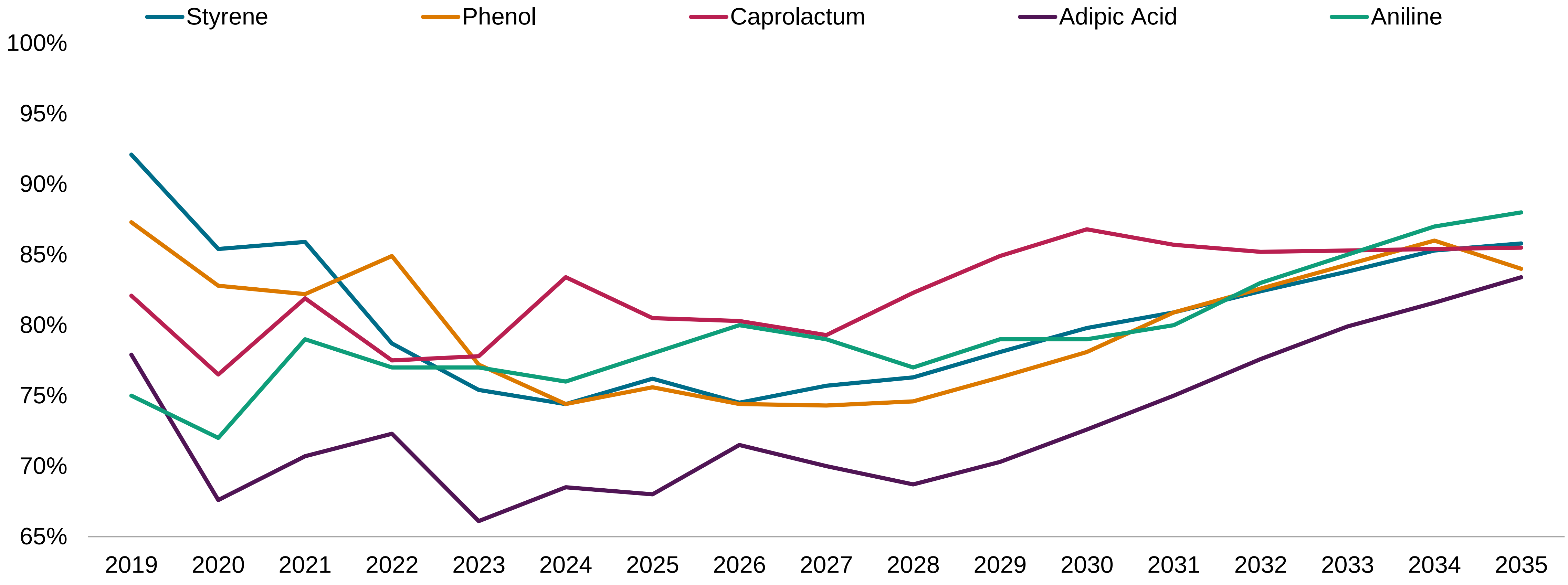
Growth in capacity for major derivatives (kt benzene equivalent)



Date compiled May 2026
includes styrene, phenol, caprolactam, adipic acid and MDI
Source: S&P Global Energy

2027-2028 remain inflection points for margins to start recovering across major benzene derivatives.

Global operating rates for major benzene derivative markets.



Date compiled, October 2025
Source: S&P Global Energy.

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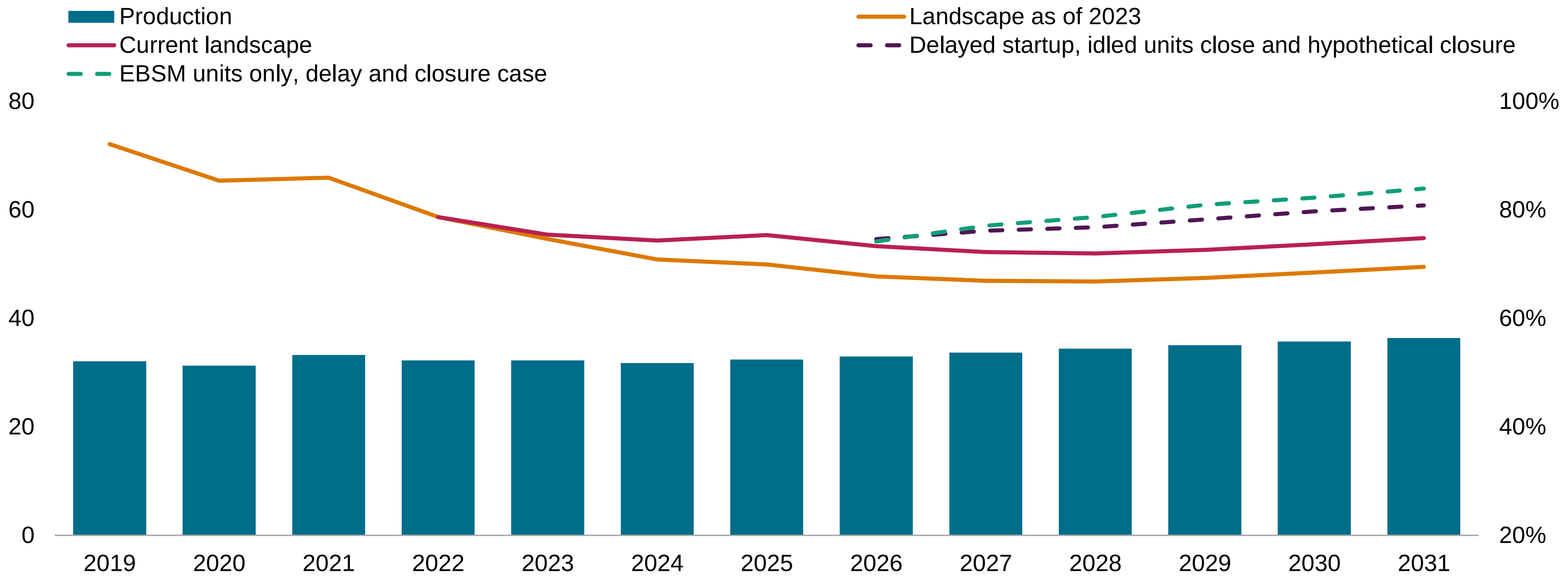
Major idling of styrene monomer capacity is already underway

Styrene production (million mt) and operating rate scenarios



Date compiled, May 2026
Source: S&P Global Energy.

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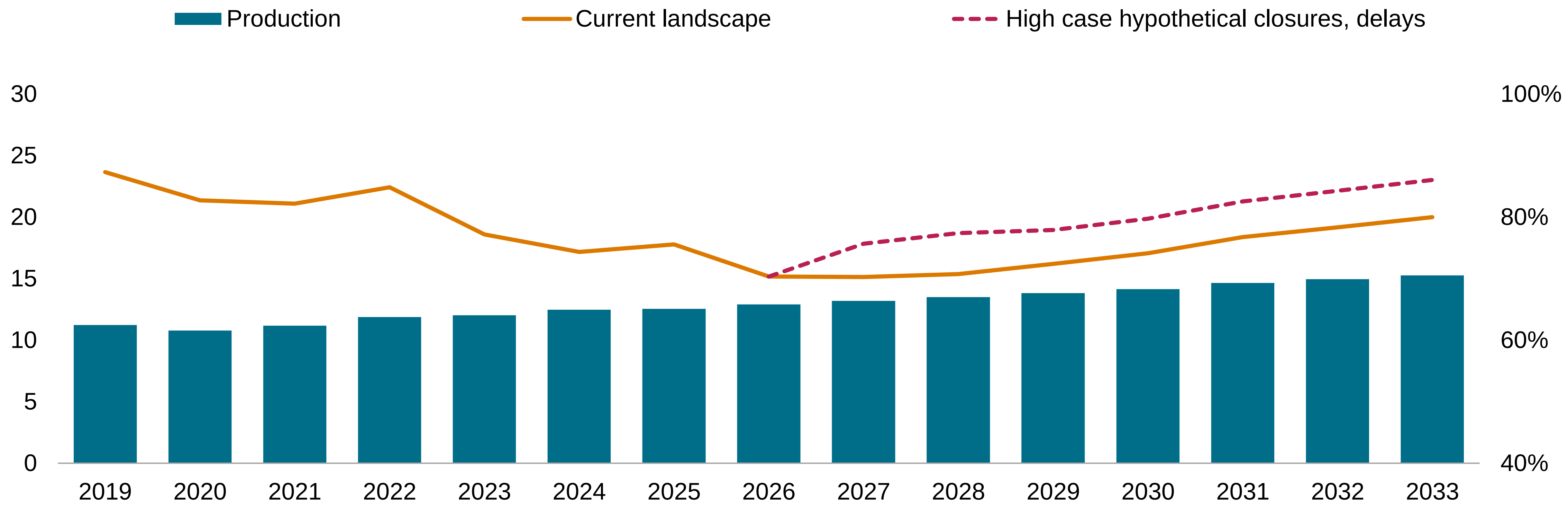
Delays and closure of merchant and smaller phenol plants could lift operating rates, but likely remain below 80% this decade

Global phenol production (million tons) & operating rate scenarios



Date compiled, May 2026
Source: S&P Global Energy.

Takeaways

Near-term volatility

Ethylene feedslate uncertainty

Post 2028 all major derivatives expected to recover

Recovery path gradual even in rationalization case

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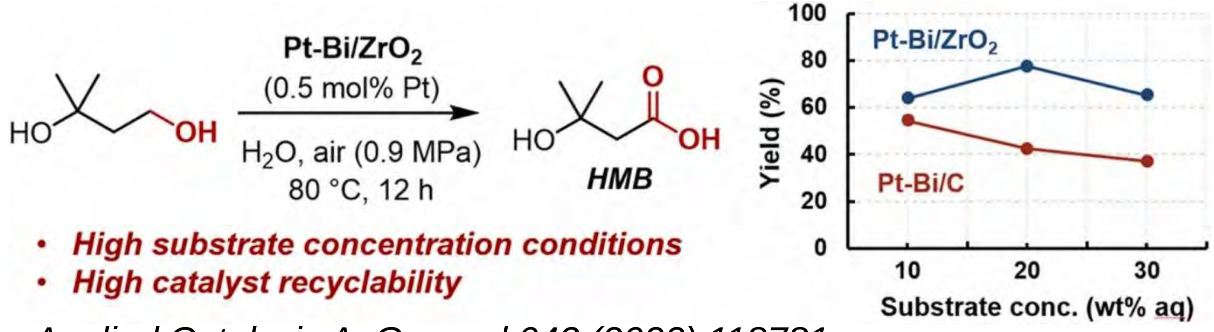
Desulfurization from alcoholic beverages with supported Au nanoparticles

Department of Chemistry, Kyushu University

Makoto Tokunaga

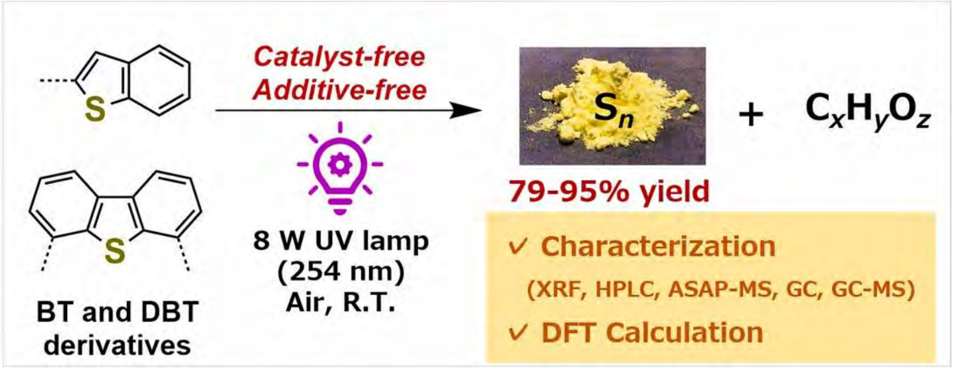
Collaborative Researches with Industries

Kuraray Co., LTD



Applied Catalysis A, General 643 (2022) 118781

Toyota Motor Corporation



Journal of Cleaner Production 370 (2022) 133402

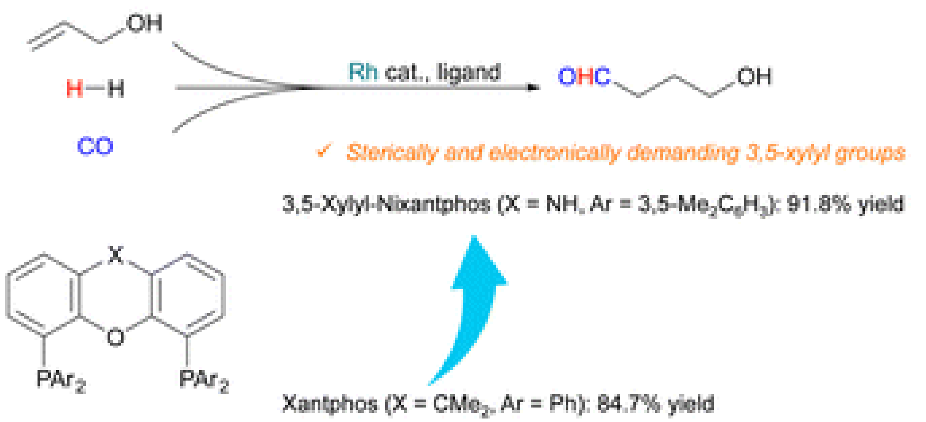
Resonac Corporation

Branch-selective alkoxycarbonylation over supported catalysts

Applied Catalysis A, General 720 (2026) 120954

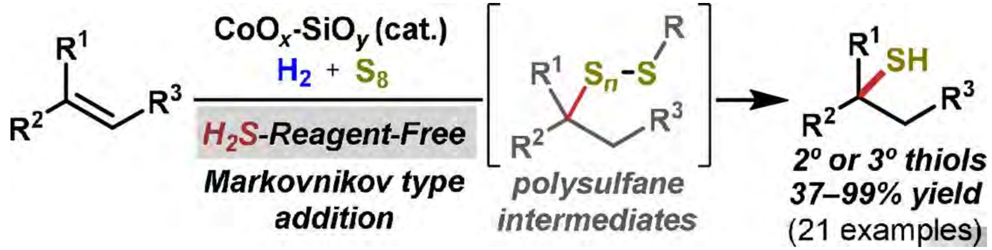
Resonac Corporation

Linear-selective hydroformylation enabled by Rh/Xantphos-type ligands



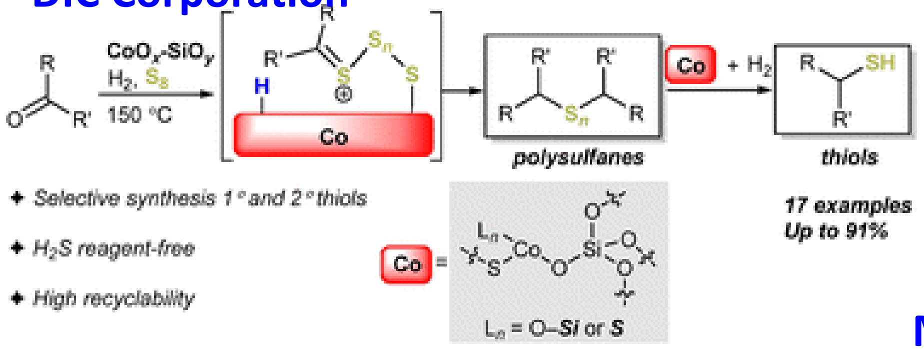
Dalton Transaction, DOI: 10.1039/d6dt01054g

DIC Corporation



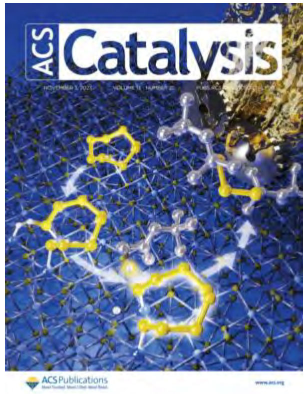
Molecular Catalysis 596 (2026) 115879

DIC Corporation



Chem. Commun., 2025, 61, 16238

DIC Corporation

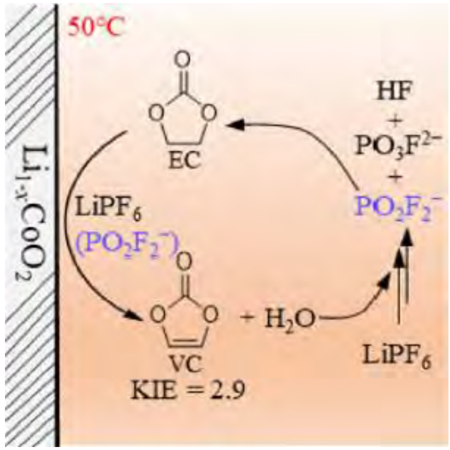


ACS Catal. 2023, 13, 14121−14130

DIC Corporation

ChemCatChem 2021, *13*, 4694–4699

Murata Manufacturing Co., Ltd.



Bull. Chem. Soc. Jpn. 2023, 96, 444–451

Mitsubishi Chemical Corporation

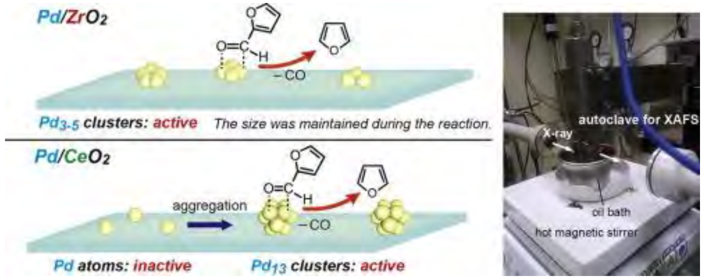
Journal of Catalysis 460 (2026) 116952

Mitsubishi Chemical Corporation

Applied Catalysis B: Environment and Energy 373 (2025) 125351

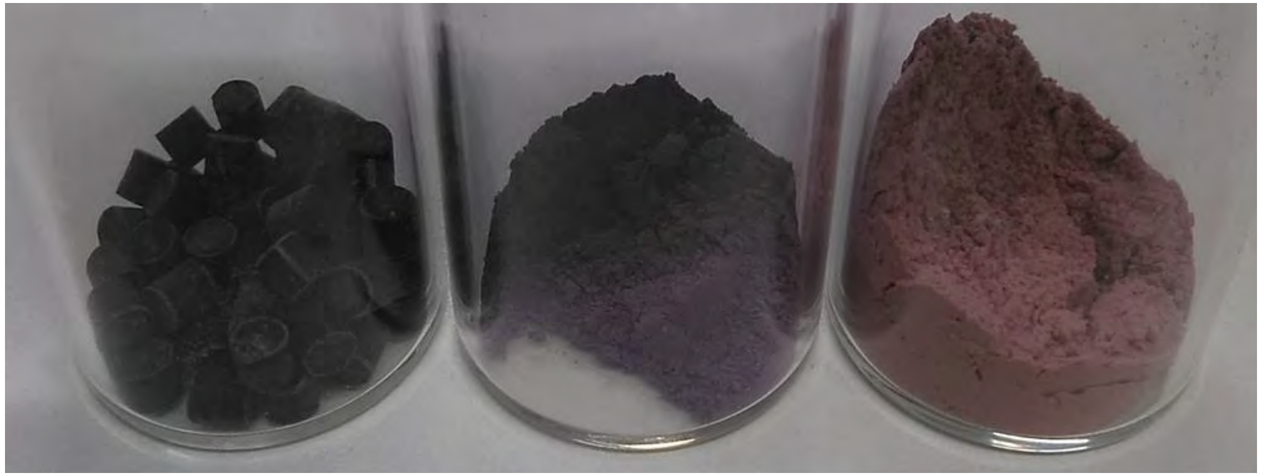
Applied Catalysis B: Environmental 296 (2021) 120333

Mitsubishi Chemical Corporation



Journal of Catalysis 374 (2019) 320–327

How to prepare supported Au nanoparticles



Au/SiO_2

With different shapes

Impregnation Method:
The **Most Practical Way** for the Bulk Production of Noble Metal Catalysts

Pt, Pd, Rh: applicable

For automobile: 5000 ton/y

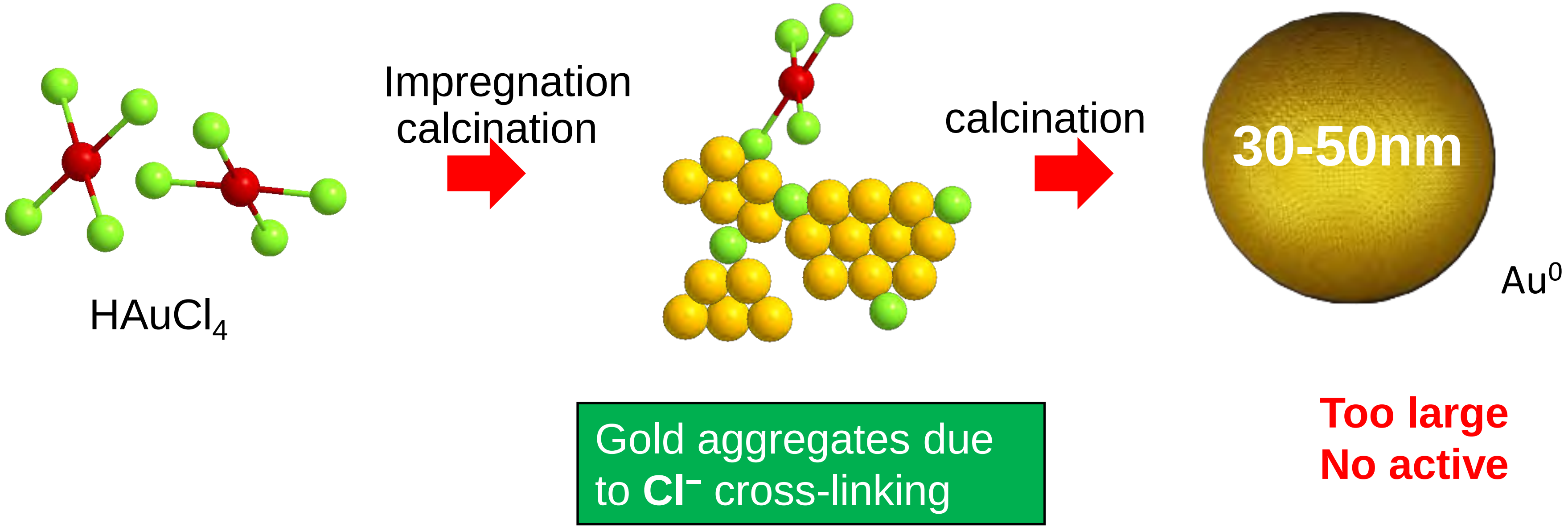
Au: not applicable

Why?

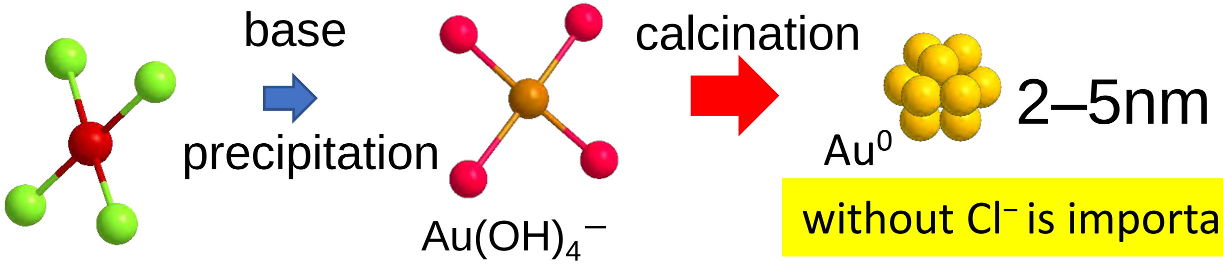
Classical Impregnation Method with Au

Precursor: $HAuCl_4$ or $NaAuCl_4$

Readily available and inexpensive precursors



Deposition-Precipitation Method with Au (1980’)



Low solubility

without Cl^- is important

Wide-spread use of Au catalysts

Cl^--free

Professor Haruta

Issues

- Dilute conditions (0.01% Au)
- Low volumetric productivity, making it unsuitable for bulk production
- Acidic supports such as silica cannot be supported due to electrostatic repulsion
- Using NH_4^- produces fulminating gold

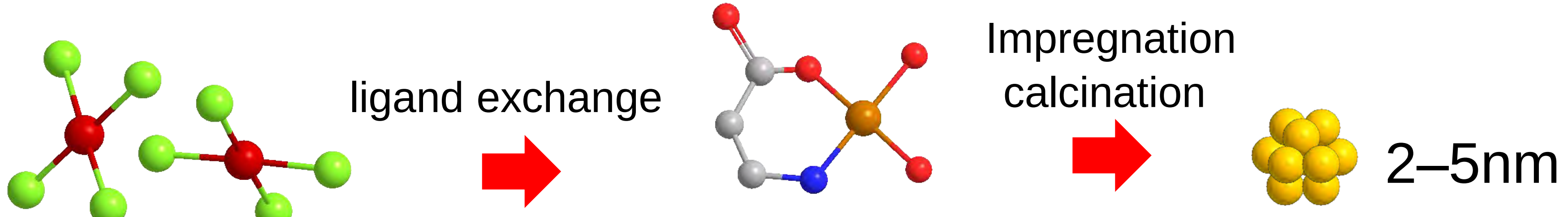
$[Au_2(\mu\text{-}NH_2)(\mu_3\text{-}NH)]Cl$

Alchemist reported fulminating gold in 16 century

Chrysoponie Schwaertzeriana (1585)

Our Impregnation Method with Au (2017)

J. Catal., **2017**, 353, 74-80. (our lab.)



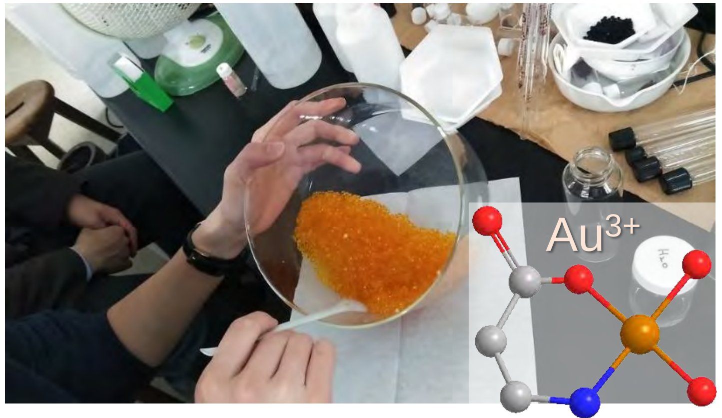
$HAuCl_4$ $[Au(\beta\text{-ala})(OH)_2]$ Au^0

Cl⁻–free

suitable for bulk production!

- High solubility
- Appropriate stability

300 g scale production in the lab.

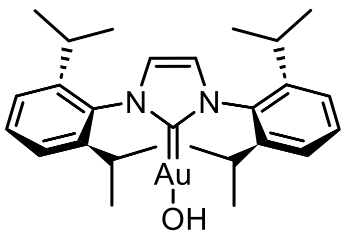


Impregnation

calcination

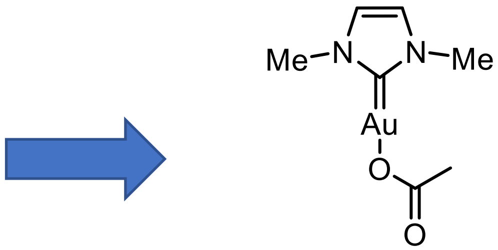
Suitable Impregnation Precursor of Au nanoparticles (our lab.)

- Cl^- -free
- High solubility
- Appropriate stability



Mol. Catal. **2023**, *549*, 113460.

Too large substituents
A little bit too stable
Moderate solubility



J. Catal. **2026**, 460, 116952.

Small substituents
Good stability
Good solubility

6 th presenter

曹 钰雪

Cao Yuxue

Application for C4 chemical transformation

Production Process of Japanese Sake

poly-saccharides （米: rice）→ rice malt fungus → mono-saccharides （麹: rice malt）→ fermentum → ethanol （清酒: sake）→ heat sterilization (**火入れ**) → sake

Stopping Biocatalytic reactions

Storage at r.t. → aged sake

Hineka
by chemical reaction

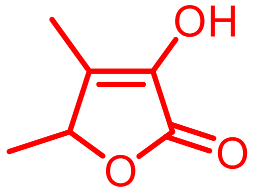
Flavor varies by time

Favorable flavor
Matured aroma （熟成香: jukuseika）
「caramel」「nuts」

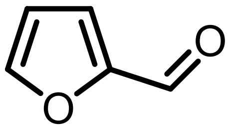
Unfavorable flavor
Aged odor (老香: hineka）
「onion」「sulfur」

Flavor Components of Japanese Sake

carbonyls

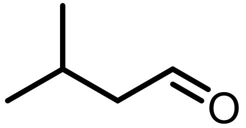


sotolon
(caramel, curry)



furfural
(caramel, burnt odor)

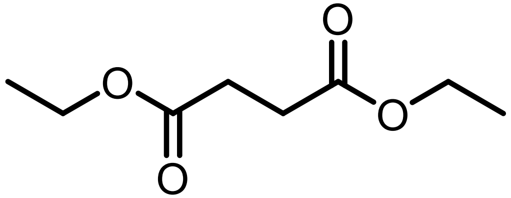
threshold
2.3 μg L^{-1}



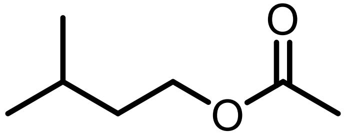
3-methylbutanal
(aldehydes, nuts)

Matured aroma
Jukuseika

esters

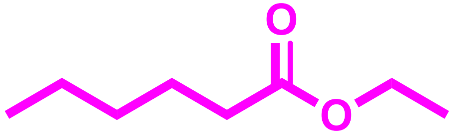


diethyl succinate



threshold 120 μg L^{-1}
isoamyl acetate
(banana, melon)

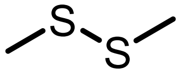
Fruity aroma
Ginjoka



ethyl hexanoate
(apple)

threshold
270 μg L^{-1}

polysulfides



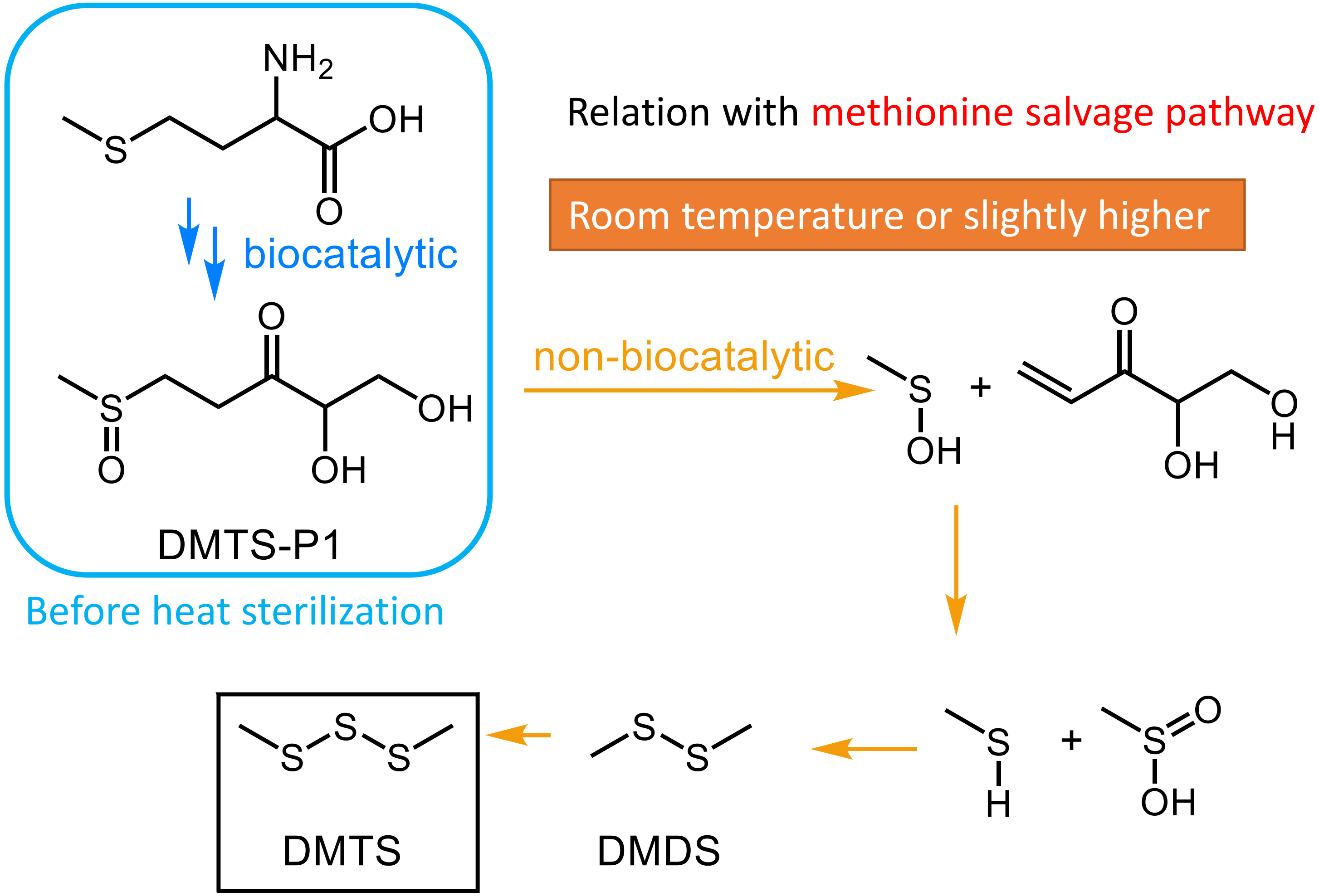
DMDS
(sulfur odor)
threshold
7 μg L^{-1}

DMTS
(sulfur odor)
threshold
0.18 μg L^{-1}

Aged odor
Hineka

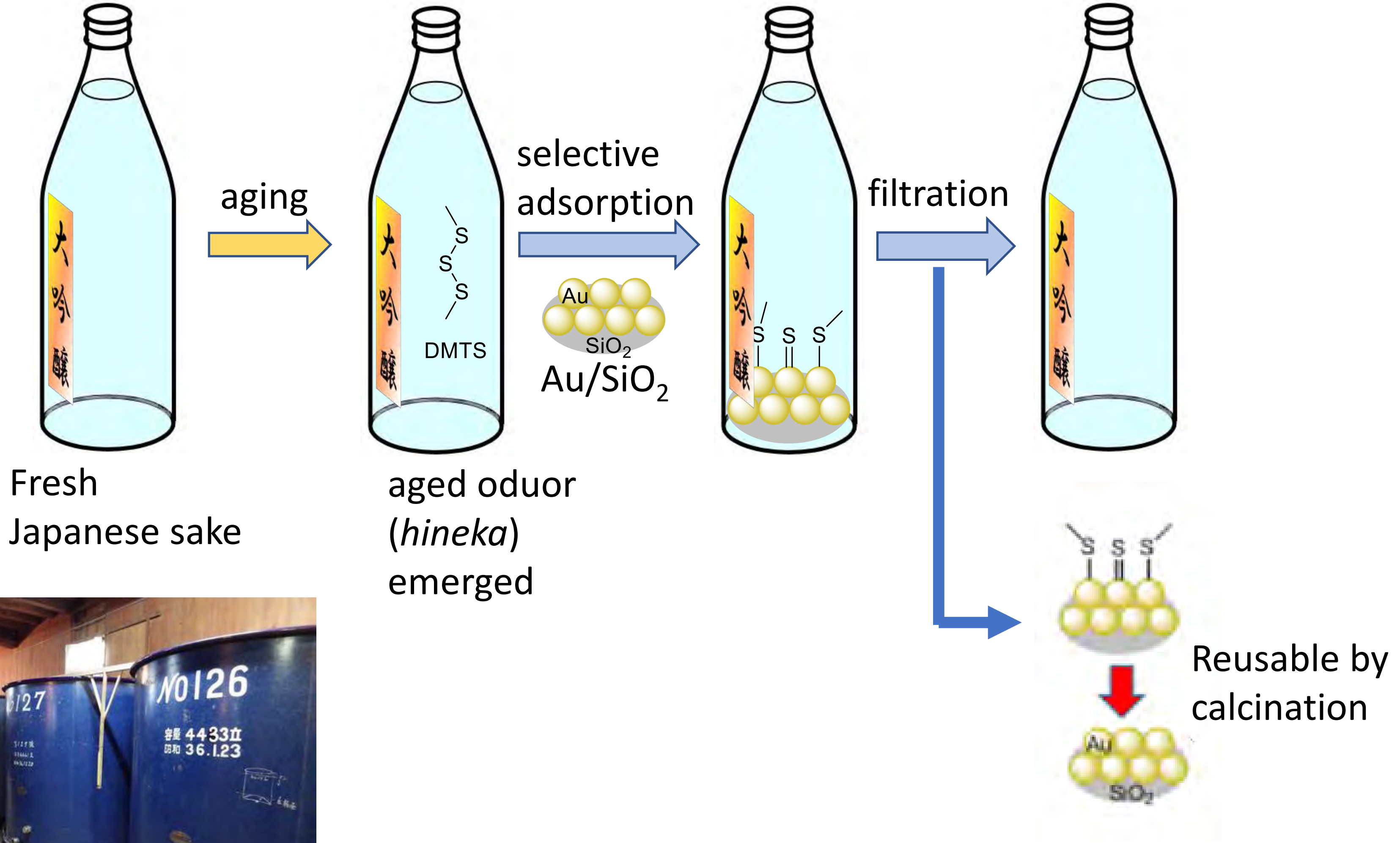
Flavors generating during storage
favorable flavor
Matured aroma (熟成香)
unpleasant flavor
Aged odor (老香)

A pathway of DMTS formation in Japanese Sake

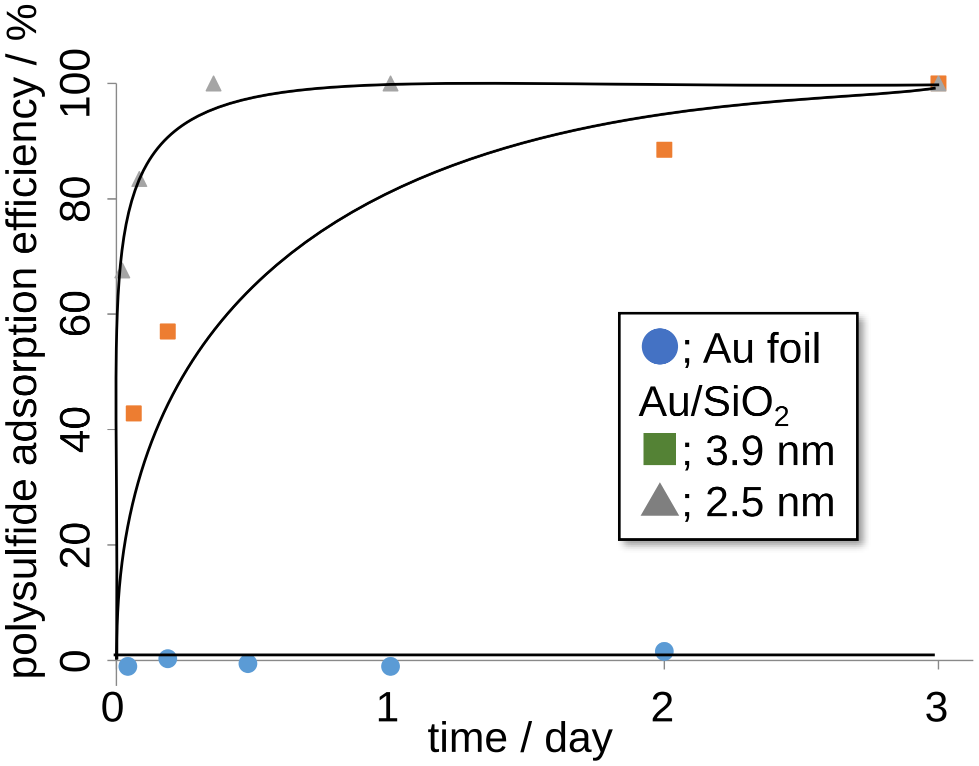


Isogai et al. *J. Agrc. Food. Chem*. **2009**, *57*, 189

Emergence of *Hineka* in bottles and tanks and their removal by Au nanoparticles

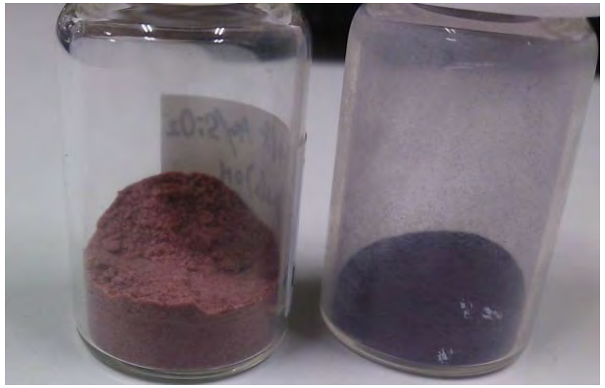


DMTS adsorption by Au nanoparticles
（4～5 mg/L DMTS in EtOH, M/S=6）



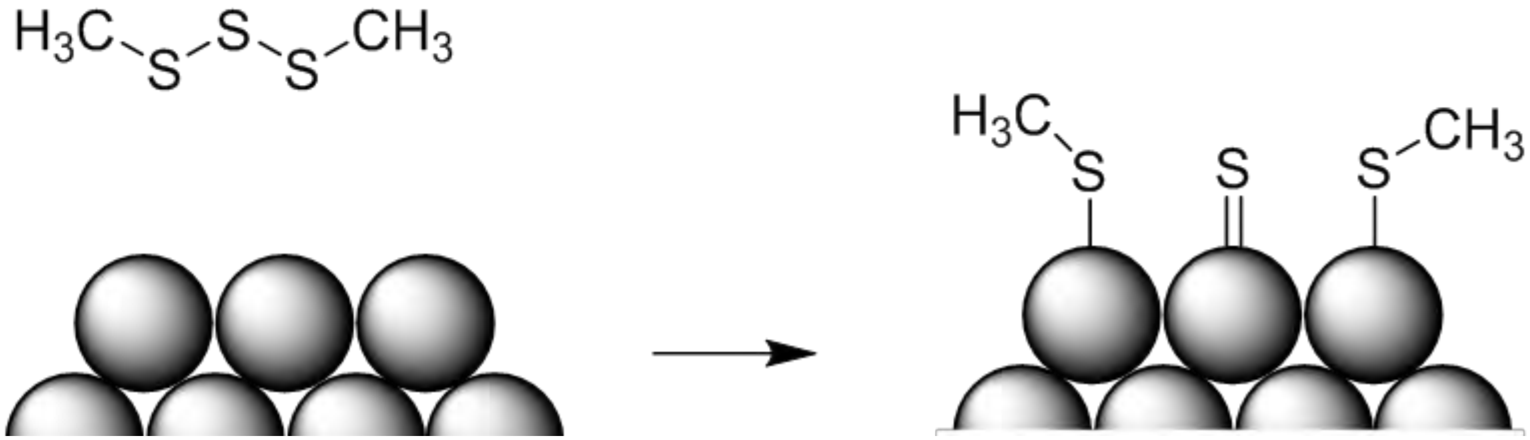
smaller Au/SiO_2 shows higher performance for adsorption

Au foil (Au > 100 nm)



Au/SiO_2 (Au < 4 nm)

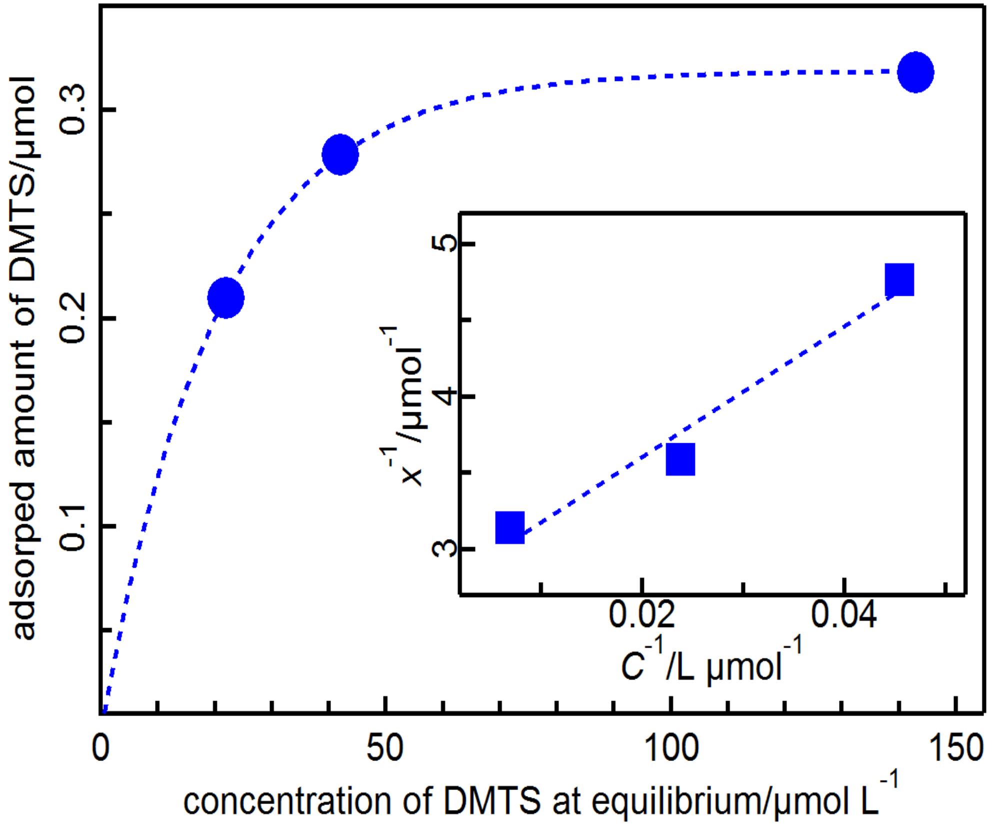
Coverage based on surface atom number



1 to 1 adsorption of Au and S atoms
single layer Langmuir-type adsorption

DMTS conc (ppm)	Au/DMTS	adsorption (%)	coverage (%)
10	8.58	71	62
15	5.72	62	81
30	2.89	36	93

