Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
1,1,1-trichloroethane	Volatile Methyl Siloxanes (VMS)	Volatile methyl siloxanes (VMS), which have been formally ruled by the EPA to be exempt from VOC or Hazardous Air Pollutant regulation, are low molecular weight silicone fluids that provide a less toxic alternative to several hazardous organic solvents. Examples of VMS include hexamethyldisiloxane, octamethyltrisiloxane, and decamethyltetrasiloxane.	Rapidly dries without leaving residue, Cleans a variety of contaminants, Can b distilled for reuse	Flammable Combustible Toxic
Acetone	Aqueous surfactants and macromolecular solutions	Aqueous surfactants and macromolecular solutions can still solubilize organic reactions by forming micelles.	Avoids volatile organic solvents, May enhance chemical yield and selectivity	Workup and extraction procedures may be tedious
	Cleaning detergents	Oftentimes the use of a hazardous chemical, whether its toxic or flammable, can be avoided simply by using commercially available cleaning detergents.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Lactate esters (such as ethyl lactate)	Lactate esters (such as ethyl lactate) have shown excellent solvent properties as safer, non-toxic, and biodegradable chemical alternatives to several halogenated compounds, making them viable replacements in as cleaning agents or reaction solvents.	Biodegradable, Non-toxic	Solvent removal requires more energy (boiling point: 154°C)
	Propylene carbonate	Propylene carbonate (PC) is a safer, more environmental friendly alternative to chlorinated solvents and generic hazardous solvents used for cleaning, such as acetone.		
	Supercritical carbon dioxide(scCO2)	Supercritical carbon dioxide(scCO2) has been used in the place of generic hazardous solvents. This includes but is not limited to methylene chloride.	Non-flammable, Tunable solvent properties, Non-toxic, Easy removal from product, Inert to oxidation and radical reactions, Dissolves perfluorinated compounds and gases well, Critical temperature low (Tc = 31.3°C)	Yields not as high traditional solvents, Reactivity with amines, although may reform amine after depressurization, Safety and cost of high pressure equipment (Pc = 72.9 atm)

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Acetonitrile	fluorided silica-alumina catalysts	Different forms of alumina support, such as fluorided silica-alumina catalysts, offer an alternative to using more hazardous catalysts in a number of chemical processes.		
	Aqueous surfactants and macromolecular solutions	Aqueous surfactants and macromolecular solutions can still solubilize organic reactions by forming micelles.	Avoids volatile organic solvents, May enhance chemical yield and selectivity	Workup and extraction procedures may be tedious
	catalytic systems	Utilizing catalytic systems in any reaction promotes principles of Green Chemistry by improving the efficiency of a reaction. Many reactions, therefore, can be improve through the use of catalysts and/or using these catalysts in alternative solvents. The catalyst itself, however, may sometimes be very toxic and alternatives for many of thes dangerous catalysts, such as hydrogen fluoride or sulfuric acid, are available.		

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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Ethanol	Ethanol is a high volume chemical that is listed by the EPA as an air contaminant.		
	Fluorous ether F-626, benzotrifluoride, fluorous dimethylformamide (F-DMF), and perfluorohexanes (FC-72)	Fluorous solvents, such as the fluorous ether F-626, benzotrifluoride, fluorous dimethylformamide (F-DMF), and perfluorohexanes (FC-72) are alternative chemicals that have been used to replace a number of hazardous chlorinated solvents in industry. Their unique properties have also caught the interest of organic chemists.	Can dissolve both organic and fluorous compounds, Easy to remove, Solvent reusable without purification, High boiling point, Can form multi-phase reaction systems, Relatively non-toxic, High solubility of gases	Yields almost comparable but not as high as traditional solvents
	1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions	Ionic liquids are typically molten salts that are liquid below 100°C and provide a less volatile and recyclable alternative to many organic solvents such as methylene chloride. Some of the most popular ionic liquids use 1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions.	Non-volatile, Recyclable, Non explosiveNon-flammable, Commercially available in laboratory quantities, Tetrafluoroborate salts may have relatively low toxicity, Can have hydrogen bond acceptors and donors, Miscibility with water can be tuned by anions, alkyl groups, and sometimes temperature, Can from one, two, or three-phase catalytic systems	Some may be toxic to environment. 1,3-dialkylimidazolium ionic liquids, for instance, are antimicrobial depending on their N-alkyl group chain lengths, May require use of organic solvents in preparation steps, High viscosity (can be lowered if CO2 is dissolved in it), Anions of some ionic liquids may hydrolyze to form undesirable products

