SOLVAY

Progress beyond

STREM CHEMICALS, INC.

Exploring the Impact of Ligand and Catalyst Selection on Petrochemical Applications

Strem Chemicals, Inc.
Ashley Bianco, Marketing Supervisor

Solvay
Dino Amoroso, Ph.D., NA Account Manager
Eamonn Conrad, Ph.D., Global BD Manager

Overview

- Solvay Phosphorus Specialties - Strem Chemicals Inc. Partnership
- Chemistry for the Manufacture of Phosphine Ligands
- Applications in Petrochemicals
- Developing Unique Solutions
- Summary and Questions

Solvay partners with Strem Chemicals for sample distribution

Strem Chemicals, Inc.

Solvay partners with Strem Chemicals for multi-kilo sample distribution!

Corporate Headquarters
Newburyport, MA USA

European Headquarters
Strasbourg, France

- Established in 1964
- More than 55 years of experience in manufacturing and handling high-quality inorganics and organometallics
- 5,000+ specialty chemicals available
- Laboratory Chemicals for R&D
- cGMP Products Manufactured in Kilo-lab Suites
- High Pressure Materials
- Custom Synthesis Projects
- Customers include:
  - Academic, industrial and government R&D laboratories
  - Commercial scale businesses in the pharmaceutical, microelectronics, chemical & petrochemical industries

ISO 9001:2015 CERTIFIED

ChemStewards®

STREM CHEMICALS, INC.
Samples available from Strem

Solvay:
A Global Leader in Phosphorus Chemistry

Differentiated products and technologies

We offer a wide range of phosphorus-based chemistry to meet precise application requirements

Innovation

160 years of know-how and innovation in phosphorus chemistry

Scale-up capabilities

From R&D to large scale; largest capacity in the industry

Partnership

We work closely with customers to translate their needs into concrete solutions

Secure and consistent supply source

Stringent quality control standards and timely order fulfillment due to global footprint and supply chain

2030 Solvay One Planet Goals

10 ambitious objectives

CLIMATE

Fight against climate crisis

Align **greenhouse gas emissions** with Paris Agreement

Reduce by 26% (-2%/y)

Phase out coal

Achieve 100%

Reduce negative pressure on biodiversity

30% reduction

RESOURCES

Embed circular business

Increase Sustainable Solutions revenues

Achieve 65% vs 50%

Increase circularity

Achieve 15% vs 7%

Reduce non-recoverable industrial waste

30% reduction

Reduce intake of freshwater

25% reduction

BETTER LIFE

Improve quality of life

Safety is a priority

Aim for zero accident

Accelerate Inclusion & Diversity

Parity in 2035 vs 24%
for mid & senior management

Extend maternity leave time and open it to co-parents

16 weeks regardless of the gender in 2021

WE PARTNER WITH CUSTOMERS AND COLLABORATE ACROSS THE VALUE CHAIN TO REDUCE GLOBAL IMPACT

The Markets we Serve

Agriculture

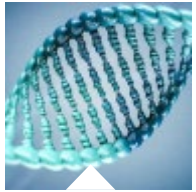
$ECO_2FUME^®$ | VAPORPH3OS®

- ✔ Cylinderized phosphine gas fumigants that efficiently eradicate insects at all life stages
- ✔ Used on post-harvest products or storage structures

Textiles

PROBAN® | THPC

- ✔ P-chemistry imparting flame-resistance to textiles & garments
- ✔ THPC for leather treatment applications



Life Sciences

CYTOP® | RhodaPhos®

- ✔ Specialty phosphorus compounds for applications requiring stringent purity profiles
- ✔ Catalysis; oligonucleotide synthesis; reagents; intermediates

Electronics

CYPURE® | CYTOP® | CYPHOS® IL

- ✔ High-purity phosphine gases & derivatives used throughout the electronics supply chain
- ✔ Dopants for LED & semi-conductors; capping ligands; solvents; quantum dot materials

Biocides

TTPC | THPS

- ✔ TTPC & THPS for control of microorganisms*
- ✔ Oilfield & industrial wastewater treatment applications

Chemical Processing

CYPHOS® | CYTOP® | RhodaPhos®

- ✔ Phosphine derivatives used in the manufacture of chemical compounds
- ✔ Organic extraction, catalysis, ligands and additives

Plastics, Epoxy & Coating

CYPHOS® | AMGARD® | Albritect®

- ✔ Phosphorus additives optimizing the performance of plastics, epoxy, and coating systems
- ✔ Epoxy resin curing; flame retardant polymers; surface coating treatment; catalysts

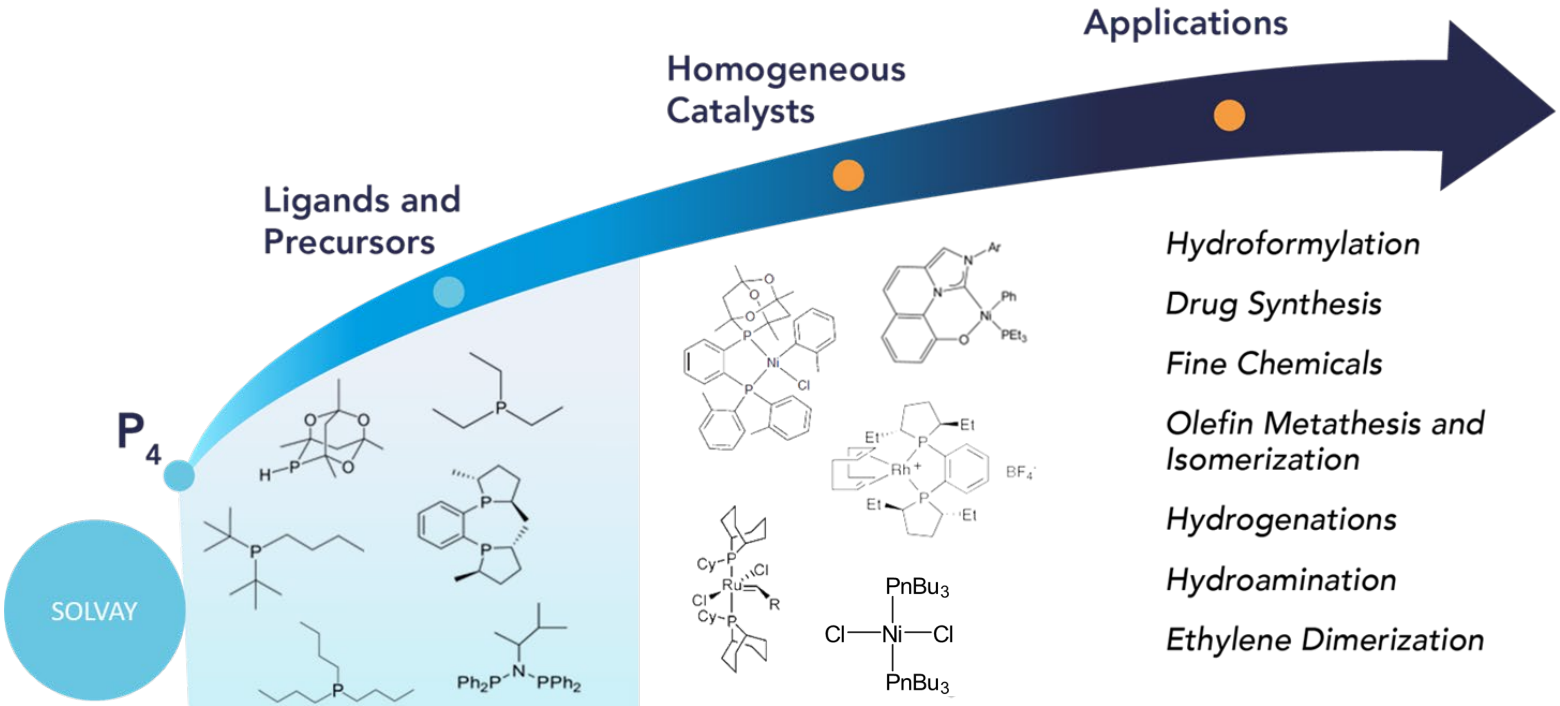
Other

Phos Acid | CYTOP® | CYPHOS ® IL

- ✔ Phosphorus-based chemistries for commodity and niche applications
- ✔ Metal extraction & recycling; liquid extractions; ionic liquids; fertilizer; other applications