Langmuir plot of DMTS adsorption by supported Au nanoparticles

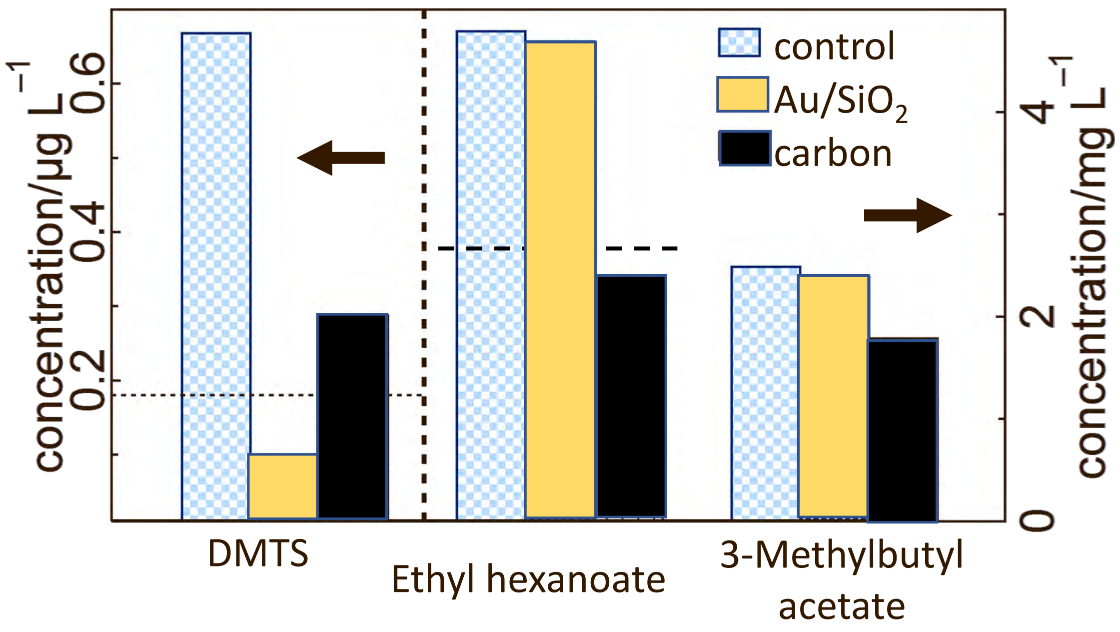


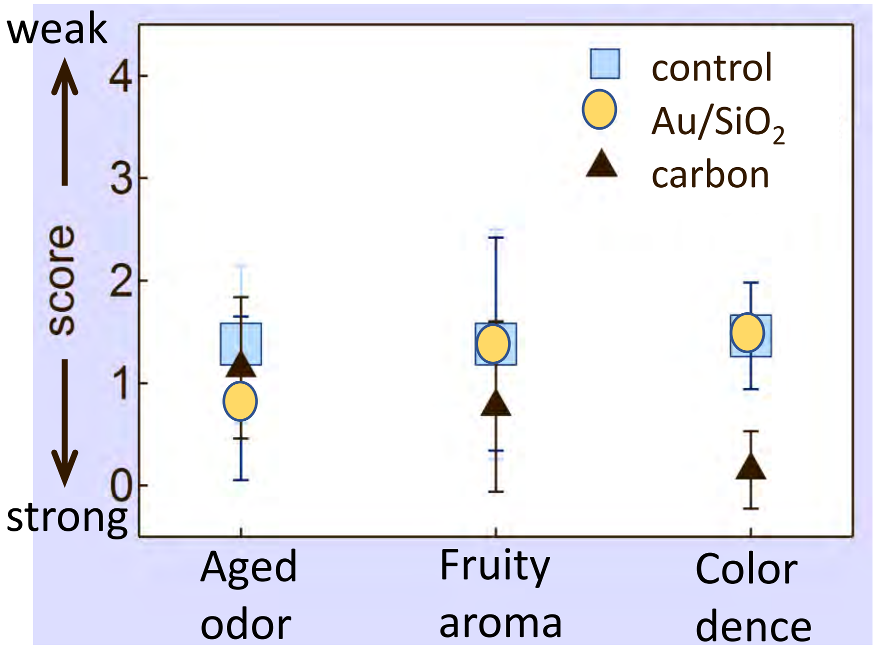
Au: 3.5 nm

Desulfurization from Daiginjo (Higher class)

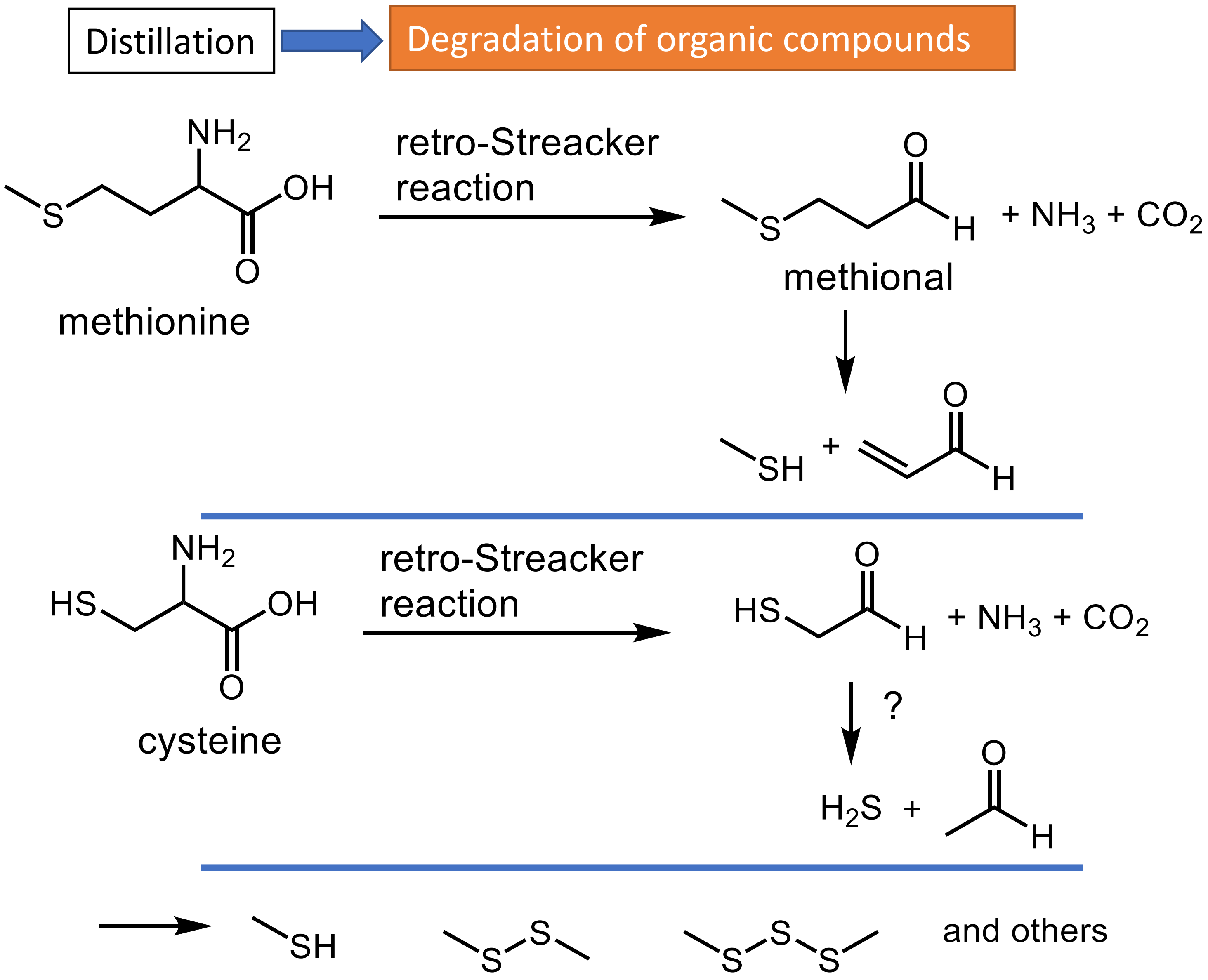
- Control has 0.67 μg/L DMTS, rather strong aged odor
- Control has 4.8 mg/L Ethyl hexanoate, good fruity flavor
- Au/SiO_2 reduced DMTS less than threshold without decrease of ethyl hexanoate
- Carbon decreased DMTS but higher than threshold, ethyl hexanoate was also decreased

Au/SiO_2 was effective !





Sufur compounds formation in distilled alcohol beverages



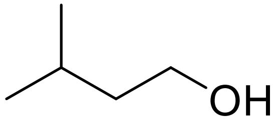
Sulfur Compounds generation in Distilled Alcohols

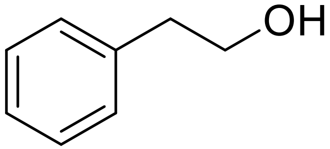
Sweet potato shochu

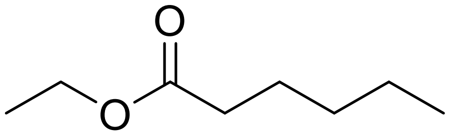
	Just after distillation Conc, µg L^{-1}	Leave 3 months →
H_2S	100—8500	Less than threshold value (60 µg L^{-1})
CH_3SH	50—300	Gradually decrease
CH_3SCH_3	30—500	Gradually decrease

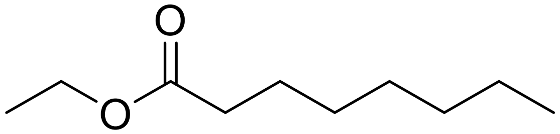
Bad smells

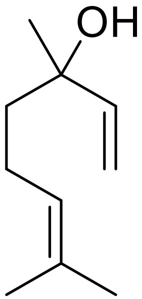
Flavor components of shochu



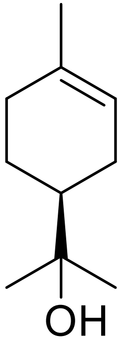








linaool



terpineol

Easy to drink

松原、今村、日本醸造協会誌 2011, *106*, 493

Desulfurization from Shochu (distilled alcohols)

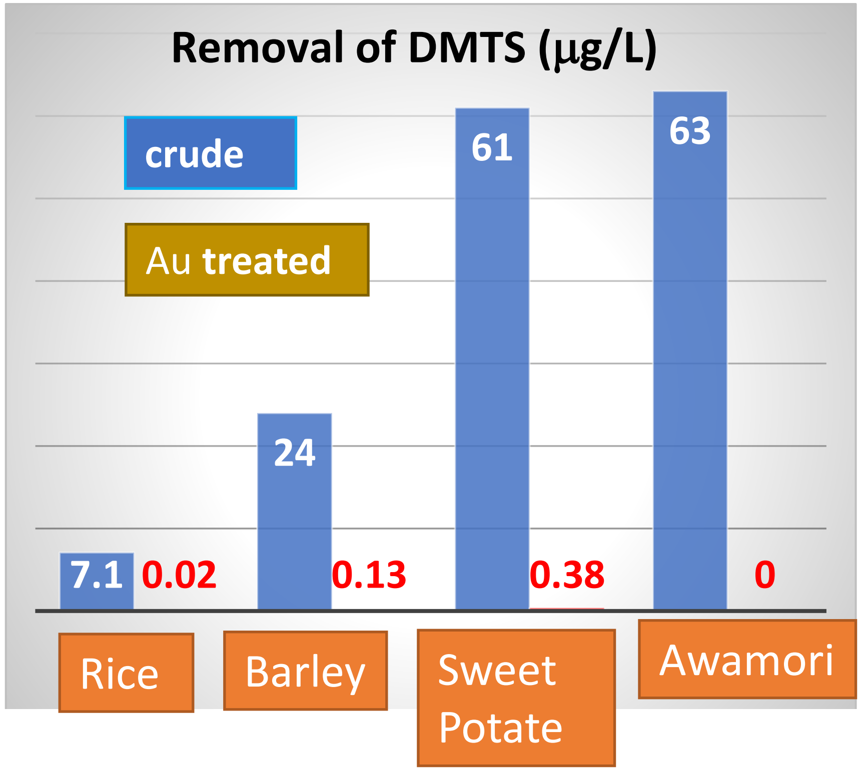
Dr. Isogai

4 type Shochu

Au/SiO_2 (300mg/150ml) 24 h,

filtrated with 0.65µm membrane filter

Panelist: 9 Young brewers in Shochu makers



- **Sulfury odor**

Au/SiO_2 lowered than control in Awamori

- **Ester flavor**

Au/SiO_2 increased than control in Rice and Awamori

- **Burnt odor**

Au/SiO_2 increased than control in Bareley and Awamori

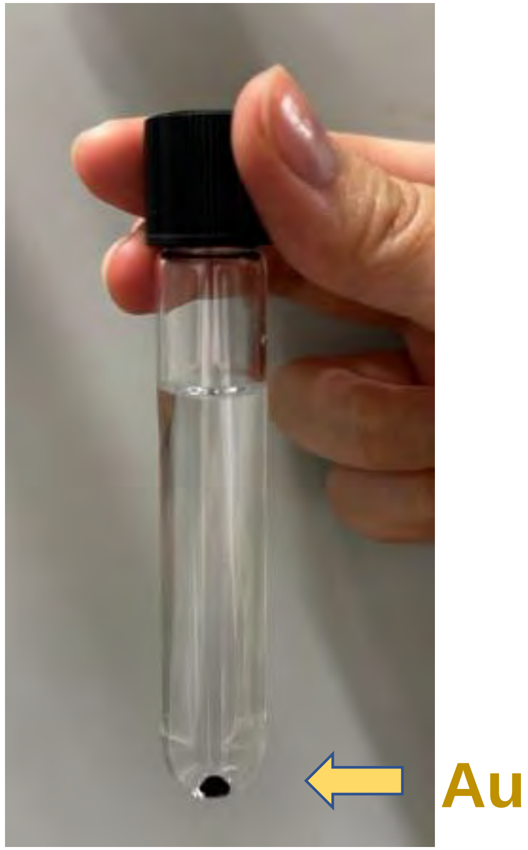
- **Preference**

7 out of 9 brewers preferred Au/SiO_2 treated Awamori

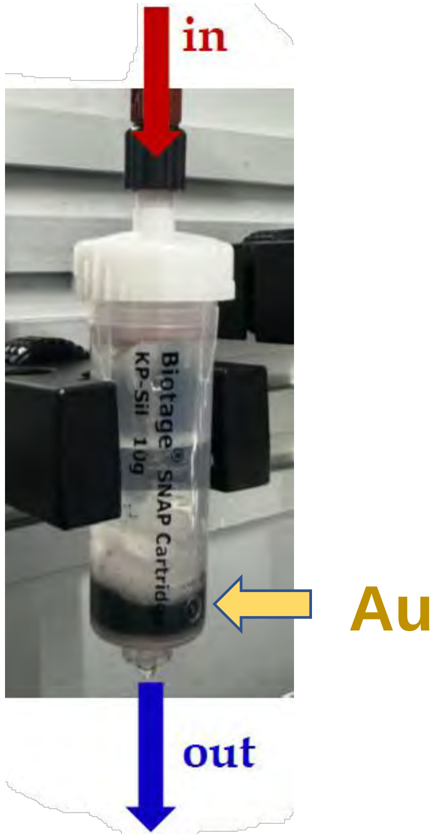
Type of adsorption

Liquid phase

Batch

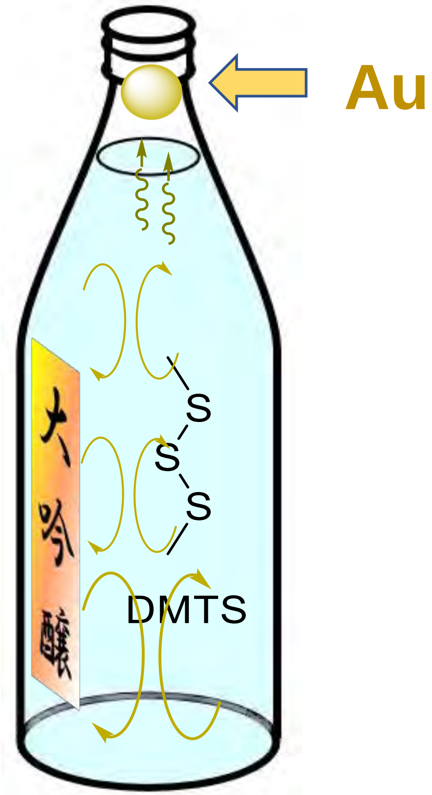


Flow



Gas phase

Batch



Batch and flow adsorption rates in liquid phase

Adsorption rate

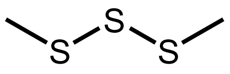
$$V_n = -\frac{d[S_n]}{dt} = kn[S_n][Au]$$

Au concentration means
(number of gold atoms per unit volume)
(the rate of surface atoms was not taken into account)

compunds	1	2	3	4	5	6
Batch	15.1	5.79	16.8	21.8	9.73	22.1
flow	**2371**	319	1474	1423	164	1071

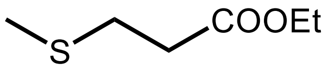
adsorption rate constants *k* (L/mol·min)

Flow adsorption gave much faster rate (***but changes depends on the shape of the support***)



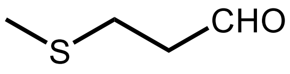
dimethyltrisulfan
(DMTS)

1



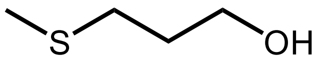
ethyl 3-(methylsulfanyl)-
propanoate

2



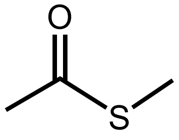
methional

3



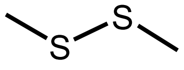
methionol

4



S-methyl
thioacetate

5



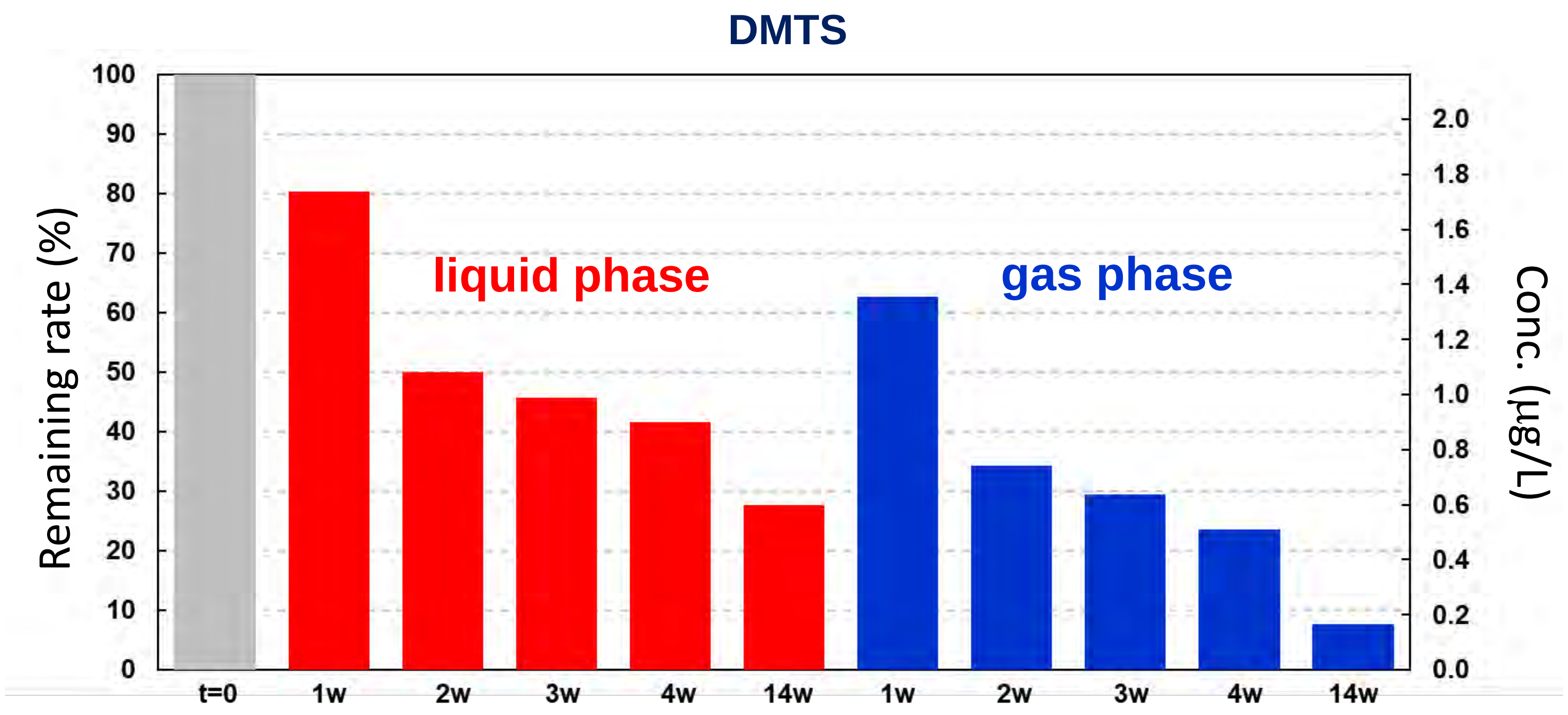
dimetyldisulfan
(DMDS)

6

Batch adsorption rates in liquid and gas phase

DMTS
2.16 μg/L

1 wt% Au/SiO_2 (Q-15)
93.2 mg (4 pellets)
in 720 mL

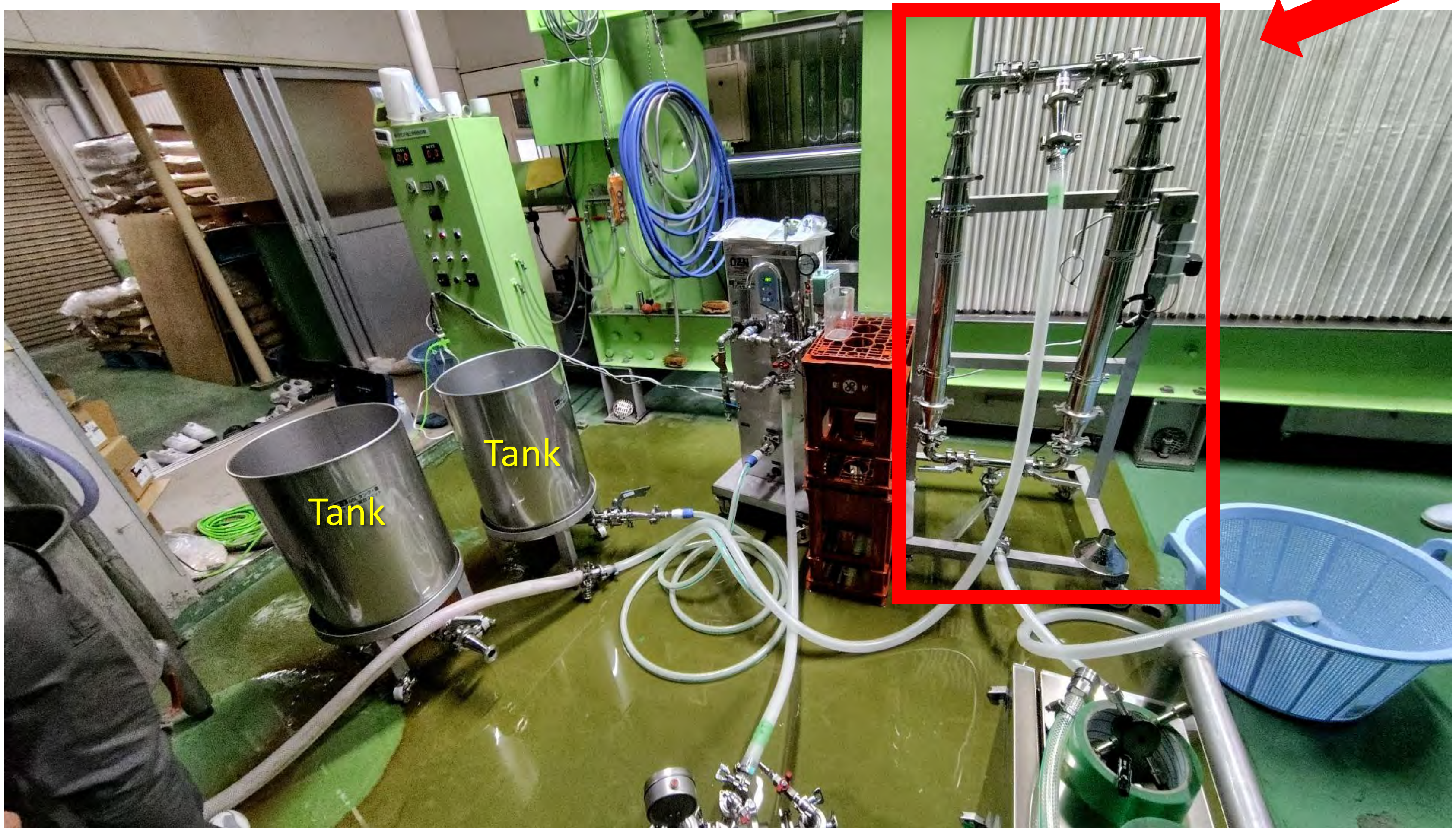


in 14 weeks
liquid phase：0.60 μg/L (72.3% adsorbed)
gas pahse：0.17 μg/L (92.3% adsorbed)

※DMTS threshold：0.18 μg/L

→ Gas-phase adsorption achieves desulfurization to levels below the DMTS odor threshold more quickly than liquid-phase adsorption

60 L Scale test run with flow-type desulfurization unit

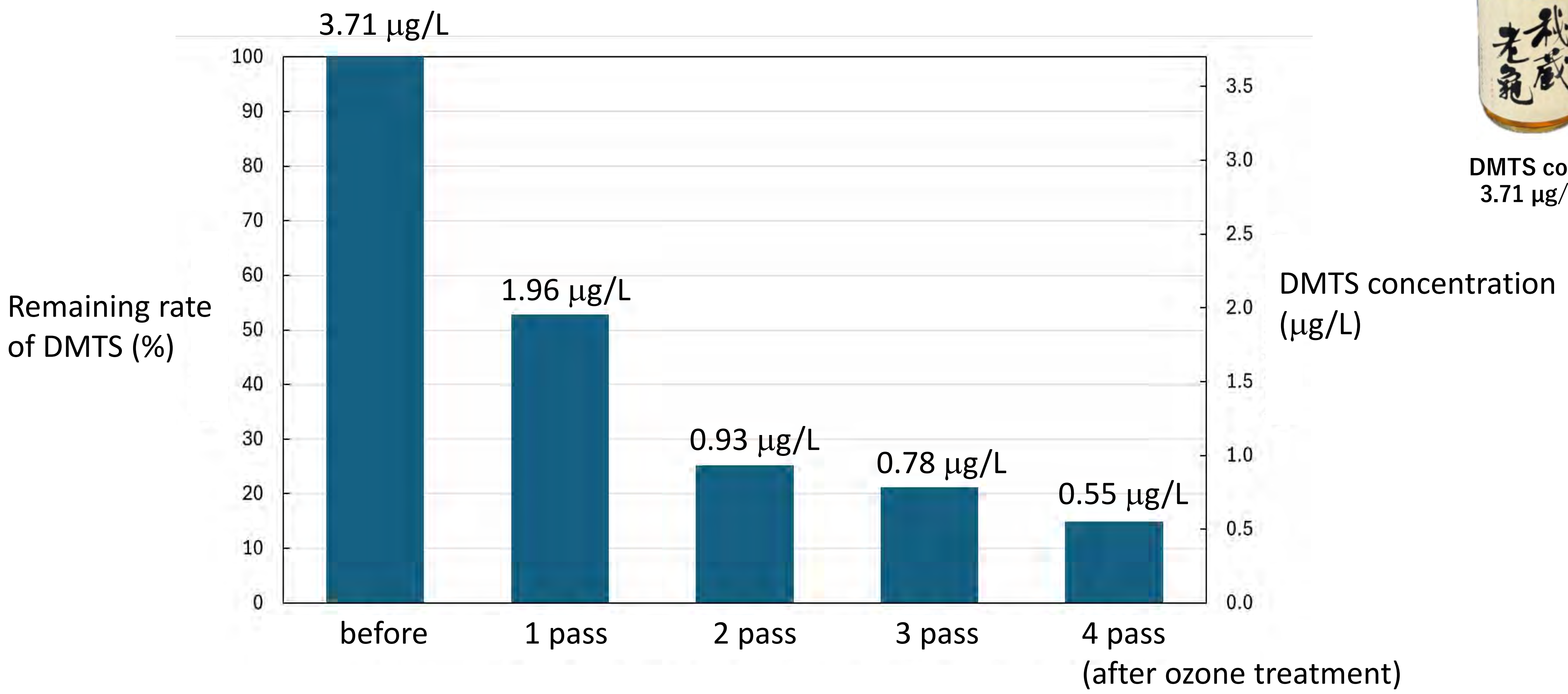


Pump

2 Columns
7 kg
0.2 wt% Au/SiO_2-Al_2O_3
(Au 14 g)

60 L scale test run with flow-type desulfurization unit

Flow rate: 5 L/min
Contact time: 1.4 min



DMTS conc
3.71 µg/L

Display at our booth

Large-scale desulfurization

Further desulfurization In lab.

1 wt% Au/SiO_2 10 g
15 mL/min then
5 mL/min (2 times)

DMTS conc 3.71 μg/L

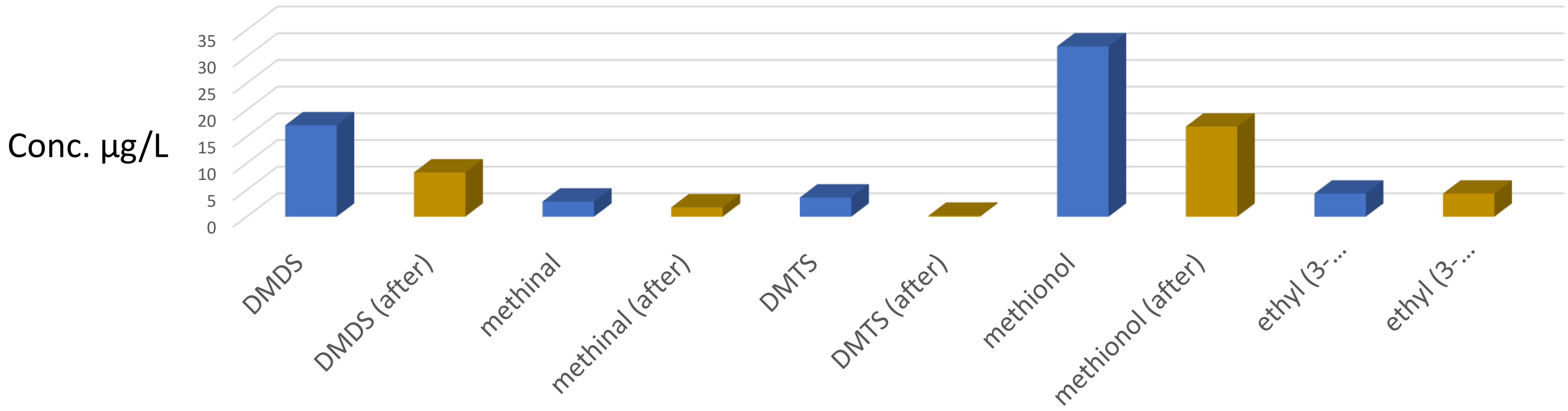
DMTS conc 0.78 μg/L

DMTS conc 0.19 μg/L

for Shochu (distilled alcohols)

Further desulfurization in lab

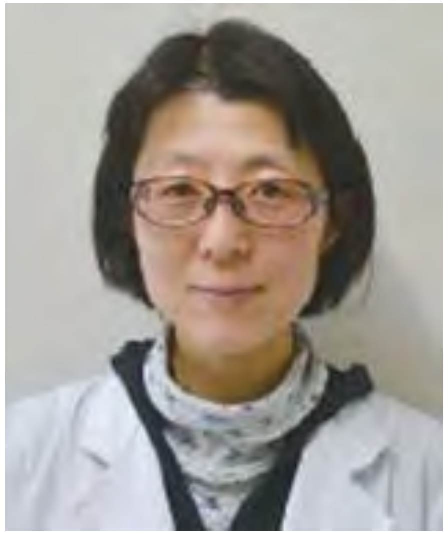
		Conc. µg/L	Adsorption rate [%]
DMDS	t=0	17.1	0
	after desulfurization	8.29	51.6
methinal	t=0	2.84	0
	after desulfurization	1.75	38.5
DMTS	t=0	3.60	0
	after desulfurization	0.19	94.8
methionol	t=0	31.9	0
	after desulfurization	16.9	47.1
ethyl (3-methylsulfanyl)propanoate	t=0	4.33	0
	after desulfurization	4.32	0.248



Acknowledgment

Kanagawa Inst. Tech.

Prof. Haruno Murayama



National Research Institute of Brewing
（国税庁　酒類総合研究所）

Dr. Atsuko Isogai

Kyushu University

Prof. Akihiro Nakayama

JKA Social Action
競輪とオートレースの補助事業

PARKS

Catalysis Organic Chemistry Lab. Kyushu University (2025)

For question & answer

Experiment with Japanese sake

(A) Daiginjo
(higher class)
5 L

(B) Junmai
(middle class)
5 L

Stored at 40 °C, 46 days

Adsorption at r. t., 24 h

Adsorbent

(1) Au/SiO_2 12.5 g / 5L sake (Au, 3.7 nm)

(2) Carbon 5 g / 5L sake

(3) Control (none)

Filtration

Tasting

Adsorption

Experiment with Japanese sake

Filtration

Yuasa cartridge membrane filter (0.4 μm)

Sensory evaluation (Blind tasting)

Brewing company　12 peoples

National Research Institute of Brewing　4 peoples

Fukumitsuya, Banjo-jozo, Matsumoto-shuzo, Nishinokinryo

Kamotsuru-shuzo, Kirei-shuzo, Fukubijin-shuzo, Hakubotan-shuzo, Saijokaku-Shuzo, Kamoizumi-shuzo

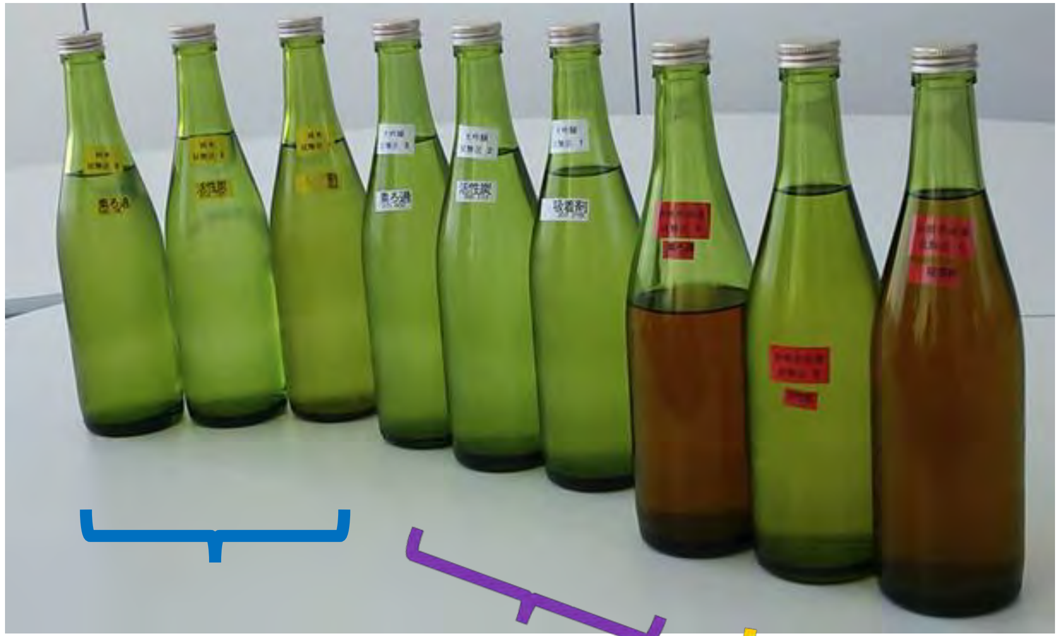
福光屋・萬乗醸造・松本酒造・西野金陵・賀茂鶴酒造・亀齢酒造・福美人酒造・白牡丹酒造・西條鶴酒造・賀茂泉酒造

Sensory evaluation (Blind tasting)

Color change of Japanese sake

Activated Carbon for sake brewing

control C Au control C Au control C Au



Junmai

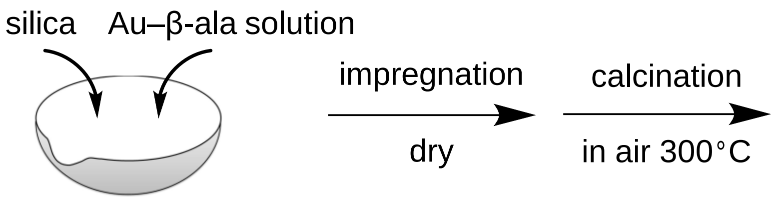
Ginjo

Jukusei
(Matured)

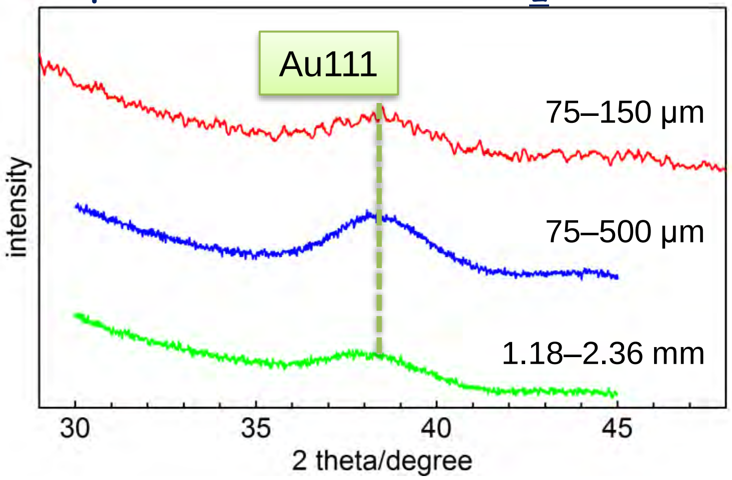
Preparation of Au/SiO_2 for flow system

富士シリシア化学株式会社よりご提供

1 wt% Au/SiO_2 preparation



XRD pattern for Au/SiO_2



75 µm–150 µm (CARiACT Q-15)

75 µm–500 µm (SYLOPUTE 80)

1.18 mm–2.36 mm (CARiACT Q-15)

Au; 2.6 nm 3.1 nm 3.3 nm

Au particles (< 5 nm) were supported on each type silica.