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Microwave irradiation	Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from days to minutes. Reactions performed in a microwave batch reactor, for instance, can be constantly monitored, and temperature and pressure can be manually controlled, often leading to more complete reactions and higher product yields.		
	Polyethylene glycol (PEG)	Polyethylene glycol (PEG) is a water soluble solid that can be used as a recyclable solvent medium in the place of volatile organic compounds.	Non-volatile, Inexpensive, Low toxicity (approved for food industry)	Viscous liquid at room temperature for PEG of molecular weights 300 and 600, Waxy solid for PEG 900, 1000, and 1500 which may become liquid under pressurized conditions (40°C at 90 bar), Terminal hydroxyl groups may be esterified or etherified PEG may be coextracted when using supercritical carbon dioxide, although PEG1500 is significantly less likely to be coextracted
Benzene	fluorided silica-alumina catalysts	Different forms of alumina support, such as fluorided silica-alumina catalysts, offer an alternative to using more hazardous catalysts in a number of chemical processes.		

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Benzotrifluoride (BTF, C7H5F3)	Benzotrifluoride (BTF, C7H5F3) is a less toxic and more environmentally friendly alternative to tetrahydrofuran and methylene chloride.	Less volatile Lower toxicity Relatively inert Stable in strongly basic conditions Non-ozone depleter Polarity between methylene chloride and ethyl acetate Dissolves organic compounds Miscible with organic solvents	Prepared industrially from toluen Solvent removal requires more energy (boiling point: 102°C) Wet commercially Hydrolyzes with acids at high temperatures Reacts with strong Lewis acids May be sensitive to reducing conditions involving electron transfer but compatible with hydride reductions and
	Dibasic esters	Dibasic esters (DBE) are by-products from the synthesis of adipic acid that are a less volatile and safer alternative to methylene chloride.	Biodegradable Solvent properties similar to methylene chloride Byproduct of current industrial processes	Solvent removal requires more energy (boiling point: 196-225°C) Incompatible with strong acids, bases, oxidants, and reducers Attracted to positively charged metal surfaces and may leave films
	Dimethoxyethane	Dimethoxyethane (DME) is a colorless liquid that may be used a substitute for more hazardous chemicals such as chloroform. DME is miscible with water.	Similar dieletric constant to chloroform	Miscible with water

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Ethanol	Ethanol is a high volume chemical that is listed by the EPA as an air contaminant.		
	Glucose	Glucose is a natural, biologically made sugar that has proven to be a viable substitute for a number of more hazardous chemicals.	Mild Renewable resource	
	Indium metal	Indium metal, a non-toxic metal often used in dental alloy is a viable alternative for many hazardous catalyst systems.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Microwave irradiation	Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from days to minutes. Reactions performed in a microwave batch reactor, for instance, can be constantly monitored, and temperature and pressure can be manually controlled, often leading to more complete reactions and higher product yields.		
	Montmorillonite clay catalysts	Montmorillonite clay catalysts, which are composed of octahedral and tetrahedral sheets of gibbsite and silicate, offer a safer and, in some cases, more effective alternativ to using more hazardous acids in catalyzing a number of chemical reactions.		
	Supercritical carbon dioxide(scCO2)	Supercritical carbon dioxide(scCO2) has been used in the place of generic hazardous solvents. This includes but is not limited to methylene chloride.	Non-flammable, Tunable solvent properties, Non-toxic, Easy removal from product, Inert to oxidation and radical reactions, Dissolves perfluorinated compounds and gases well, Critical temperature low (Tc = 31.3°C)	Yields not as high traditional solvents, Reactivity with amines, although may reform amine after depressurization, Safety and cost of high pressure equipment (Pc = 72.9 atm)