*Supplied via Novecare GBU

Solvay in Phosphorus Catalysis



Solvay is the leader in supplying P-based ligands at industrial scale

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Samples available from Strem

Chemistry for the Manufacture of Phosphine Ligands

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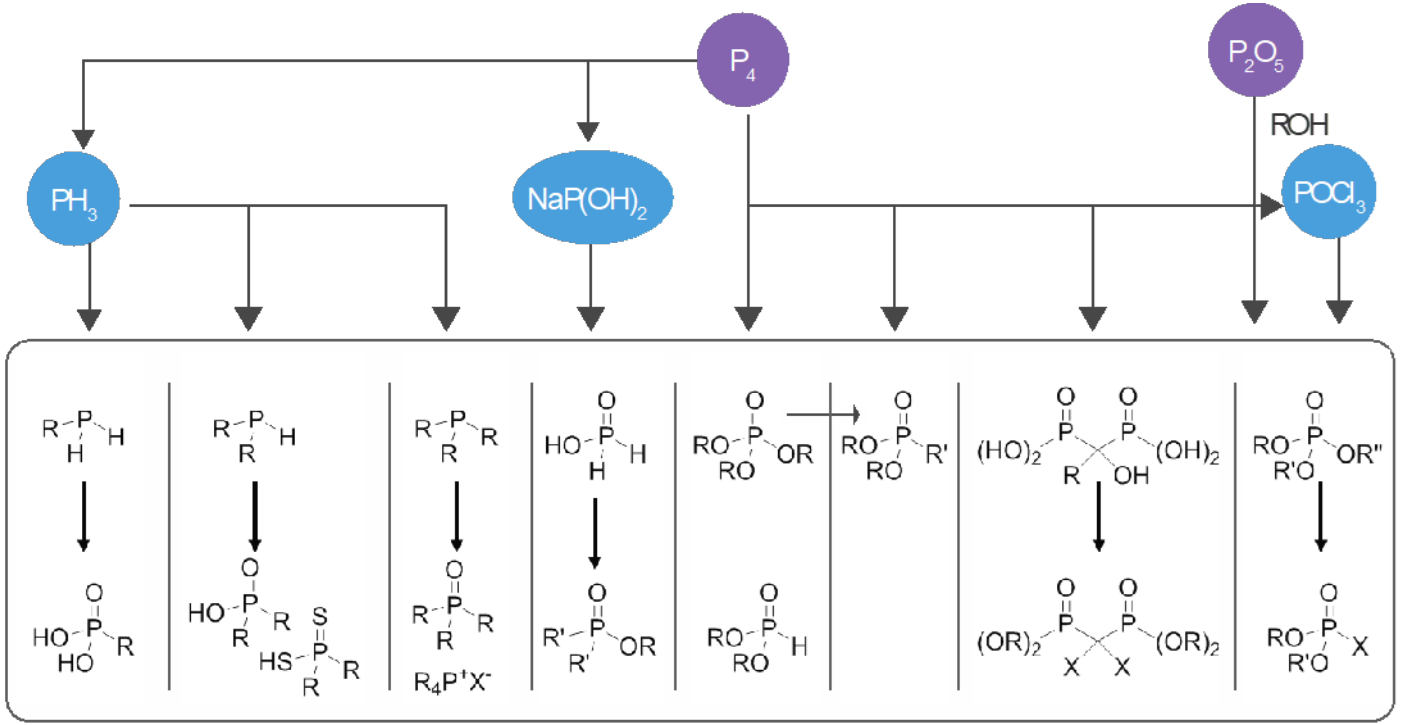
Phosphorus Specialties Product Platform



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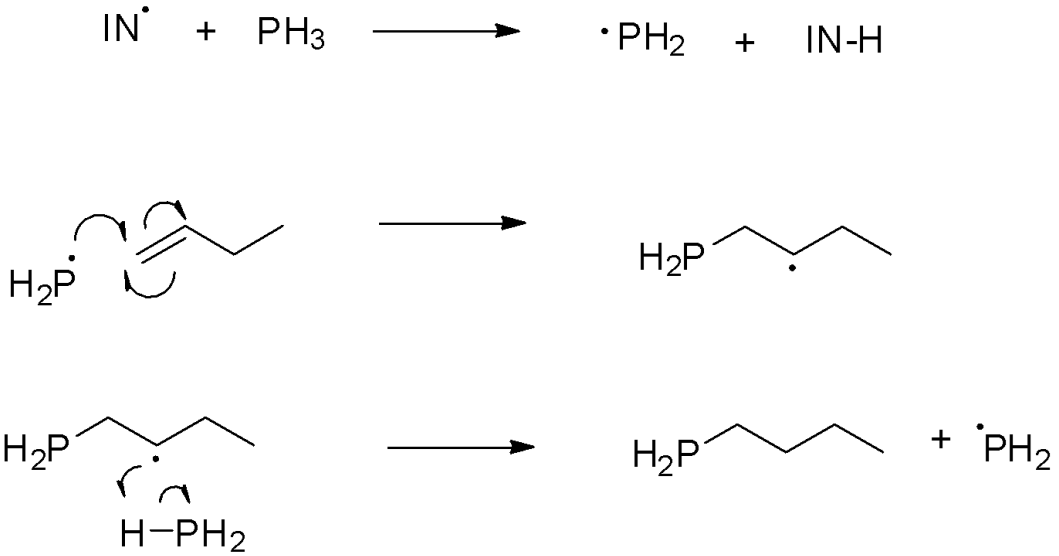
Foundational Chemistry

- Free radical addition of PH_3 to olefins is a major component of Solvay's alkylphosphine derivatives technology (alkylphosphine route)



(1) Rahut, M. et.al., *J. Org. Chem*. **1961**, *26*, 5138
(2) Pellon, J., *J. Am. Chem. Soc*. **1961**, *83*, 1915

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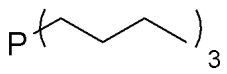
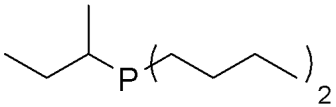
Samples available from Strem

Example – CYTOP® 340

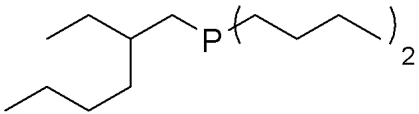
- Product distribution is dependent on the nature of the olefin
- Initiator fragments and some olefin oligomers are formed
- Olefin diversity translates to product diversity