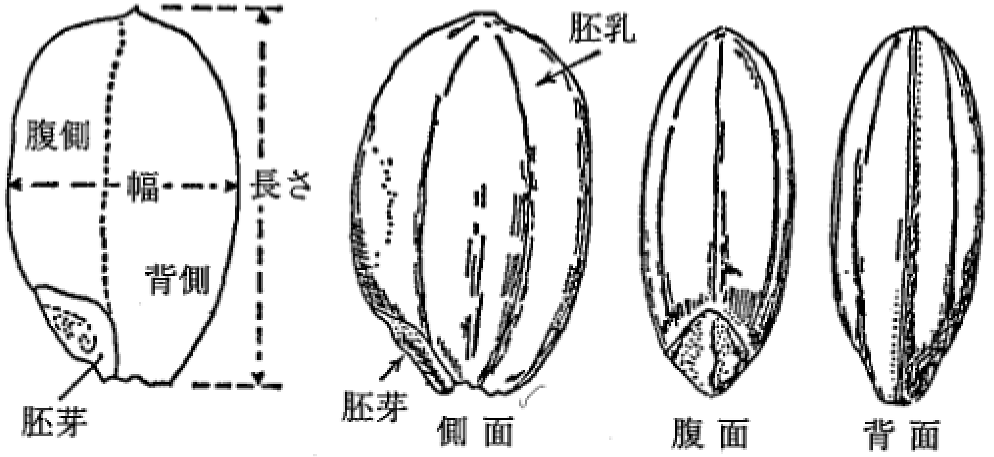


図４・１　玄米の外部形態

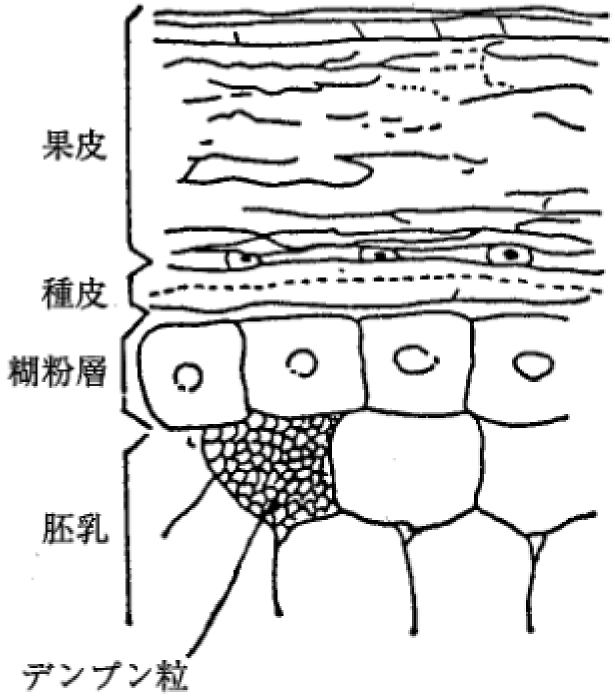


図４・２　玄米の内部構造

アミノ酸やたんぱく質は胚芽や米の外側に多い

表4・3　精米による米の成分変化の一例

成分／米の品種／精米歩合	水分(%)		粗タンパク質(%)		粗脂肪(%)		灰分(%)		デンプン価	
	A	B	A	B	A	B	A	B	A	B
玄　　米	14.8	15.0	6.55	7.95	2.28	1.90	1.00	1.06	70.88	69.63
80%精米	14.0	14.3	5.12	6.36	0.111	0.108	0.247	0.245	74.25	74.62
70%　〃	12.8	13.2	4.41	5.83	0.095	0.076	0.190	0.201	76.12	75.75
60%　〃	11.0	11.5	4.06	5.47	0.069	0.045	0.196	0.183	76.30	76.88
50%　〃	10.5	10.8	3.80	5.12	0.051	0.035	0.154	0.194	77.62	78.34

注）A：山田錦（兵庫）　B：一般米（千葉）

Deposition precipitation: Electrostatic interaction of Au precipitation and oxide support

isoelectric point

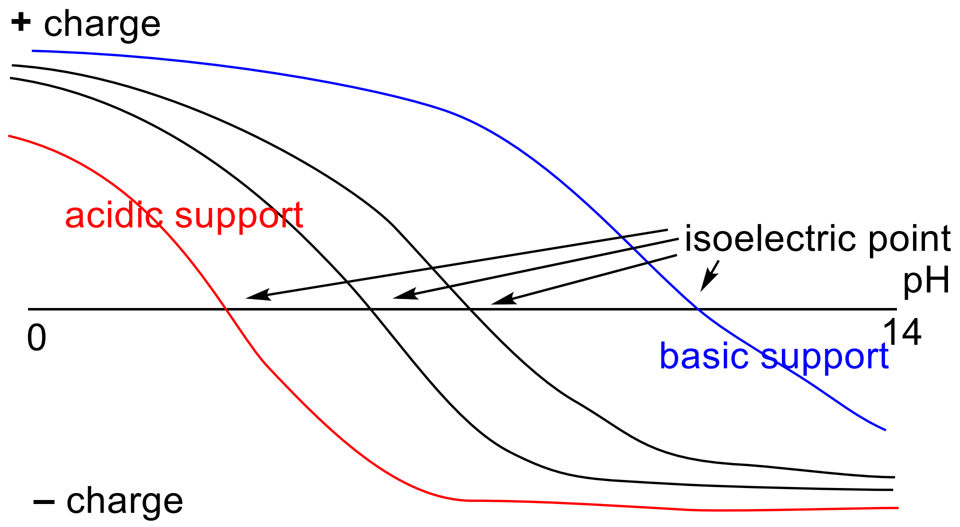
WO_2	0～1
SiO_2	2～3
TiO_2	6～8
Al_2O_3	7～9
MgO	9～11

Au precipitation by base addition

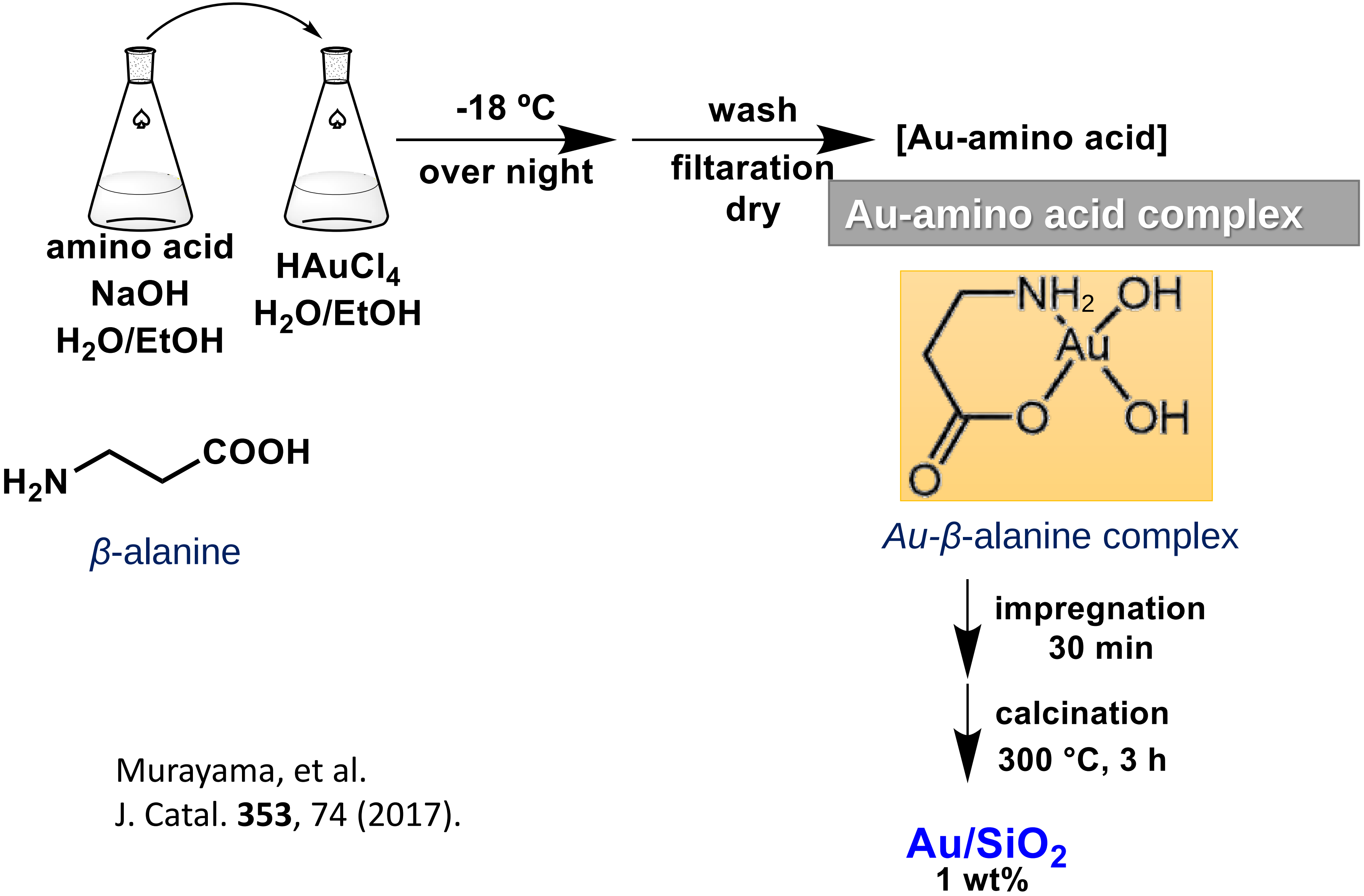
$$HAuCl_4 + 4\ OH^- \longrightarrow Au(OH)_3 + 4\ Cl^- + H_2O$$

$$Au(OH)_3 + OH^- \longrightarrow \mathbf{Au(OH)_4^-} \quad (pH > 7)$$

electrostatic repulsion with acidic support



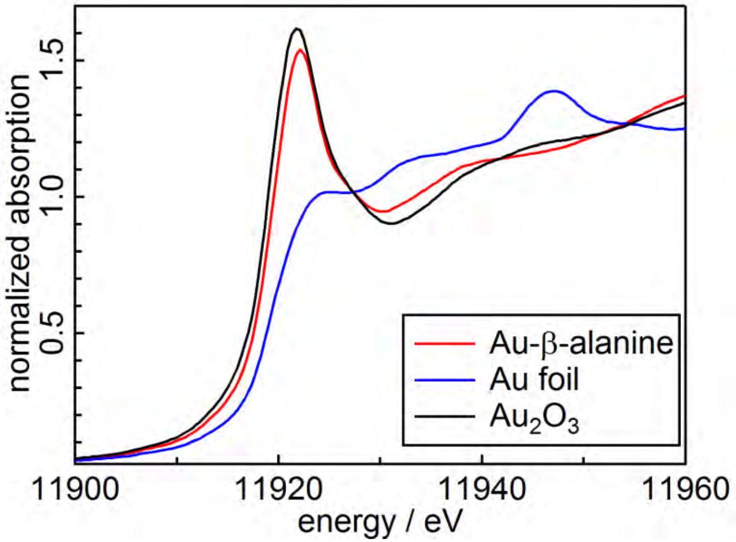
Novel preparation method of Au/SiO_2



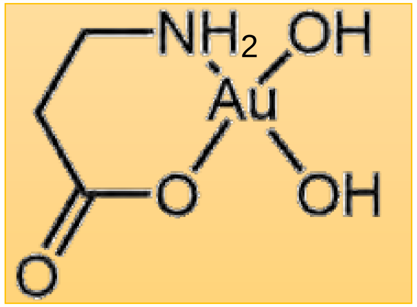
Murayama, et al.
J. Catal. **353**, 74 (2017).

Structure of Au-*β*-alanine complex (XAFS)

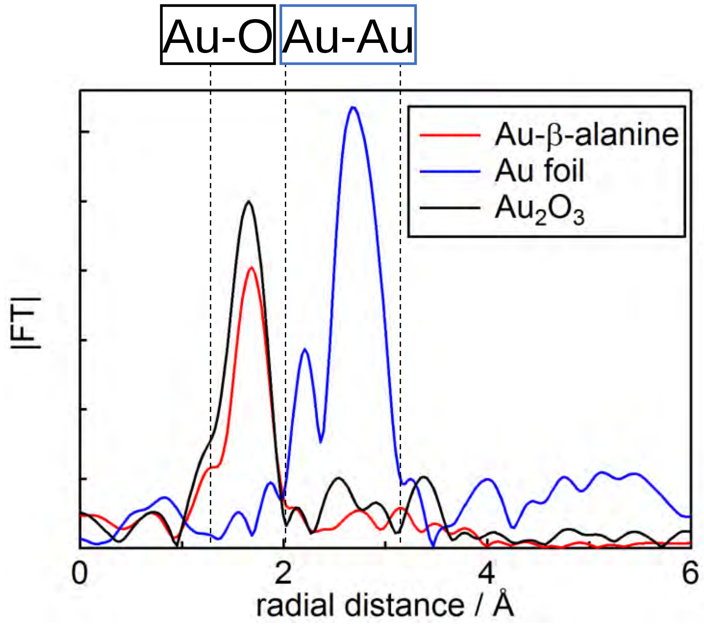
"white line"
attributes to excitation from $2p_{2/3}$ to 5d or 6s states



Oxidation state of Au-*β*-alanine; +3



Curve-fitting analyses for Au-O coordination

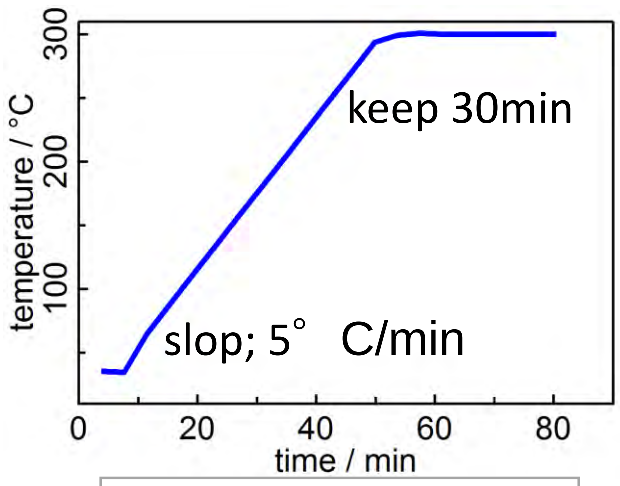


sample	number	distance/Å	*dE*/eV	σ/Å
Au-*β*-alanine	3.7	2.04	-0.13	0.05
Au_2O_3	4	2.01	0	0.06

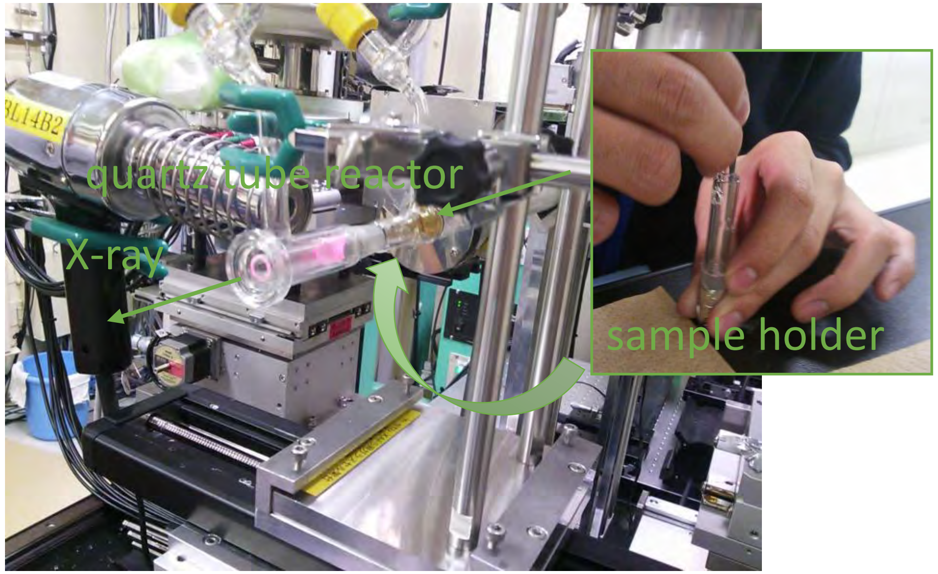
In situ XAFS measurements

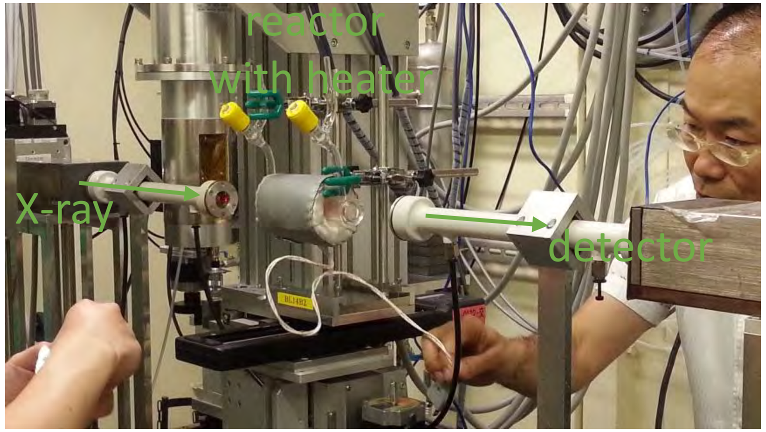
<u>Au L_3-edge XAFS measurements</u>

- BL14B2 at SPring8
- transmission mode
- quick scanning with Si(311) double crystal monochromator
- 3.5 min/ spectrum

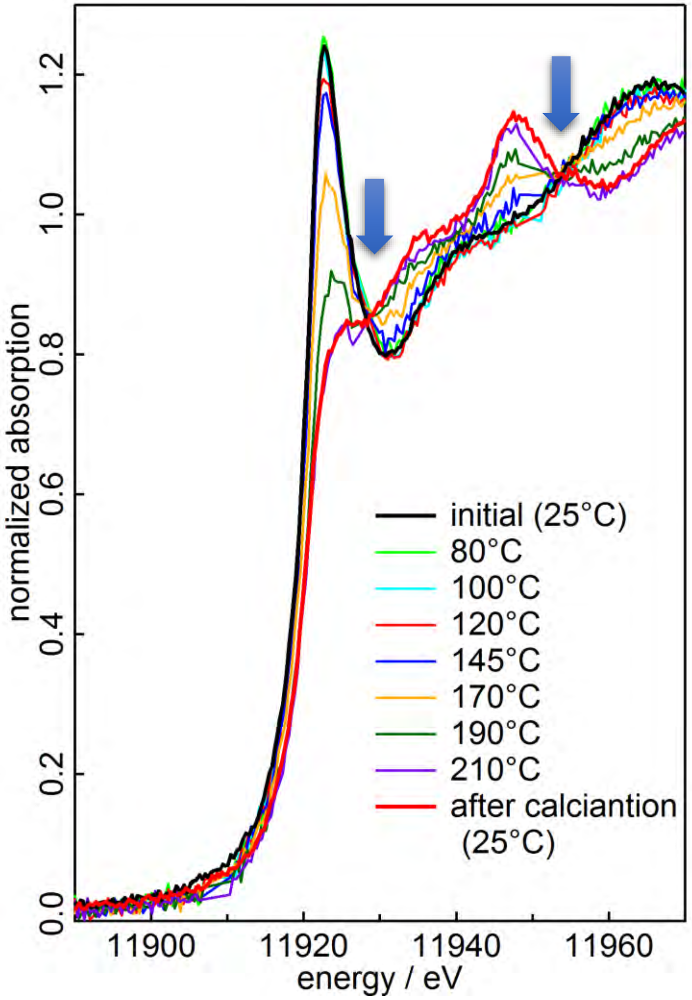


temperature program for calcination

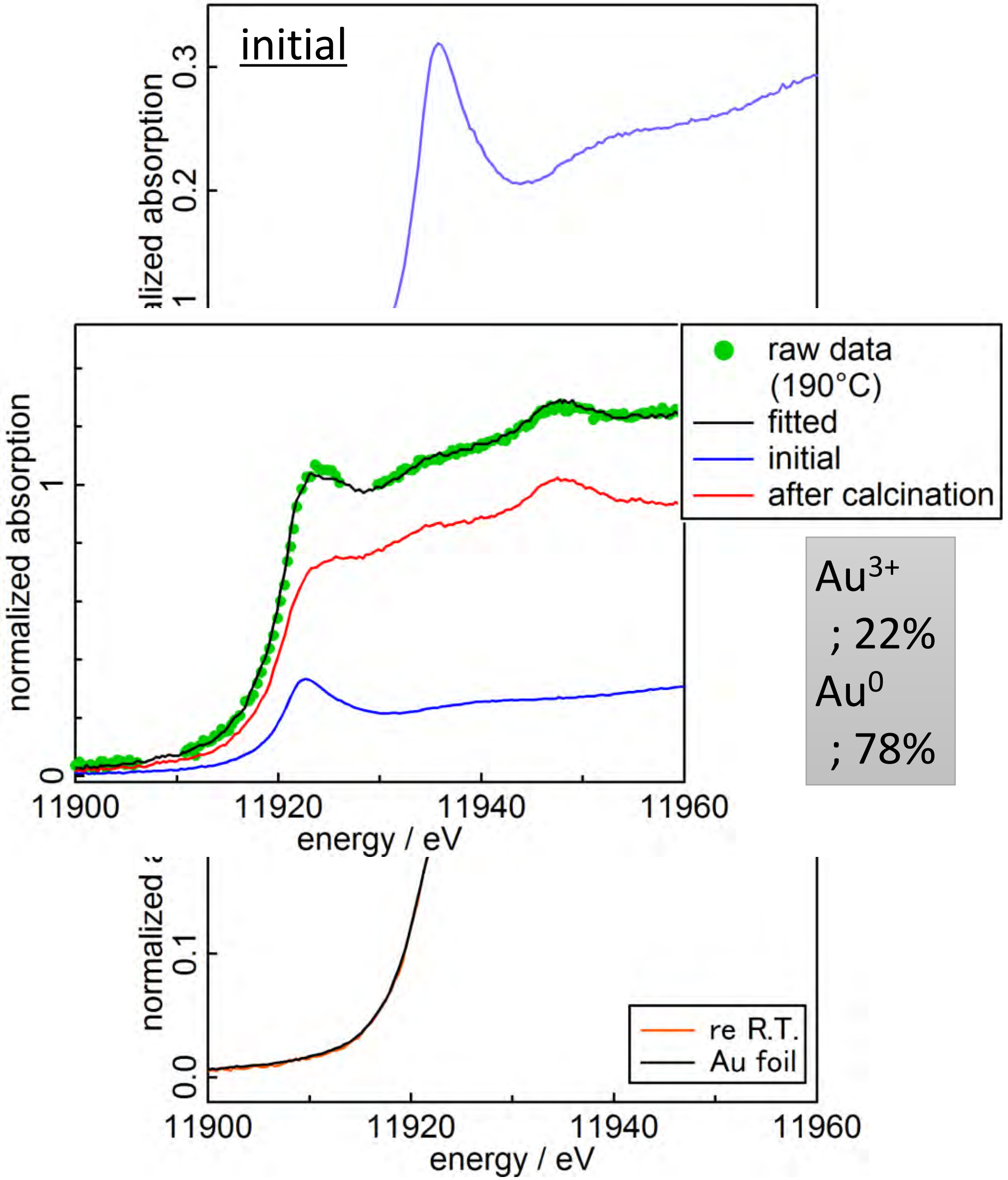




in situ XAFS for Au/SiO_2 preparation



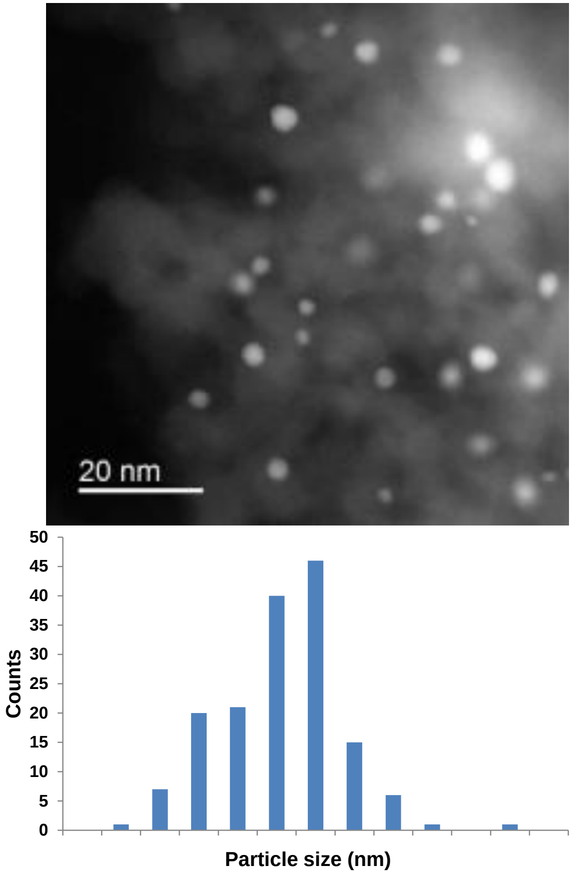
$Au^{3+} \rightarrow Au^0$

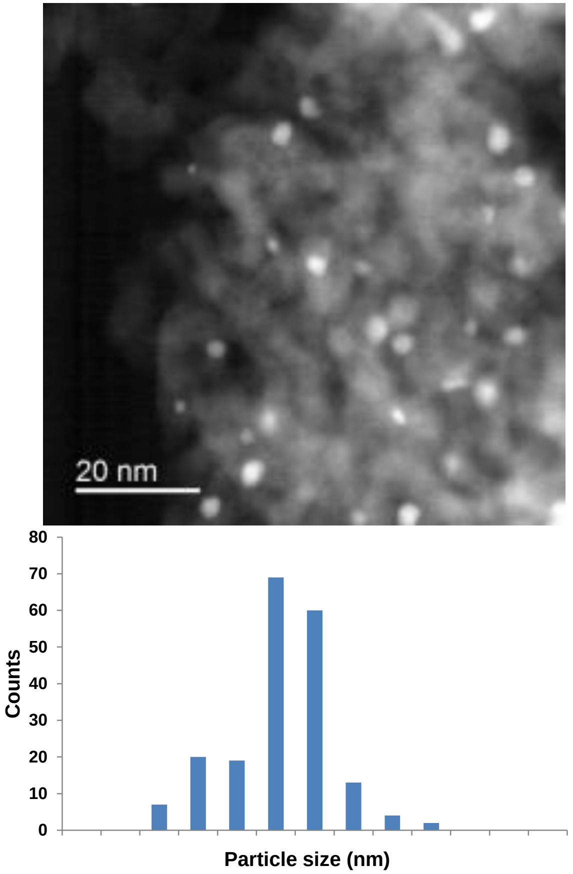


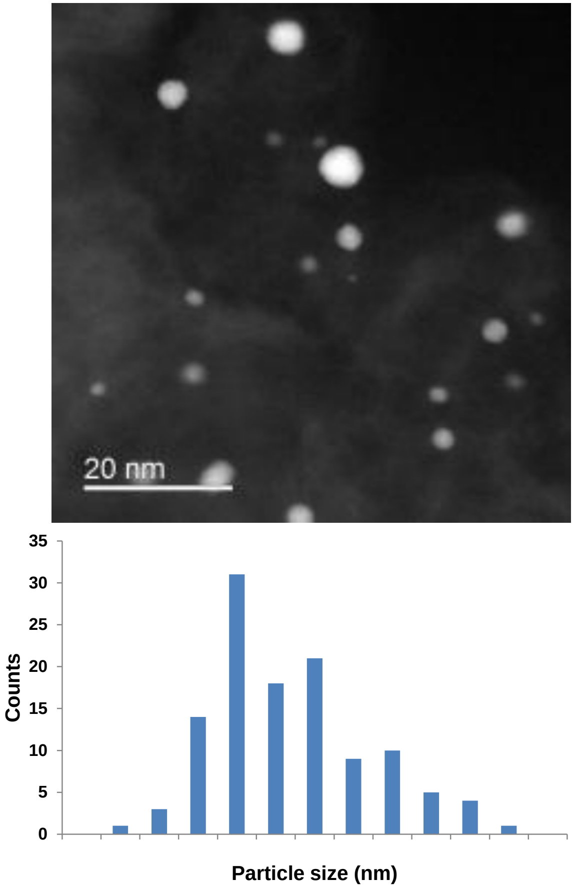
Au^{3+} ; 22%
Au^0 ; 78%

Applicability of impregnation with Au-amino acid complexes

- **Au/SiO_2**
- **Au/TiO_2**
- **Au/C**





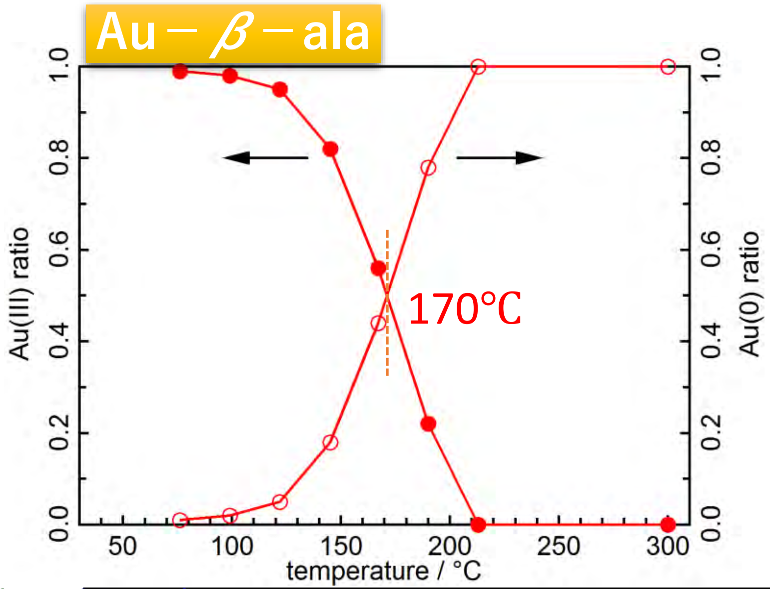


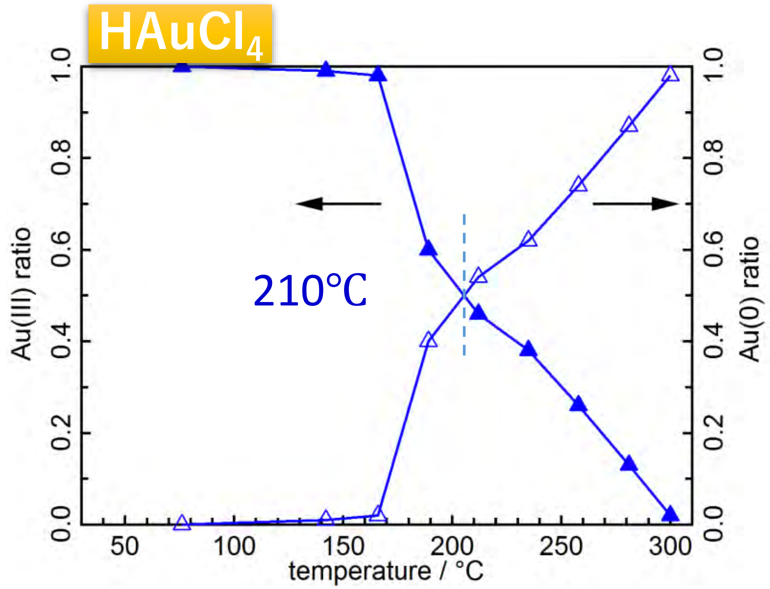
Average size:
2.8 ± 0.8 nm

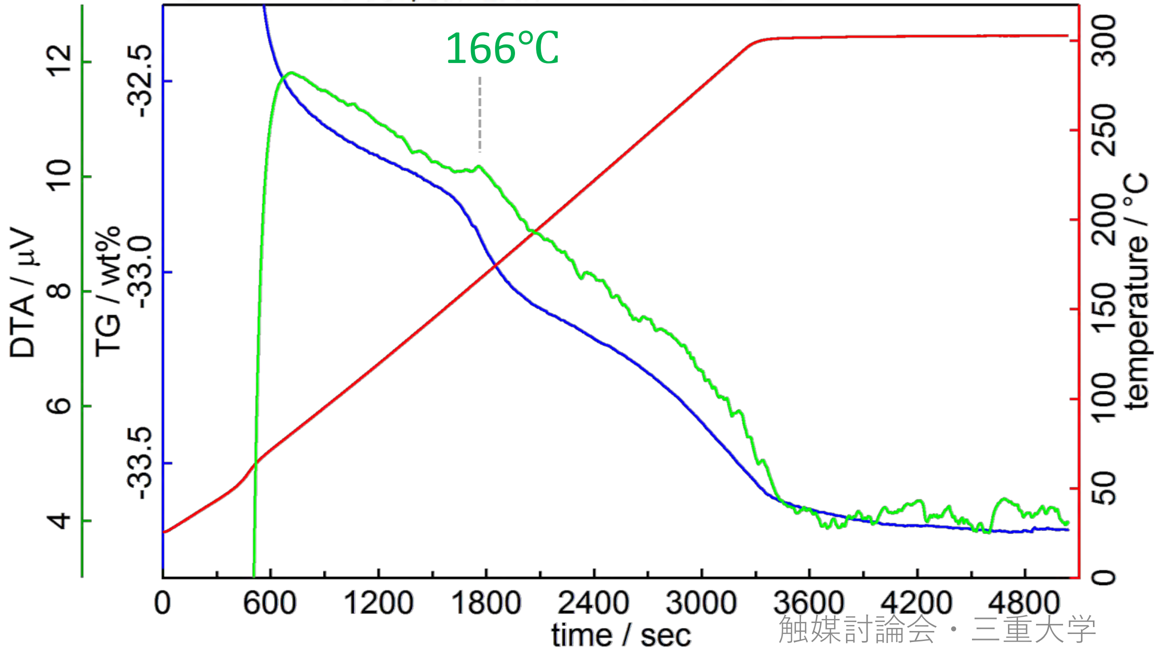
Average size:
2.8 ± 0.7 nm

Average size:
2.9 ± 1.0 nm

in situ XAFS for Au/SiO_2 preparation



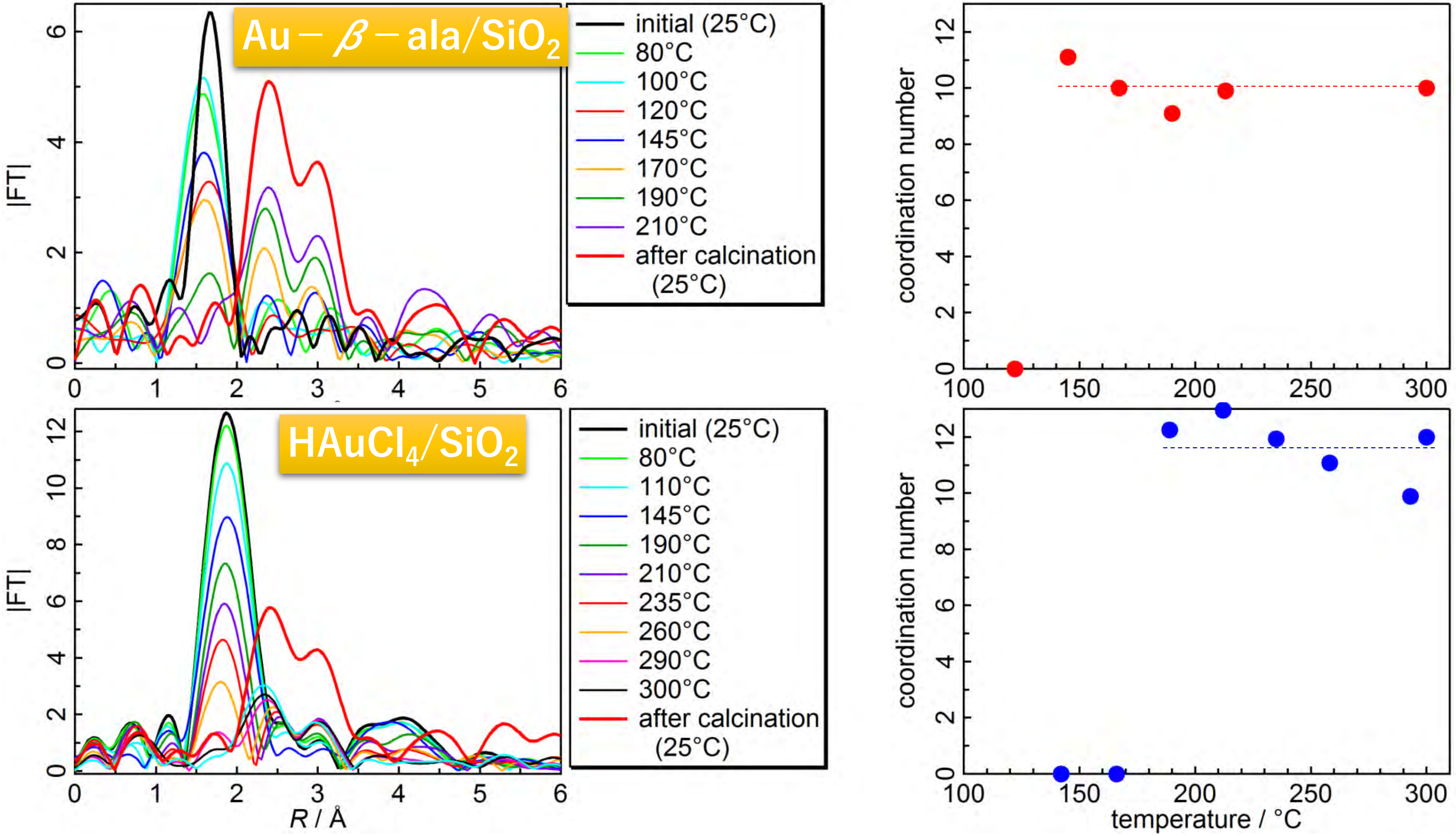




Degradation of ligands and Au reduction takes place at the same time

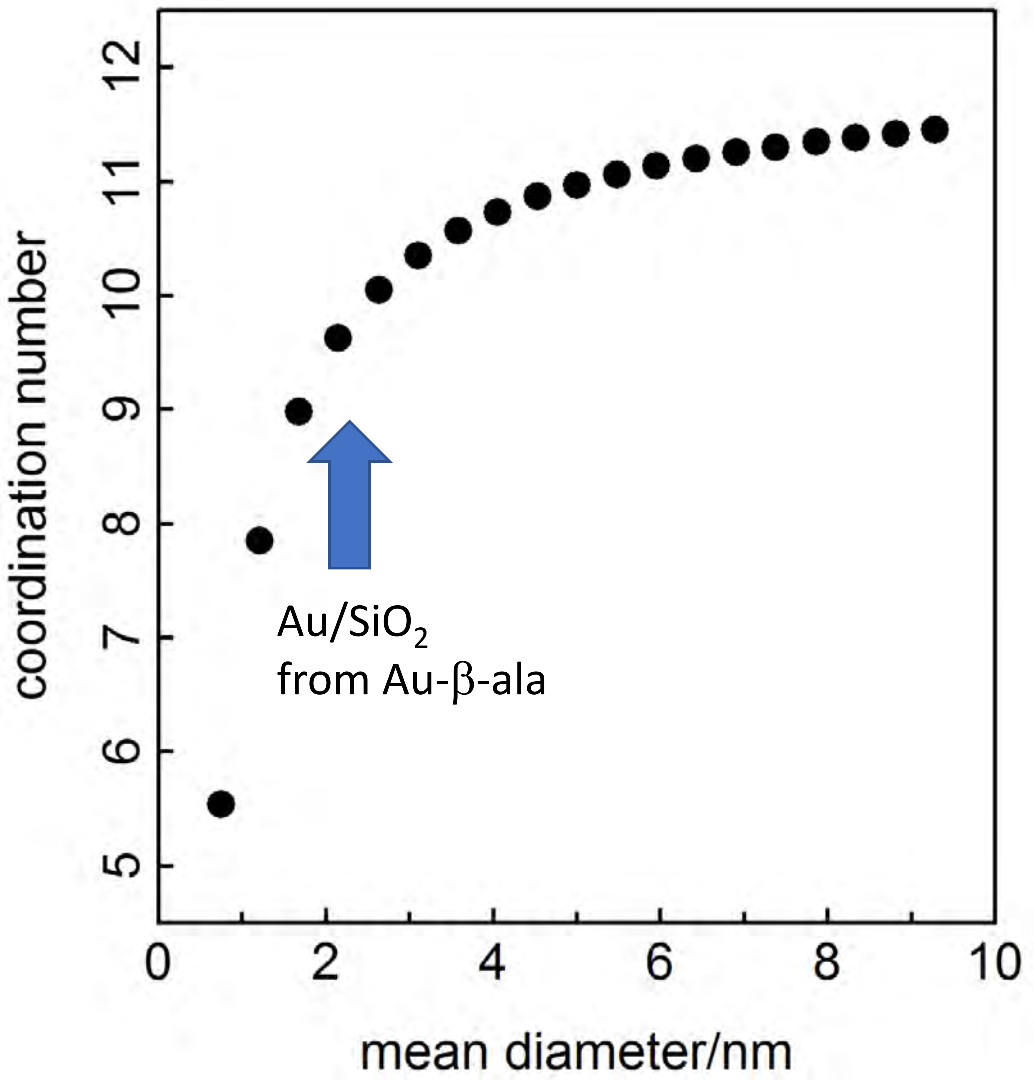
Au-*β*-ala < $HAuCl_4$

Au－Au coordination number during calcination



CN keeps nearly constant during calcination

Coordination number and Au particle size

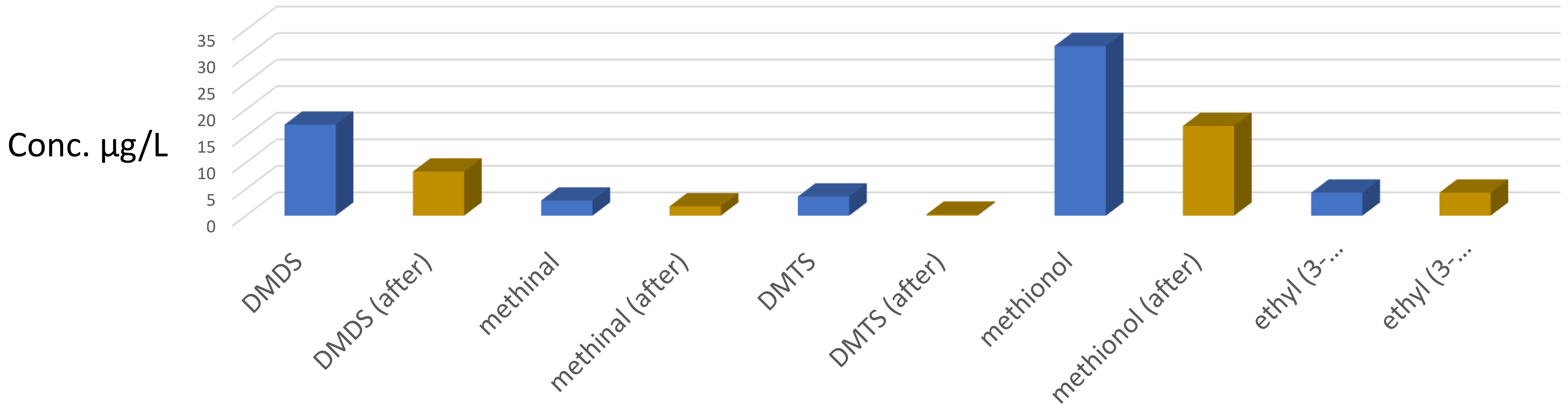


Au/SiO_2
from Au-β-ala

Au/SiO_2
from $HAuCl_4$

Further desulfurization in lab

		Conc. µg/L	Adsorption rate [%]
DMDS	t=0	17.1225275	0
	after desulfurization	8.294451919	51.55825026
methinal	t=0	2.840460621	0
	after desulfurization	1.746628647	38.50896457
DMTS	t=0	3.595494962	0
	after desulfurization	0.186029418	94.82604147
methionol	t=0	31.93500147	0
	after desulfurization	16.88484455	47.12746589
ethyl (3-methylsulfanyl)propanoate	t=0	4.331018642	0
	after desulfurization	4.32026802	0.248223869



DMTS and sulfur smell vegetables

Brassicaceae

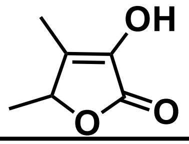
Takuan

cabbage

broccoli

Jukusei (Matured)

Matured sake (1998, 2003) 20 mL
Au/SiO_2 200 mg (10 g/L)



sake	Au/SiO_2 (g/L)	DMTS (μg/L)	Remained (%) at 24 h	sotolon濃度 (μg/L)	Remained (%) at 24 h
1998		0.71		1.9	
1998	10	0.09	13	1.8	95
2003		0.07		2.7	
2003	10	0.01	18	2.9	106

threshold；0.18 μg/L　　threshold ；2.3 μg/L

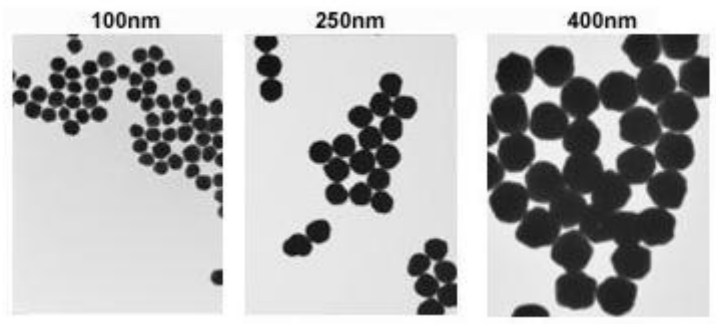
DMTS were reduced blew threshold value

Gold Nanoparticles

Colloidal Nanopartcles

Virtually Homogeneous

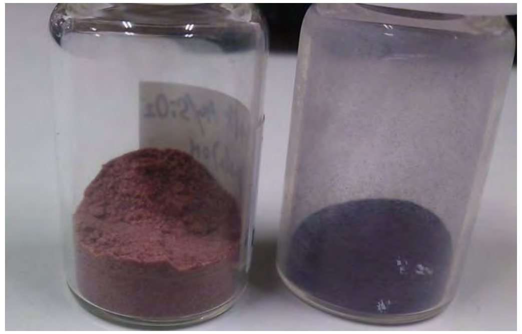
Au NPs with various particle sizes



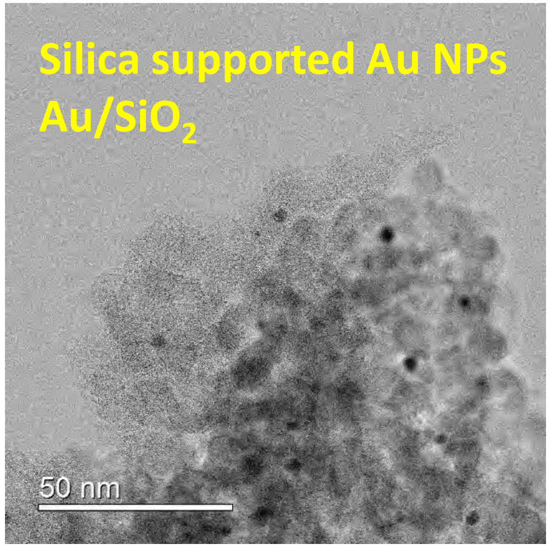
from Sigma-Aldrich Home Page

Supported Nanopartcles

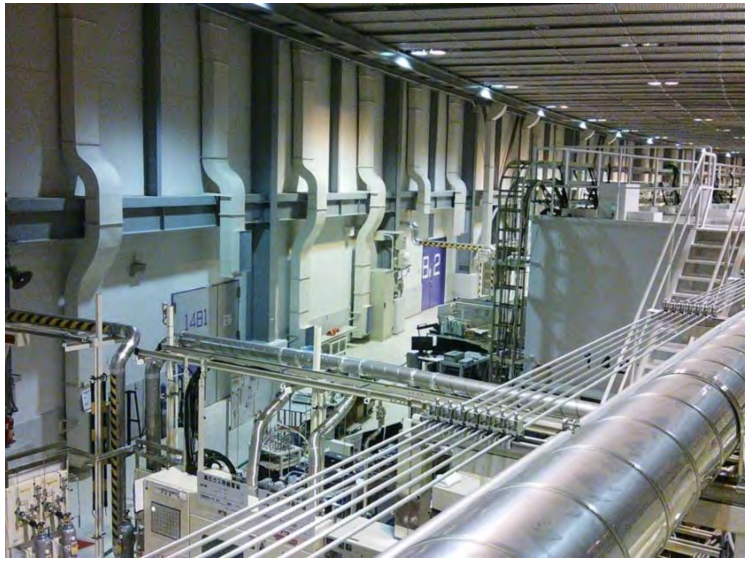
Heterogeneous, not soluble

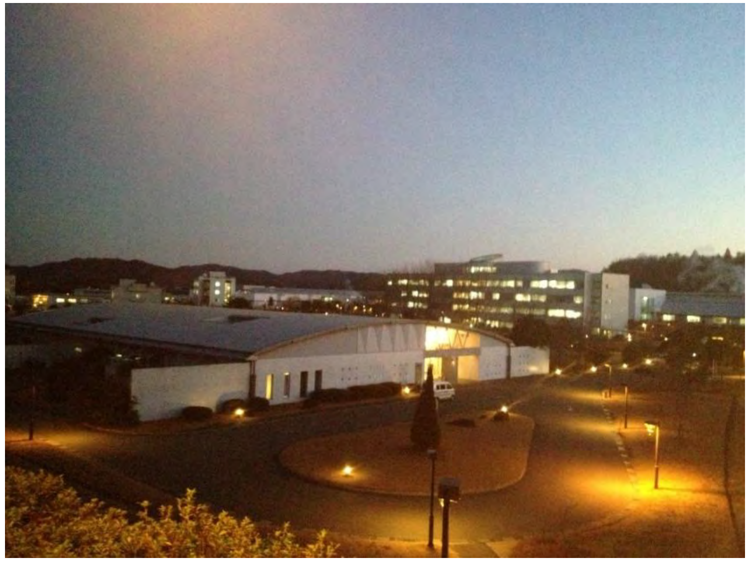


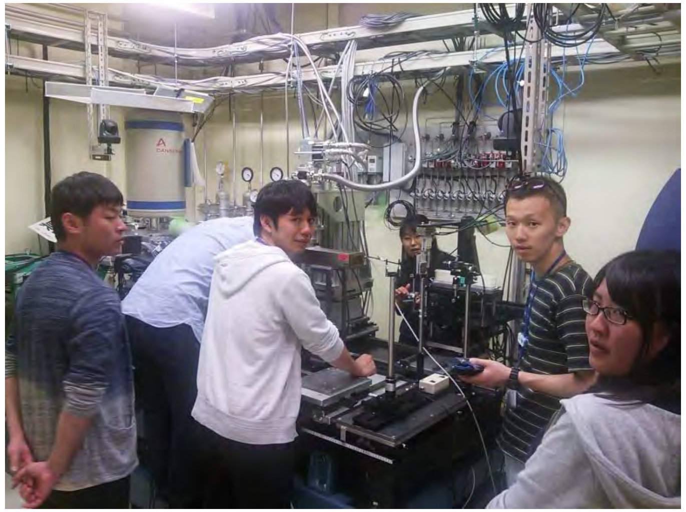
Separable by filtration

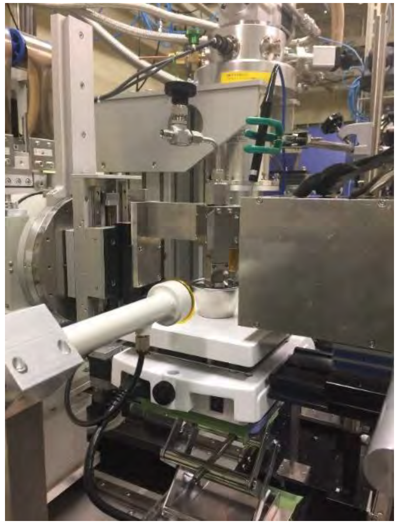


XAFS experiments at SPring-8 and SAGA-LS (Kyushu U. BL)