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Bromine	Cetyltrimethylammonium tribromide	Cetyltrimethylammonium tribromide (CTMATB or CetTMATB), a type of organic ammonium tribromide (OATB), can be used in the place of bromine in bromination reactions.	Good brominating and oxidizing agent	Some syntheses of this reagent may involve hazardous conditions and/or chemicals
	Poly-n-bromosuccinimide	Poly-n-bromosuccinimide (PNBS) can be used to replace bromine in bromination reactions.		
	Tetrabutylammonium bromide	Tetrabutylammonium bromide (TBAB) is a chemical that can be used as a phase-transfer catalyst and can be used to replace bromine in bromination reactions.	Good brominating and Some syntheses of this reagent may involve hazardous conditions and/or chemicalsoxidizing agent	Some syntheses of this reagent may involve hazardous conditions and/or chemicals

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Tetrabutylammonium tribromide	Tetrabutylammonium tribromide (TBATB), a type of organic ammonium tribromide (OATB), can be used to replace bromine in bromination reactions.		
Carbon Tetrachloride	Benzotrifluoride	Benzotrifluoride (BTF, C7H5F3) is a less toxic and more environmentally friendly alternative to tetrahydrofuran and methylene chloride.	Less volatile Lower toxicity Relatively inert Stable in strongly basic conditions Non-ozone depleter Polarity between methylene chloride and ethyl acetate Dissolves organic compounds Miscible with organic solvents	Prepared industrially from toluen Solvent removal requires more energy (boiling point: 102°C) Wet commercially Hydrolyzes with acids at high temperatures Reacts with strong Lewis acids May be sensitive to reducing conditions involving electron transfer but compatible with hydride reductions and
	Cyclohexane	Cyclohexane is listed as an air contaminant and hazardous substance but in some instances can be used as a safer alternative to more hazardous chemicals.	Dielectric constant and boiling point similar to carbon tetrachloride	Freezing point lower than carbon tetrachloride by 30 degrees

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Methyl acetate	Methyl acetate, although regulated as an air contaminant, is a viable alternative for a number of more hazardous solvents.		
Carbon monoxide	Titanosilicate molecular sieves	Titanosilicate molecular sieves can avoid the use of many hazardous chemicals and/or processes by effectively catalyzing a number of reactions including the synthesis of many carbonates and carbamates.		
	Zeolites	Zeolites are crystalline solids that can replace a number of hazardous catalysts used in traditional reactions such as oxidation and reduction reactions, hydrogen-exchange reactions, and the syntheses of carbamates..		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Carbonyl chloride	1,1-Carbonylbisbenzotriazole	1,1-Carbonylbisbenzotriazole is a chemical compound tha can be used in the place of phosgene in syntheses reactions.		
	1,1-Carbonylbisimidazole	1,1-Carbonylbisimidazole has been a viable chemical alternative for phosgene in syntheses reactions.		
	Bis(4-nitrophenyl)carbonate	Bis(4-nitrophenyl)carbonate is a safer chemical compoun that can be used in the place of phosgene in syntheses reactions.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Di-tert-butyl dicarbonate	Di-tert-butyl dicarbonate (BOC anhydride) is chemical compound often used in organic syntheses as a protecting agent or as a precursor in syntheses. It can be used in the place of phosgene in syntheses reactions.		
	Dimethyl carbonate	Dimethyl carbonate (DMC) is a viable, green alternative f hazardous methylating agents such as dimethyl sulfate.	Non-toxic Non-mutagenic Methoxycarbonylating agent at 90°C Methylating agent at 160°C Avoids unwanted inorganic salt byproducts Only needs a catalytic amount of base	Requires pressure over 3 bars for batch processes because boiling point of DMC is 90°C Flammable
	S,S-dimethyldithiocarbonate	S,S-dimethyldithiocarbonate (DMDTC) is a milder chemical compound that can be used in the place of phosgene in syntheses reactions involving carbonylation.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Trihaloacetylchlorides	Trihaloacetylchlorides are safer chemical compounds that can be used in the place of phosgene in syntheses reactions.		
	Triphosgene	Triphosgene , though still hazardous, may be used as an easier to handle substitute for phosgene in chemical reactions.		
	Zeolites	Zeolites are crystalline solids that can replace a number of hazardous catalysts used in traditional reactions such as oxidation and reduction reactions, hydrogen-exchange reactions, and the syntheses of carbamates..		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Chlorinated solvents	Benzotrifluoride	Benzotrifluoride (BTF, C7H5F3) is a less toxic and more environmentally friendly alternative to tetrahydrofuran and methylene chloride.	Less volatile Lower toxicity Relatively inert Stable in strongly basic conditions Non-ozone depleter Polarity between methylene chloride and ethyl acetate Dissolves organic compounds Miscible with organic solvents	Prepared industrially from toluen Solvent removal requires more energy (boiling point: 102°C) Wet commercially Hydrolyzes with acids at high temperatures Reacts with strong Lewis acids May be sensitive to reducing conditions involving electron transfer but compatible with hydride reductions and
	d-Limonene	d-Limonene is a naturally derived citrus terpene or solvent that can be used to replace methylene chloride as a cleaning agent	Biodegradable	Solvent removal requires more energy (boiling point: 175.5-178°C) Suspected carcinogen Air oxidation of this chemical may create allergens.
	Diacetone Alcohol (DAA),	Diacetone Alcohol (DAA), though regulated as an air contaminant, is a higher flashpoint solvent that can be used to replace chlorinated solvents and generic hazardous solvents such as acetone as a cleaning agent	Higher flashpoint	Federally regulated as hazardous substance