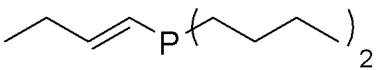
94%



2.5 - 3.0%



0.8%



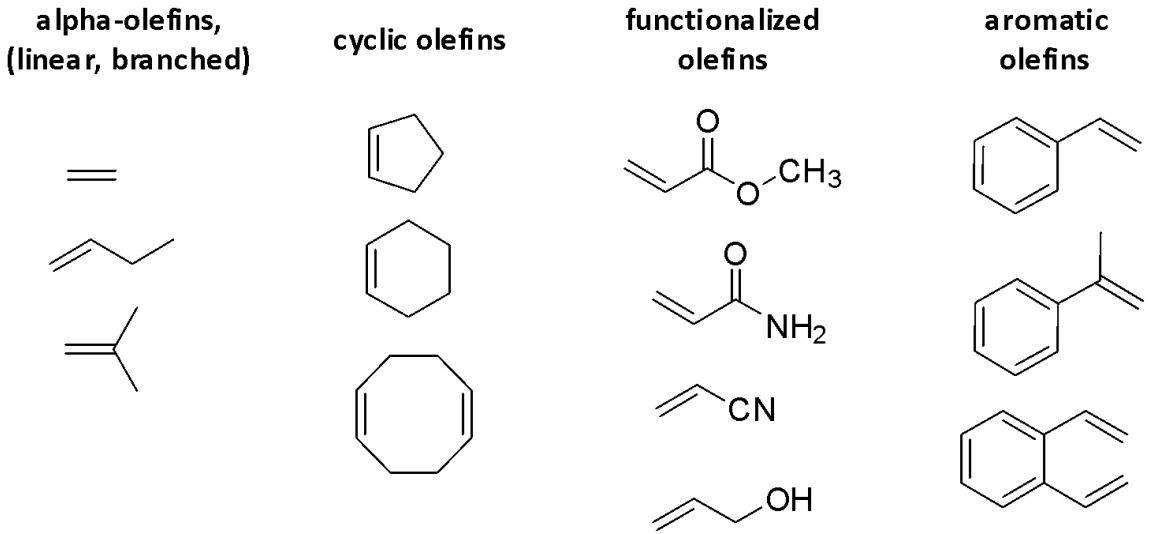
0.5%

- **CYTOP® 340** (Strem: 97-5801)
- Tri(n-butyl)phosphine
- CAS No. 998-40-3

STREM CHEMICALS, INC.
Samples available from Strem

Foundational Chemistry - Olefin Variety

- Product distribution is dependent on the nature of the olefin



- Reactivity of olefins and the product compositions depend on number of double bonds and positions

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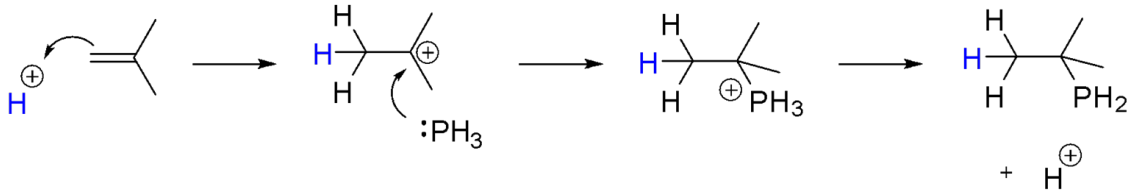
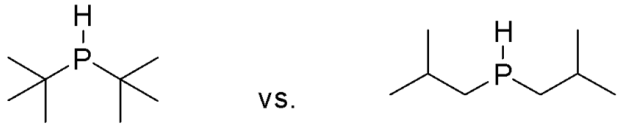
Samples available from Strem

Acid-Catalyzed Addition to Olefins

- Acid-catalyzed addition to olefins allows access to useful products not accessible through free radical routes





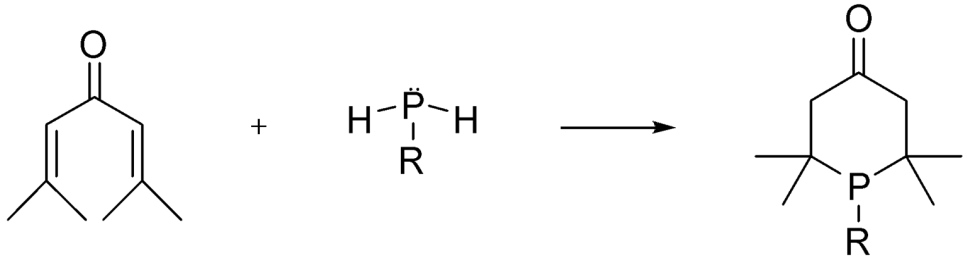
- **CYTOP® 341** (Strem: 97-5750)
- tri(isobutyl)phosphine
- CAS No. 4125-25-1

- Tri-*tert*-butylphosphine cannot be prepared under acid catalysis
- Tri-*iso*-butylphosphine is readily accessible - CYTOP® 341 (Strem: 97-5750)

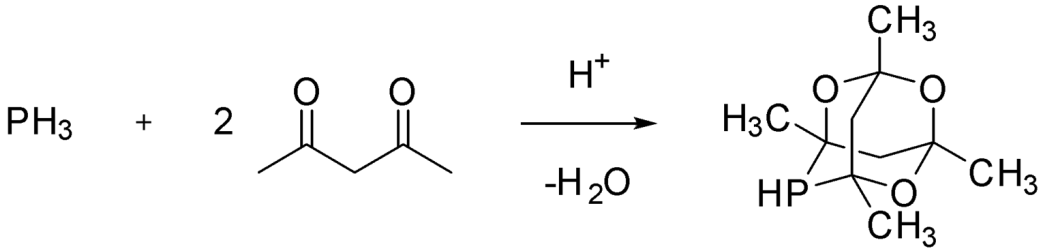
STREM CHEMICALS, INC.
Samples available from Strem

Extensive Toolbox for Synthesis

- Michael Addition to activation olefins



- Addition to 2,4-pentadione



- **CYTOP® 216X** (Strem: 97-1310)
- 1,3,5,7-tetramethyl-2,4,6-trioxa-8-phosphaadamantane
- CAS No. 26088-25-5

(1) Welcher, *J. Org. Chem*. **1962**, *27*, 1824
(2) Epstein, B, *J.Am.Chem.Soc*., **1961**, *83*, 3279

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Samples available from Strem

Applications in Petrochemical Catalysis

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Catalysts - A Great Opportunity to Innovate

- Catalysts facilitate the conversion of one molecule to another
- They are essential to industries such as pharma, petro, specialty chemicals, polymers, etc.
- A key enabler to sustainable processes
  - Reduce CO_2 emissions
  - Reduce chemical use
  - Reduce energy input
  - Less waste
  - Higher yields of desired products
- Petrochemical catalysis is critical to basic building blocks in chemistry
- Petrochemical catalysis is valued at greater than $33 billion USD/year and growing (~25% homogeneous)

Homogeneous catalysts are needed when heterogeneous catalysts cannot provide the desired selectivity, activity, and/or lifetime - many of these require a phosphine ligand at industrial scale

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Why the Interest in Phosphorus for Catalysis?

- ***Tunability***: Diversity of structure, steric/electronic effects, thermal and chemical stability, reactivity, selectivity
- ***Key balances*** between P ligands and metals (Cr, Co, Rh, Ni, etc.) critical to ***process efficacy***
- ***Available in multiple forms*** for ease of handling (product stewardship, safety, etc.)
- ***Established manufacturing*** routes, ***Right*** Scale

Solvay is a leader in the safe supply of phosphine ligands to the market.