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CHEMICAL MARKET ANALYTICS

APIC 2026
Asia Petrochemical Industry Conference
FUKUOKA, JAPAN

Two Worlds Colliding:

The Shifting Dynamics of the Methanol Industry

29 May 2026

Xiaomeng Ma
Director, Methanol - Asia
Xiaomeng.ma@chemicalmarketanalytics.com

Agenda

- Methanol Market Fundamentals
- The Middle East Supply Shock
- An Industry in Transition: Low Carbon Methanol and Marine Fuel
- Key Takeaways

The changing face of methanol demand

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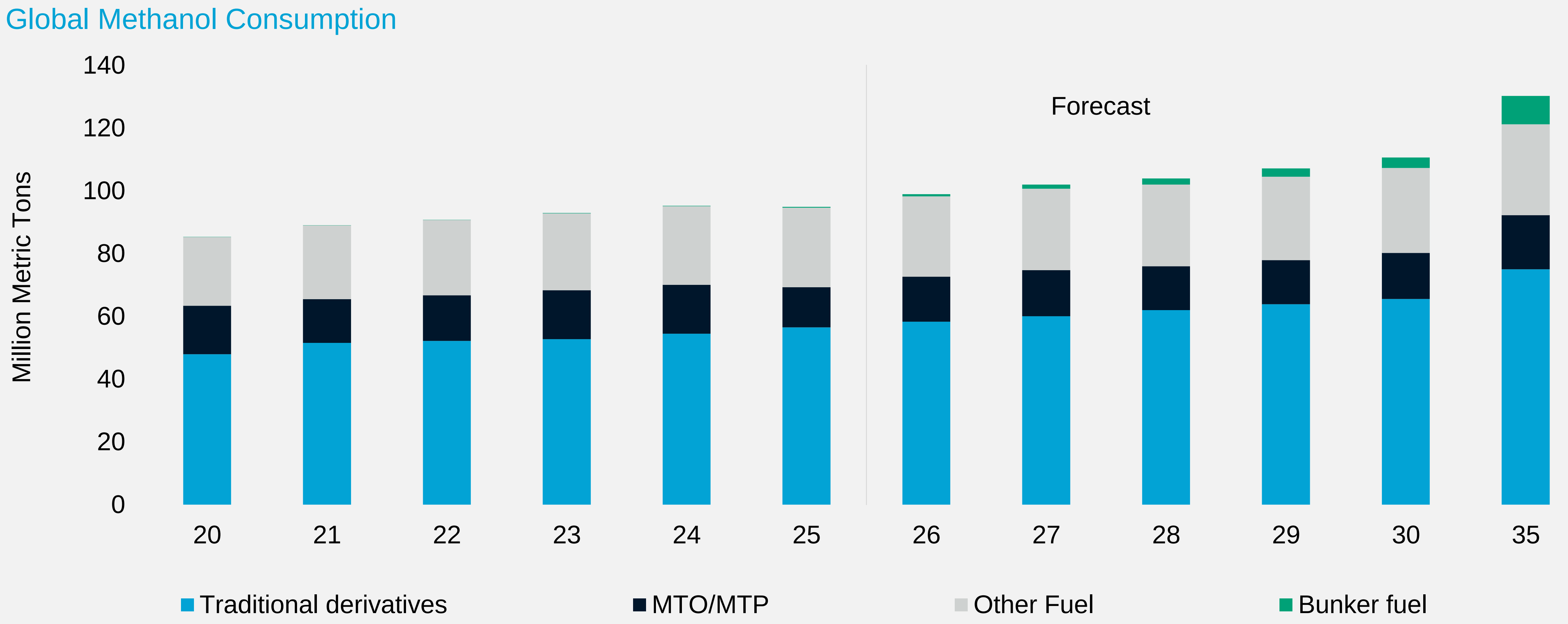
CHEMICAL MARKET ANALYTICS

Methanol to grow at a rate similar to GDP: Reliant more on chemical demand, less on MTO and fuels. Marine fuel is growing in importance…



Source: Chemical Market Analytics by OPIS

Global Operating Rates Set to Decline from 2025 to 2026, but Were Forecast to Pick Up from 2026

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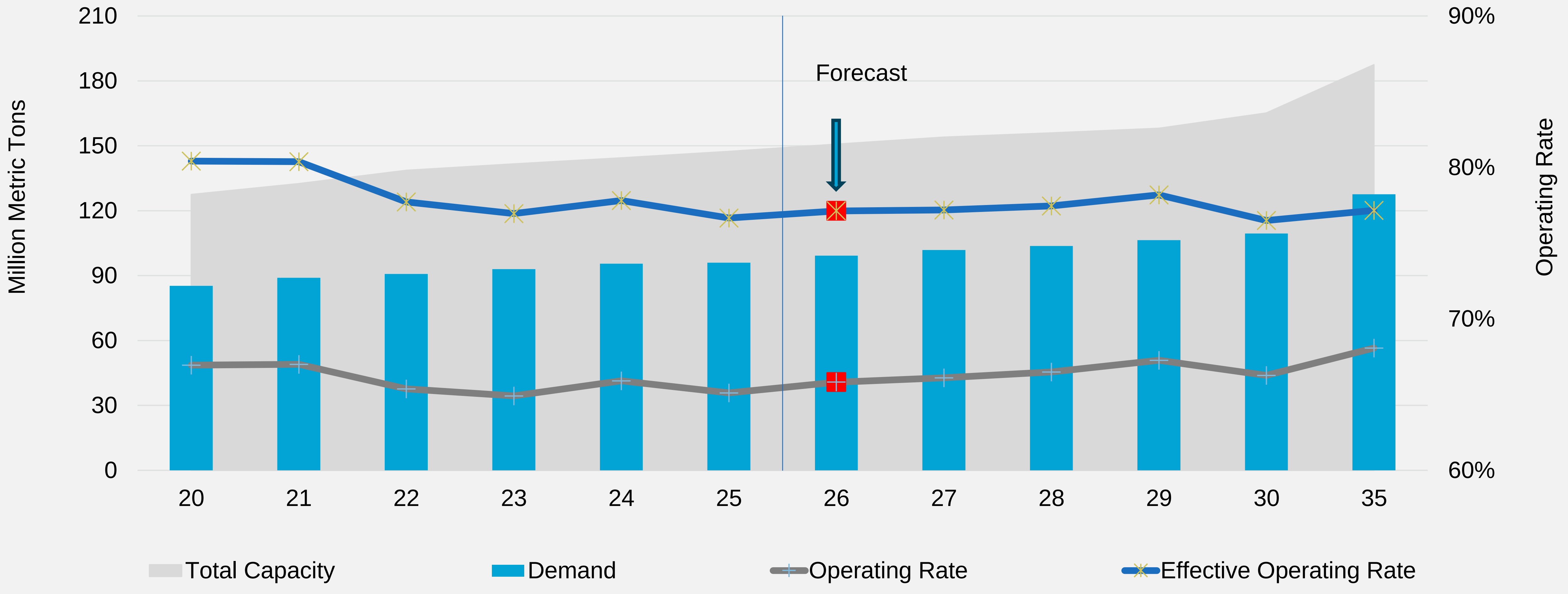
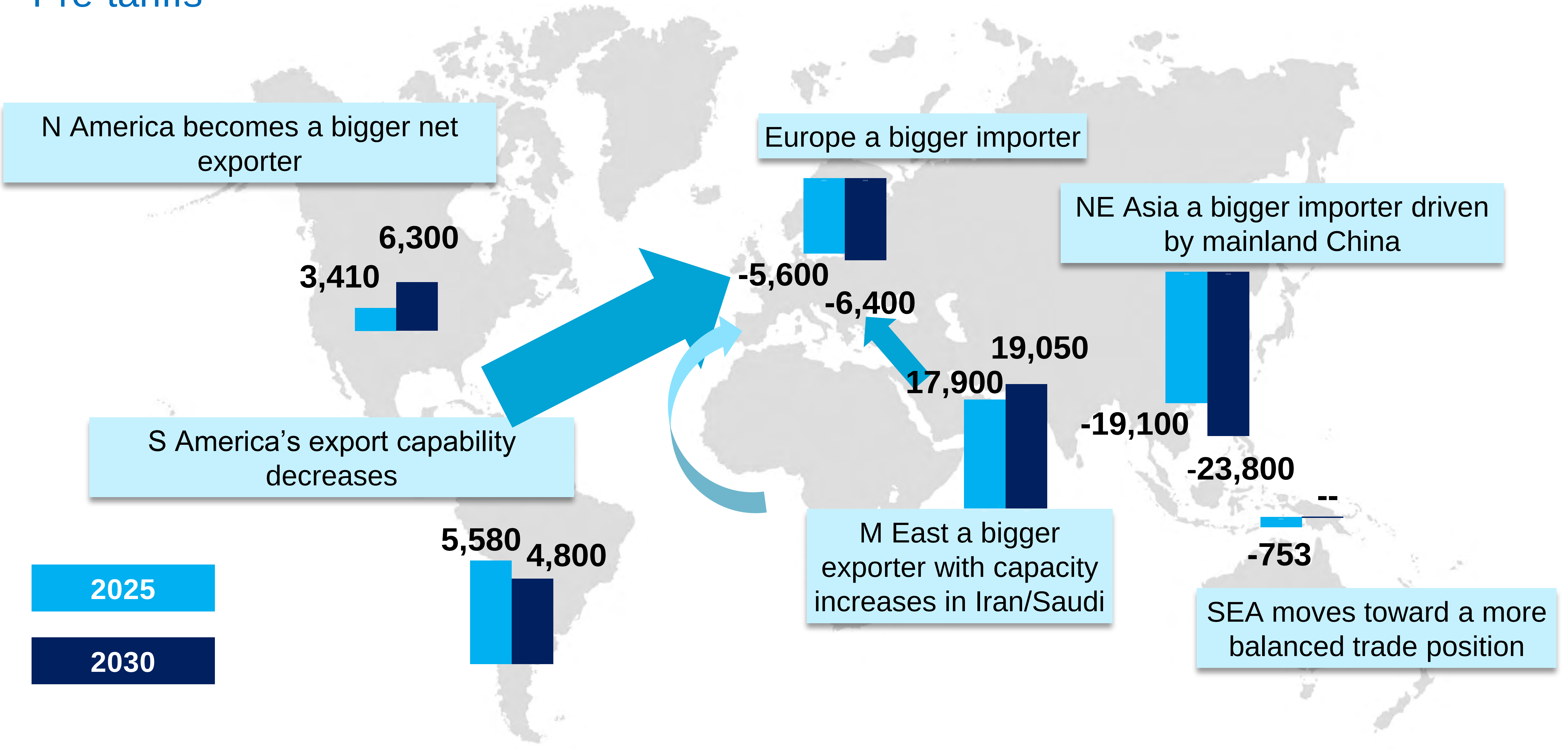
Global Methanol Nameplate Capacity vs Effective Capacity



Source: Chemical Market Analytics by OPIS

Methanol Net Trade Position 2025-2030 (kt)

Pre-tariffs



US/Israel–Iran Conflict: Impact on Methanol Market

Iran supply: Production and exports halted

Logistics: Strait of Hormuz remains (at least partially) blocked

Freight: Transportation costs rising globally

Middle East supply: Output significantly reduced

Feedstocks: Oil, gas, and coal prices increasing

China & India: Strong upward price pressure. Inventory drawdown

Middle East Conflict to Drive Prices Higher Before Expected Stabilization – but At a Higher Level Than in Recent History

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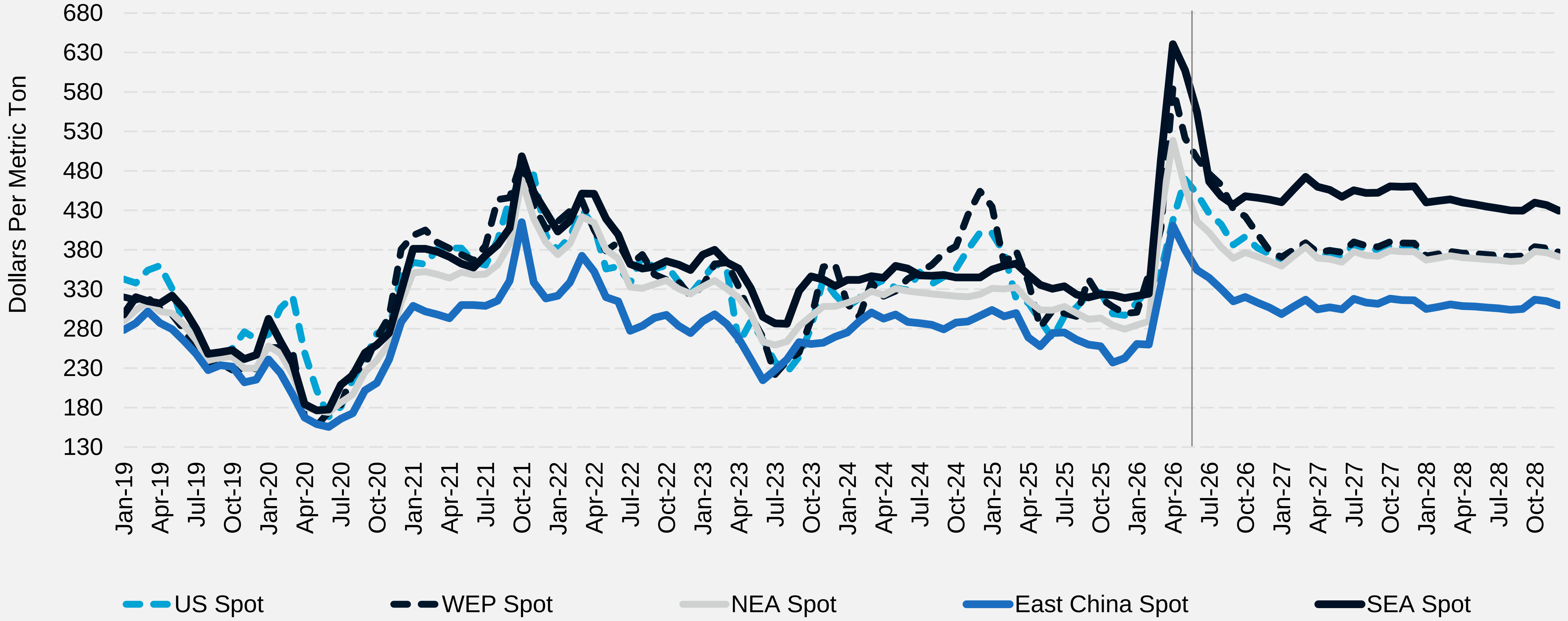
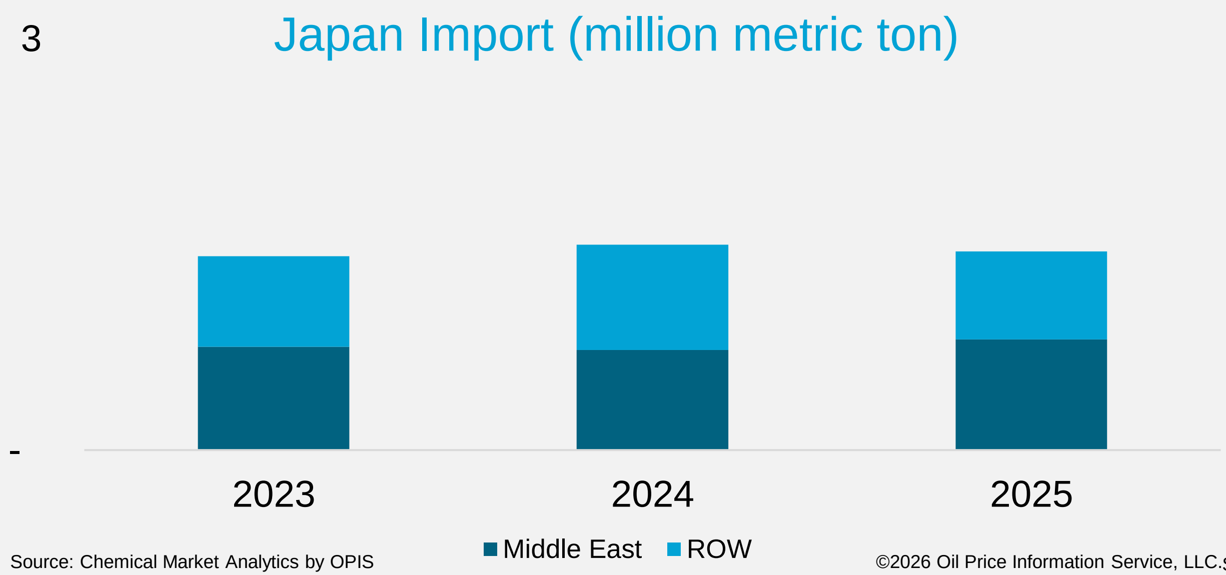
CHEMICAL MARKET ANALYTICS

Methanol Monthly Regional Price Comparison (Spot)

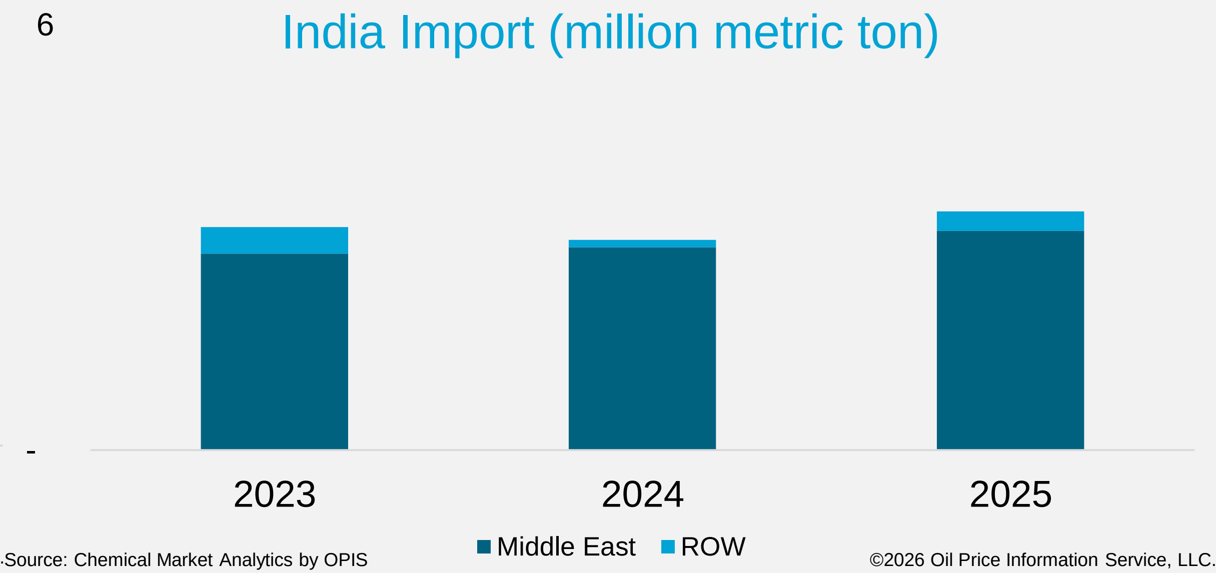


Source: Chemical Market Analytics by OPIS

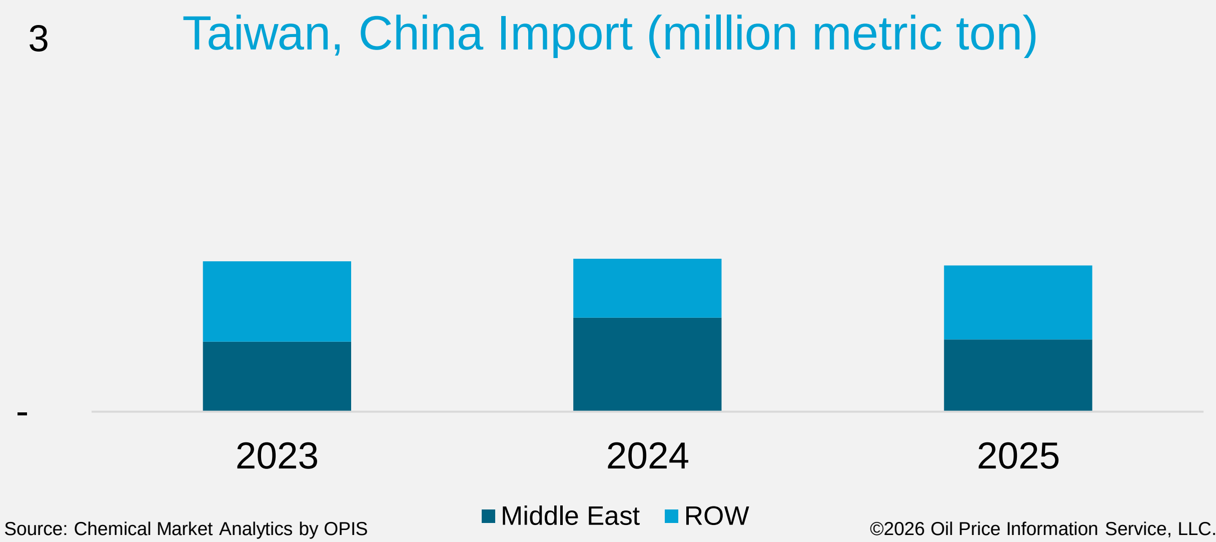
The Middle East
Key Methanol Supplier to mainland China and the rest of Asia



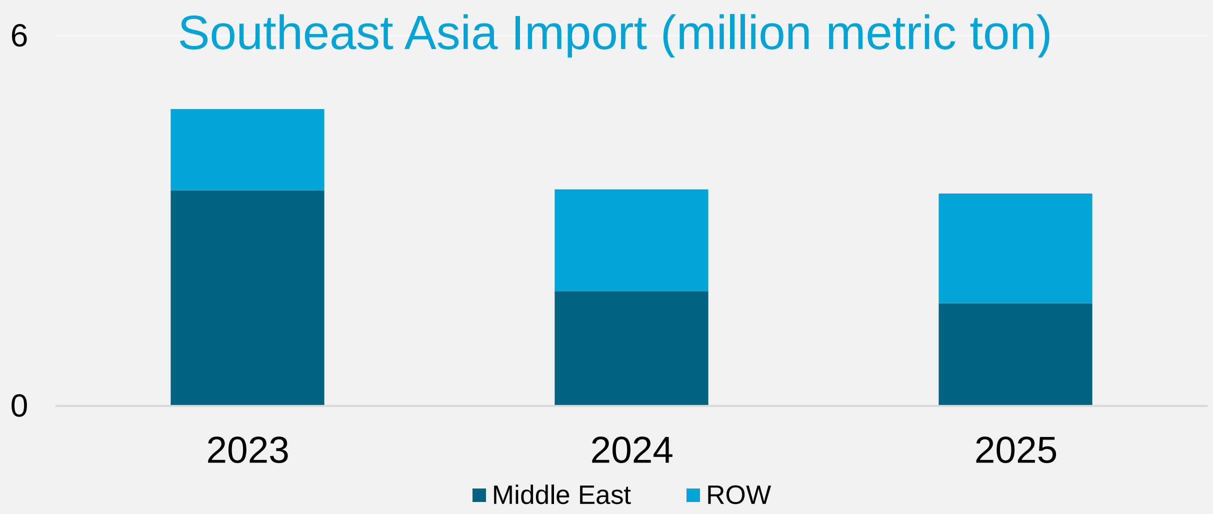
Source: Chemical Market Analytics by OPIS



Source: Chemical Market Analytics by OPIS



Source: Chemical Market Analytics by OPIS



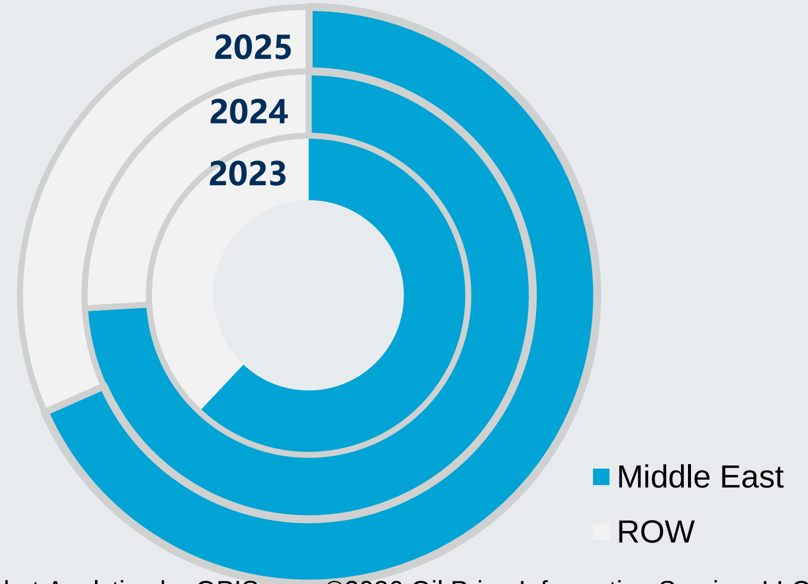
Source: Chemical Market Analytics by OPIS

Current Status of the Methanol Value Chain in Mainland China

Supply and Demand Balance (Feb to May 2026)

	February	March	April	May
OR of effective capacity	76%	79%	81%	80%
Production	3.5 mmt	3.7 mmt	3.9 mmt	3.8 mmt
Coastal Inventory	1200 kt	1050 kt	740 kt	600 kt
Imports	885 kt	435 kt	500 kt (E)	400 kt (E)
Monthly CFR	$260/mt	$335/mt	$411/mt	$380/mt

Mainland China Methanol Imports (million metric tons)



Source: Chemical Market Analytics by OPIS

Measures

- Import Dependency: 20-25%
- A 50% reduction in imports
- Domestic producers have increased operating rates
- Port inventories are being progressively drawn down

Future

- Supply disruptions persist
- Existing inventory buffers becomes insufficient
- Clear decline in MTO production
- The market is gradually rebalancing, but prices are unlikely to return to pre-conflict levels in the near term.

The Industry's Game Changer: Methanol to Olefins
15% of Global Methanol Demand, 24% in Mainland China in 2026

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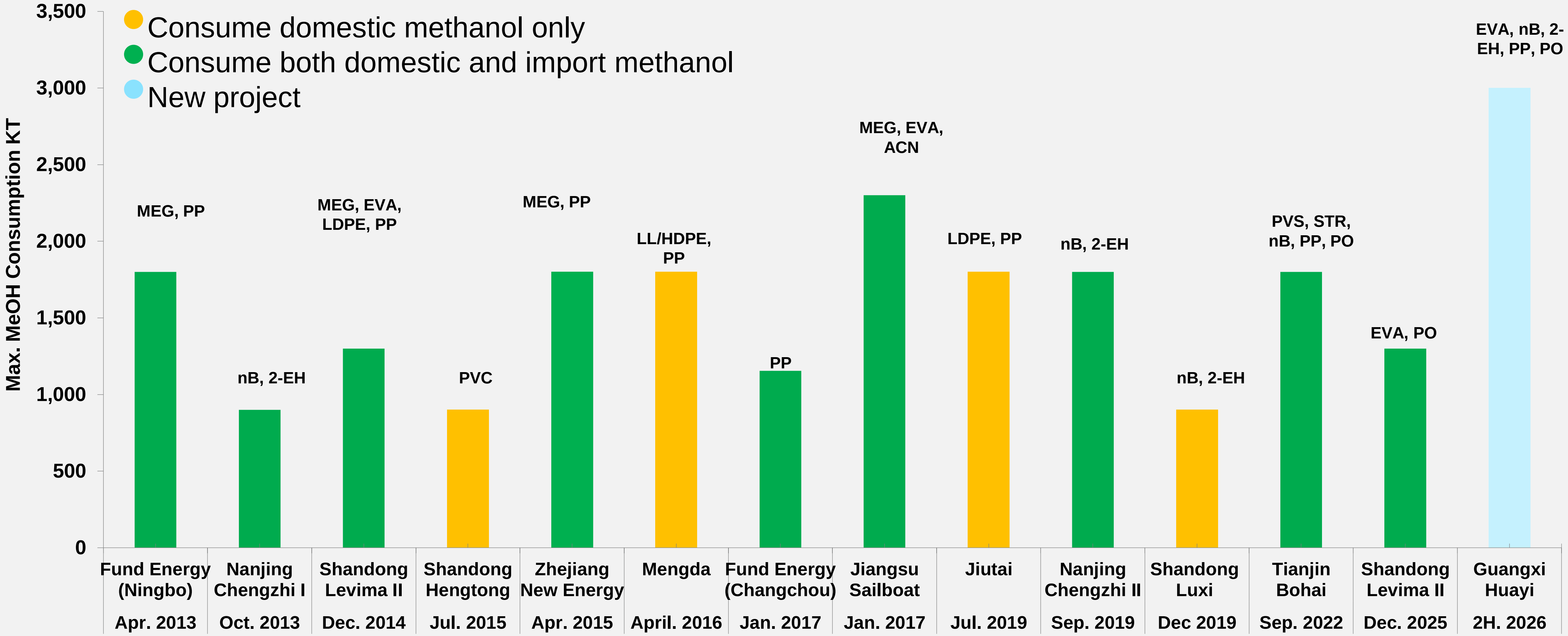
CHEMICAL MARKET ANALYTICS

MTO Facilities 2026



Source: Chemical Market Analytics by OPIS

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Sustainability and the Methanol Industry

Less than 1% of existing methanol production is green

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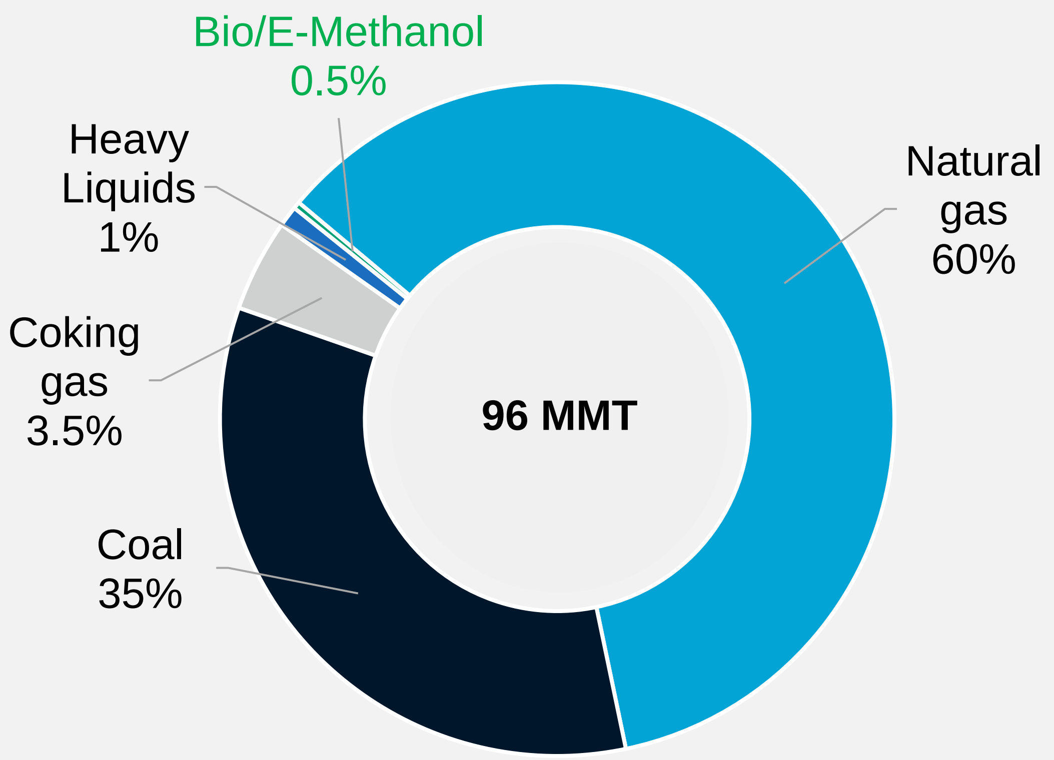
2025 Methanol Production



Source: Chemical Market Analytics by OPIS

Methanol Production Routes and carbon footprint

Grey/brown Methanol	Conventional methanol produced from coal, natural gas and coking gas
CO2 Methanol	Combination with traditional methanol some part of the feedstock, usually CO2, is from CCUS.
Bio - Methanol	Made from biomass, such as crop waste and paper pulp, or biogas gathered at landfills and sewage plants.
E - Methanol	Combining hydrogen with CO2. The H2 involved is from renewable electrolysis of water.

Source: Chemical Market Analytics by OPIS

Sustainable Methanol Projects Around the World

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CO2 to MeOH

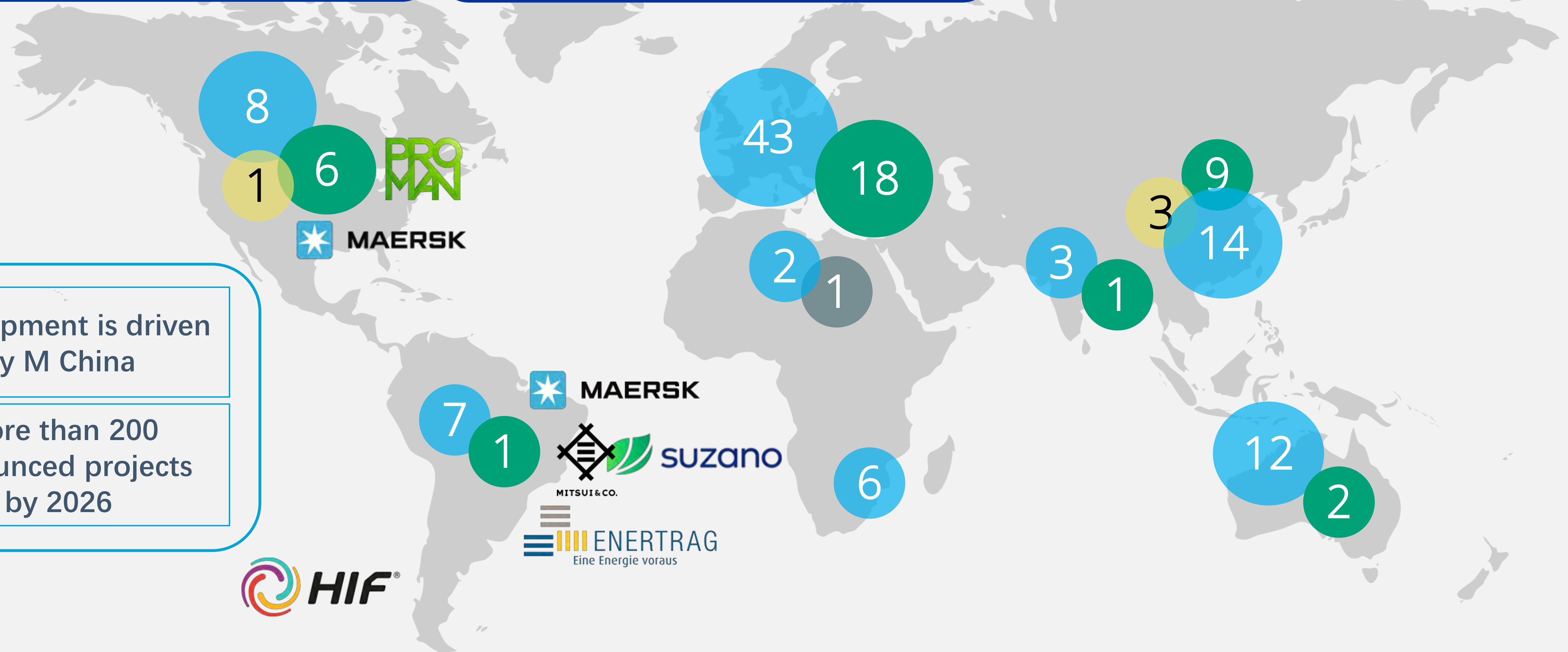
Anyang Shunli, Jiangsu Sailboat and Tianying in CHN

E-Methanol

Perstorp in Swissland, Goldwind, Taonan, China Energy and etc. in CHN

Bio-Methanol

OCI and Methanex in US, BASF in Germany,
C2X in Spain, Yigao, Huayi in CHN



Development is driven by M China

More than 200 announced projects by 2026

Methanol and Sustainability: Will low-carbon methanol supply keep pace with demand, especially for marine fuel?

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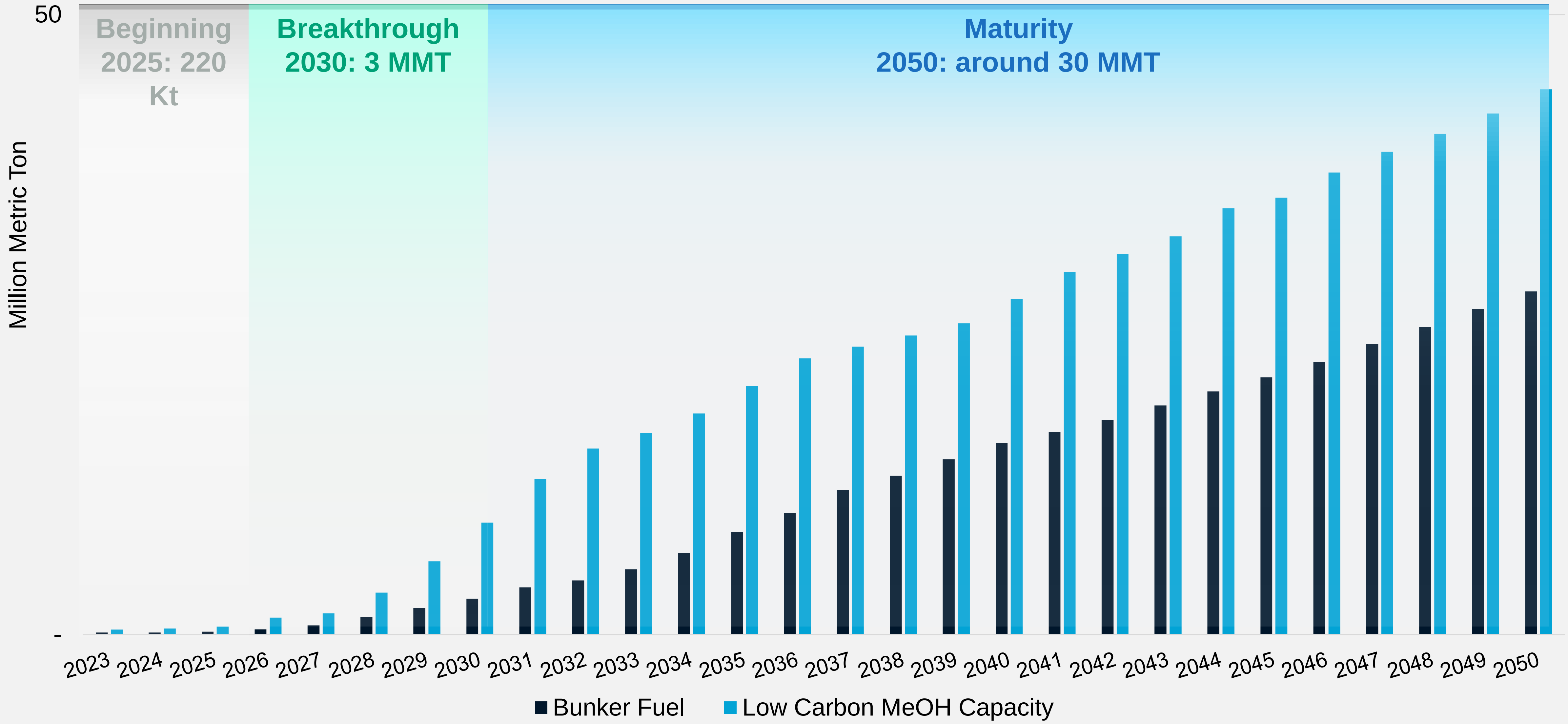

Policy Support, Cost Reduction & New Demand Are Key to Low-Carbon Methanol Growth

Policy Opportunities and Uncertainty

- EU and IMO policies will shape future demand
- Mainland China export VAT rebates and upcoming regulations are watchpoints

Supply & Infrastructure

- Mainland China and EU accounts for majority of global low carbon methanol projects
- Methanol bunkering ports all over the world.
- Optimization of production cost will drive global expansion

Industry Outlook

- Healthy supply with efficient technology
- In a long term, green methanol demand from various applications, not only replying on marine fuel


World Methanol Conference
Methanol: An Island of Stability in a Stormy Global Market?
OPIS
A DOW JONES COMPANY
CHEMICAL MARKET ANALYTICS
29 Sept – 1 Oct 2026 | Rotterdam, Netherlands
chemicalmarketanalytics.com/wmc

Conclusions

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The Asian methanol value chain is searching for opportunities in the energy transition

- **2026:** The Middle East conflict has pushed prices up, increased uncertainty, constrained supply and raised the issue of affordability and the impact on demand

- **2027/2028:** Higher crude oil and international gas prices are likely to lead to higher production costs and freight rates, keeping prices higher than previously forecast

- **Longer Term:**
  Little new capacity to come onstream will lead to higher operating rates
  Long-term global demand to grow at level just above GDP
  More reliance on traditional chemical demand, less on fuels, MTO
  Wild cards are Iranian sanctions, marine fuel, low-carbon methanol production

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Prospects of Methanol as an Alternative Marine Fuel

Becky Zhang, Argus Asia Methanol Lead Consultant

APIC

28-29 May 2026, Fukuoka

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Argus publishes more than 42,000 daily and weekly spot and forward price assessments, along with commentary, news and analysis for global commodities and energy markets.