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Ethanol	Ethanol is a high volume chemical that is listed by the EPA as an air contaminant.		
	Lactate esters	Lactate esters (such as ethyl lactate) have shown excellent solvent properties as safer, non-toxic, and biodegradable chemical alternatives to several halogenated compounds, making them viable replacements in as cleaning agents or reaction solvents.	Biodegradable Non-toxic	Solvent removal requires more energy (boiling point: 154°C)
	Methyl acetate	Methyl acetate, although regulated as an air contaminant, is a viable alternative for a number of more hazardous solvents.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Methyl soyate	Methyl soyate, a type of methyl ester, is a biodegradable, less toxic alternative that can replace methylene chloride as a cleaning agent.	Lower toxicity Non-irritant to eyes and skin High flashpoint Cleaning performance is similar to NMP and DMF Biodegradable Renewable	Solvent removal requires more energy (boiling point: > 200°C) Slow evaporation may leave film on surfaces
	N-methyl pyrrolidone	N-methyl pyrrolidone (NMP) is a higher flashpoint solvent that can be used in the place of many chlorinated or generic hazardous solvents used for cleaning, such as acetone.		Regulated in California under the Known Carcinogen and Reproductive Toxicants List
	Polyethylene glycol (PEG)	Polyethylene glycol (PEG) is a water soluble solid that can be used as a recyclable solvent medium in the place of volatile organic compounds.	Non-volatile, Inexpensive, Low toxicity (approved for food industry)	Viscous liquid at room temperature for PEG of molecular weights 300 and 600, Waxy solid for PEG 900, 1000, and 1500 which may become liquid under pressurized conditions (40°C at 90 bar), Terminal hydroxyl groups may be esterified or etherified PEG may be coextracted when using supercritical carbon dioxide, although PEG1500 is significantly less likely to be coextracted

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Propylene carbonate (PC)	Propylene carbonate (PC) is a safer, more environmental friendly alternative to chlorinated solvents and generic hazardous solvents used for cleaning, such as acetone.	Fairly biodegradable Non-toxic	High boiling point: 240°C May decompose in aqueous environments
	Supercritical carbon dioxide(scCO2)	Supercritical carbon dioxide(scCO2) has been used in the place of generic hazardous solvents. This includes but is not limited to methylene chloride.	Non-flammable, Tunable solvent properties, Non-toxic, Easy removal from product, Inert to oxidation and radical reactions, Dissolves perfluorinated compounds and gases well, Critical temperature low (Tc = 31.3°C)	Yields not as high traditional solvents, Reactivity with amines, although may reform amine after depressurization, Safety and cost of high pressure equipment (Pc = 72.9 atm)
	Vertec Gold	Vertec Gold is a chemical combination of lactate esters and methyl soyate that exhibits a higher evaporation rate than its components and may be a viable alternative for many hazardous solvents.	Good solvency for cleaning	Not compatible with strong oxidizing agents High boiling point: 144°C