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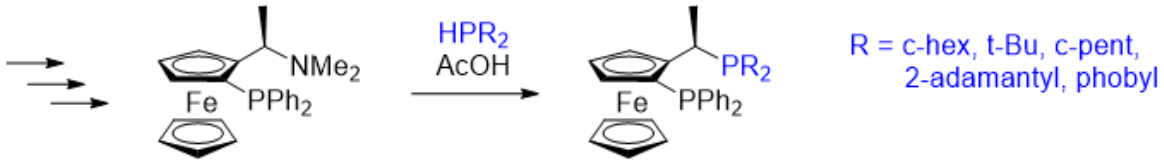
Samples available from Strem

Diverse Ligands Enable Diverse Applications

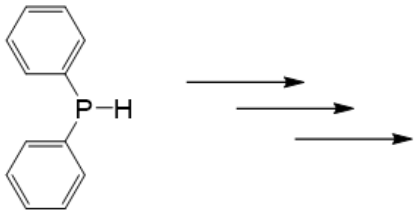
Multifunctional building blocks

- Ability to tune ligand/catalyst properties via changes in composition: a key feature in all successful ligands
- Modularity leads to breadth in applications, i.e., Josiphos™

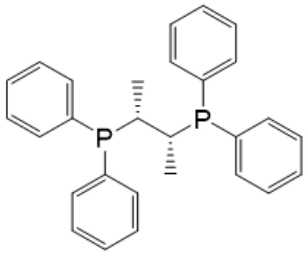


R = c-hex, t-Bu, c-pent, 2-adamantyl, phobyl

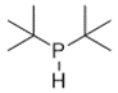
- Achiral primary and secondary phosphines can be made into chiral motifs for life sciences catalysis



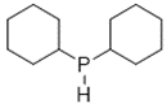
RhodaPhos® DPP
(Strem: 15-1701)



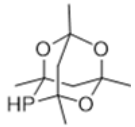
RhodaPhos® CP100R
(Strem: 97-0165)



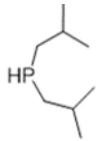
CYTOP® 242
(Strem: 97:1000)



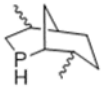
CYTOP® 266
(Strem: 97-1120)



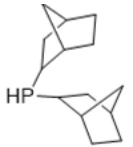
CYTOP® 216X
(Strem: 97-1310)



CYTOP® 241
(Strem: 97-1030)



CYTOP® 170
(Strem: 15-7605)



CYTOP® 222
(Strem: 97-1460)

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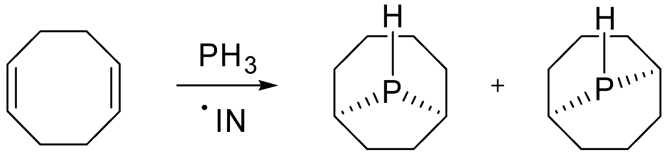
Samples available from Strem

CYTOP® 282T – Bulky Phosphine

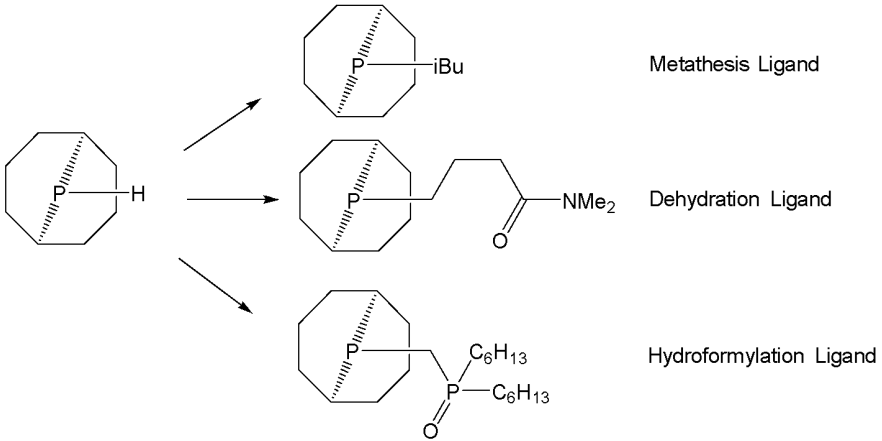
Ligand Precursor

- CYTOP® 282T– sterically bulky secondary phosphine
  - Isomers can be separated via selective protonation



- **CYTOP® 282T**
  (Strem: 15-7535)
- 9-phosphabicyclononane [3.3.1] and [4.2.1]
- CAS No. 13887-02-0/ 13396-80-0

- CYTOP® 282T is a cost-effective alternative to tertiary-butyl and adamantyl substituents
- Modularity leads to a breadth of applications – Metathesis, Dehydration and Hydroformylation chemistry



(1) Pringle, P.G. et al. *Adv. Synth. Catal.*, **2005**, *347*, 1345
(2) Patent, Pringle, P.G. et al. WO2012072594 A1, June 7, 2012
(3) Patent, Drent, E. et al. US 20080081909 A1, April 3, 2008
(4) Nolan, S.P. et al. *Chem. Commun*. **2014**, *50*, 2205

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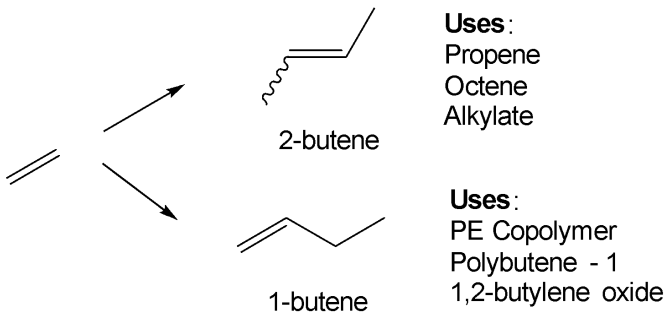
Samples available from Strem

Ethylene Conversion Applications

Control of conversion is critical

- Ethylene is one of the most import building blocks in chemistry (150+ million tons in 2018)
- Conversion of ethylene to higher value products and different functionalities is critical to a variety of applications
- ***Control of this conversion*** is key (C4, C6, C8, C10, etc.) and isomers
- Dimerization, oligomerization, oxidation, halogenation, hydroformylation, alkylation, etc. are required



(1) IHS Markit Report 2019

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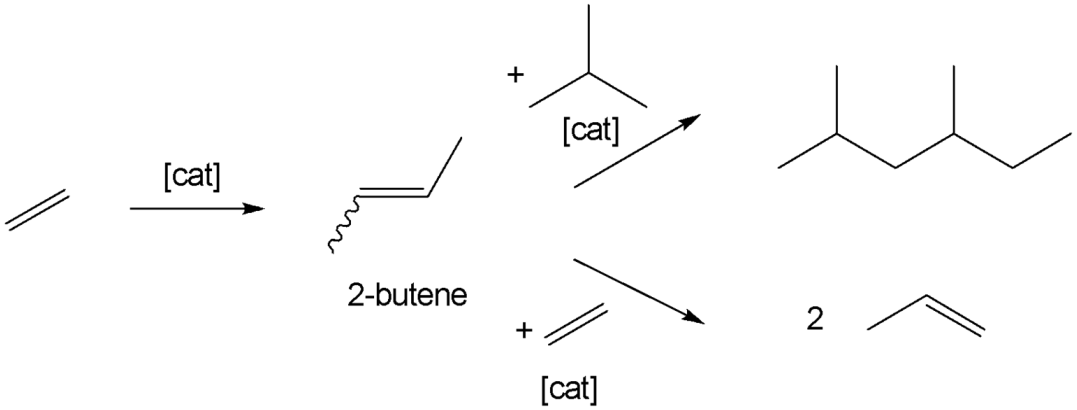
Samples available from Strem

Ethylene to 2-Butene

Key Raw Material for Propylene and Alkylate

- 2-butene is mostly recovered and used in the production of gasoline alkylate
- Increased demand for 2-butene in the production of propylene
- Critical to use the right catalyst for high conversion to 2-butene – maximize productivity and quality



(1) Chauvin, Y. Einloft, S.; Olivier, H. *ind. & Eng. Chem. Res*. **1995**, *34*, 1149
(2) Behr, A.; Bayrak, Z.; Stochniol, G. et al. *Chem. Eng. & Tech*. **2016**, *39*, 263
(3) WO 2019105844 A1, June 6, 2019
(4) Hulea, V. *Catal. Sci. & Tech*. **2019**, *9*, 4466