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- Biofuels
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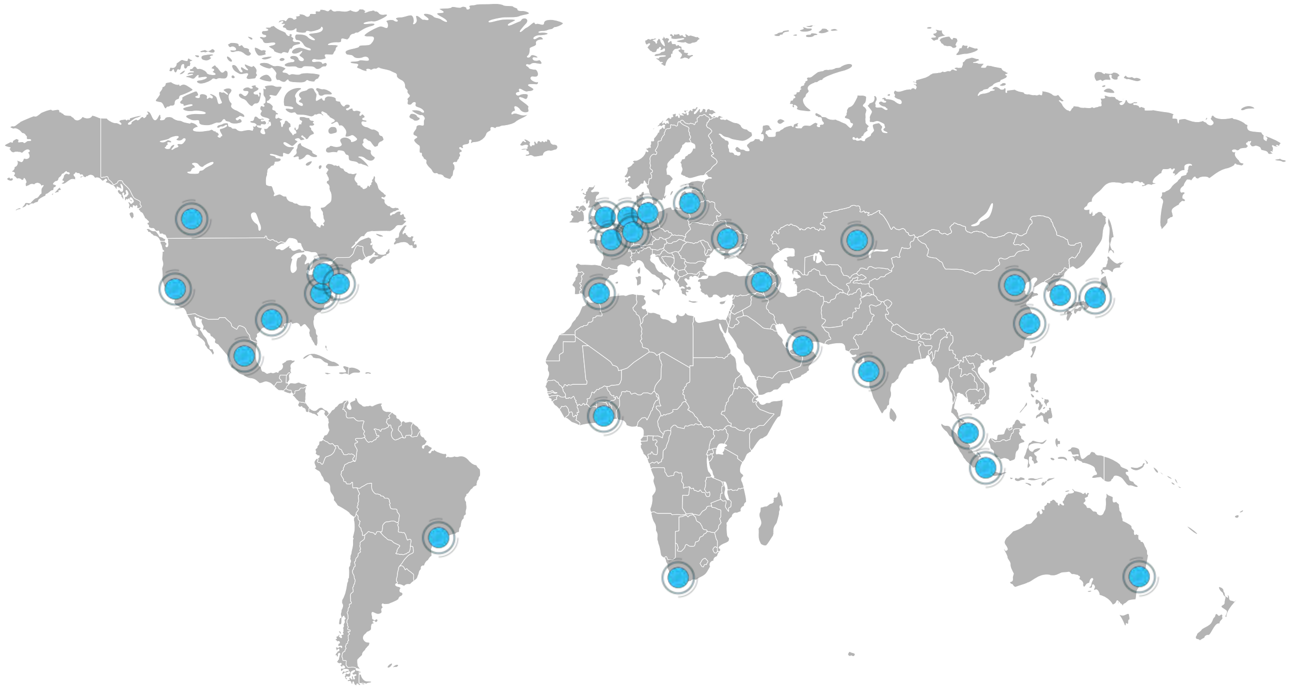
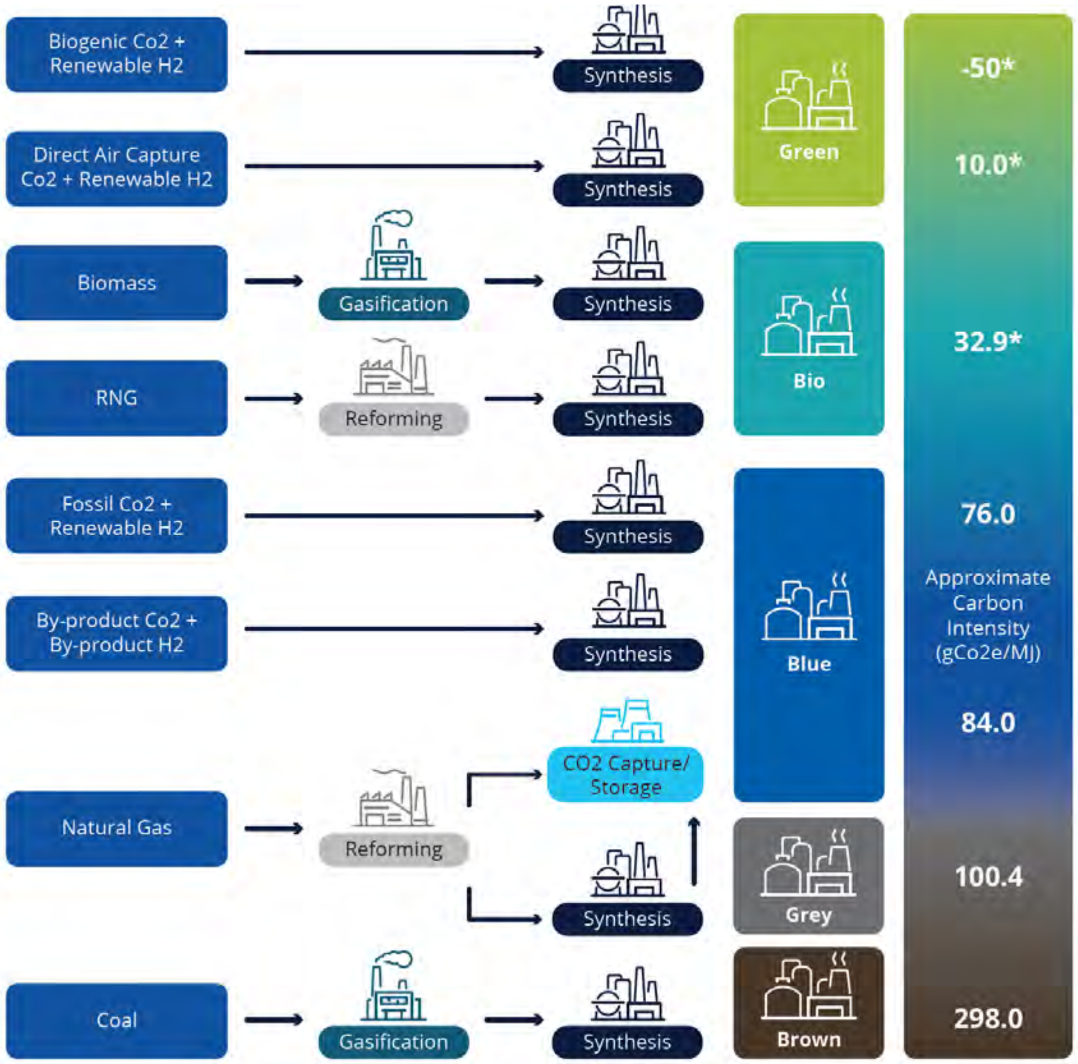
- US and European environmental markets



Agenda

- Definition and Status quo
- Grey methanol as a marine fuel
- Green methanol as a marine fuel
- Outlook

Methanol definitions: Methanol production pathways



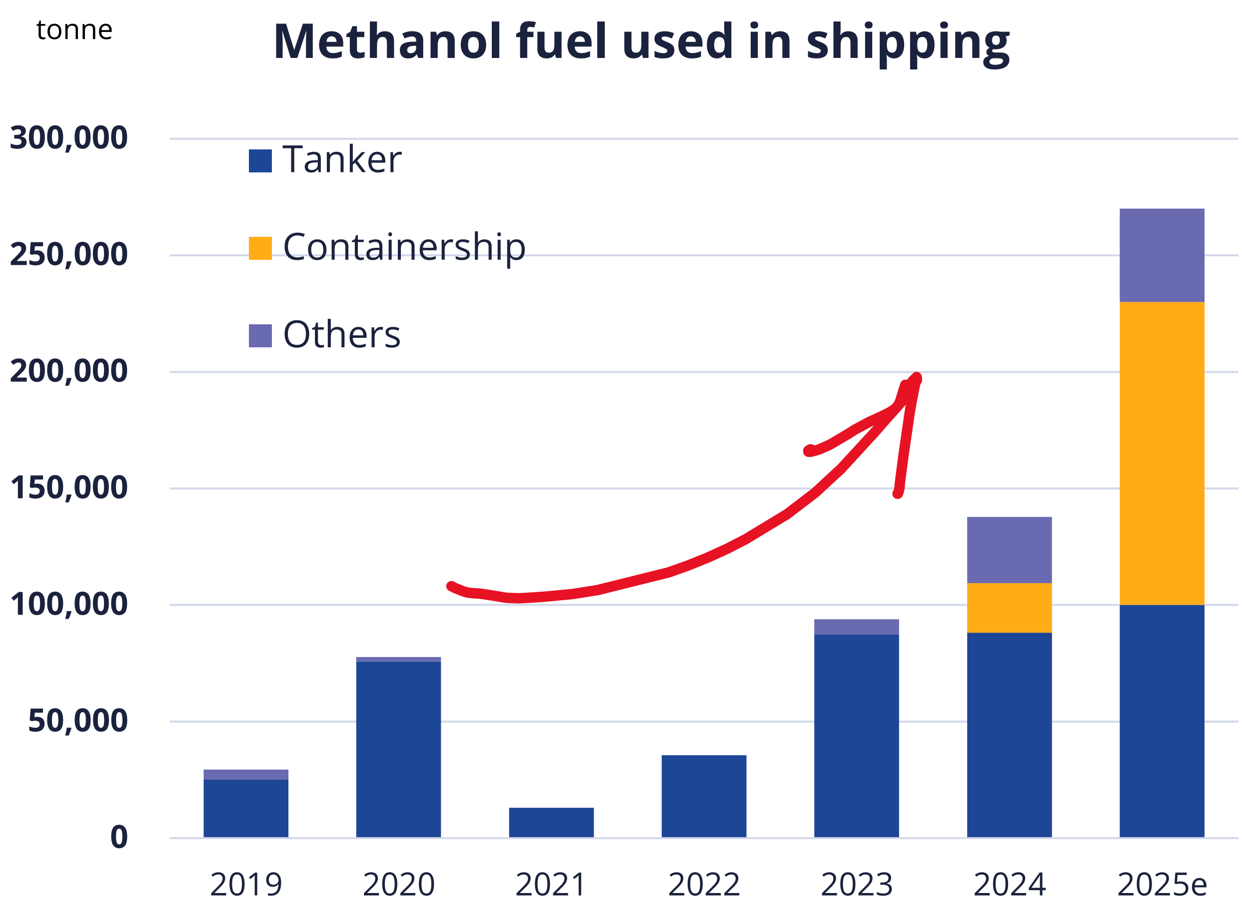
Path-ways	Carbon Intensity and GHG Savings	
	LCA Carbon Intensity CI, gCO2e/MJ	GHG Emissions against Fuel Oil 94 gCO2e/MJ
E-methanol (Green)	5-12	- (87-96)%
Biomethanol (Green)	-50-32	- (65-153)%
Coal-based methanol (Grey)	300	+ 219%
NG-based methanol (Grey)	95-105	+ (1-12)%
Blue methanol	45-75	- (20-52)%

Note: Methanol’s calorific value is 19.95 MJ/kg

- GHG savings are based on VLFSO 94gCO2 equivalent/MJ
- RED biomethanol: minimum 65pc GHG savings
- RED e-methanol: minimum 70pc GHG savings

Emerging demand: Methanol (grey + green) consumption as an alternative marine fuel is increasing

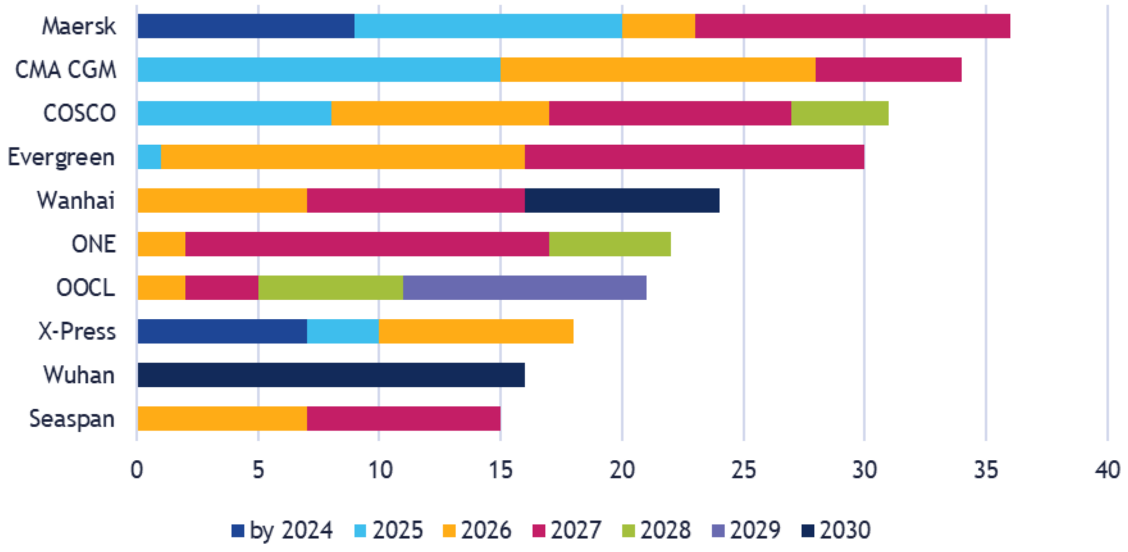
- Methanol's relatively lower price versus fuel oil is **driving interest as a substitute**, particularly for MGO and ULSFO
- Total consumption of methanol (including green) as a marine fuel **reached 138kt in 2024**, up by 47pc from 2023, and may hit ~250kta in 2025
  - Shanghai Port alone bunkered nearly **60kt** of conventional methanol in 2025
- Argus expects methanol bunker demand to remain supported, driven by:
  - More methanol dual-fueled vessels
  - Increasing demand for engine testing
  - Economically competitive versus fuel oil
  - An excellent replacement for ultra low sulfur fuel oil under emission control area (ECA) rules

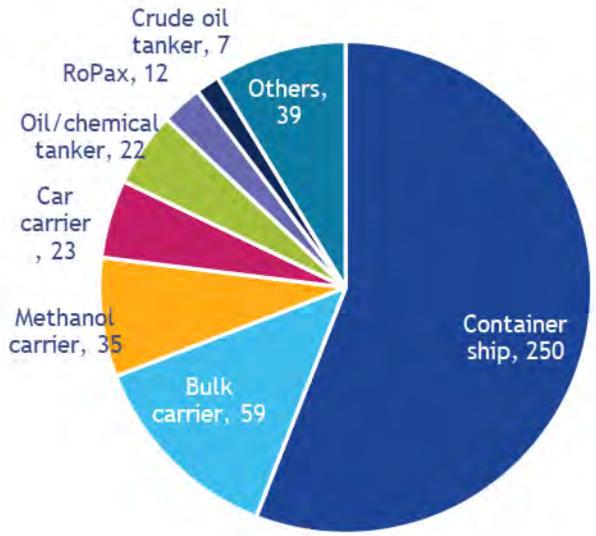


Source: IMO, Argus consulting

On paper, methanol demand as marine fuel shall increase with more delivery of methanol vessels in 2026-27

Delivery schedule of methanol dual-fuelled vessels



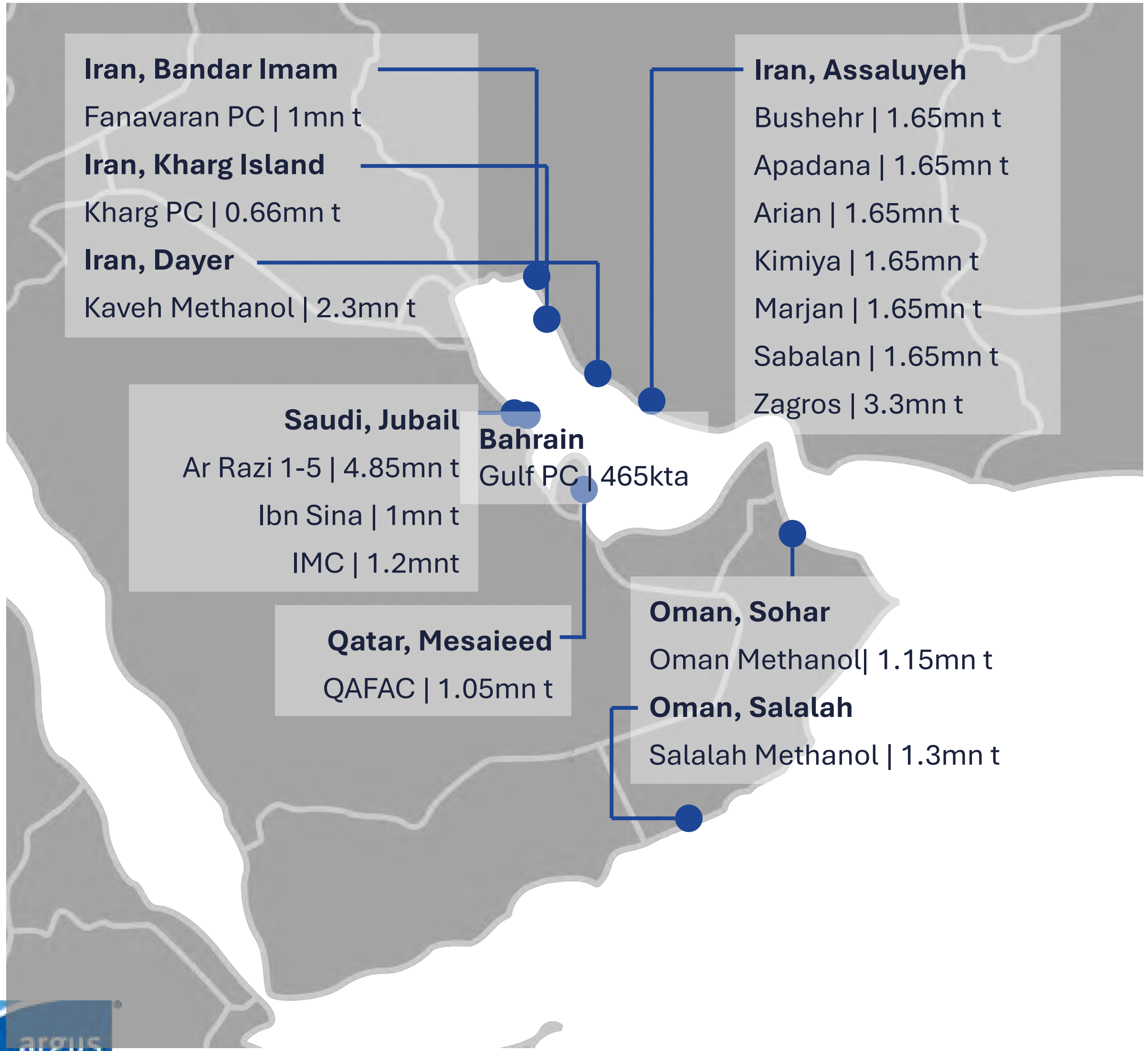


Data source: DNV

- More than 100 methanol fleets are operational globally. This number will increase to 236 by end-2026, and 450+ by end-2028.
- Container ships account for 56%, followed by bulk carriers 13% and methanol carriers 8%. Top ship owners who ordered the most methanol fleets are Maersk, CMA CGM, COSCO, Evergreen, Wan Hai, and ONE

Grey Methanol as a Marine Fuel

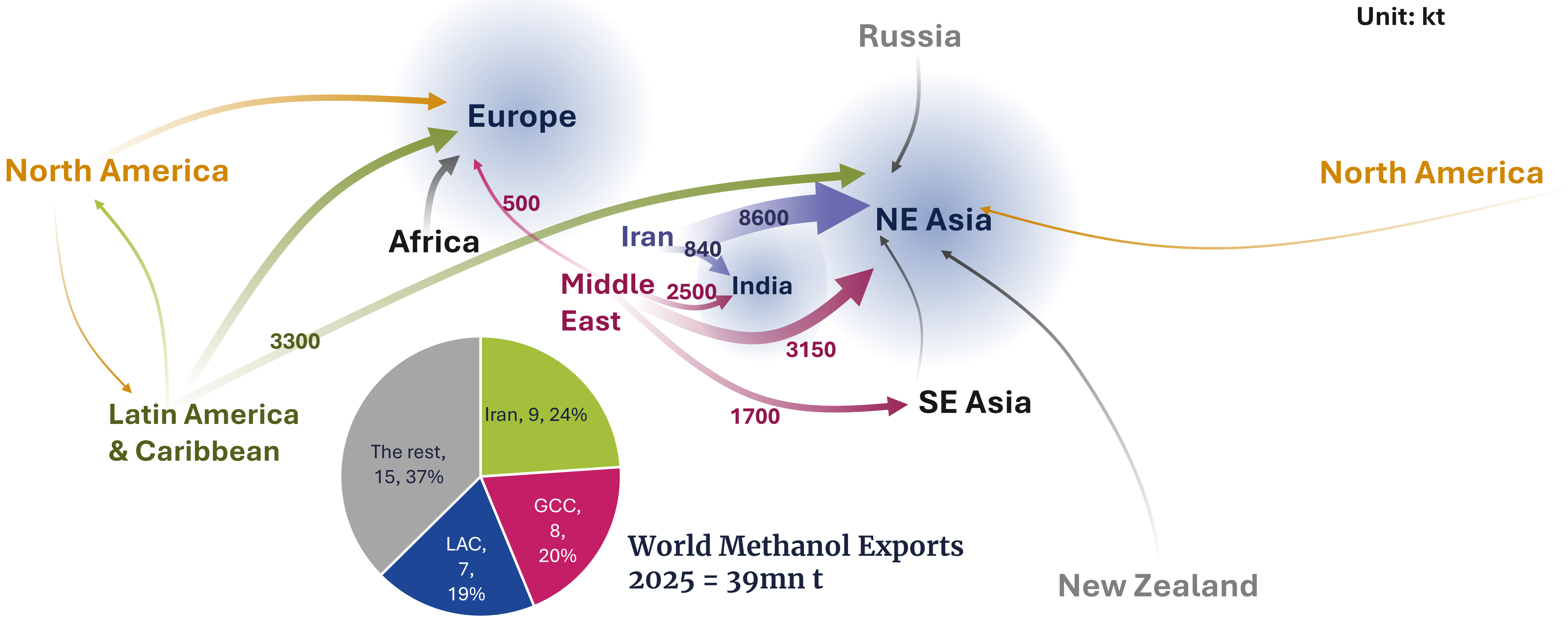
Moving into 2026: The Middle East war and the closure of Hormuz Strait disrupted Asia methanol supply



Iran	Capacity, kt/yr	Operating status		Shipping
		Pre-war	Latest	
Zagros 1	1,650	√23Feb	X	Limited
Zagros 2	1,650	√2Feb		
Fanavaran	1,000	√	X	X
Kharg	660	√	√low	X
Kaveh	2,300	X	√low	X
Apadana	1,650	X	X	X
Marjan	1,650	X	√low	X
Bushehr	1,650	√	√low	Limited
Arian	1,650	√25Feb	√low	X
Kimiya	1,650	X	X	X
Sabalan	1,650	X	X	X
Total	17,160	48%	~ 20%	

GCC	Methanol units	Capacity, kt/yr	Operating status		Shipping
			Pre-war	Latest	
Saudi	Ar Razi	4850	√	√low	X
	Chemanol	230	√	√low	X
	Ibn Sina	1,000	√	√low	X
	IMC	1,200	√	X	X
Qatar	QAFAC	1,050	√	X	X
Oman	Salalah	1,300	√	√	√
	Oman M	1,150	√	√	√
Bahrain	Gulf PC	465	√	X	X
	Total	11,245	100%	~ 20%	

Supply tightened across Asia: The closure of Hormuz Strait cut ~40% of global trade (exports)



Source: Global Trade Tracker, Argus

Import dependence drives impact: India and Southeast Asia face the most severe methanol supply shortfall

Country/Region	Sum of 2024	Sum of 2025	2025-2024
Iran	**10,000**	**9,500**	**-500**
China	8,300	8,600	+300
India	1,700	840	-860
ME (ex-Iran)	**8,100**	**8,100**	**/**
India	1,179	2,255	+1,076
SE Asia	1,910	1,690	-220
other NE Asia	2,127	1,689	-438
China	1,993	1,461	-532
Europe	440	490	+50

Affected region	Import dependence	ME% among imports (2025)
India	**100%**	**92%**
SEA	**9%**	**90%**
Japan	**100%**	**56%**
Taiwan	**100%**	**49%**
China	26%	70%
Korea	100%	18%

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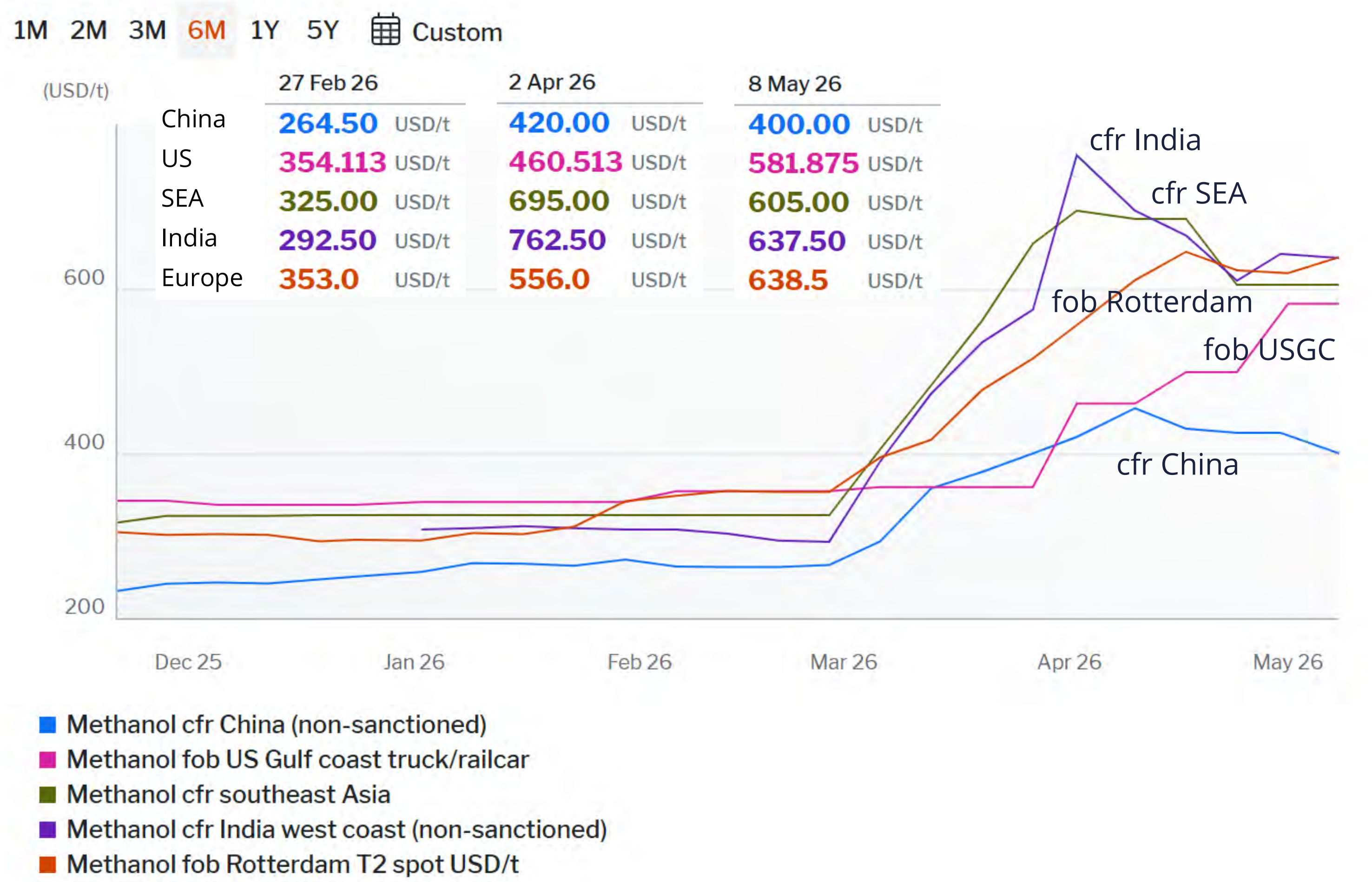
The extent of impact drives respective prices: India, SEA prices rose the most, followed by Europe, US and China

Global Methanol Price Trend



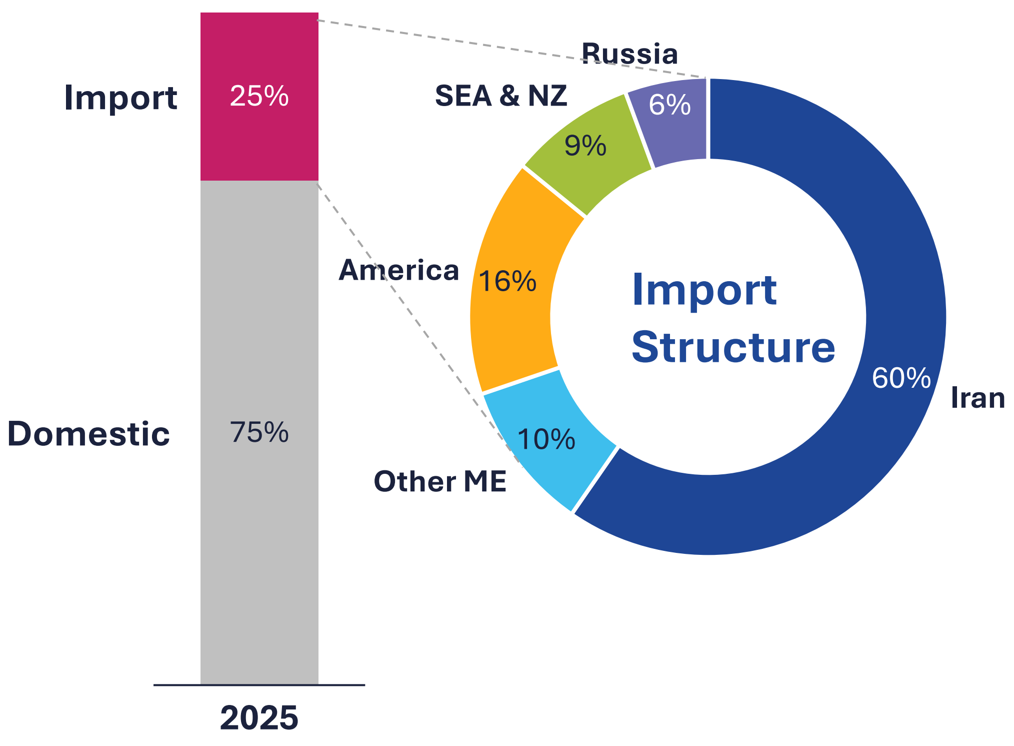
- China spot prices rose the least among Asian regions, buffered by sufficient domestic supply and elevated port inventories
- India prices soared with heavy reliance on Middle East supplies.
- SEA prices rallied because of insufficient domestic supply and supply cuts from the Middle East
- Europe prices surged partly because of supply cuts from the Middle East, partly because of hefty gas prices
- US prices hiked following crude and higher prices in ROW

Trade flow shifts accordingly: Limited availability goes to the shortest regions for highest profits

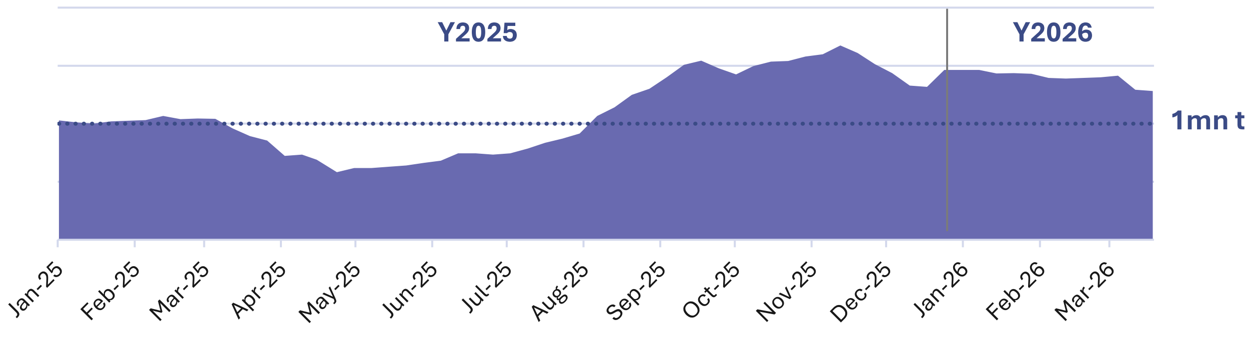
- China exported a total **460kt** of grey methanol in the past 2.5mth, compared with a total of 290kt for the entire 2025.
- 4 export modes from China:
  - Divert cfr China directly
  - Re-export import cargoes
  - Export custom cleared imports
  - Export China-made methanol (NG based)

Why China prices keep low: Elevated inventories and high domestic production cushioned impact

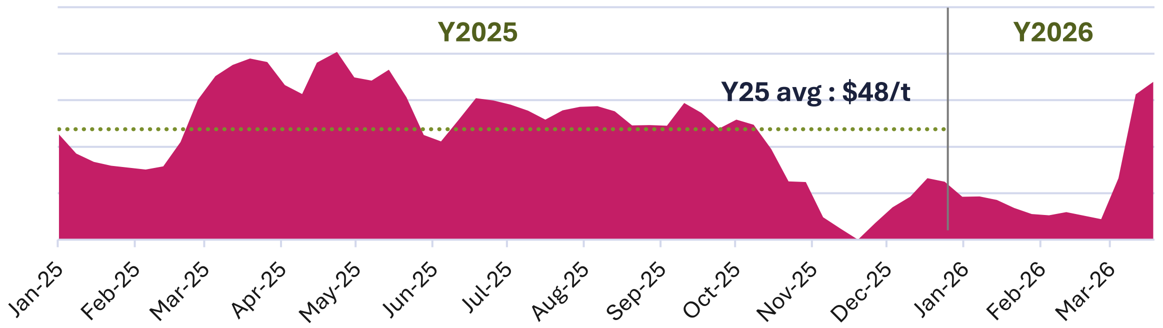
China's methanol supply structure, 2025



Port inventories at high levels



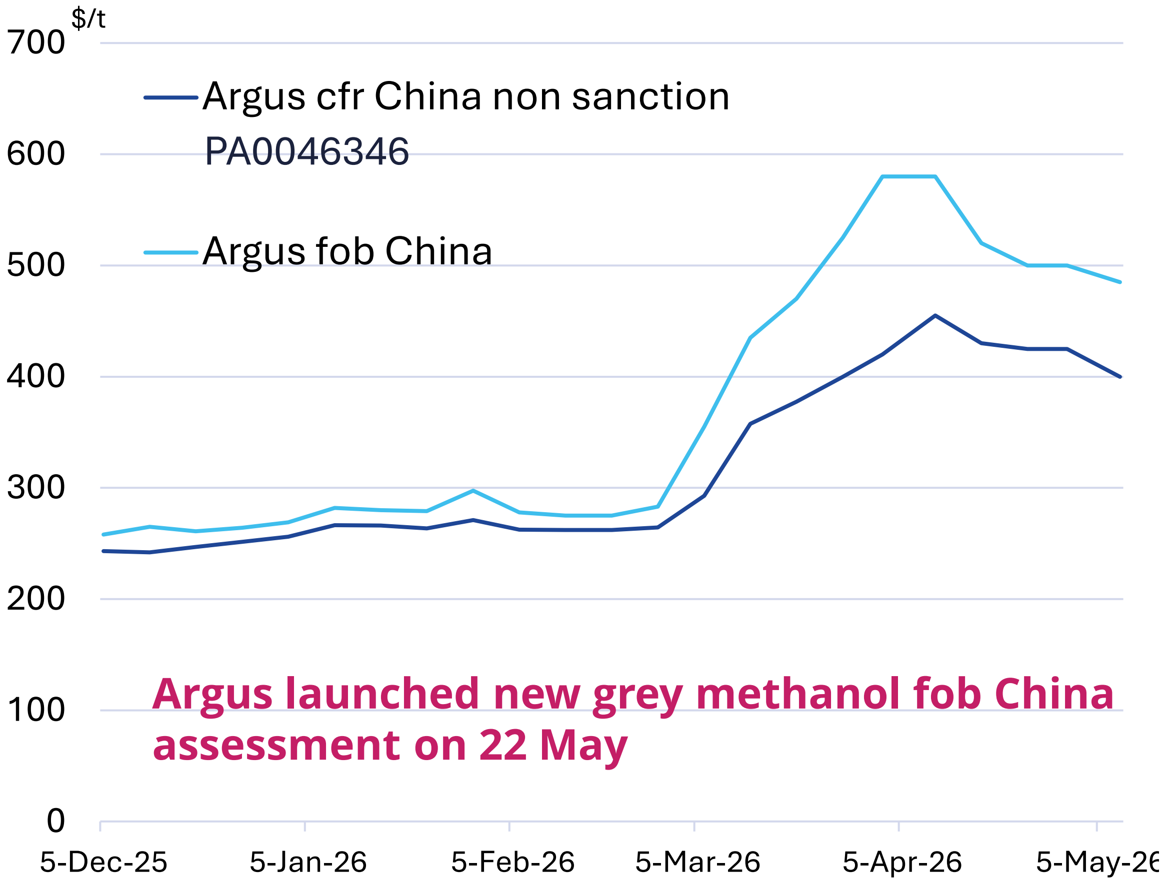
Coal based methanol run high on strong margins



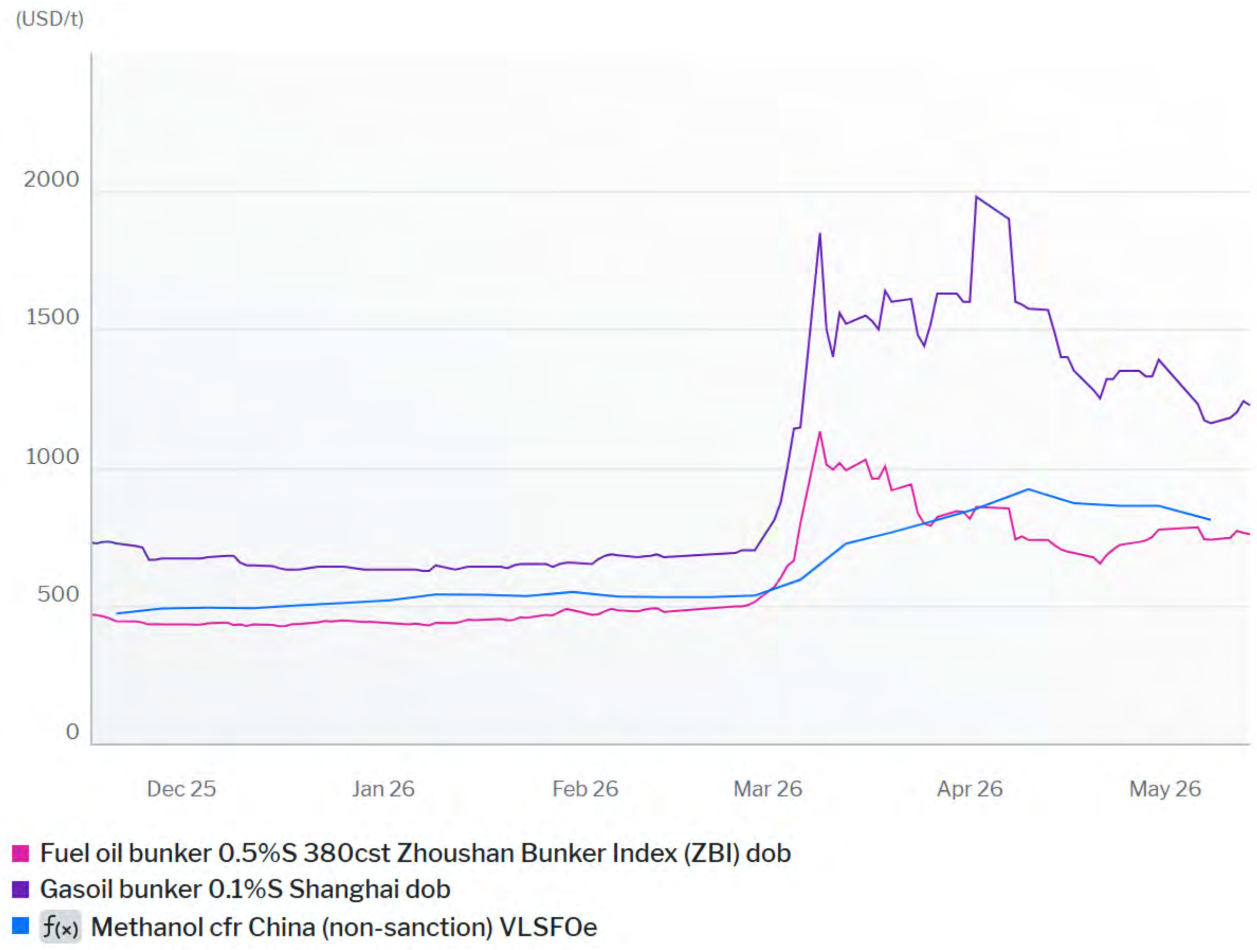
数据来源： Argus, Global Trade Tracker

Implications for grey methanol bunkering in China in 2026: Volume, origin, price are uncertain

- **Supply is not guaranteed**
  - Fewer cargoes will go to China because of its lowest price in the world. Suppliers minimize their contract fulfillment to China.
  - Even China itself is re-exporting import cargoes to other higher netback regions, including SEA, India and Taiwan
- **Suppliers with available cargoes are extremely limited**, mainly restricted to producers or distributors that are not affected by the Middle East war and that still maintain sales exposure to China
- **Prices are extremely volatile** and **the spread** between import Cfr China and export fob China prices **widened.**



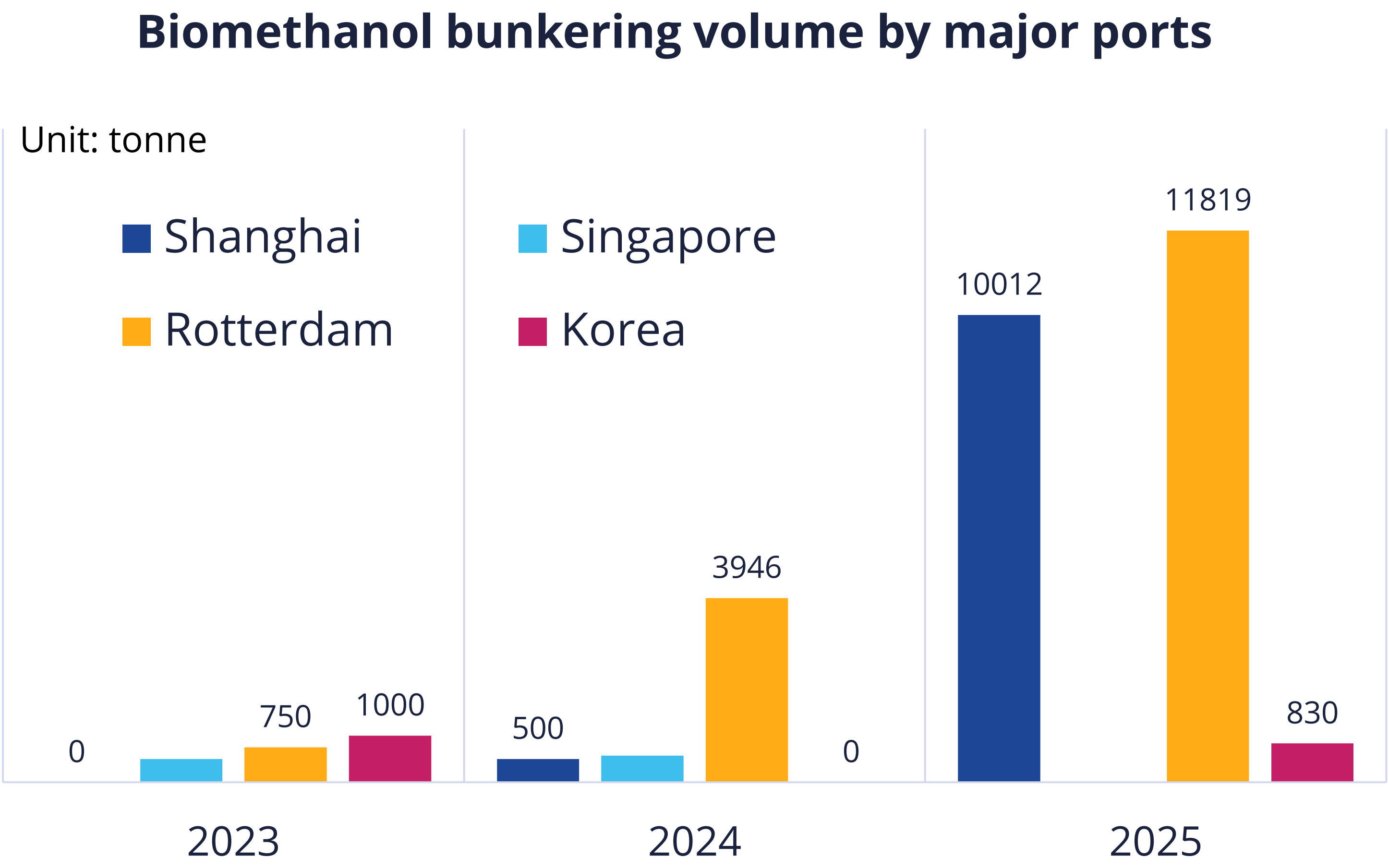
Grey methanol remains competitive against conventional fuel oil: Buying interest as marine fuel continues



- Before the war, grey methanol prices (converted to VLSFO heat equivalent basis) were slightly higher than VLSFO, and lower than MGO
- After the outbreak of war, grey methanol prices on VLSFO equivalent basis commanded a big discounts against fuel oil and MGO
  - Prices now returned to VLSFO + premium and the premium is narrowing again recently
  - The big discounts against MGO have continued
- The super low sulfur content of methanol at maximum 0.5ppm fulfill MARPOL's Sox ECA policy (sulfur < 0.1pc fuel oil or 1000ppm)

Green Methanol as a Marine Fuel

Global biomethanol bunkering: Commercial bunkering emerges; scale growth awaits stronger incentives



- **Shanghai port**'s green methanol bunkering volume rose sharply from 500t in 2024 to 10kt in 2025
- **Rotterdam port** bunkered 12 kt in 2025, nearly triple year-on-year
- **Singapore** struggles to locate biomethanol bunkering demand since the issuance of bunkering license in Nov 2025
- **South Korea** sees occasional bunkering trials
- Biomethanol bunkering remains largely **spot-based, small-scale and trial-led**, with limited term commitments