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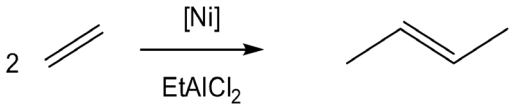
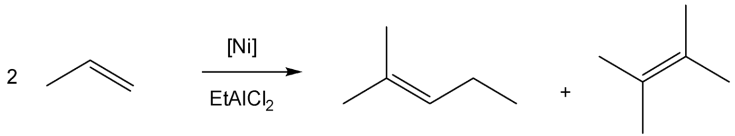
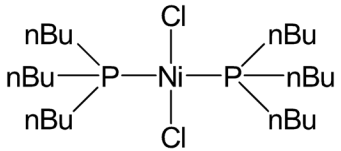
Ethylene to 2-Butene

Key Raw Material for Propylene and Alkylate

- RhodaPhos® NICAT is a nickel catalyst most commonly employed in dimerizations of olefins of varying lengths (butenes, propenes, ethenes, etc.) – many of these products serve as precursors







RhodaPhos® NICAT
(Strem: 28-0075)

- Favors formation of 2-butene in ethylene dimerization
- RhodaPhos® NICAT is also applied in processes for polymer formation, cycloadditions of olefins and isomerizations of olefins
- Also employed in dimerization of propylene

(1) Chauvin, Y. Einloft, S.; Olivier, H. *ind. & Eng. Chem. Res*. **1995**, *34*, 1149
(2) Behr, A.; Bayrak, Z.; Stochniol, G. et al. *Chem. Eng. & Tech*. **2016**, *39*, 263
(3) WO 2019105844 A1, June 6, 2019
(4) Hulea, V. *Catal. Sci. & Tech*. **2019**, *9*, 4466
(5) Chemical Week, 20 November 1985, p. 54
(6) Scott, A. Chemical Week, 3 November 1999, p. 41

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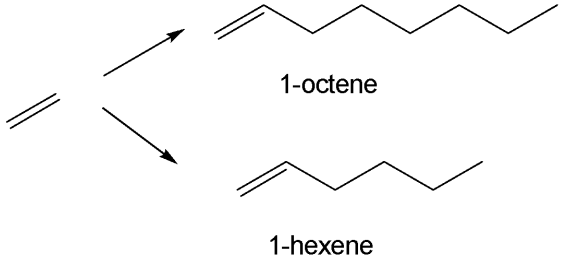
Samples available from Strem

Ethylene to 1-Hexene and 1-Octene

Control is key to form desired oligomers

- Control over trimerization vs tetramerization of ethylene is critical
- 1-hexene and 1-octene are BOTH required for different polyester grades (among other applications)
- Control of the ratio of formation is important to simplify purification processes

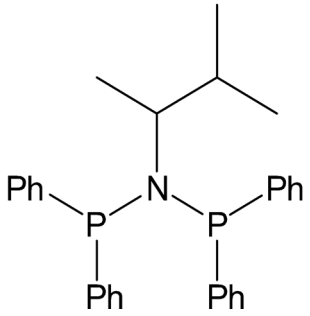


Uses:
PE Comonomer
C9 Aldehydes
Plasticizers

Uses:
PE Comonomer
HDPE
LDPE
Heptanal

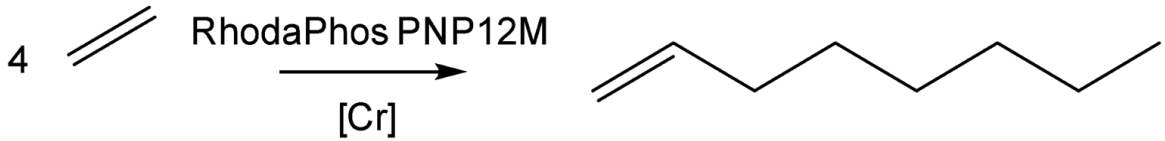
STREM CHEMICALS, INC.
Samples available from Strem

RhodaPhos® PNP 12M
Oligomerization of Ethylene



RhodaPhos® PNP 12M
(Strem: 15-0745)

- RhodaPhos® PNP12M is employed in chromium-catalyzed tetramerization of ethylene
- Selective formation of 1-octene in tetramerization
- High-yielding reaction (1-hexene is second major product)
- Ligand can be modified to include other functional groups at both the phosphorus and the nitrogen atom



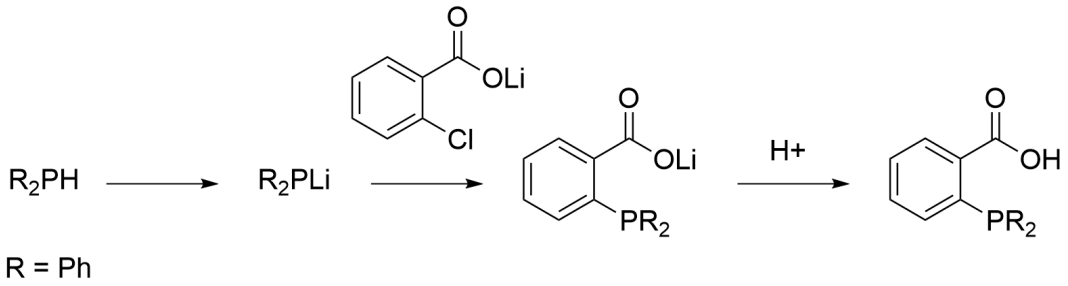
(1) Blann, K. et al. Sasol, US Patent 7511183

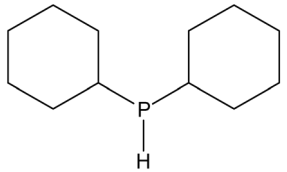
STREM CHEMICALS, INC.
Samples available from Strem

SHOP Process

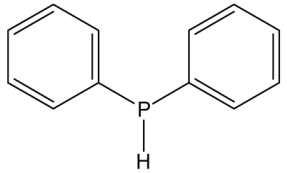
Derivatization of secondary phosphines

- Development of complex and specific ligands is a hallmark of homogeneous catalysis
- SHOP = Shell Higher Olefin Process (1977)
- Ethylene oligomerized to high-purity, even-numbered, linear-alpha olefins followed by isomerization and hydroformylation to make alcohols





CYTOP® 266
(Strem: 97-1120)
Di(cyclohexyl)phosphine
CAS No. 829-84-5



CYTOP® 186TOP
(Strem: 15-1705)
Diphenylphosphine
CAS No. 829-85-6

- Process requires industrial quantities of a phosphine ligand

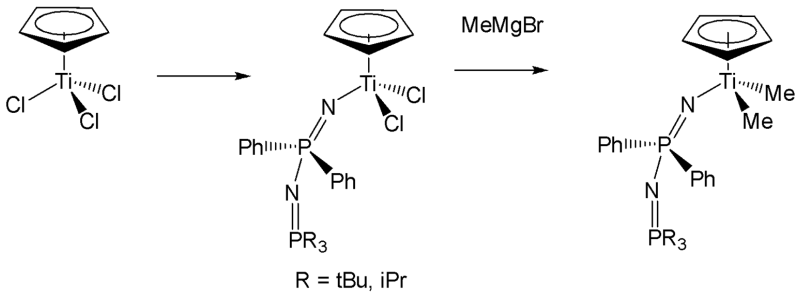
(1) Kemp, R.A. *Phosphorus, Sulfur, Silicon and the Related Elements*, **1994**, *87*, 83

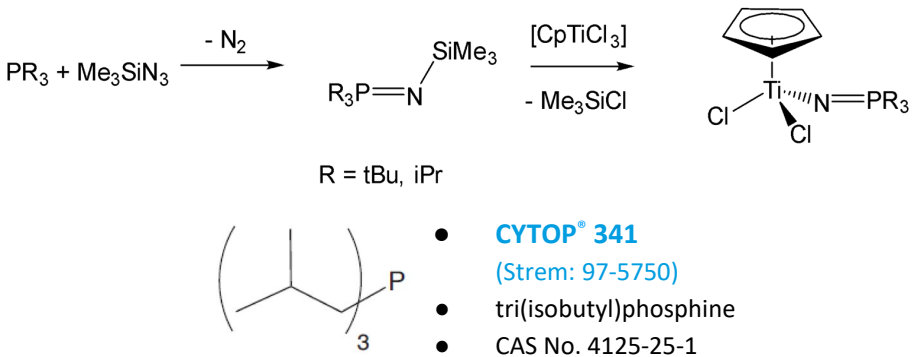
STREM CHEMICALS, INC.
Samples available from Strem

Ethylene Polymerization

Control of Polymer Chain Length

- Ethylene polymerization is a straightforward method to produce high-value polyolefins with properties such as adhesiveness, improved barrier effects, dyeability and printability, among others
- Single-site catalysts effectively control molecular weight and size distribution
- Ti:P complexes offer good control over molecular weight and distribution. They are also relatively stable, easy to handle and easily modified





- **CYTOP® 341**
  (Strem: 97-5750)
- tri(isobutyl)phosphine
- CAS No. 4125-25-1

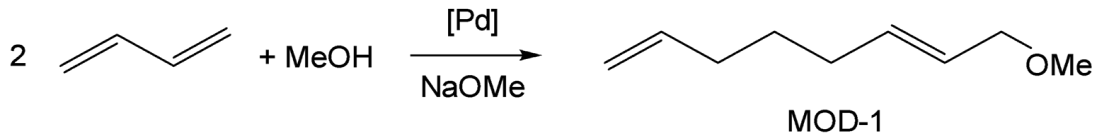
(1) Yue, N.L.S.; Stephan, D.W. *Organometallics*, **2001**, *20*, 2303
(2) Stephan, D.W. et al. *Organometallics*, **1999**, *18*, 1116

STREM CHEMICALS, INC.
Samples available from Strem

P Ligands for Telomerization of Dienes

Specialty Chemicals from Petrochemical Feedstocks

- Telomerization of dienes is an industrially relevant process to provide specialty chemicals
- It is 100% atom economical and tolerant to nucleophiles; chemistry requires P ligands
- Current systems (PPh_3) are susceptible to oxidation and have low selectivity
- Replacing with CYTOP® 292:10% increased yield, significant cost improvements at industrial scale



MOD-1

CYTOP® 216
(Strem: 97-1310)

CYTOP® 292
(Strem: 15-5375)

	CYTOP® 292	PPh_3
Conv.	96%	88%
Selectivity	94%	91%
Yield	90%	80%

(1) Klinkenberg, J.L., Lawry, K.P. *Org. Process Res. Dev.* **2019**, *23*, 1654

STREM CHEMICALS, INC.
Samples available from Strem

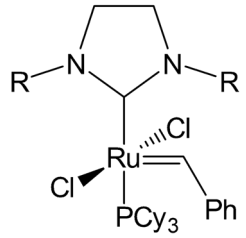
Production of Alpha Olefins

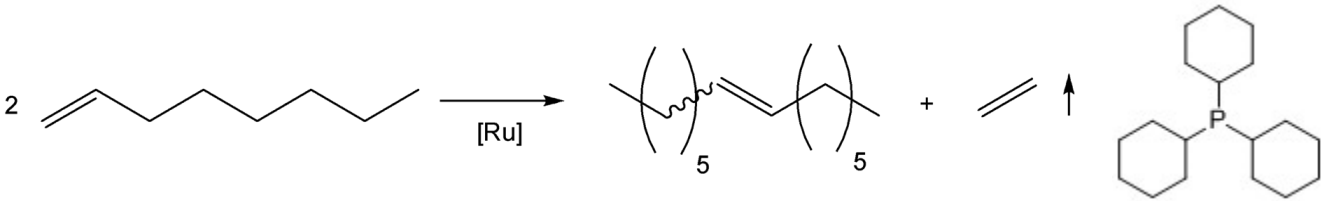
Metathesis catalysts for 1-octene and methyl oleate

- Metathesis exists predominantly in petrochemical applications as a heterogeneous process

- Highly attractive ruthenium-based catalysts offer an alternative in synthesis of alpha olefins
  - Robustness to air, water and oxygenates
  - High reaction rates and selectivity

- CYTOP® 366 is an effective ligand in the self-metathesis of 1-octene & methyl oleate
  - TON 64,000 – 600,000 with high selectivity (>98%)
  - TOF 3,800/s
  - High activity: combination of bulk and electron donating capabilities of ligand set and stability of catalyst (faster rates than TPP analogues)





- **CYTOP® 366**
  (Strem: 15-6152)
- Tricyclohexylphosphine
- CAS No. 2622-14-2

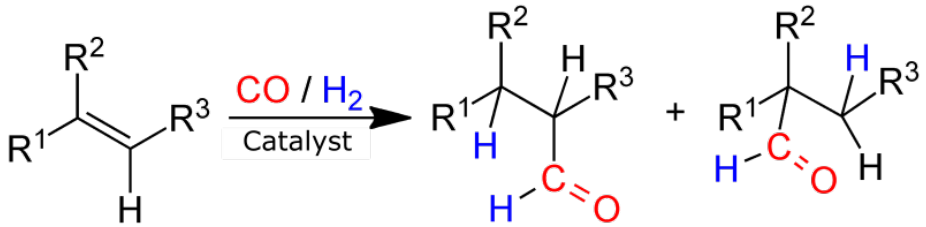
(1) M.B. Dinger, J.C. Mol, *Adv. Synth. Catal*. **2002**, *344*, 671.

STREM CHEMICALS, INC.
Samples available from Strem

Hydroformylation

Critical Process for the Production of Aldehydes

- Hydroformylation - the “oxo” reaction - is one of the highest volume homogeneous-catalyzed reactions in the world
- The conversion of alkenes, hydrogen and CO to aldehydes and related products at a rate of over 10 million metric tons/year



- Phosphine-modified versions were discovered initially in the 1960s
- Homogeneous catalysis is dominated by Rhodium and Cobalt systems, many which require a phosphorus-based ligand

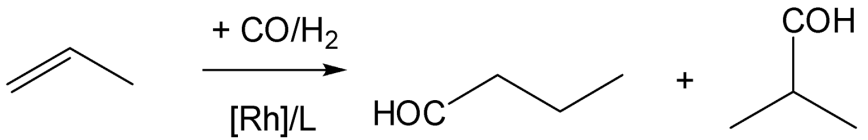
(1) Sluagh, L.H.; Millineaux R.D. J. *Organomet. Chem.* **1968**, *13*, 469

STREM CHEMICALS, INC.
Samples available from Strem

Hydroformylation

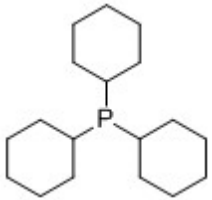
Monodentate phosphines as additives to P-containing catalyst systems

- Many complex, bidentate or chelating ligand systems are known for hydroformylation
- Rh-catalyzed hydroformylation of propylene, addition of phosphines improves activity without impacting branching
- TCHP (tricyclohexylphosphine) shown to substantially increase activity, no change on N/Iso ratio.
- TOP (trioctylphosphine) did not have the same impact but rather decreases activity
- Sterically hindered phosphines enhance activity while non-hindered do not!

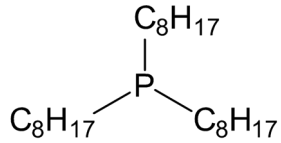


Monodentate Phosphine	Mole ratio PR_3:Rh	N/Iso Ratio	Activity lb HBu /g Rh·h
none	n/a	2.32	2.78
TCHP	3/1	2.30	4.10
TCHP	6/1	2.31	4.30
TOP	3/1	2.43	2.10
TOP	6/1	2.58	1.05

CYTOP® 366
(Strem: 15-6152)
Tricyclohexylphosphine
CAS No. 2622-14-2



CYTOP® 380
(Strem: 97-6665)
Trioctylphosphine
CAS No. 4731-53-7

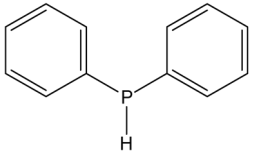


(1) Devon et al., US 4960949 October 2, 1990.