Data source: Argus & Rotterdam Port

2025: Asia bunkered 12,364t, Shanghai led the way

No.	Date	Port/Dock	Qty, t	Mode	Shipowner	Origin
1	30 Mar	Shanghai	2,902	S-S	HMM	Towngas
2	5 May	Shanghai	3,110	S-S	HMM	Towngas
3	2 Jul	Yangpu, Hainan	200	T-S	COSCO	CNOOC
4	11 Jul	Shanghai	1,000	S-S	COSCO	Towngas
5	15 Jul	Dalian	500	S-S	COSCO	Towngas/Daqing
6	25 Jul	Haimen, Jiangsu	100	T-S	CM	Towngas
7	22 Sep	Tianjin	300	T-S	CM	Towngas
8	28 Sep	Ulsan, S Korea	830	P-S	NYK	Methanex
9	29 Sep	Ningbo Zhoushan	222	*S-S*	COSCO	Towngas
10	5 Nov	Shanghai	3,000	S-S	Evergreen	Biaofa
11	3 Dec	Shenzhen	200	S-S	COSCO	CIMC

argus Data source: Argus

China biomethanol pricing: Spot prices driven by bunker tenders, new start-ups and policy shifts

Argus Asia RED biomethanol pricing

Green methanol as a marine fuel alternative – Policy: GHG emission legislations by EU, FuelEU Maritime and IMO drive green fuel demand

- In 2023, RED III was finalized to apply to **all transport sectors including marine and aviation**
- In 2025, **40%** of the CO_2 emissions from voyages and at berth stays in 2024 will be subject to the ETS, rising to **70%** in 2026 and **100%** in 2027
- 2024 only count CO_2, 2026 **expand to CH_4/N_2O/Slip**, qualified biofuels is considered zero CO_2 emission

Emissions Trading Scheme (ETS)

EU

- The regulation sets targets for reducing the yearly average GHG intensity of the energy used by a ship.
- The required GHG intensity reduction **starts at 2% in 2025** (2020 baseline), reaching 6% in 2030 and 14.5% in 2035, **through to 80% by 2050**.
- A penalty or reward is then calculated based on the extent of under- or over-performance

FuelEU Maritime Regulation

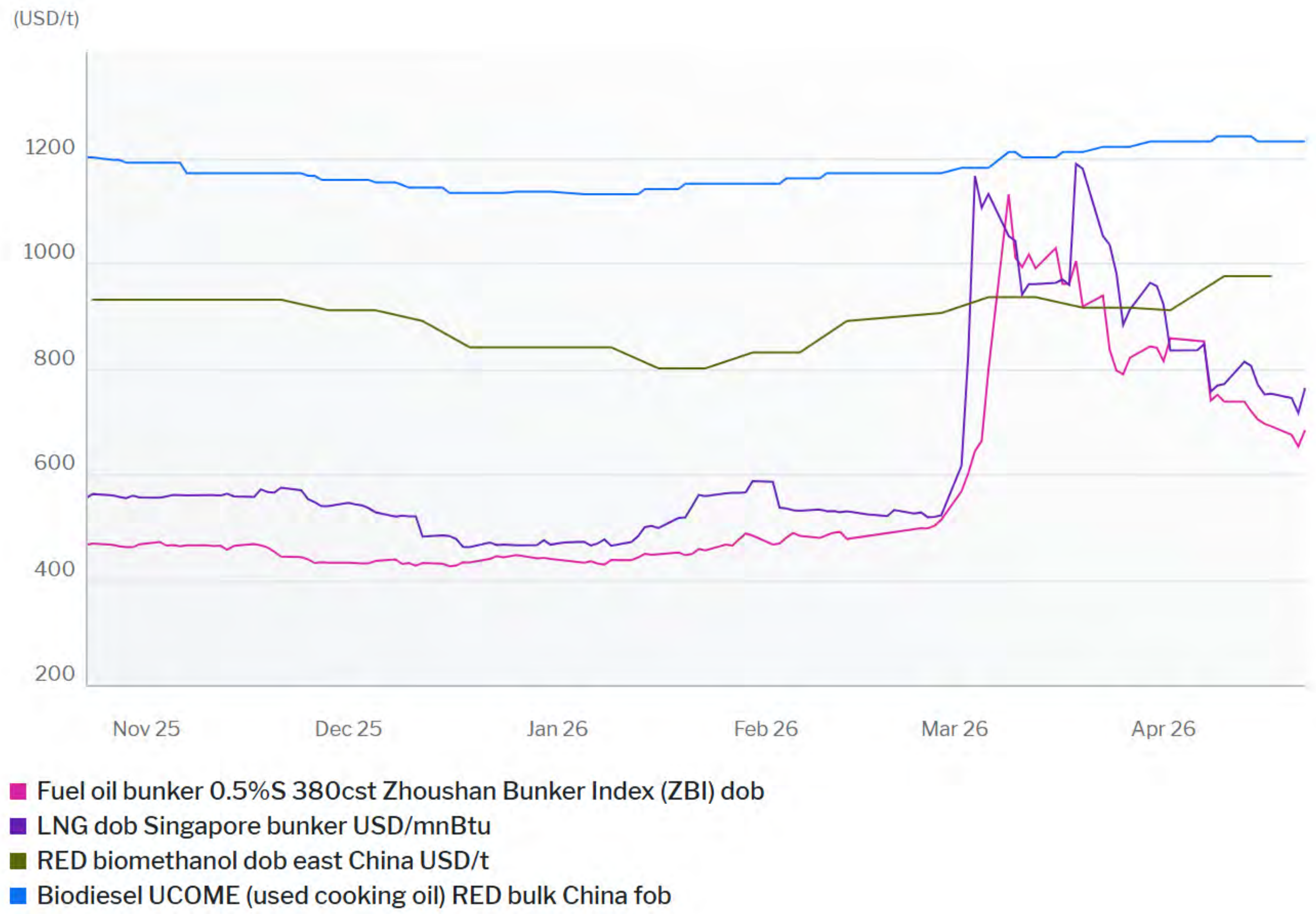
EU

- MEPC 83 proposed **two-tier pricing mechanism**.
- MEPC 84 decided to **delay IMO voting** by a year, facing pressures from the US and Saudi
- MEPC 85 advanced lifecycle-based emission regulation and compliance design, but many details still under discussion
- **1st edition:** By 2030, to reduce carbon intensity of 20% striving for 30%, take low/zero carbon fuels of at least 5%, striving for 10%; By 2040, to reducing carbon intensity of 70% striving for 80%; **By 2050**, to **achieve net-zero** CO_2 emissions
- cIMO is more feedstock agnostic with a simpler approach to decarbonization

International Maritime Organization (IMO)

War impact on green fuel prices: Green fuel prices diverge from fossil fuels, narrower premiums may support demand

Argus Alternative Marine Fuel Pricing



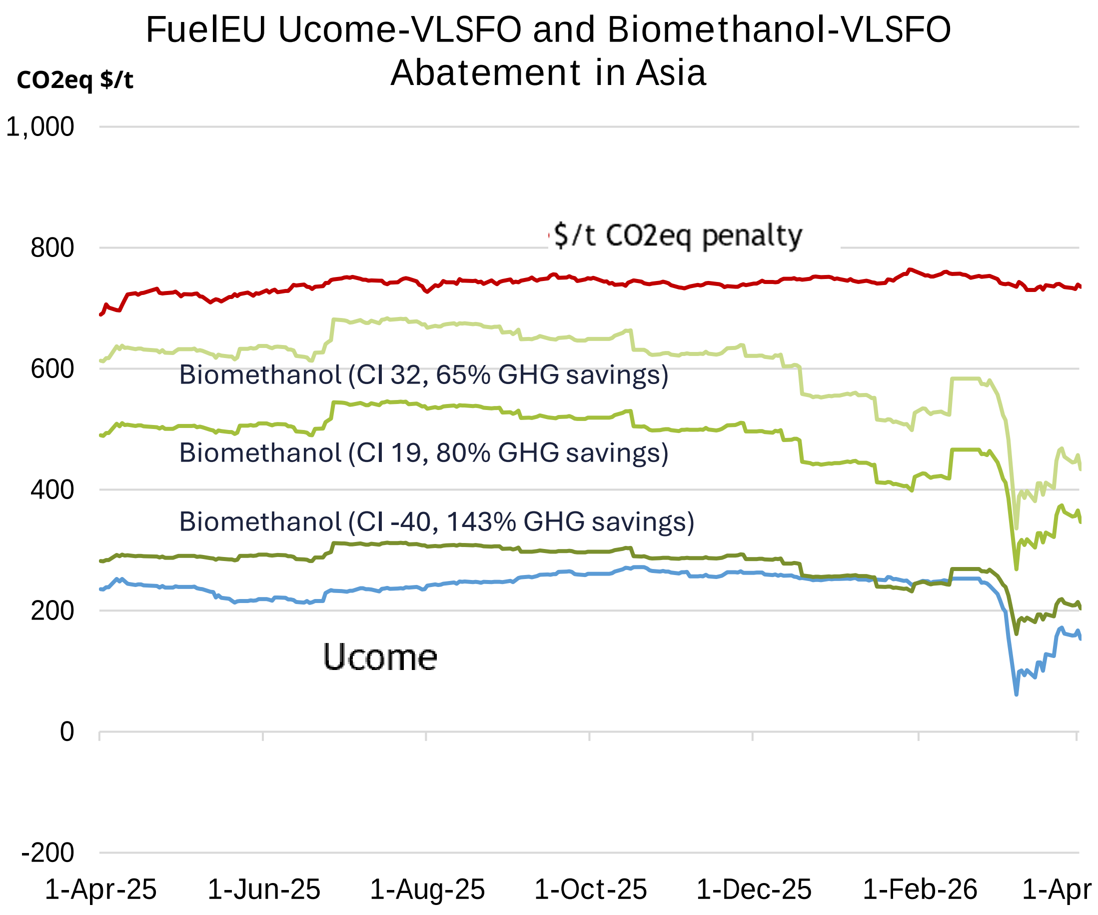
Fossil marine fuel prices become highly volatile after the outbreak of the US-Iran war, till 22 Apr

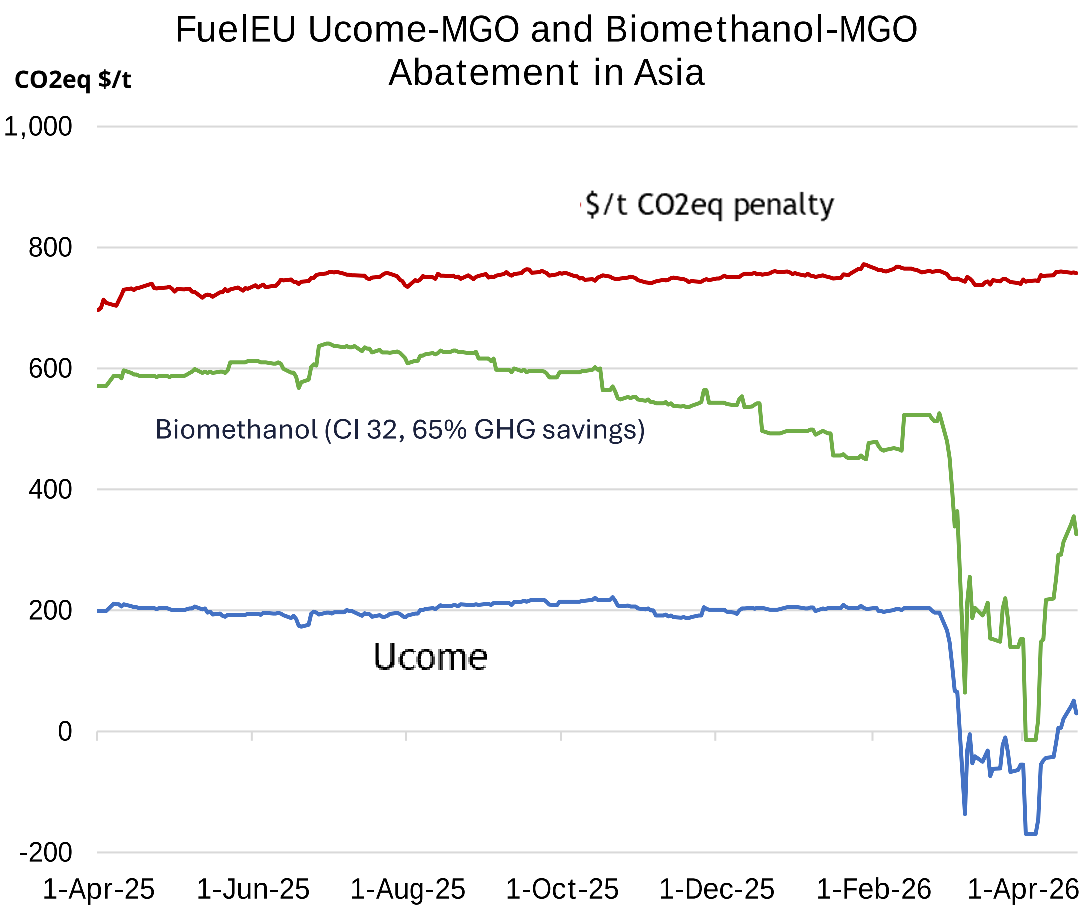
- Argus VLSFO dob Zhoushan, up 33%
- Argus LNG dob Singapore, up 46%

By contrast, biomethanol and biodiesel (UCOME) prices rose marginally by 8% and 5% respectively, reflecting:

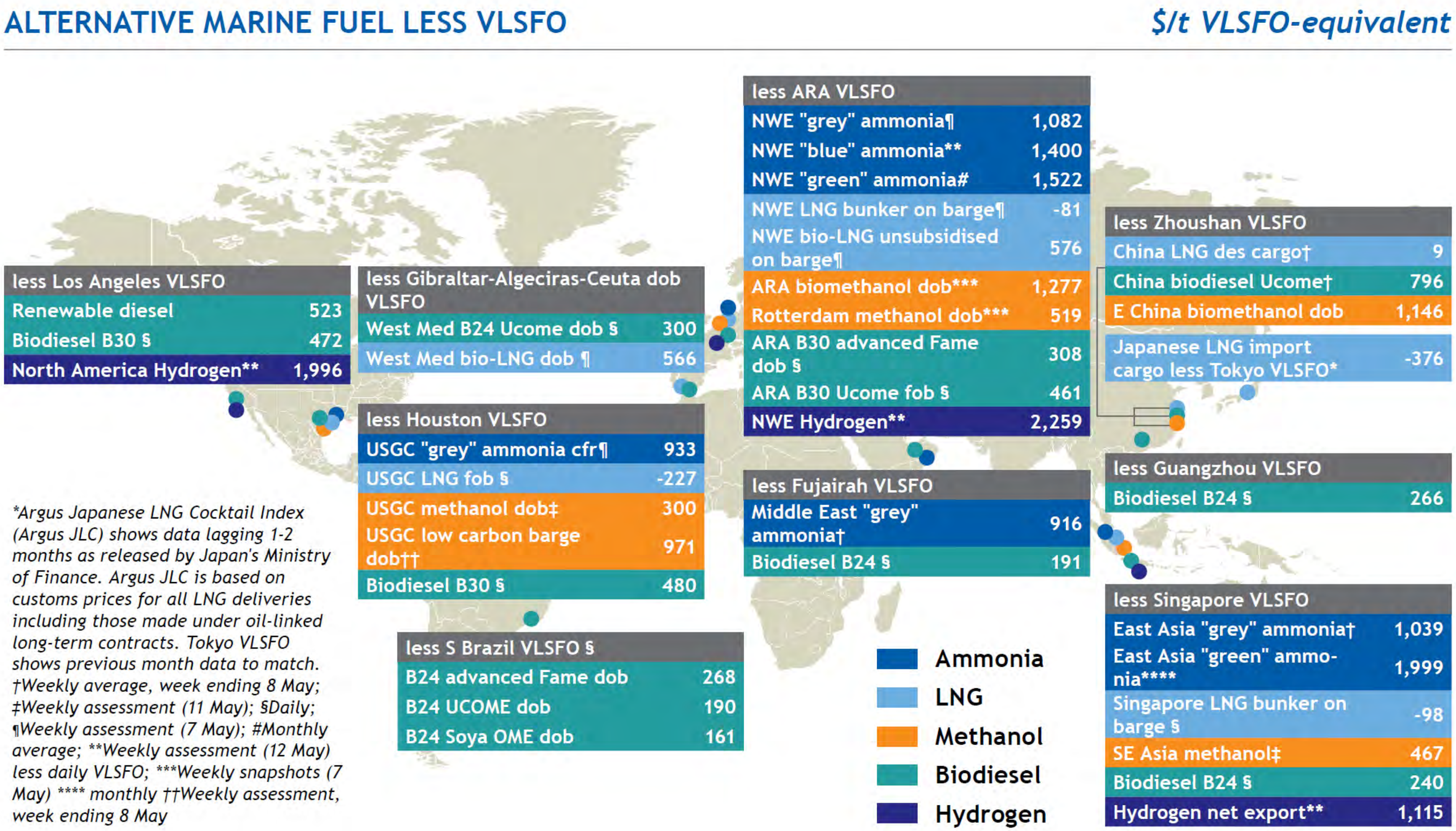
- Market focus on Middle Eastern supply disruption, rather than decarbonization
- Sharp fuel oil price spikes constraining shipowners' affordability of higher-cost green fuels
- The Middle East conflict disrupted key shipping routes and trade flows, reducing vessel activity and contracting bunker fuel oil consumption

Biomethanol abatement cost in Asia: Price rallies in fuel oil reduced biomethanol's abatement cost





Ranking alternative fuels on cost competitiveness: LNG, biodiesel, bio-LNG, biomethanol



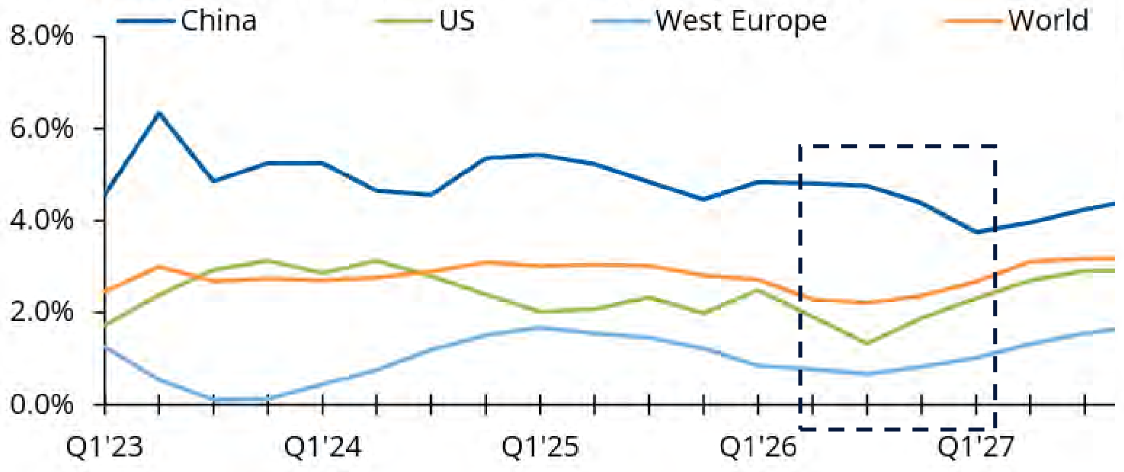
*Argus Japanese LNG Cocktail Index (Argus JLC) shows data lagging 1-2 months as released by Japan's Ministry of Finance. Argus JLC is based on customs prices for all LNG deliveries including those made under oil-linked long-term contracts. Tokyo VLSFO shows previous month data to match. †Weekly average, week ending 8 May; ‡Weekly assessment (11 May); §Daily; ¶Weekly assessment (7 May); #Monthly average; **Weekly assessment (12 May) less daily VLSFO; ***Weekly snapshots (7 May) **** monthly ††Weekly assessment, week ending 8 May

Market Outlooks

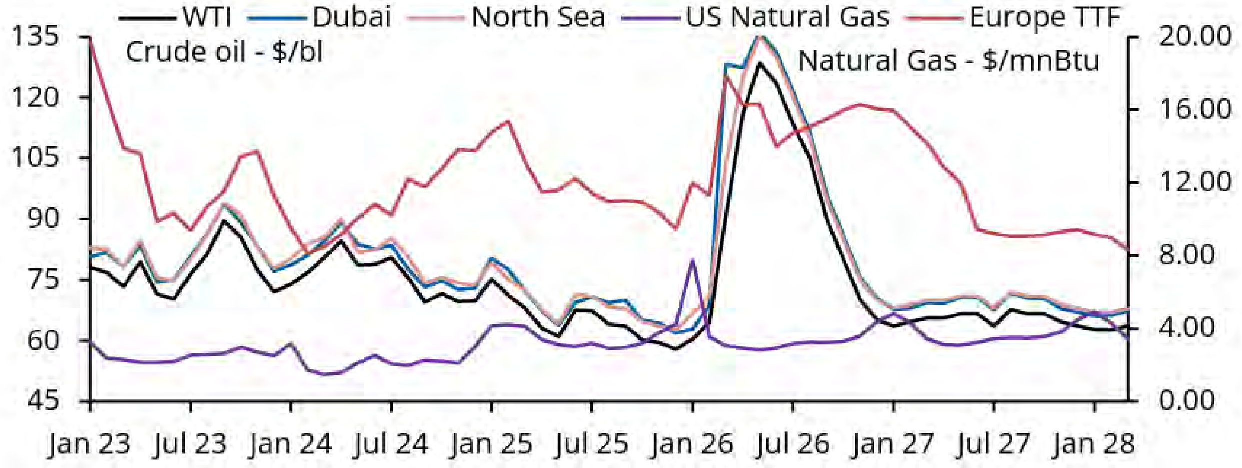
Macro: What's changed in the economy and energy

GDP forecasts see further downward revision in light of the situation in the Middel East. 1-4pc GDP growth bounds remain, with upside waning. Oil prices remain volatile.

Economic indicators: Y-o-Y quarterly GDP



Crude oil and natural gas price history/forecast



- The US/Israel-Iran conflict and the accompanying surge in energy prices prompted Oxford Economics (OE) to lower world GDP growth forecast to 2.4pc, expecting a more prolonged disruption to shipping activity through the Strait of Hormuz. The ceasefire seems fragile, but even if maintained, it will take time for energy production and shipping to return to normal levels.
- OE latest assumption is The Strait remains effectively closed until end-April. Traffic levels then rise to around 50pc in May and June, before gradually recovering to normal over the following 6 months.
- Global crude price forecasts are up 40pc for Q2 and 33pc for Q3, before hoping to see numbers around $65-70/bl levels by year's end.

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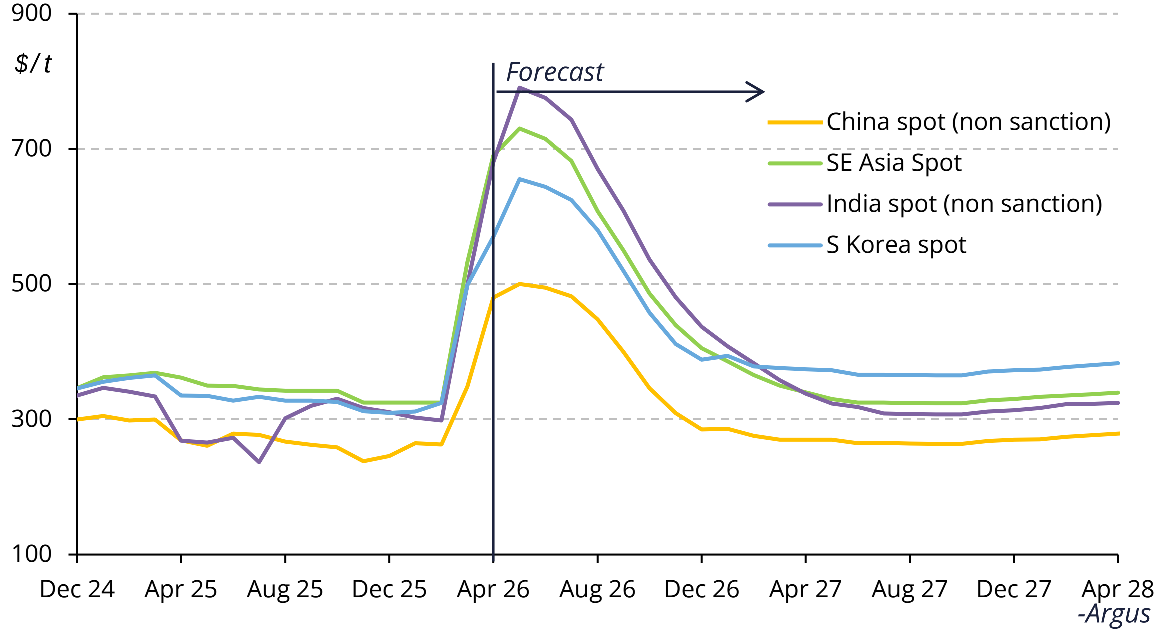
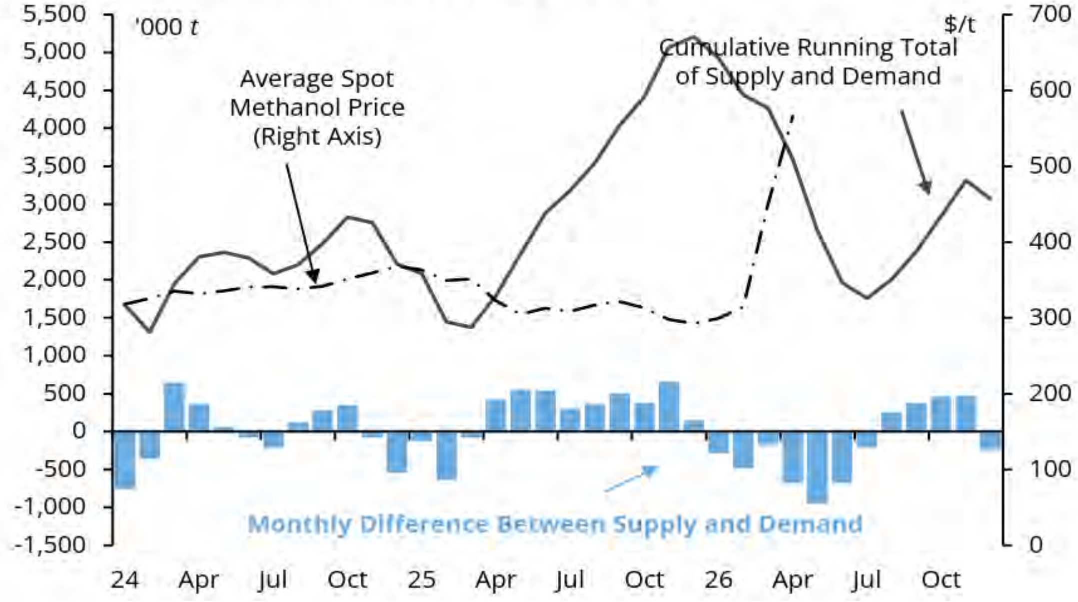
Grey methanol: The progress of the strait will determine industry fundamentals and forward direction

Asia, India and southeast Asia, are most impacted by the current ME conflict. All markets still jolted by the ongoing ME conflict. Price and supply driven demand destruction is occurring.

Asia methanol price history/forecast



Supply/demand versus spot pricing



- Industry fundamentals revolve around the ME situation and forward direction. Regardless, the current pull-on global inventories is non-recoverable likely until Q4 and, along with price, will drive demand destruction.
- China's record high coastal inventories are fast falling as increasing MTO production until late May and re-exporting of methanol in storage ramps up.
- Increased China domestic coal-based methanol production driven by fly-up margins will compensate in part some losses but will be hard to restore these lost inventory levels.

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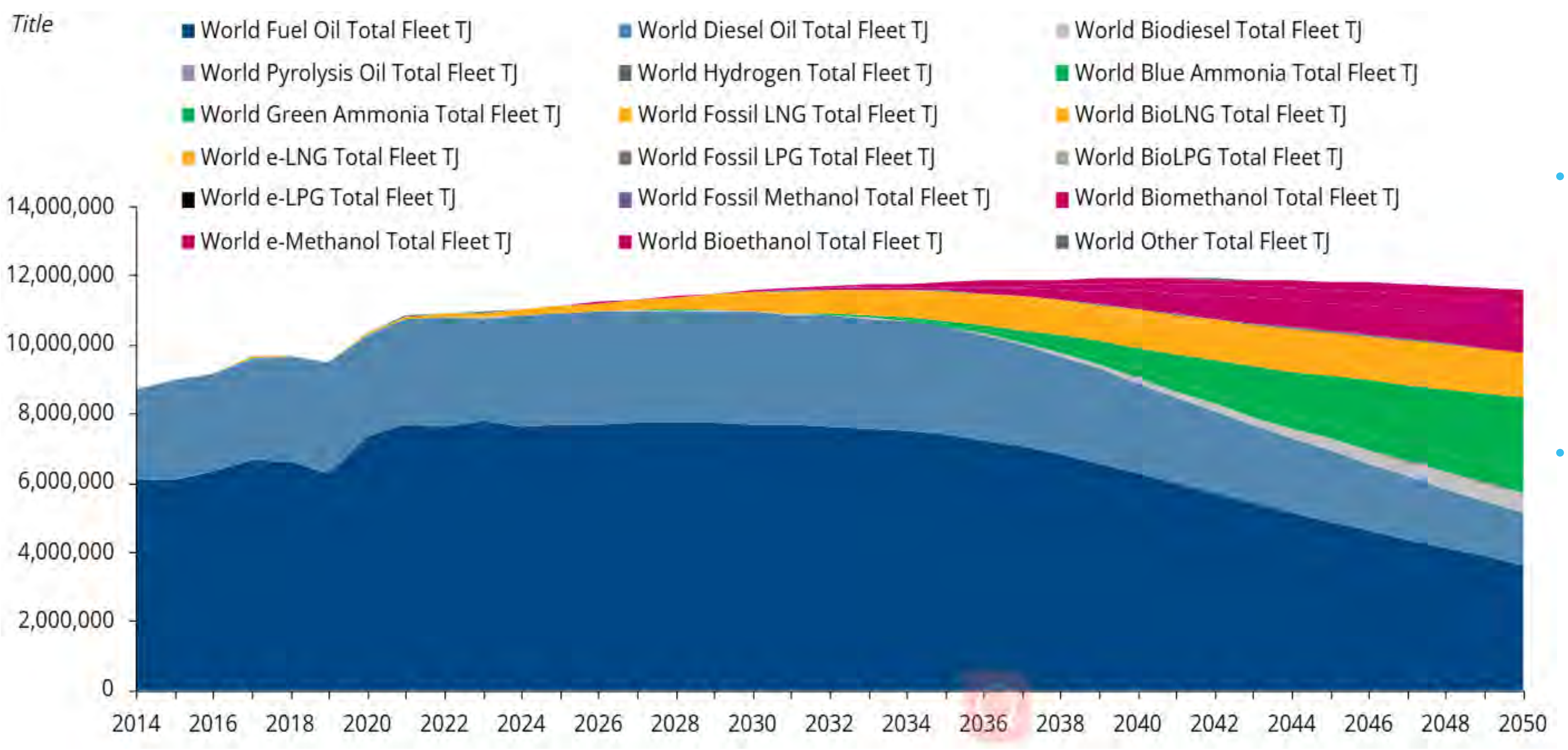
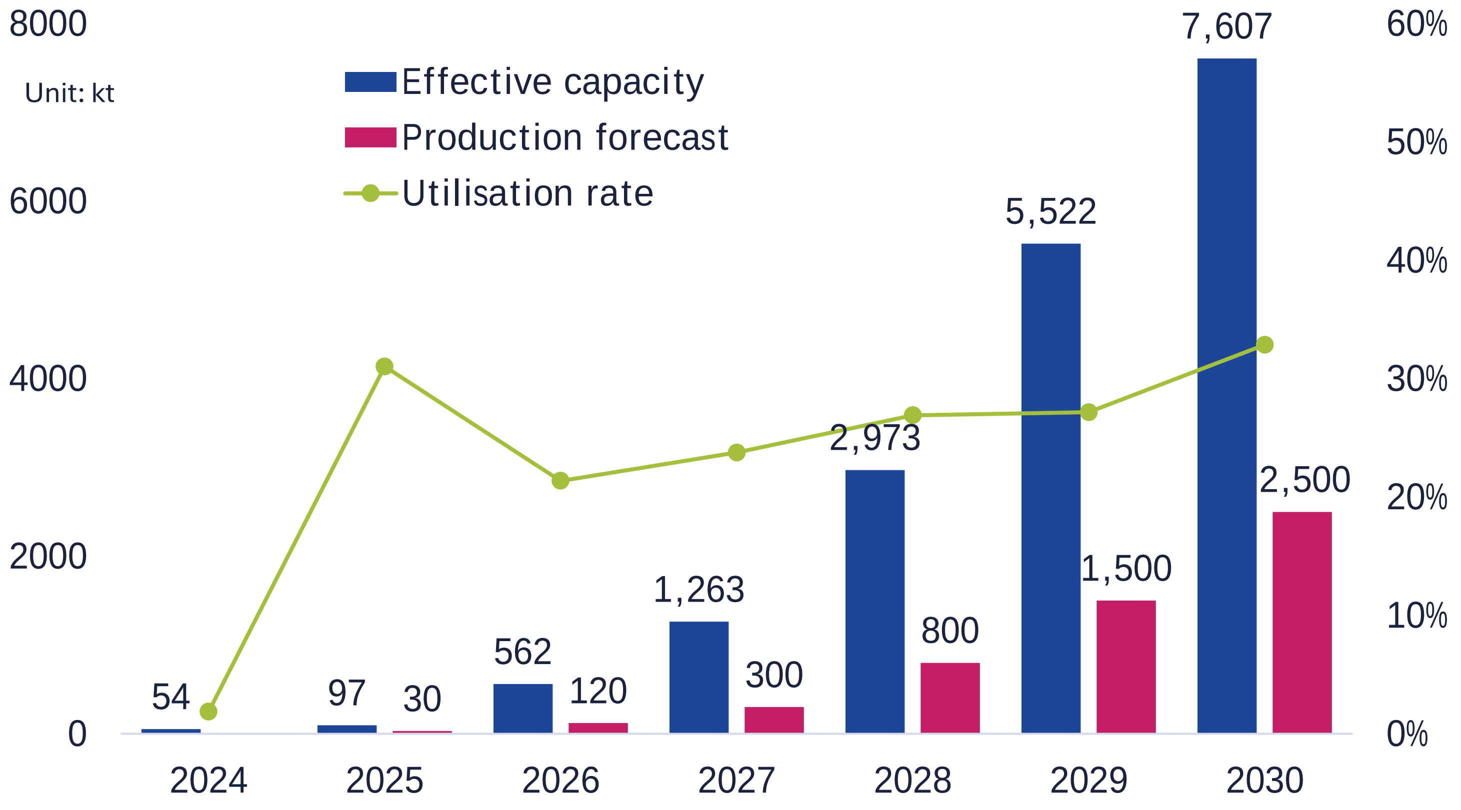
Green methanol: Industrial scale-up hinges on clearer net-zero frameworks



- **Demand remains voluntary:** Current policies are not enough to incentivize scaled demand.
- **Policy clarity is critical:** Stronger and clearer global decarbonisation frameworks are th key to encourage investment and offtake, growth.
- **Easy scale-up fundamentals:** 400+ methanol vessels and relatively mature storage and bunkering infrastructure position methanol as an easier scalable low-carbon fuel.

Green methanol availability: China leads bio- and e-methanol investment despite policy and return risks

China Biomethanol Supply Scenario



- China is moving faster than other Asian regions in green methanol investment
  - Current biomethanol capacity: ~ 390kta
  - Capacity pipeline:
    - ~ 2.5mn t under construction
    - ~ 1.7mn t at FID/FEED
    - 4.6mn t under feasibility studies
- While based on conservative bunker demand forecasts, China's green methanol output is expected to exceed 1 mn t/yr only toward the late 2020s
- This implies a low overall utilisation rate of around 30pc by 2030

Data source: Argus

Thank you!

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Supported Au Catalysts Prepared from Novel Au Precursors: Application to C4 Chemical Transformation

(Department of Chemistry, Graduate School of Science, Kyushu University)
〇 Yuxue Cao ・Akina Yoshizawa・Yuji Masaki・Tomohiro Fukae ・Haruno Murayama・Akihiro Nakayama・Tetsuo Honma・Eiji Yamamoto・ Takashi Sato・ Yousuke Suzuki・ Makoto Tokunaga

29 May

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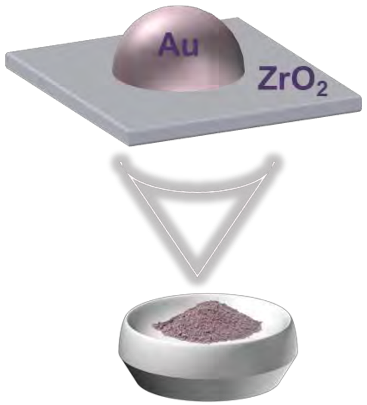
    Isomerization of allylic esters (3,4-DABE)
    Au precursors used in the IP-Calcination Method

2. Au precursors for supported Au NPs

    Synthesis
    Characterization

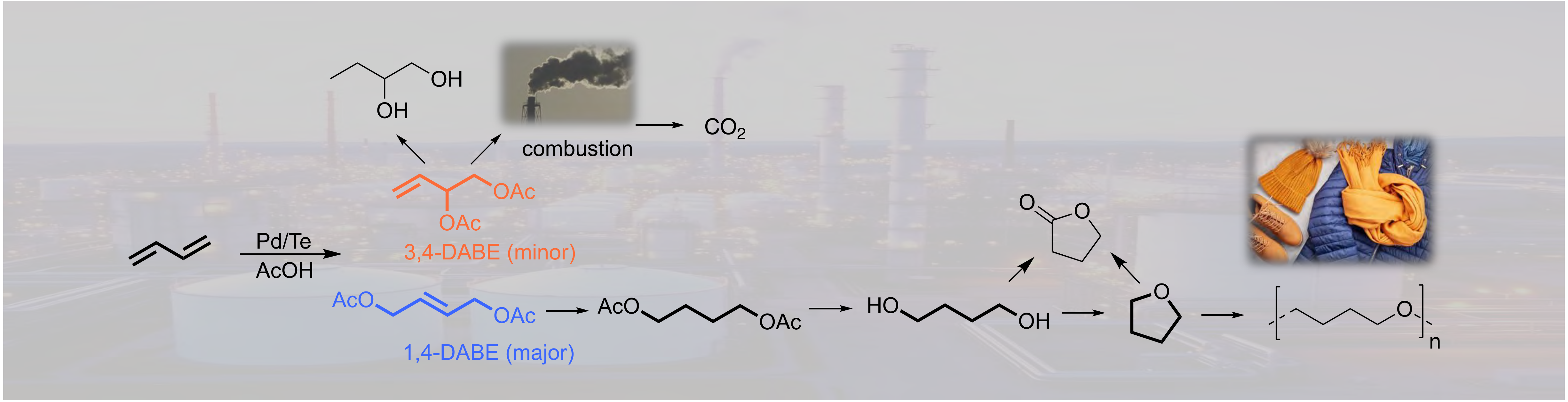
3. Catalytic activity test

    Isomerization of allyl esters

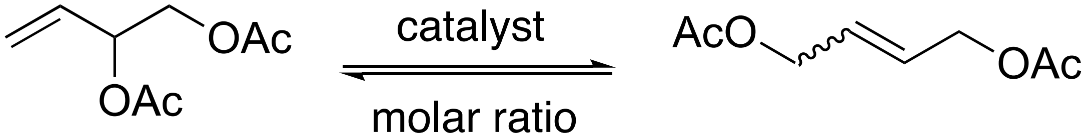


Introduction

Synthesis of C4 derivates (MCC method)



Isomerization of allylic esters (3,4-DABE)



3,4-DABE (1)

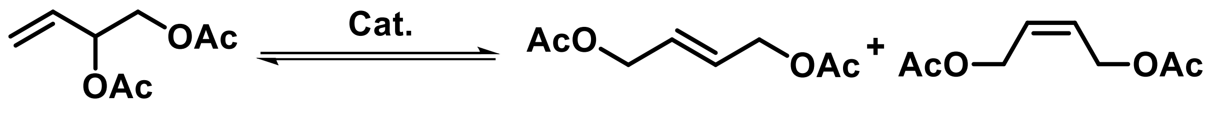
molar ratio at equilibrium
1 : **2** = 37:63

1,4-DABE (2)

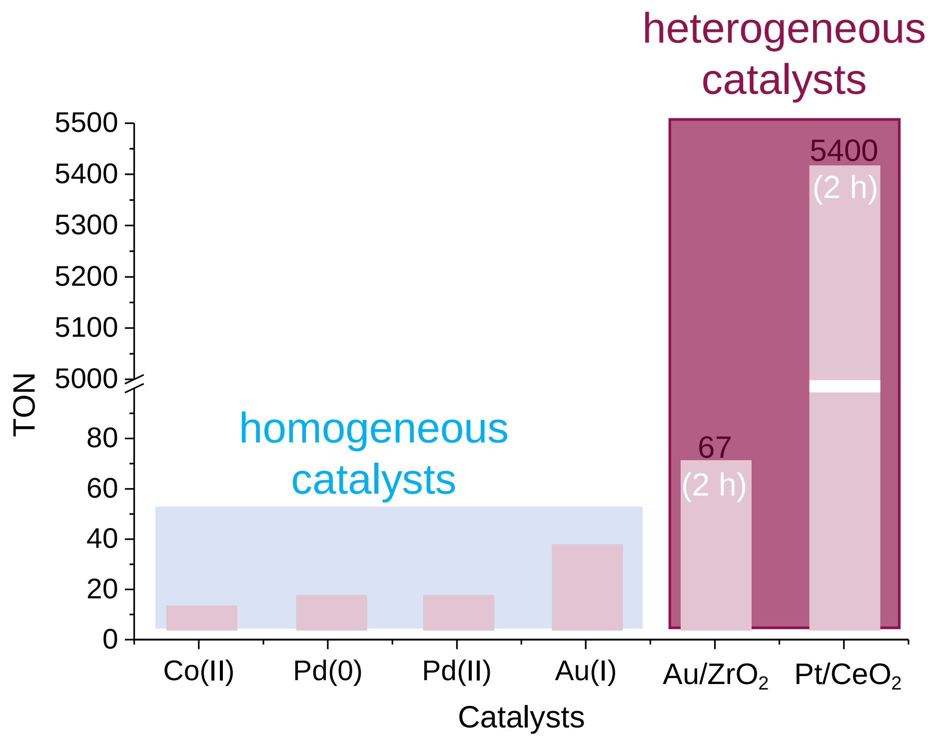
J. Muzart, et al., *Eur. J. Org. Chem.*, **2001**, *17*, 3301.

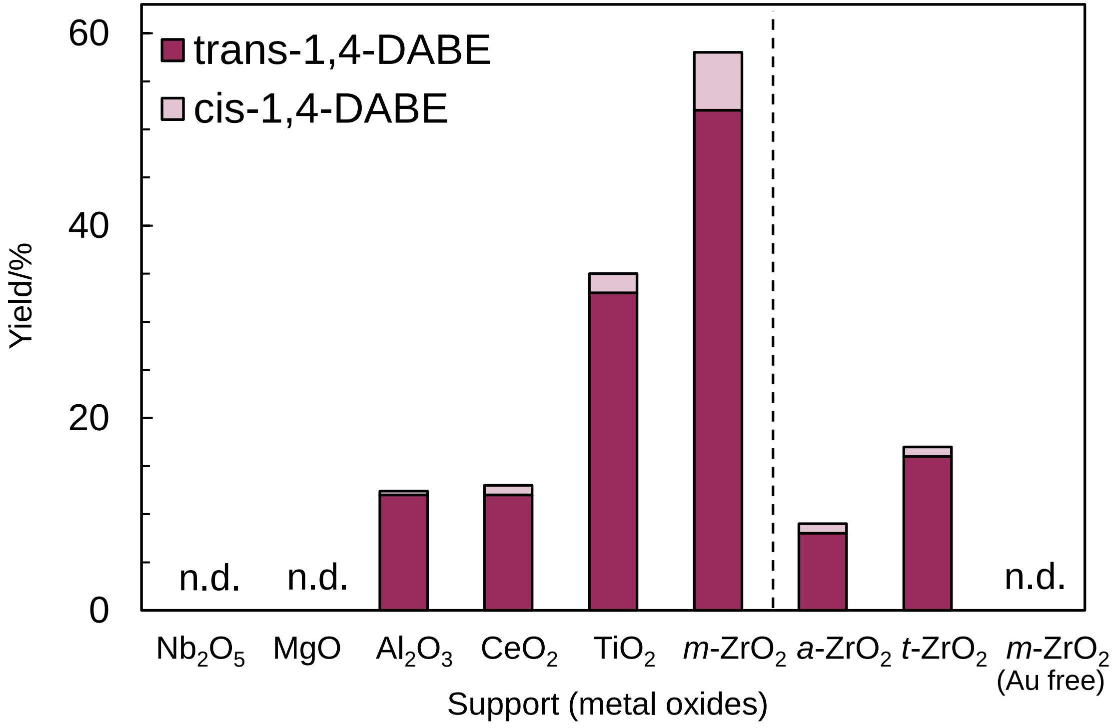
Introduction

Previous research



1 (1 mmol) **(*E*)-2** **(*Z*)-2**





Q.-A. Huang, et al., *Appl. Catal. B Environ.*, **2021**, *296*, 120333.
Q.-A. Huang, et al., *Appl. Catal. B Environ.*, **2025**, *373*, 125391.

Introduction

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Approach for preparing gold heterogeneous catalysts

DP Method

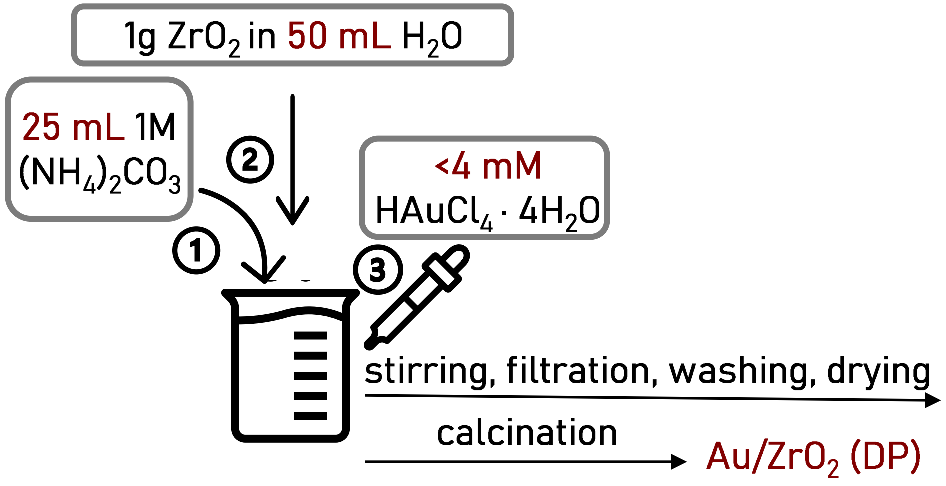
- Laboratory-scale
- Waste liquid generation
- Explosion risk

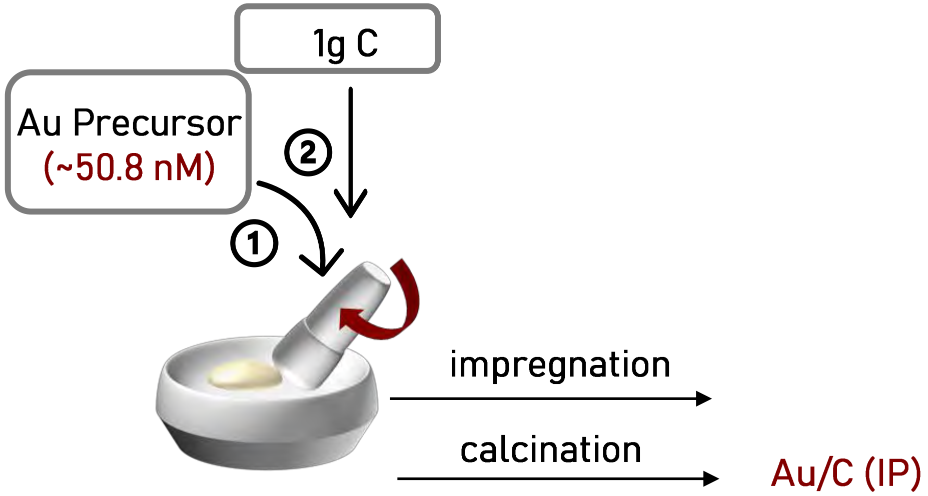
–fulminating gold

IP-Calcination Method

- Scalable process
- No waste liquid
- High industrial value

As an example, Au/support was prepared



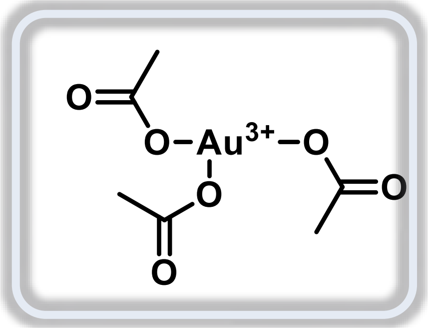


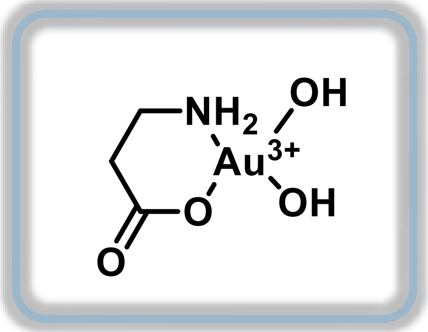
Q.-A. Huang, et al., *Appl. Catal. B Environ.*, **2025**, *373*, 125391

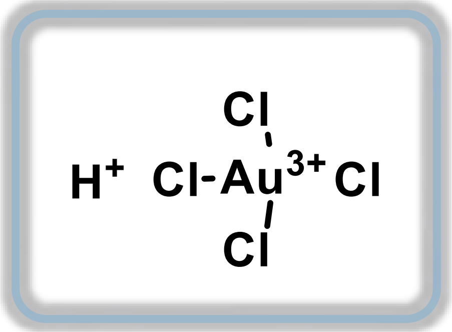
Q.-A. Huang, M. Takaki, H. Murayama, A. Yoshizawa, E. Yamamoto, L. X. Dien, M. Tokunaga, *Mol. Catal*. **2023**, 549, 113460.

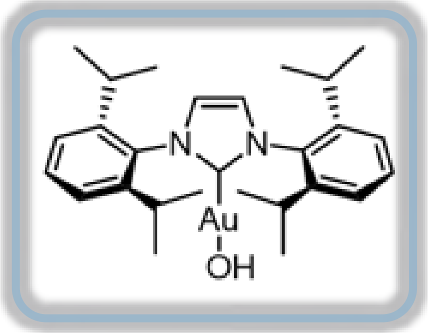
Introduction

Au precursors used in the IP-Calcination Method



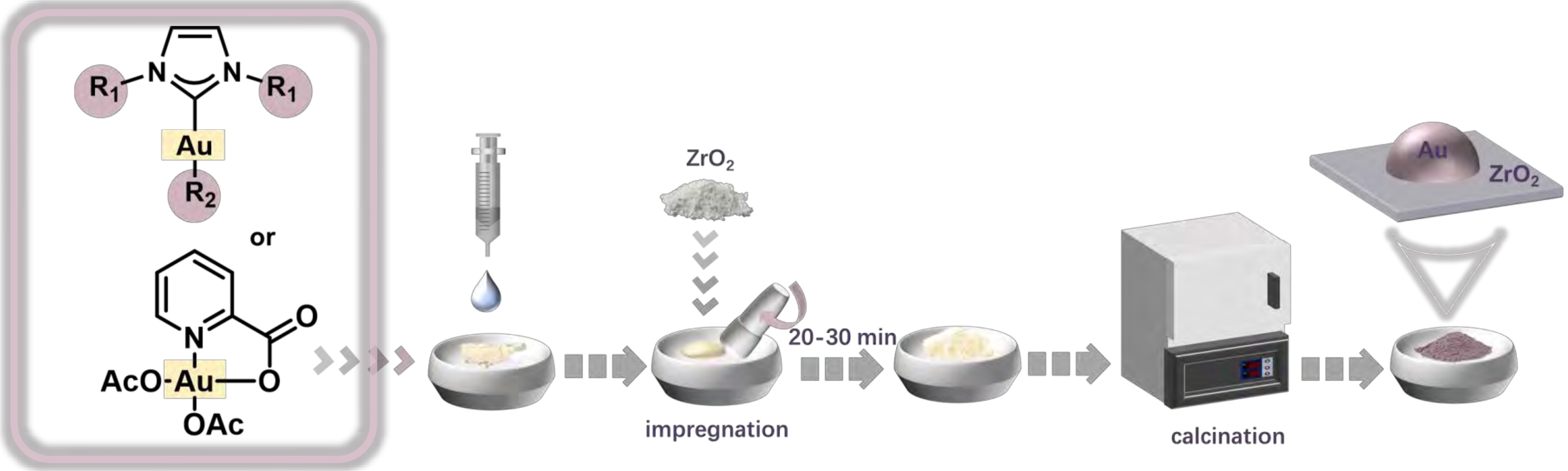






- Low solubility in water
- Unstable precursor
- Low catalytic activity

This work



- AuNPs (3.9 nm)
- High solubility in water
- Organic species are fully removed at 300 ° C
- Good catalytic activity

Au precursors for supported Au NPs

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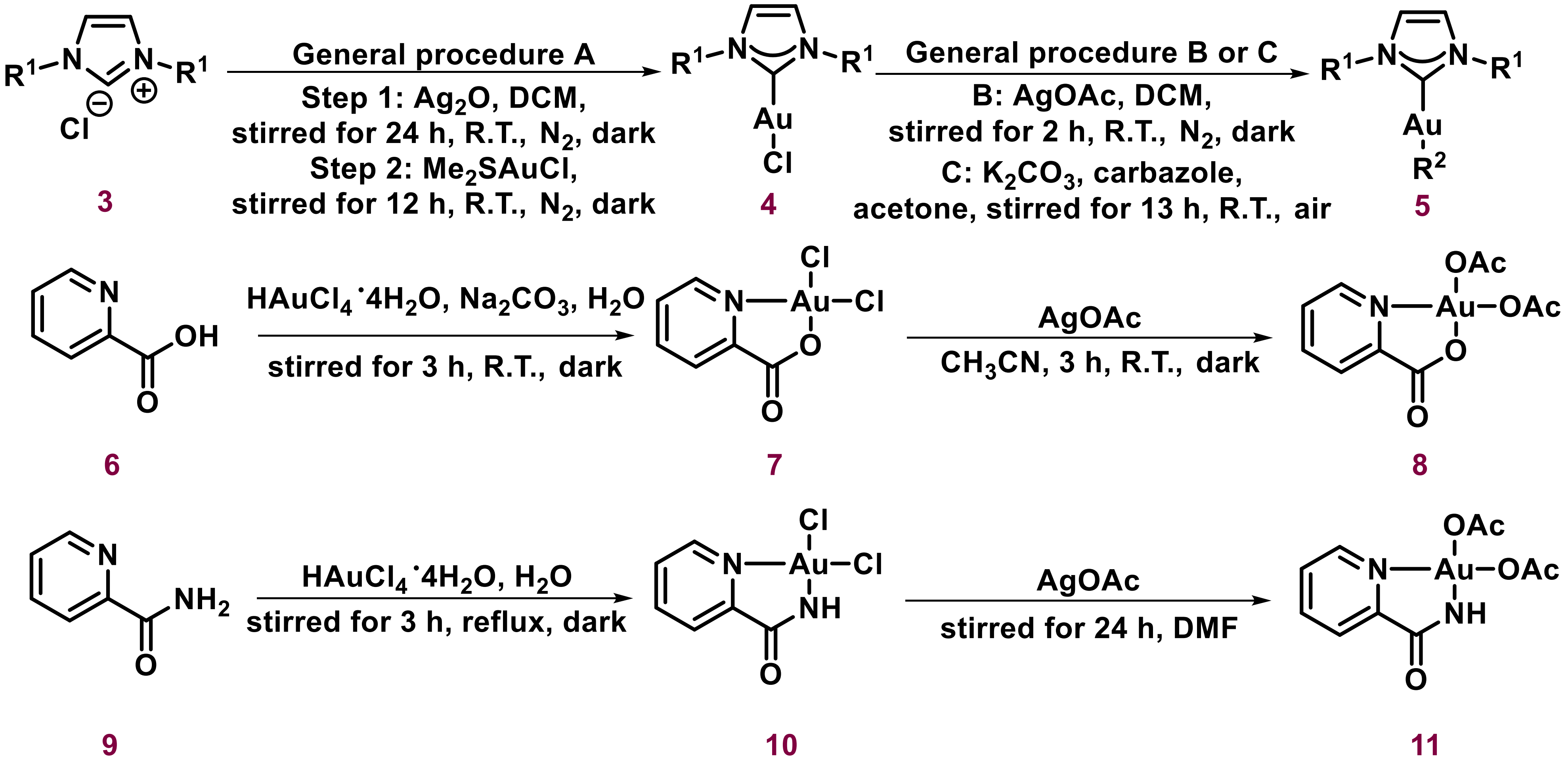
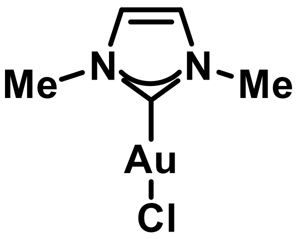
Synthesis Au precursors



Au precursors for supported Au NPs

Preparation of Au precursors for supported Au NPs



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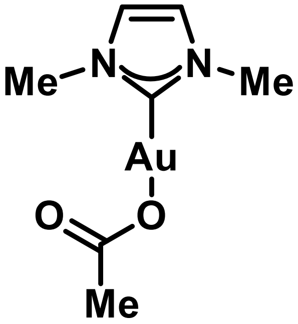

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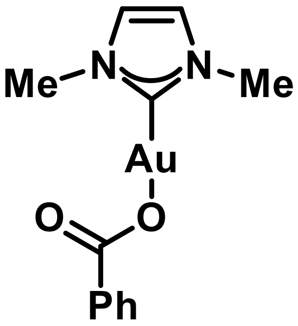

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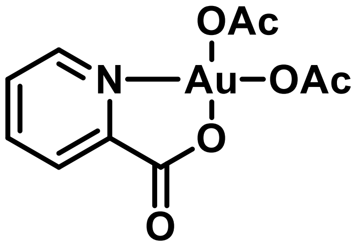

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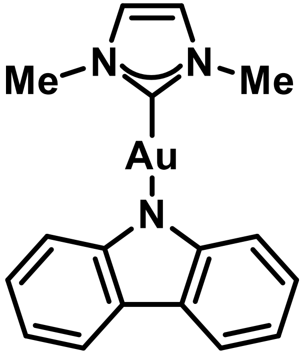

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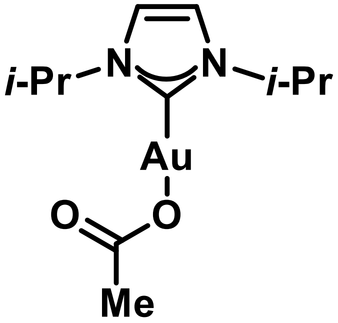

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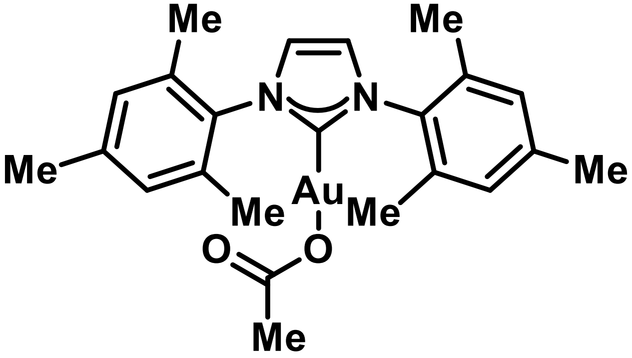

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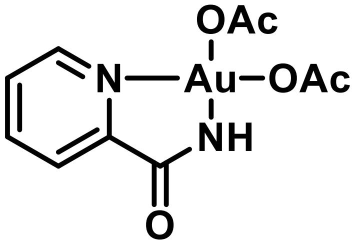

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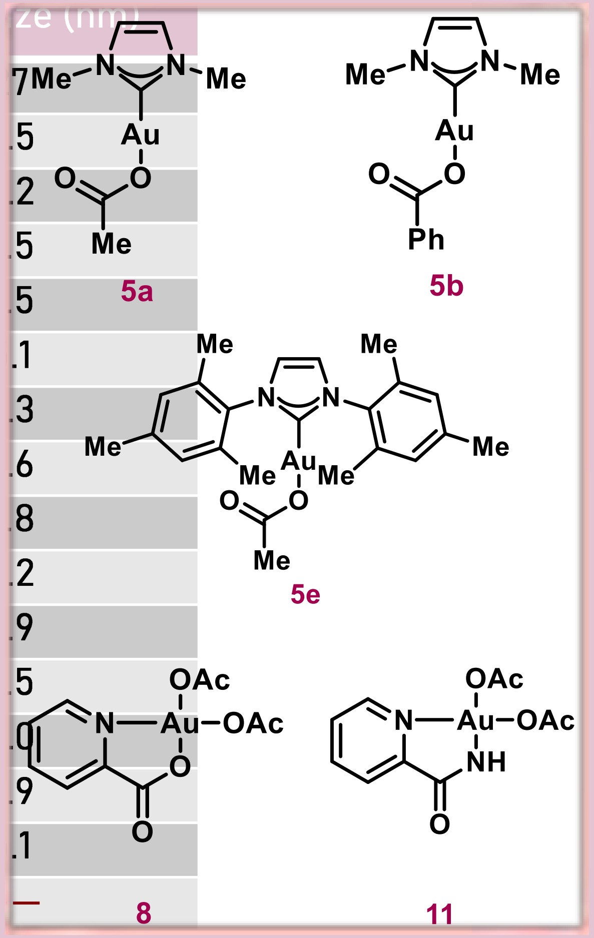
Characterization

AuNP sizes on supports

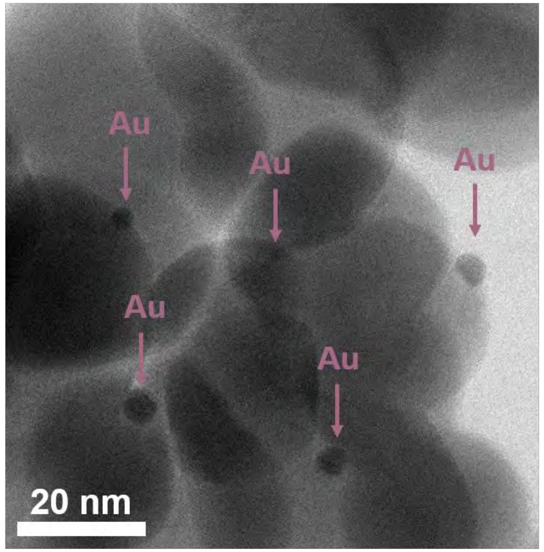
Au precursors + Support —(Impregnation; Solvent, R.T., 30 min)→ Au precursors/Support —(Calcination; Step 1: R.T. to 300 °C, 1 h, air; Step 2: 300 °C, 30 min, air)→ 1 wt% Au/Support

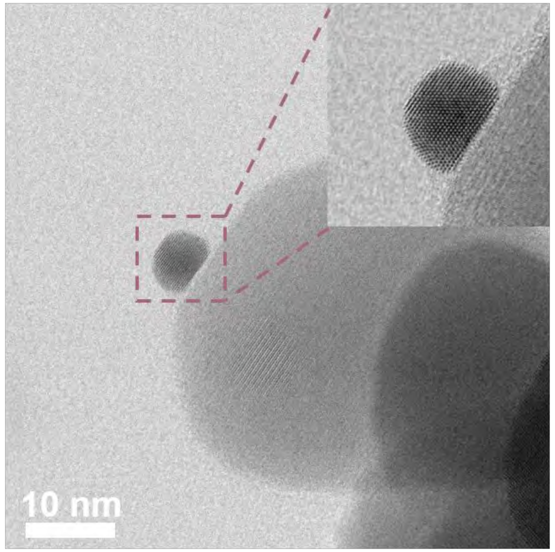
Entry	Precursor	Support	Solvent	AuNP size (nm)
1	4a	SiO_2	THF/H_2O	[illegible]7
2	5a	SiO_2	THF/H_2O	[illegible].5
3	5b	SiO_2	THF/H_2O	[illegible].2
4	5c	SiO_2	THF/H_2O	[illegible].5
5	5d	SiO_2	THF/H_2O	[illegible].5
6	5e	SiO_2	THF/H_2O	[illegible].1
7	8	SiO_2	CH_3CN	[illegible].3
8	11	SiO_2	DMF	[illegible].6
9	5a	ZrO_2	THF/H_2O	[illegible].8
10	5b	ZrO_2	THF/H_2O	[illegible].2
11	5c	ZrO_2	THF/H_2O	[illegible].9
12	5d	ZrO_2	THF/H_2O	[illegible].5
13	5e	ZrO_2	THF/H_2O	[illegible]
14	5a	ZrO_2	H_2O	[illegible].9
15	8	ZrO_2	CH_3CN	[illegible].1
16	11	ZrO_2	DMF	–

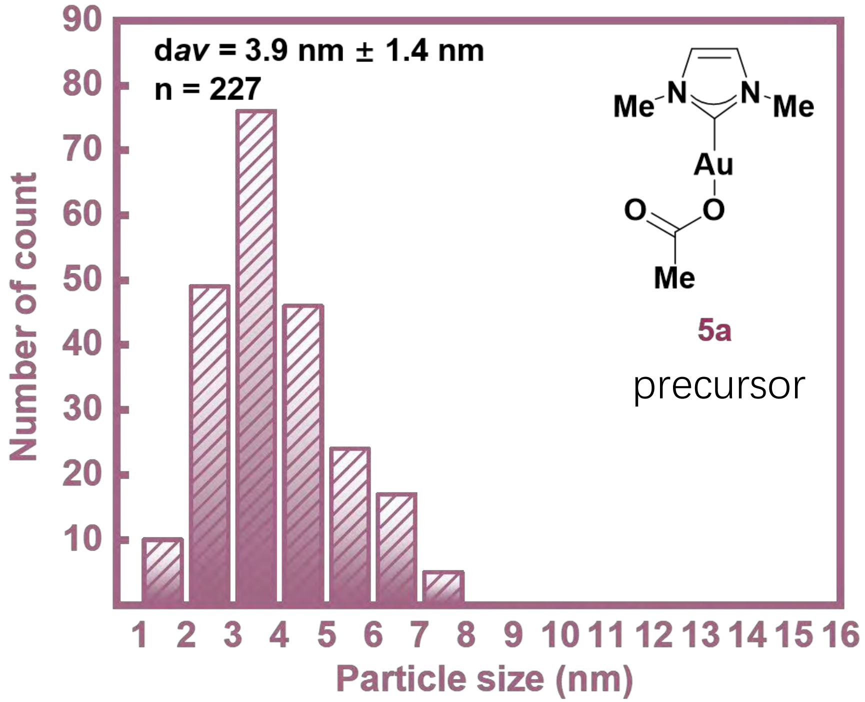


Characterization

BF-STEM images

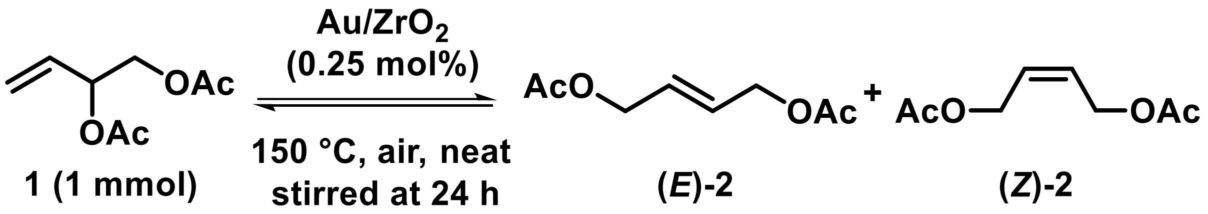




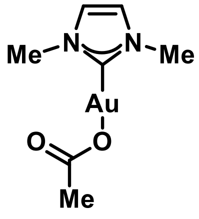


Catalytic activity test-isomerization of allyl esters

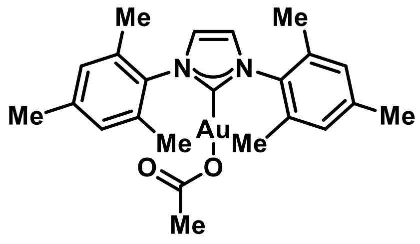
Catalytic activity in isomerization of allyl esters



Entry	Precursor	Conv. (%) [a]	Yield (%) [a]
1	5a	57	56
2	5b	55	47
3	5c	55	47
4	5d	53	46
5	5e	5	1
6	8	50	40
7	11	12	6



5a



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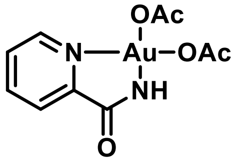

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[a] Determined by GC analysis using tridecane as an internal standard.

Catalytic activity test-isomerization of allyl esters

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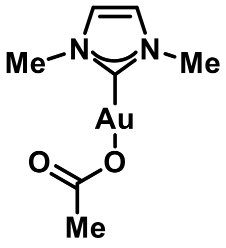
Catalytic activity in isomerization of allyl esters

High catalytic activity



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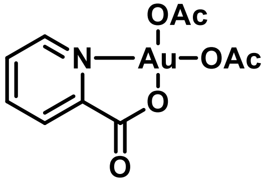

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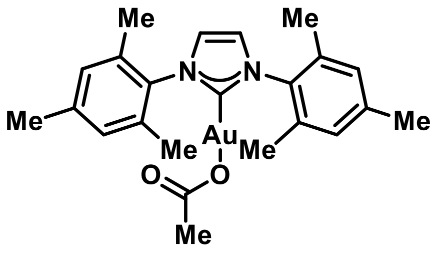
Low catalytic activity



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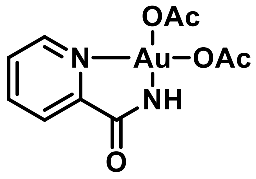

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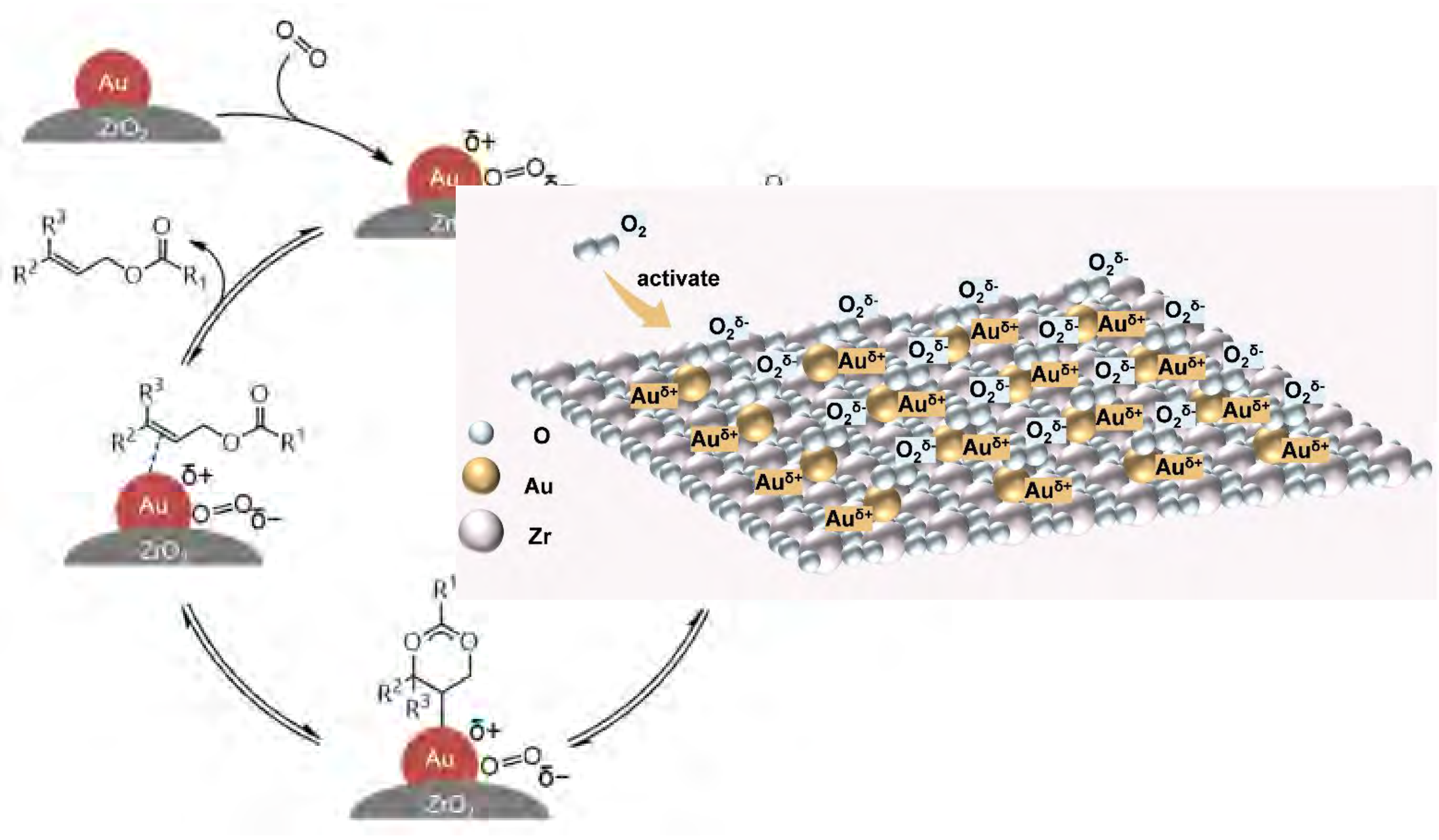
Catalytic activity test-isomerization of allyl esters

Reaction Mechanism



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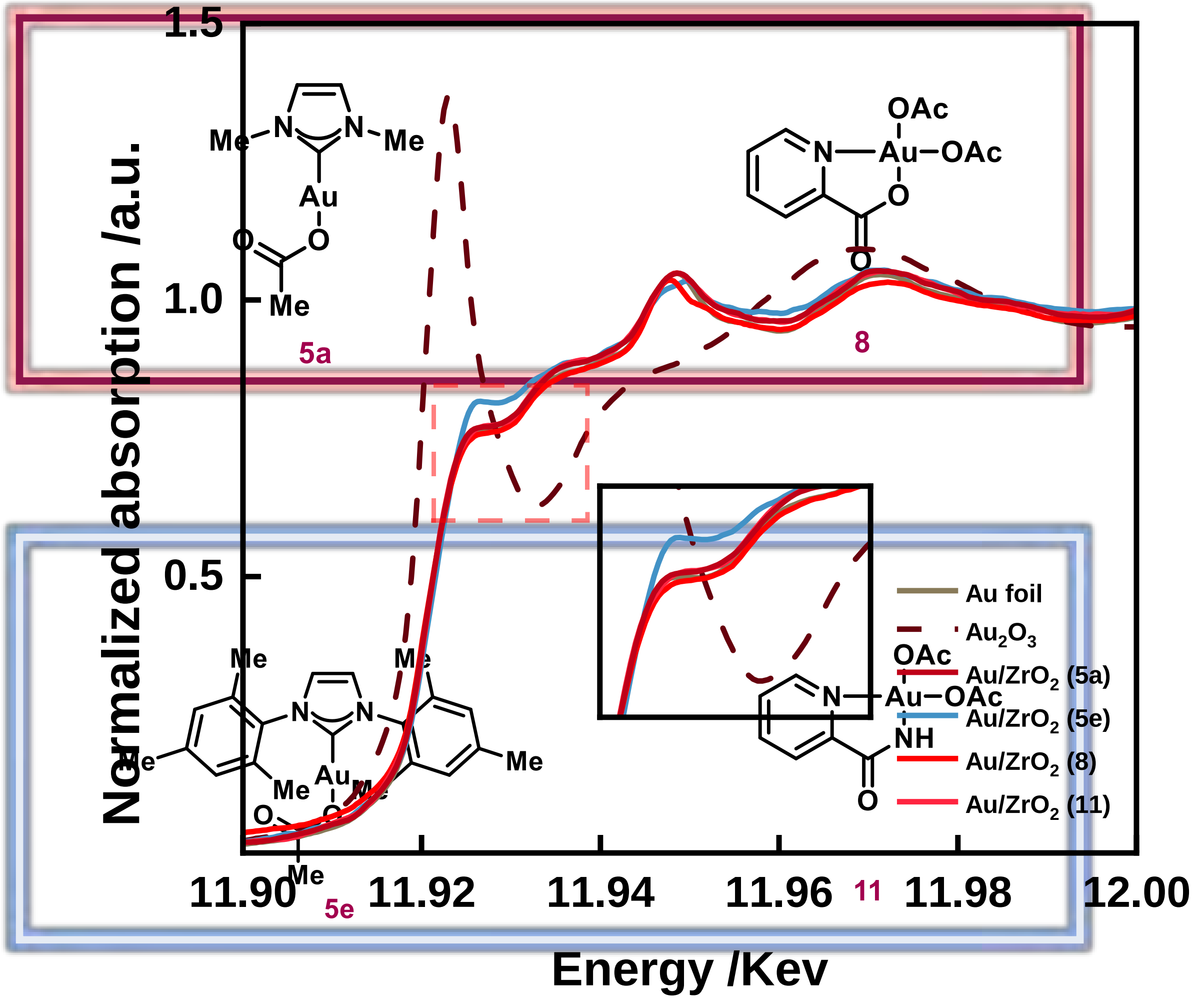
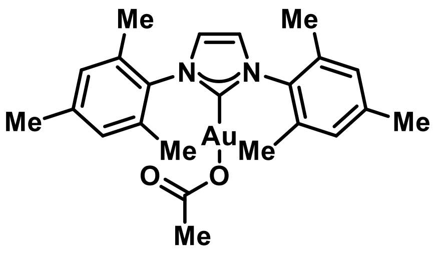
Characterization

Au LIII-edge XANES spectra of 3.0 wt% Au/ZrO_2



Characterization

In situ Au LIII-edge XANES spectra of 3.0 wt% Au/ZrO_2 (5e)



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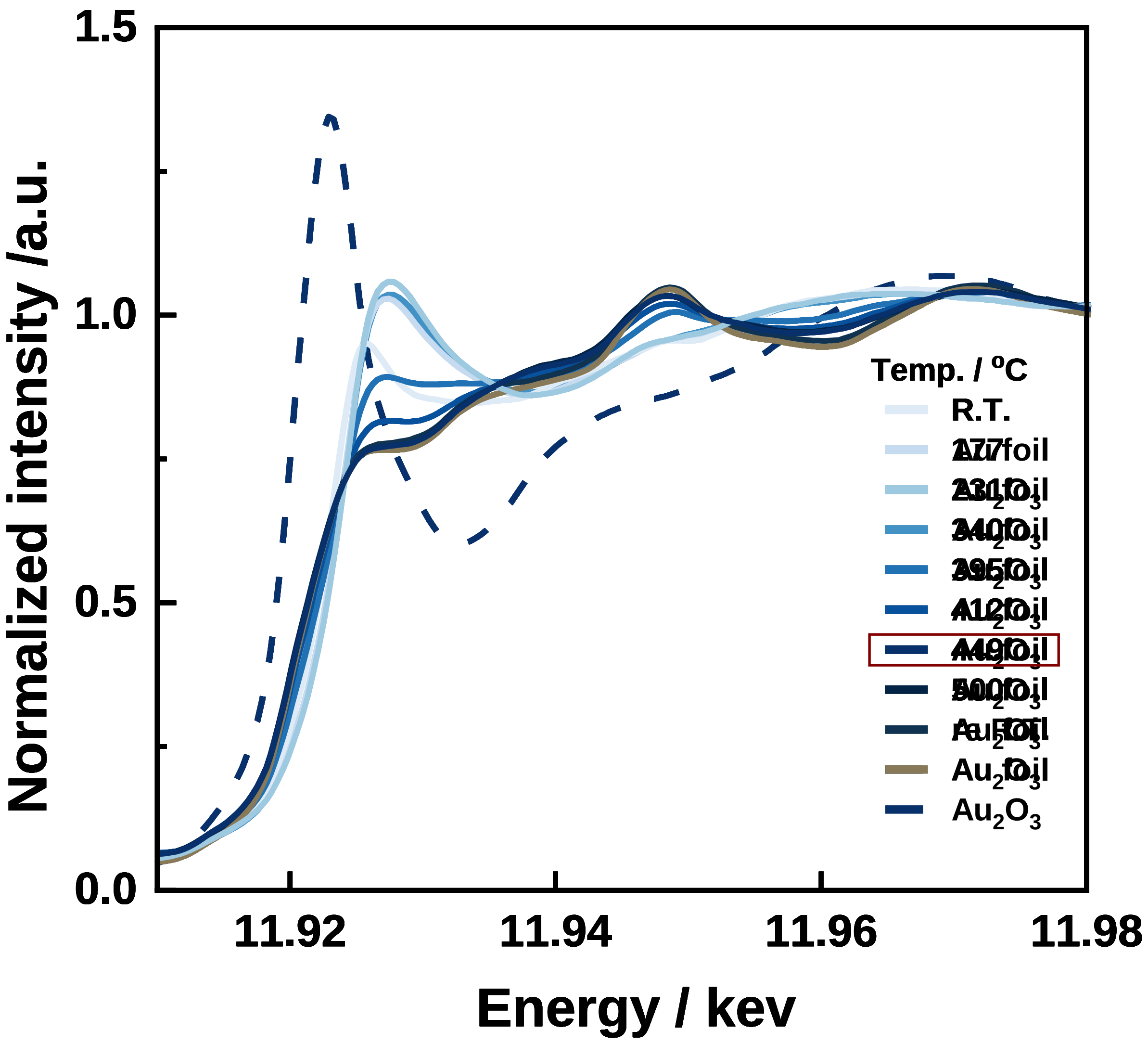
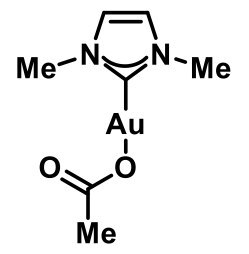
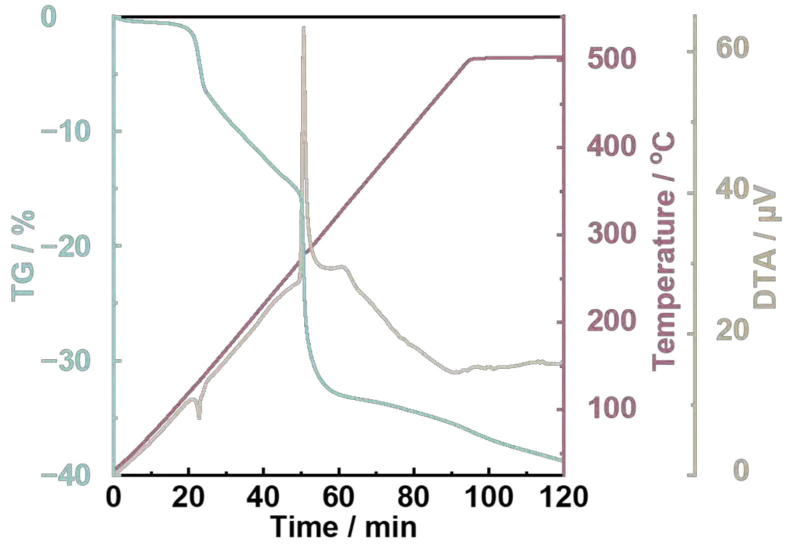
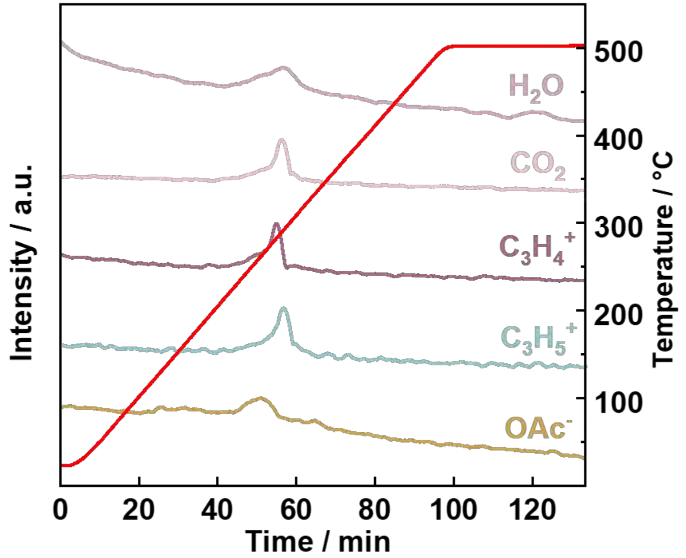


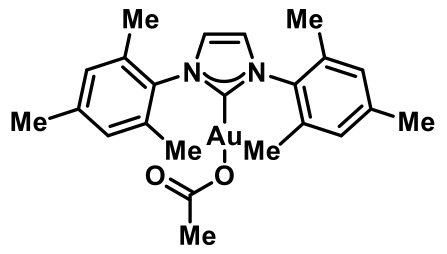
Characterization



5a







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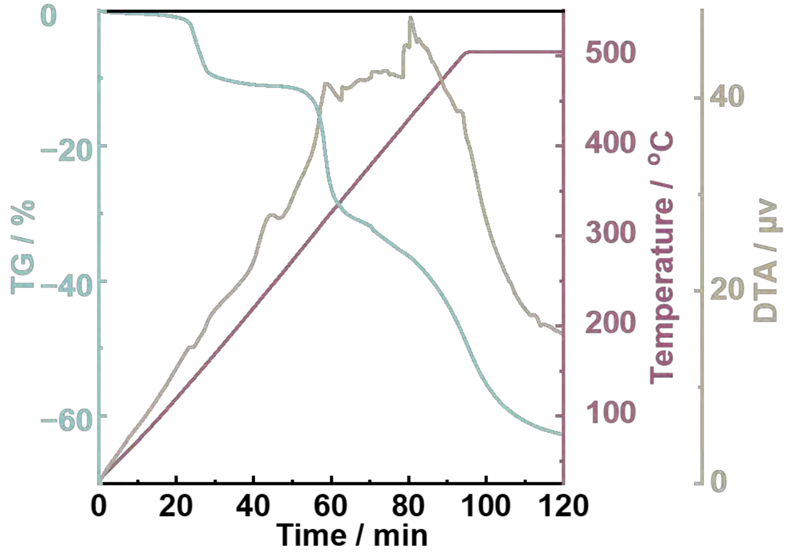

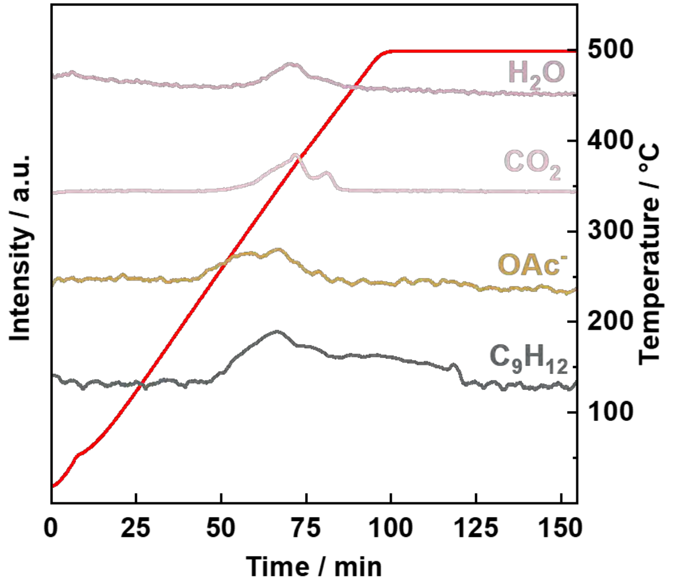

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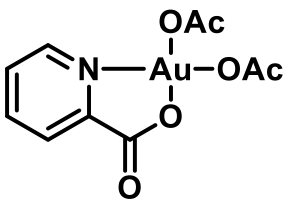
Characterization



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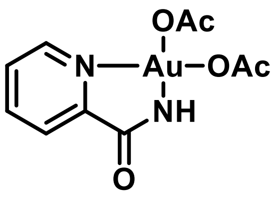