STREM CHEMICALS, INC.
Samples available from Strem

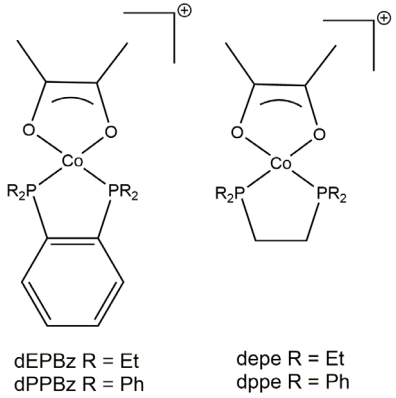
Hydroformylation

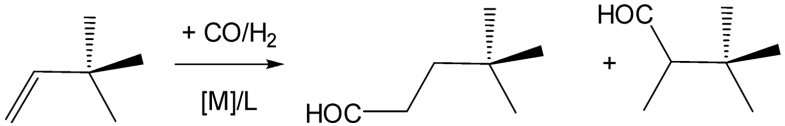
New reactivity for a classic reaction



CYTOP® 186TOP
(Strem: 15-1705)
Diphenylphosphine
CAS No. 829-85-6

- New cationic cobalt supported by phosphines have high reactivity and isomerization activity leading to high L:B selectivities for internal olefins





Catalyst	Temp (°C)	Pressure (bar)	Aldehyde (%)	Aldehyde L:B	Alkane (%)
[Co:DPPBz]+	140	30	60.0	58	0.8
[Co:dppe]+	140	30	64.1	57	1.0
[Co:depe]+	140	30	77.1	54	1.2
[Co:DEPBz]+	140	30	84.8	51	1.2

- New ligands offer exceptional stability, high reactivity, and high L:B ratios for internal olefins
- Opens the path to medium-pressure hydroformylation technology
- ***New efforts make for exciting, industrially relevant discoveries***

(1) Stanley, G.G. et al. *Science*, **2020**, *367*, 542

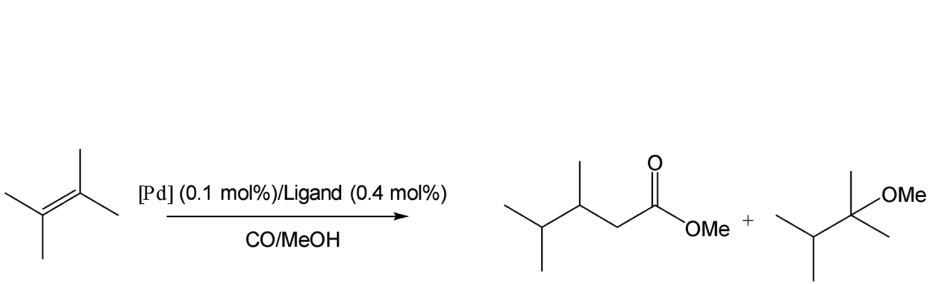
STREM CHEMICALS, INC.
Samples available from Strem

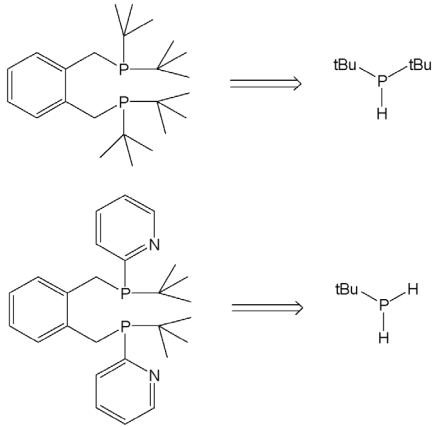
Alkoxycarbonylation of Alkenes

Increasing productivity with P-based ligands

- Carbonylation (hydroformylation) of alkene is one of the most important homogeneous industrial processes
  - Can require complex challenges to meet specific needs (improve activity, etc.)

- Recent developments have shown improved routes for sterically hindered and demanding olefins





CYTOP® 242
(Strem: 97-1000)
Di(tert-butyl)phosphine
CAS No. 819-19-2

CYTOP® 142
(Strem: 97-0966)
mono(tert-butyl)phosphine
CAS No. 2501-94-2

- ***Bulk ethylene can be functionalized with high activity (TON >1,425,000: TOF 44,000/hr) and high selectivity (>99%) with certain P-based ligands***

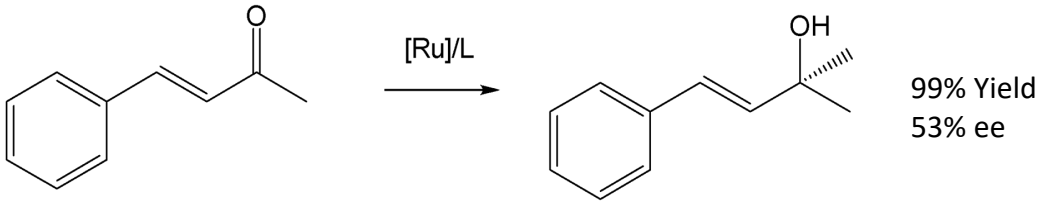
(1) Beller, M. et al. *Nature Comms*. **2017**

STREM CHEMICALS, INC.
Samples available from Strem

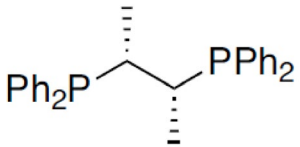
Hydrogenation

Homogeneous catalysis for asymmetric or symmetric hydrogenations

- Hydrogenation is used to convert alkenes and aromatics into saturated alkanes (paraffins) and cycloalkanes
- Hydrogenation is also used to convert olefins from refining feedstocks to value-added chemicals
- Homogeneous catalysis offers controlled reactivity under milder conditions
- RhodaPhos® CP100R can be employed in the chemoselective production of chiral alcohols



99% Yield
53% ee



- **RhodaPhos® CP100R**
  (Strem: 97-0165)
- (2R,3R)-(+)-Bis(diphenylphosphino)butane
- CAS No. 74839-84-2

- RhodaPhos® CP100R has also been employed as a bidentate ligand in chromium-based ethylene oligomerizations

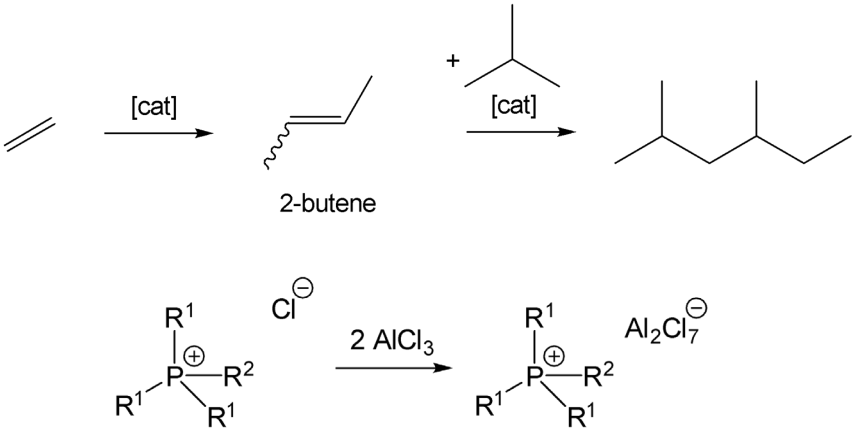
(1) US 5763688A
(2) WO Patent 2011108772
(3) WO Patent 2009022770