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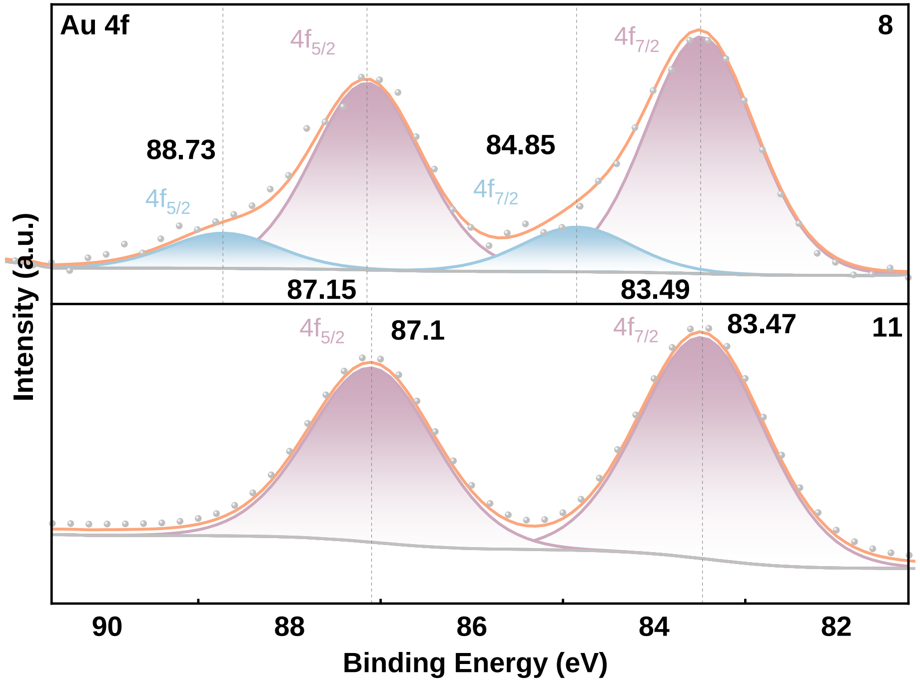
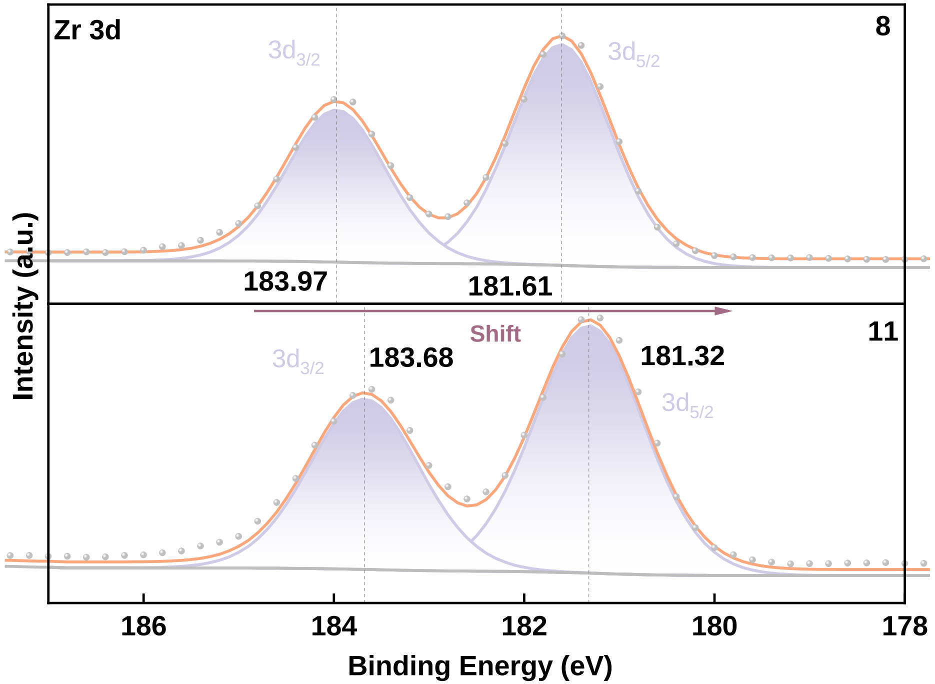
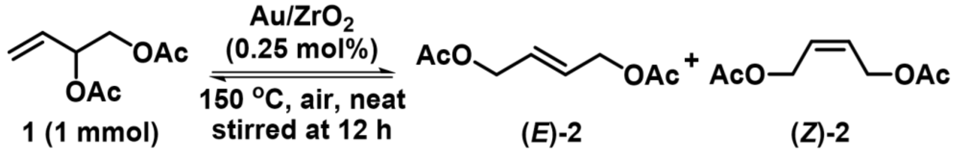


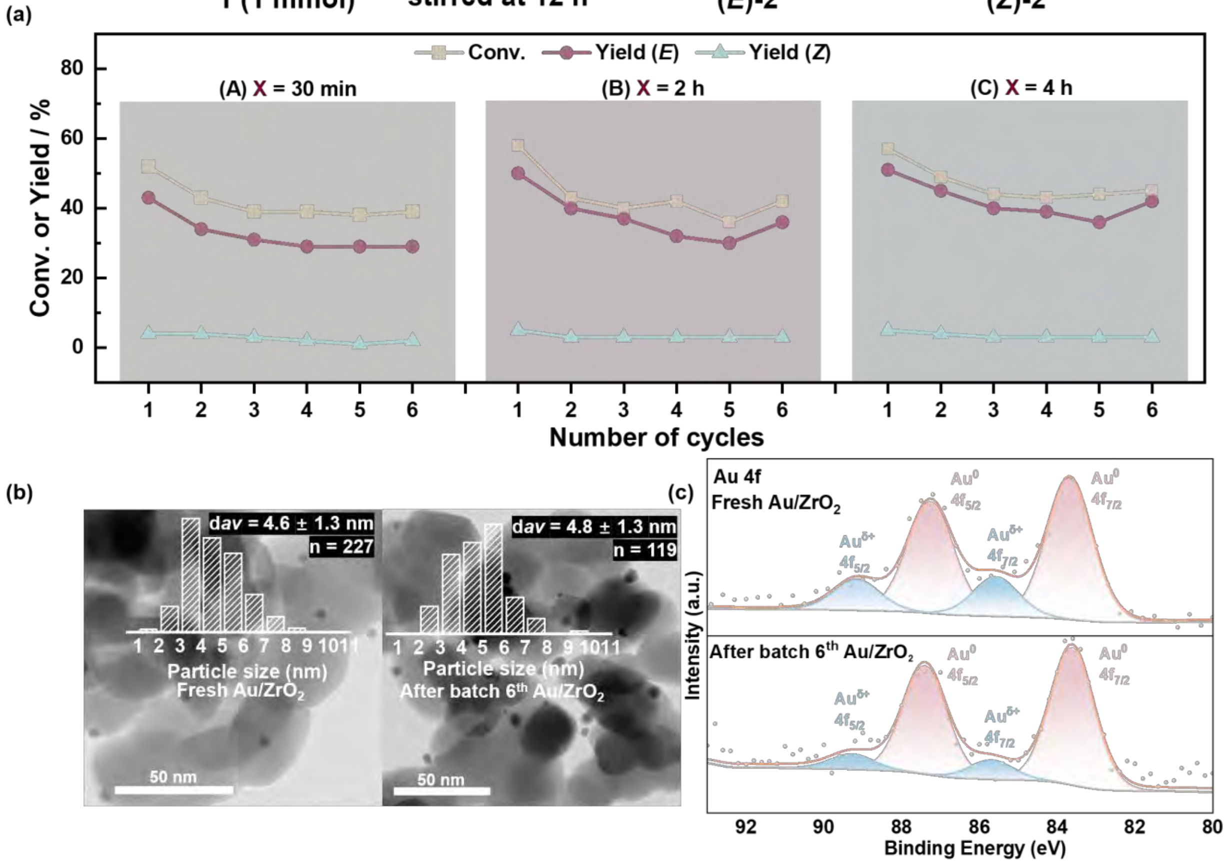


Reusability

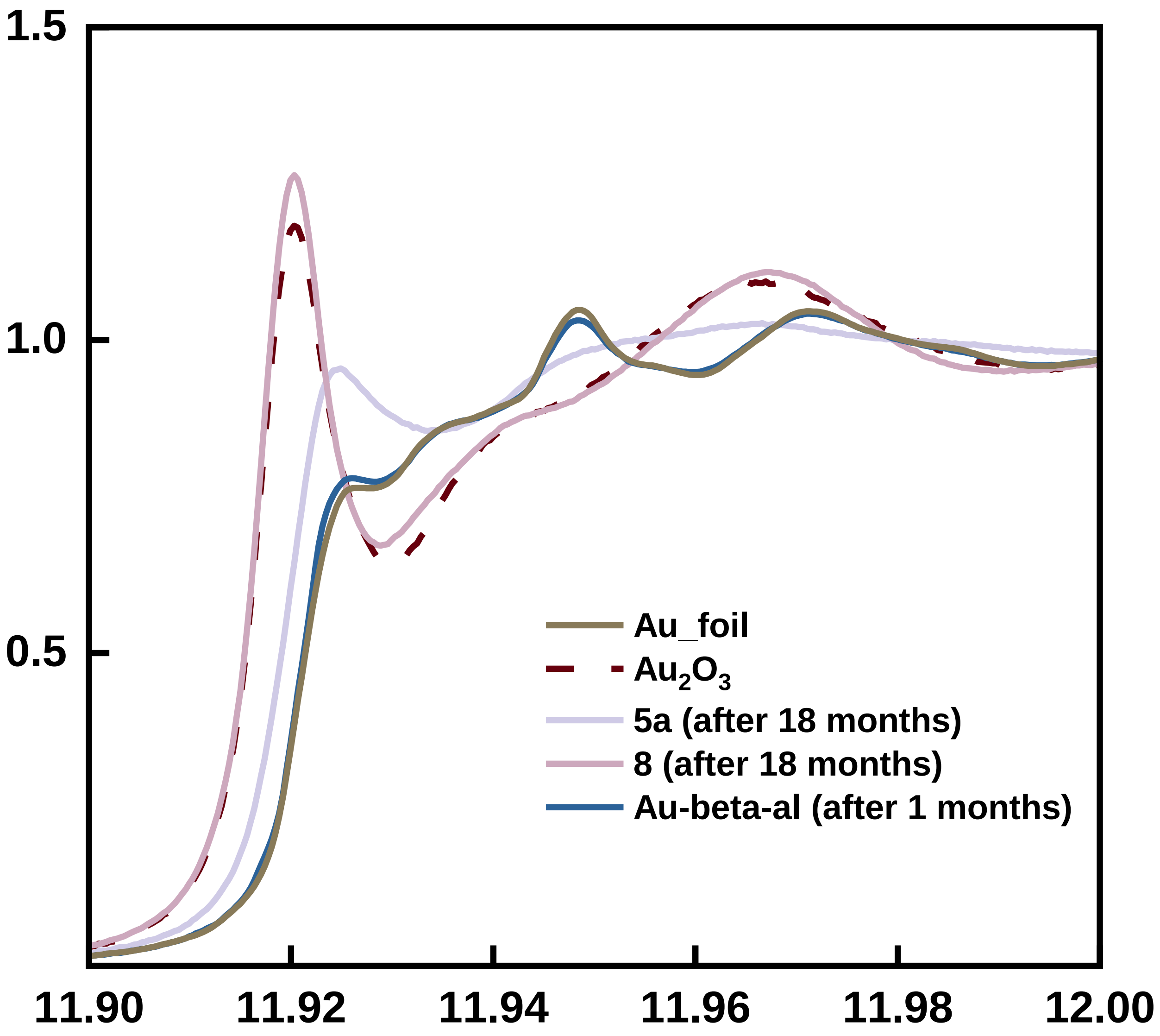
Preparation of supported AuNP catalysts used in reusability tests

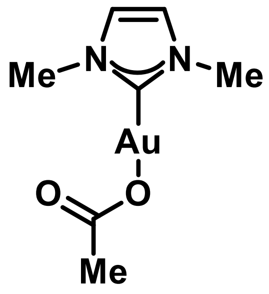
5a + ZrO_2 —(Impregnation; H_2O, R.T., 30 min)→ **5a**/ZrO_2 —(Calcination; Step 1: R.T. to 300 °C, 1 h, air; Step 2: 300 °C, X, air)→ 1 wt% Au/ZrO_2





Stability





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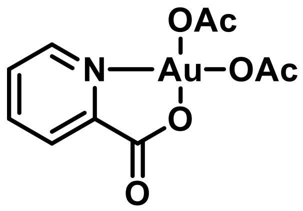

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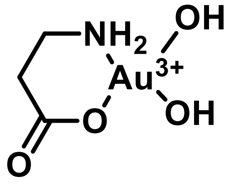
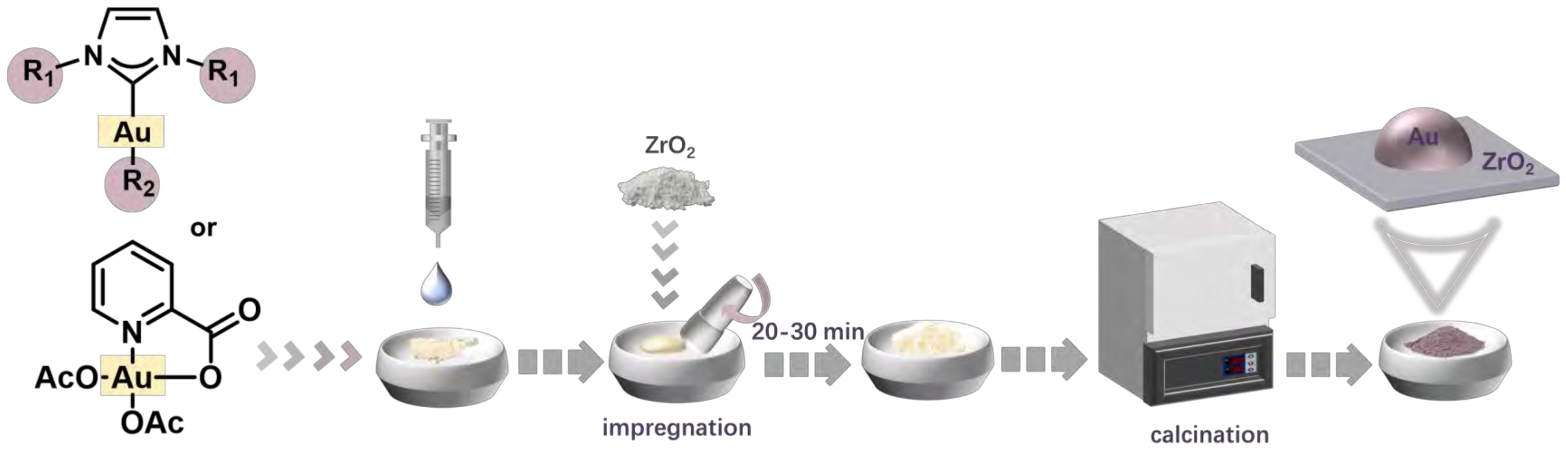
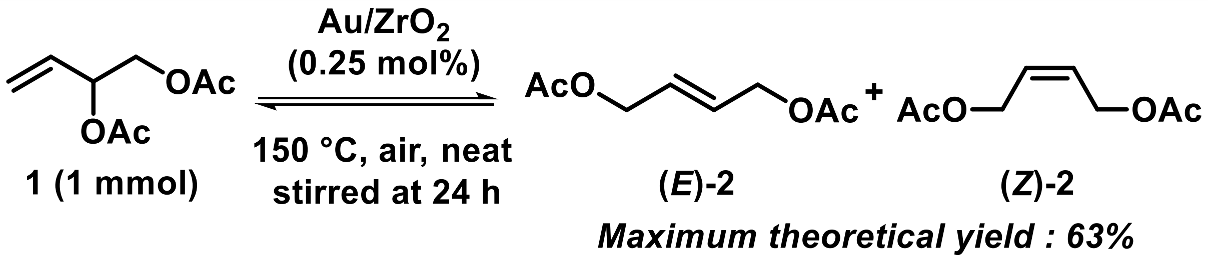


Au-beta-ala

Conclusion

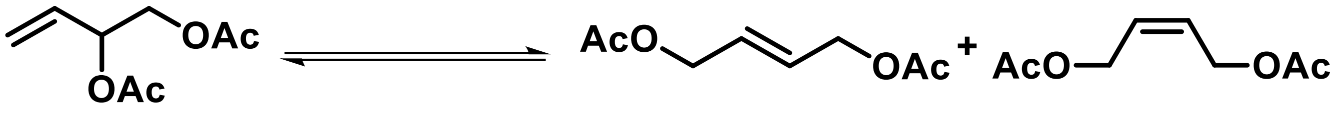




Conv. =57%
Yield =56%

Support information

Maximum Theoretical Yield from Equilibrium Ratio



1 (*E*)-2 (*Z*)-2

Maximum theoretical yield : 63%

Experimental equilibrium ratio:

2 / 1 ≈ 1.7

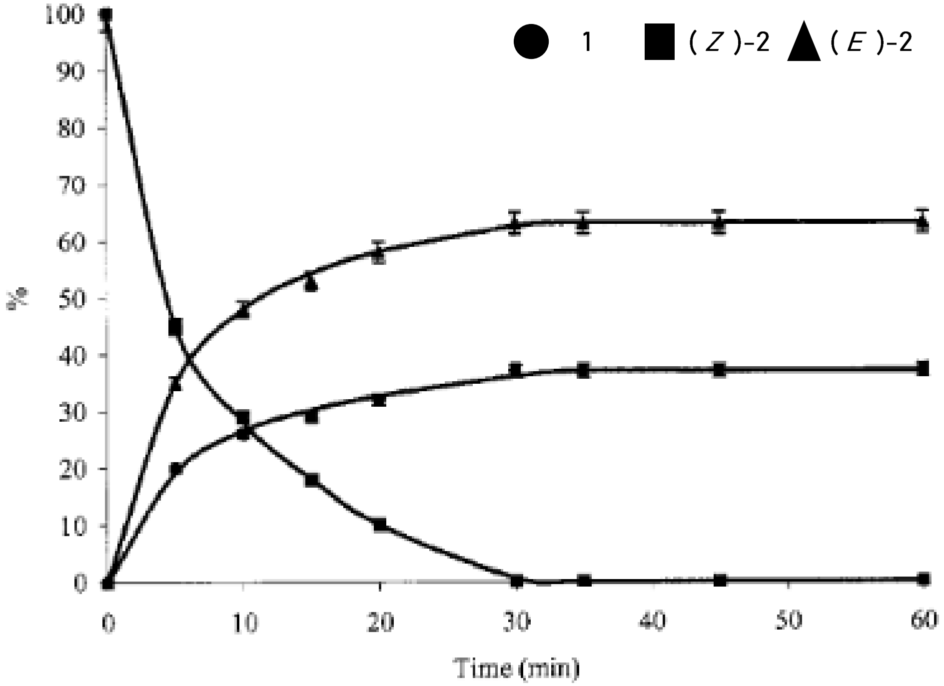
Let 1 = x

Then 2 = 1.7x

Total = 1.7x + x = 2.7x

Fraction of product 2 = 1.7 / 2.7 ≈ 0.63 (63%)

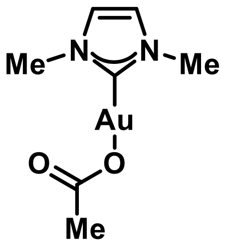
Fraction of product 1 = 1 / 2.7 ≈ 0.37 (37%)



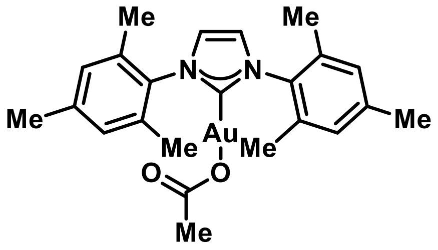
Eur. J. Org. Chem. 2001, 330123305

Support information

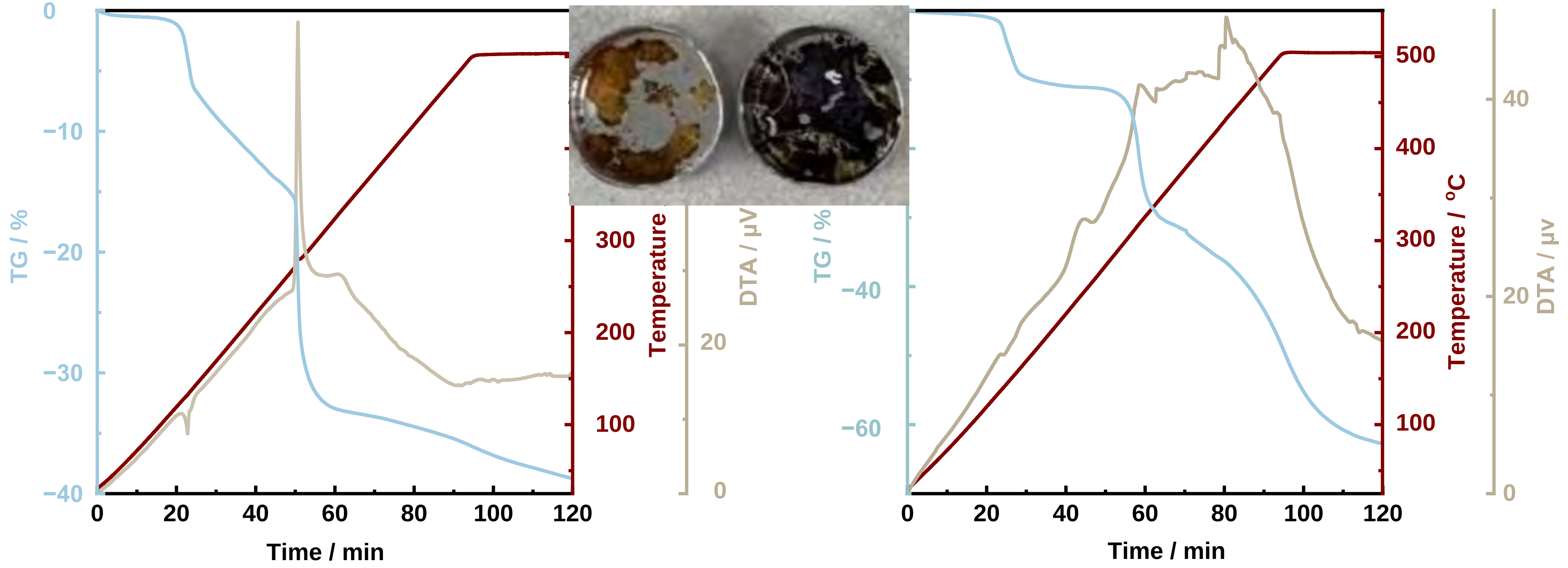
TG–DTA profiles of 5a and 5e



5a

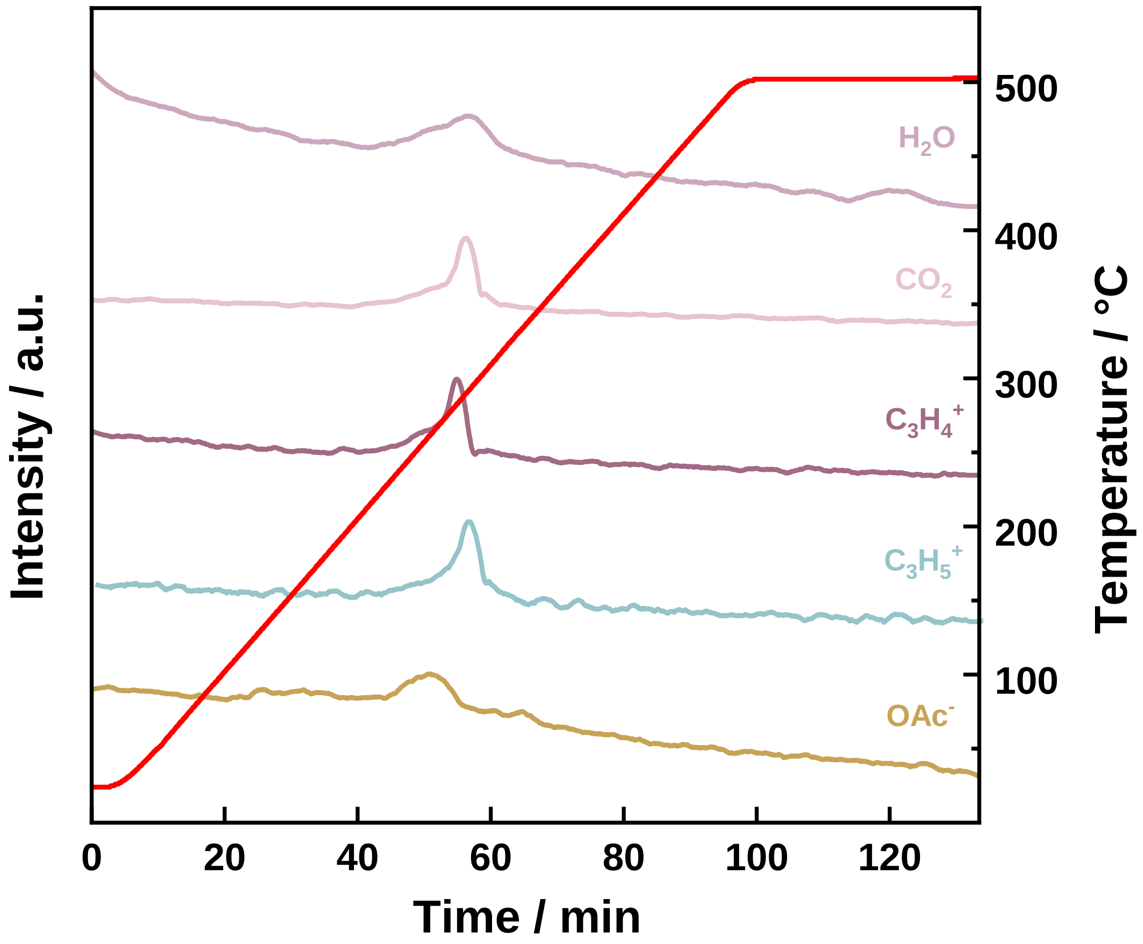


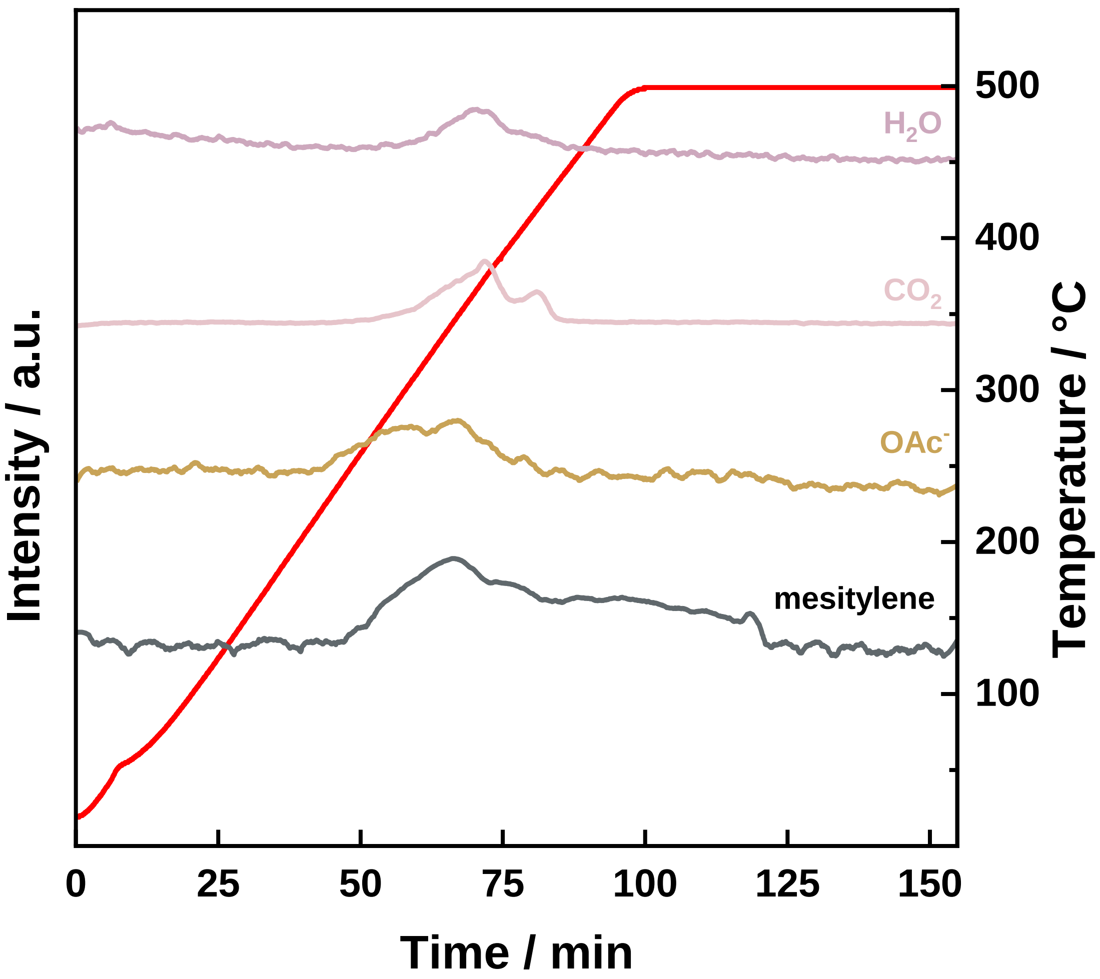
5e



Support information

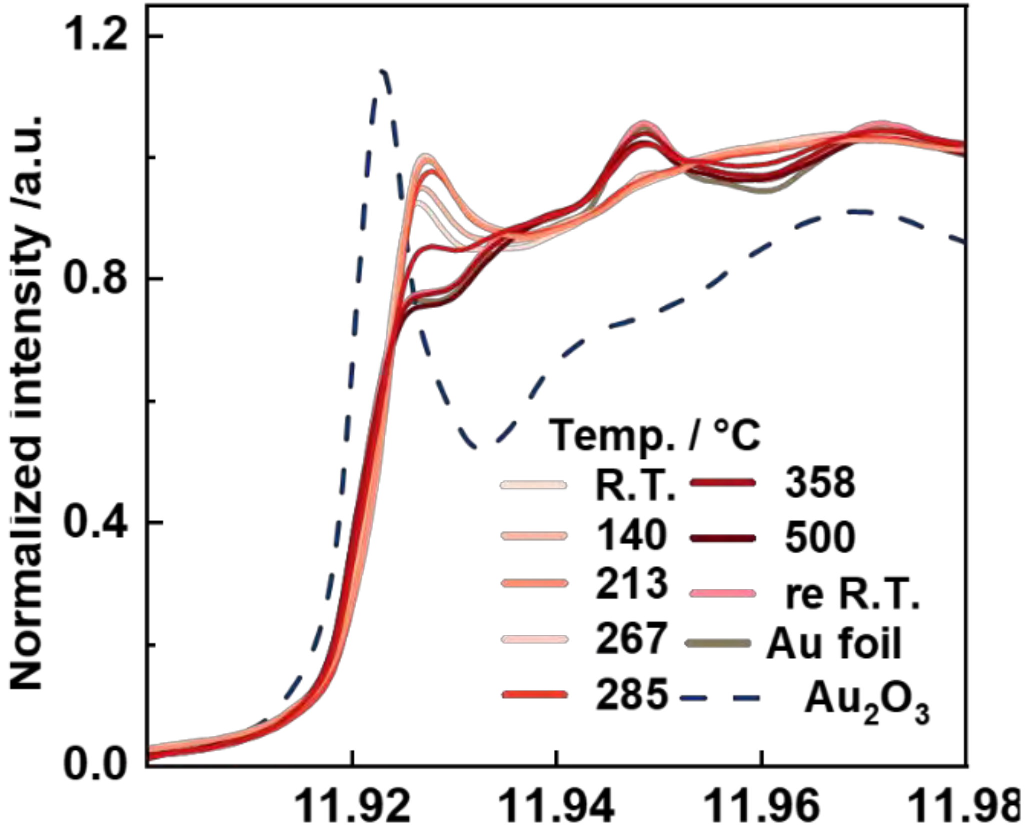
EGA profiles of Au/ZrO_2 (5a and 5e)

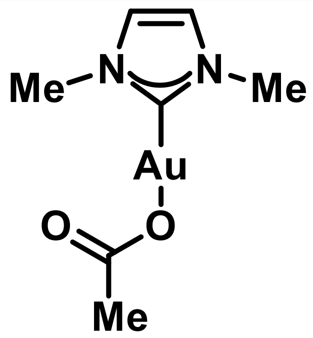




Support information

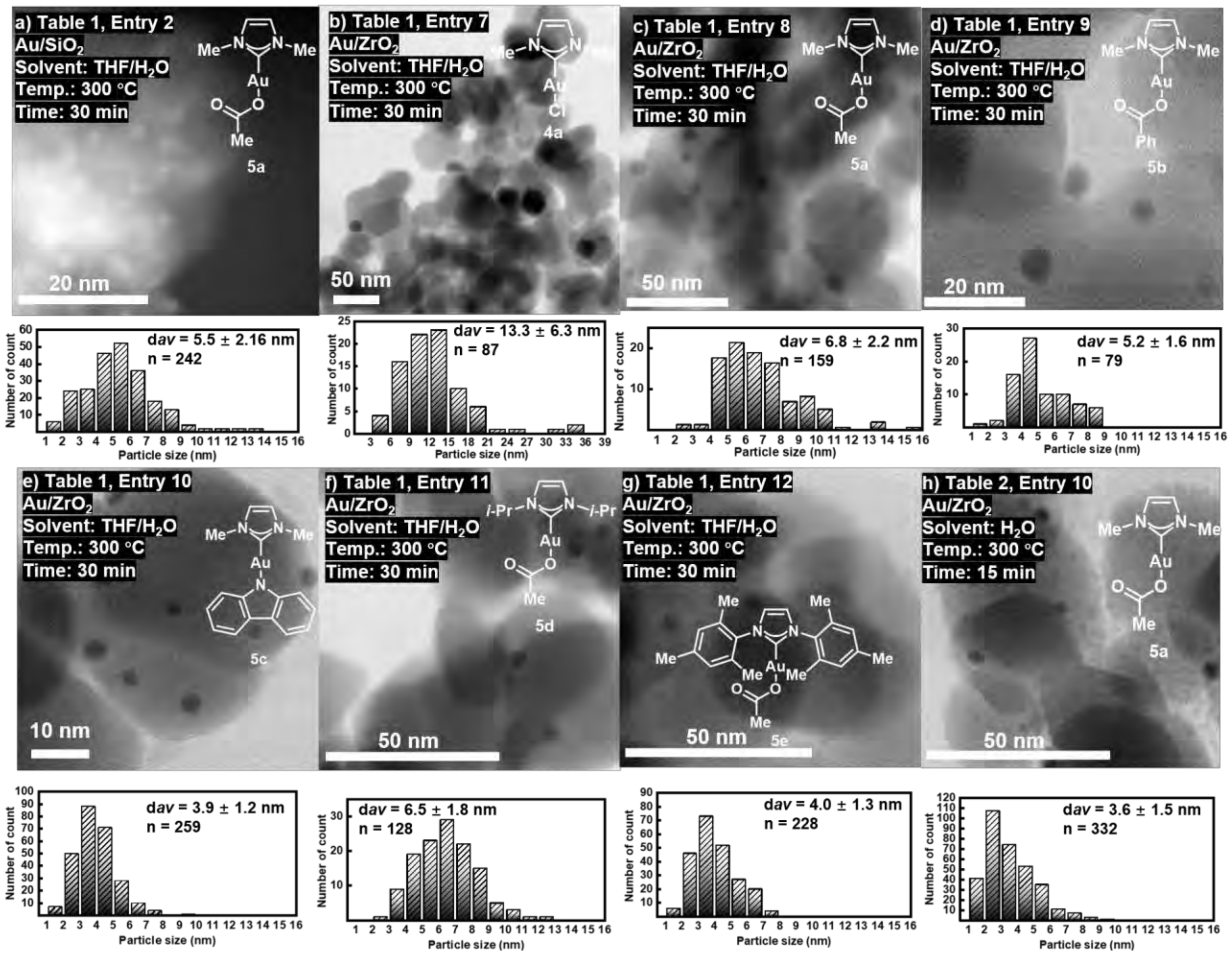
In situ Au LIII-edge XANES spectra of 3.0 wt% Au/ZrO_2 (5a)

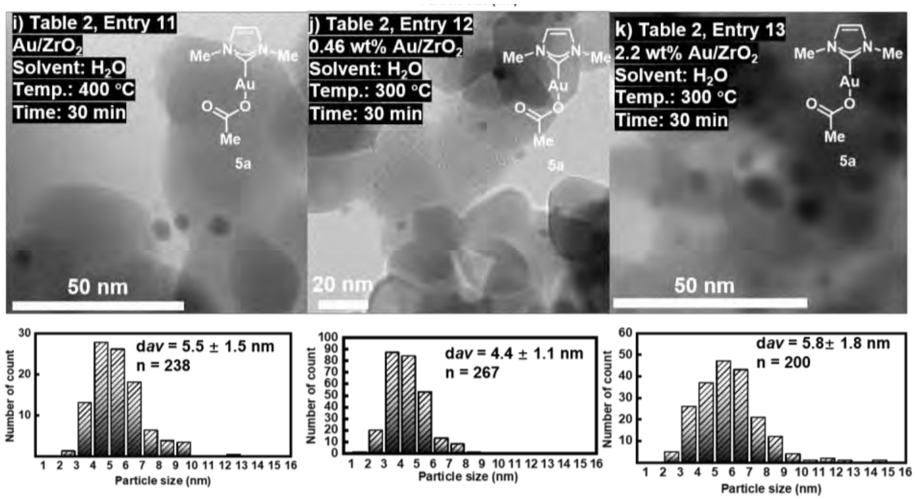


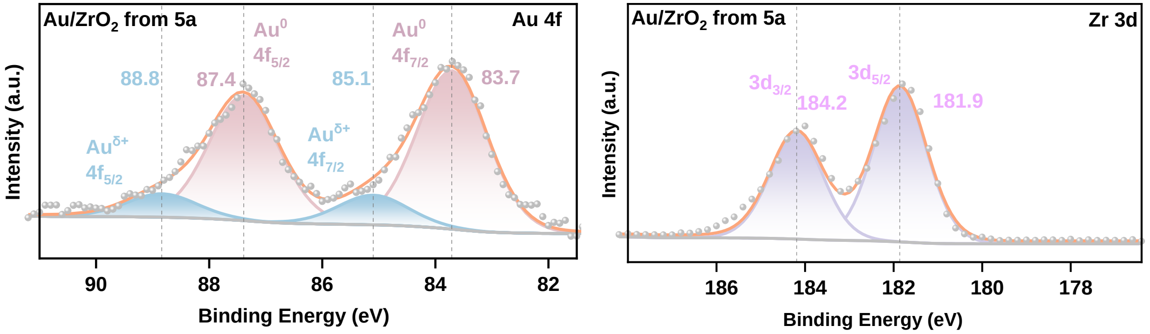


5a

Support information







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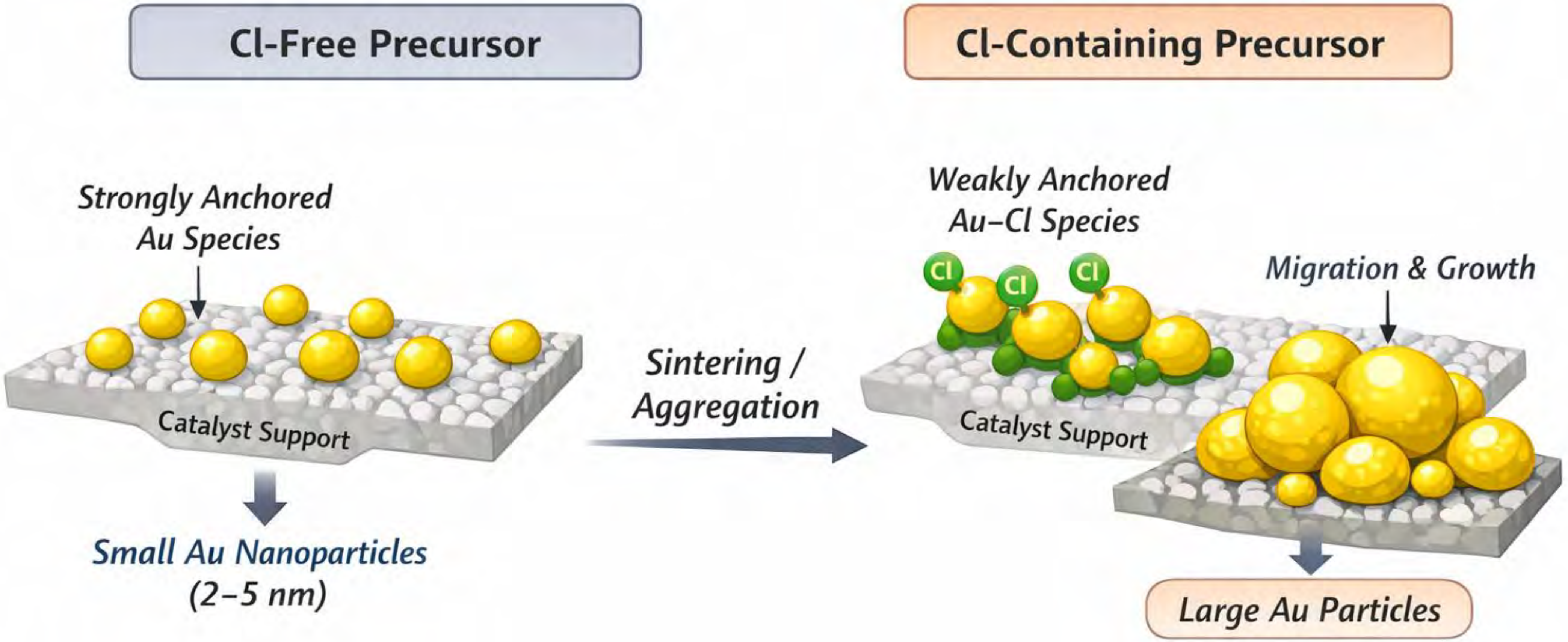

Haruta, M. Chem. Rec. 2003, 3, 75–87.

Support information

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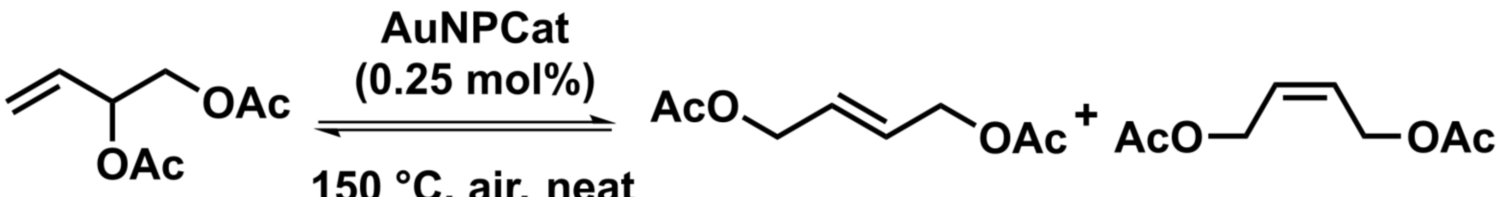

1 (1 mmol) (*E*)-2 (*Z*)-2

Entry	Catalyst	Conv.[a]/%	Yield[a]/%		Au loading amount/wt%	Support
			(*E*)	(*Z*)		
1[b]	Au/Al_2O_3	24	16	1	0.96	JRC-ALO-6
2	Au/CeO_2	38	6	0.2	0.93	JRC-CEO-3
3	Au/TiO_2	24	9	0.5	0.93	P-25
4	Au/50%CeO_2-ZrO_2	22	14	1	0.95	50%CeO_2-ZrO_2
5	Au/3%SO_4-ZrO_2	58	19	1	0.93	3%SO_4-ZrO_2
6	Au/30%TiO_2-ZrO_2	28	9	0.3	0.96	30%TiO_2-ZrO_2
7	Au/ZrO_2	33	29	2	1.06	JRC-ZRO-4
8	Au/ZrO_2	51	38	1	0.85	NND
9	Au/ZrO_2	55	42	5	0.72	SPZ

[a]. Determined by GC analysis using tridecane as an internal standard. [b]. Pre-calcination treatment: The Al_2O_3 sample was heated from room temperature to 1000 °C, held for 1 hour, and then maintained at 1000 °C for 3 hours.

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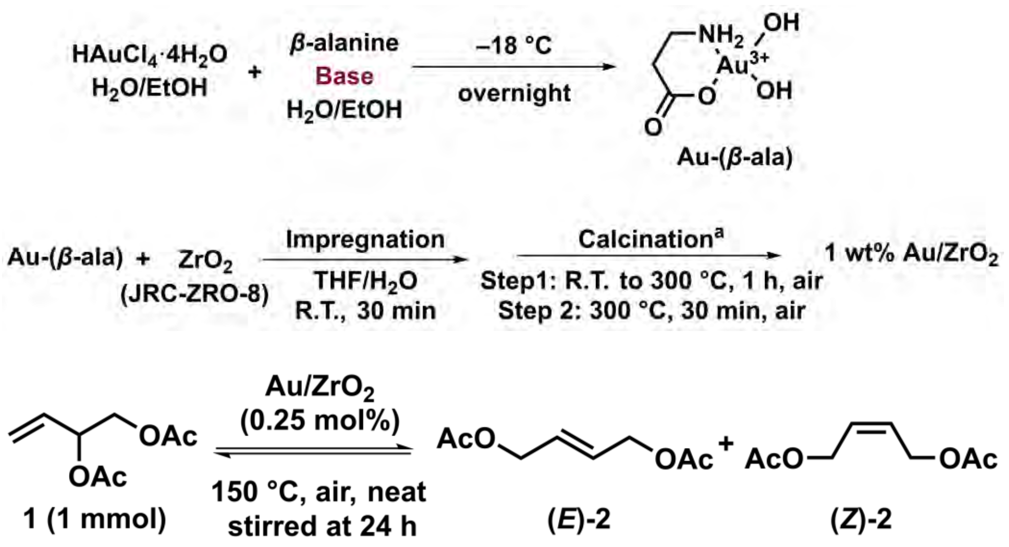

Entry	Base	Washing	Conv.[a] (%)	Yield[a] (%)		bases species loading [b] (wt%)
				(*E*)	(*Z*)	
1	NaOH	no washed	15	12	1	0.34
2	KOH	no washed	32	26	2	0.05
3	KOH	washed	44	40	3	n.d. [c]
4	K_2CO_3	no washed	5	4	n.d. [c]	0.16
5	K_2CO_3	washed	40	34	2	n.d. [c]

[a] Determined by GC analysis using tridecane as an internal standard.
[b] Determined by MP–AES. [c] n.d., not detected.

Support information