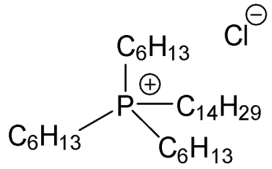
STREM CHEMICALS, INC.
Samples available from Strem

Alkylation Chemistry – C8

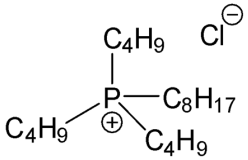
Phosphonium ionic liquids as catalysts

- Alkylation of paraffins with olefins for the production of alkylate for gasoline can use a variety of catalysts
- Many processes involve harsh conditions such as hydrofluoric acid (HF) or sulfuric acid
- Phosphonium ionic liquids can be employed for conversion at near ambient conditions (C8 selectivity >70%)
  - Lewis acidity allows ionic liquid to act as a catalyst

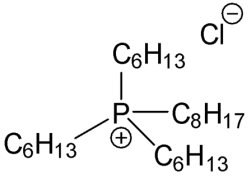




CYPHOS® IL 101
(Strem: 15-6382)
CAS No. 258864-54-9



CYPHOS® IL 253
(Strem: 15-7575)
CAS No. 56315-19-6



CYPHOS® IL 356
(Strem: 15-7590)
CAS No. 850134-85-9

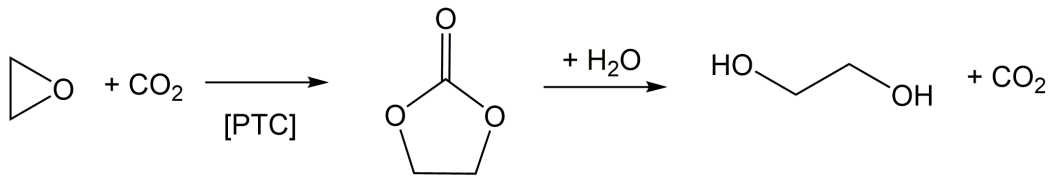
(1) US Patent 20130345482

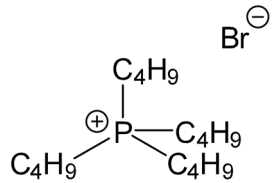
STREM CHEMICALS, INC.
Samples available from Strem

P Based Phase Transfer Catalysts - PTC

Phosphonium ionic liquids as PTC

- The OMEGA process (Shell) is a catalytic system to produce MEG
  - Applications in manufacture of polyester, antifreeze, dioxanes, etc.
  - MEG is 92% of EG market at about 26.8 MMT (2017)
  - Requires a PTC
- Key advantages of this process are 99% conversion efficiency vs ~90% for traditional methods
- Further advantages include less steam use and less wastewater production
- Chemistry can be catalyzed by P based ionic liquids





CYPHOS® 442
(Strem: 97-1579)
CAS No. 3115-68-2

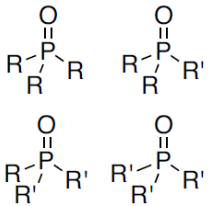
(1) US Patent 7728164
(2) US Patent 8735607
(3) WO Patent 2007104730

STREM CHEMICALS, INC.
Samples available from Strem

Acetic Acid Process

Phosphine oxides as Additives to Reduce Corrosion

- The carbonylation of methanol is a long-established route to acetic acid.
- Rhodium catalysts affect the carbonylation of methanol via addition of CO using added HI or MeI.
- The result is a highly acidic medium that can quickly corrode reactors, process vessels etc.
- CYTOP® 503 has been shown to significantly reduce corrosion while at the same time increasing stability and thus activity of the catalyst system!
  - *Phosphine oxide shown to complex and extract HI very effectively!*



R = n-hexyl
R' = n-octyl

CYTOP® 503
(Strem: 97-1337)

Stabilizer	Molarity	Corrosion (%)
None	n/a	0.516
CYTOP 503	0.25	0.490
CYTOP 503	0.5	0.327
CYTOP 503	1	0.181

316L, 0.5M HI, 3.2 wt% H_20, HOAc, CO, 70°C, 48hrs

Additive	Time (s)	Active Rh(I) (%)	MeI (M)	MeOAc (M)	Feed Conversion (%)
None	912	6	0.008	0.008	44
TPPO	1341	0	0.010	0.010	53
CYTOP 503	1814	36	0.008	0.008	80

1. Hallinan et al., US 2015/0246866 Sept 3, 2015

STREM CHEMICALS, INC.
Samples available from Strem

Why Work With Solvay?

- **Get the speed, flexibility and intimacy of a small company with strong corporate support**
- Ability to meet demanding purity, supply and scale-up needs, successfully transitioning chemistries from lab quantities to industrial-scale production
- Proven track record of developing innovative and practical routes to market
- Diverse and expanding R&I organization prepared to support today's applications and tomorrow's innovations
- Safe handling and processing of laboratory and large-scale air-sensitive material
- Logistics, registration support, toxicology support

Together, let's unlock the potential of phosphorus chemistry to support your sustainable growth

Custom Solutions - Critical to Sustainability

- Each company has its own feedstocks, equipment, objectives, etc.
- Many situations require a custom ligand or catalyst solution - our specialty
- Solvay has **over 60 years of experience** providing customer-specific ligand solutions
- We have the ability to partner with users and developers to create sustainable, cost-effective and value-added solutions
- Let's talk about your ligand next!

What Does ***Your*** Future Hold?

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Samples available from Strem

Thank You

Dino Amoroso, Ph.D., North American Account Manager
dino.amoroso@solvay.com

Eamonn Conrad, Ph.D., Global Business Development Manager
eamonn.conrad@solvay.com

Ashley Bianco, Marketing Supervisor
abianco@strem.com

SOLVAY

Progress beyond

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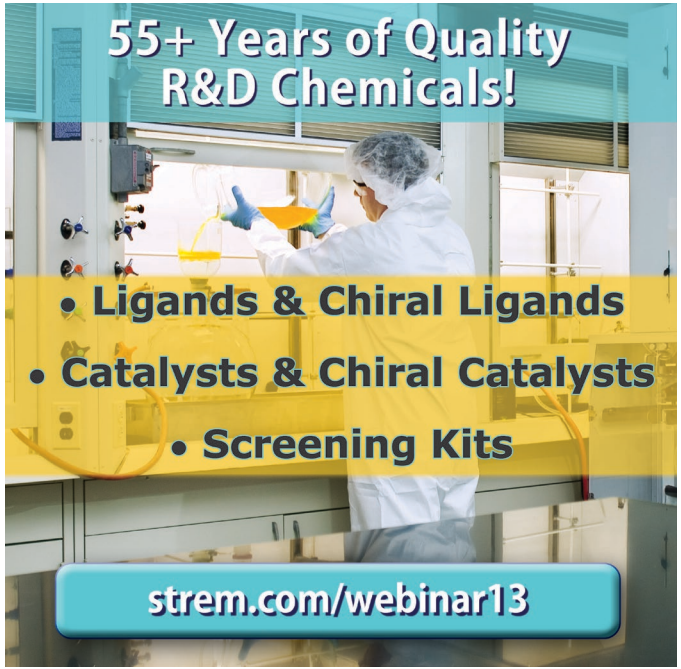
Samples available from Strem

Follow us on

Exploring the Impact of Ligand and Catalyst Selection on Petrochemical Applications

Multi-kilo Samples available from Strem



Industrial Scale from Solvay

Innovation:

160 years of know-how and innovation in phosphorus chemistry

Partnership:

We work closely with customers to translate their needs into concrete solutions

Differentiated products and technologies:

We offer a wide range of phosphorus-based chemistry to meet precise application requirements