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Chlorobenzene	fluorous ether F-626, benzotrifluoride, fluorous dimethylformamide (F-DMF), and perfluorohexanes (FC-72)	Fluorous solvents, such as the fluorous ether F-626, benzotrifluoride, fluorous dimethylformamide (F-DMF), and perfluorohexanes (FC-72) are alternative chemicals that have been used to replace a number of hazardous chlorinated solvents in industry. Their unique properties have also caught the interest of organic chemists.	Can dissolve both organic and fluorous compounds Easy to remove Solvent reusable without purification High boiling point Can form multi-phase reaction systems Relatively non-toxic High solubility of gases	Yields almost comparable but not as high as traditional solvents
Chlorofluorocarbons (CFCs)	d-Limonene	d-Limonene is a naturally derived citrus terpene or solvent that can be used to replace methylene chloride as a cleaning agent	Biodegradable	Solvent removal requires more energy (boiling point: 175.5-178°C) Suspected carcinogen Air oxidation of this chemical may create allergens.
	Lactate esters	Lactate esters (such as ethyl lactate) have shown excellent solvent properties as safer, non-toxic, and biodegradable chemical alternatives to several halogenated compounds, making them viable replacements in as cleaning agents or reaction solvents.	Biodegradable Non-toxic	Solvent removal requires more energy (boiling point: 154°C)

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Methyl soyate	Methyl soyate, a type of methyl ester, is a biodegradable, less toxic alternative that can replace methylene chloride as a cleaning agent.	Lower toxicity Non-irritant to eyes and skin High flashpoint Cleaning performance is similar to NMP and DMF Biodegradable Renewable	Solvent removal requires more energy (boiling point: > 200°C) Slow evaporation may leave film on surfaces
	Volatile methyl siloxanes (VMS)	Volatile methyl siloxanes (VMS), which have been formally ruled by the EPA to be exempt from VOC or Hazardous Air Pollutant regulation, are low molecular weight silicone fluids that provide a less toxic alternative to several hazardous organic solvents. Examples of VMS include hexamethyldisiloxane, octamethyltrisiloxane, and decamethyltetrasiloxane.	Rapidly dries without leaving residue Cleans a variety of contaminants Can be distilled for reuse	Flammable Combustible Toxic
Chloroform	Dimethoxyethane (DME)	Dimethoxyethane (DME) is a colorless liquid that may be used a substitute for more hazardous chemicals such as chloroform. DME is miscible with water.	Similar dieletric constant to chloroform	Miscible with water

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Lactate esters	Lactate esters (such as ethyl lactate) have shown excellent solvent properties as safer, non-toxic, and biodegradable chemical alternatives to several halogenated compounds, making them viable replacements in as cleaning agents or reaction solvents.	Biodegradable Non-toxic	Solvent removal requires more energy (boiling point: 154°C)
	Methyl tert-butyl ether (MTBE) has been used to replace dichloromethane in chromatography and extractions.	Methyl tert-butyl ether (MTBE) has been used to replace dichloromethane in chromatography and extractions.	Lower toxicity than halogenated solvents	Groundwater contaminant after being used as a fuel additive Possible human carcinogen at high doses
	Methylene chloride (DCM or dichloromethane)	Methylene chloride (DCM or dichloromethane) is a commonly used halogenated and volatile organic solvent that is a suspected carcinogen.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Polyethylene glycol (PEG)	Polyethylene glycol (PEG) is a water soluble solid that can be used as a recyclable solvent medium in the place of volatile organic compounds.	Non-volatile, Inexpensive, Low toxicity (approved for food industry)	Viscous liquid at room temperature for PEG of molecular weights 300 and 600, Waxy solid for PEG 900, 1000, and 1500 which may become liquid under pressurized conditions (40°C at 90 bar), Terminal hydroxyl groups may be esterified or etherified PEG may be coextracted when using supercritical carbon dioxide, although PEG1500 is significantly less likely to be coextracted
Chloroformyl chloride	1,1-Carbonylbisimidazole	1,1-Carbonylbisimidazole has been a viable chemical alternative for phosgene in syntheses reactions.		
	1,1-Carbonylbisbenzotriazole	1,1-Carbonylbisbenzotriazole is a chemical compound that can be used in the place of phosgene in syntheses reactions.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Bis(4-nitrophenyl)carbonate	Bis(4-nitrophenyl)carbonate is a safer chemical compoun that can be used in the place of phosgene in syntheses reactions.		
	Di-tert-butyl dicarbonate (BOC anhydride)	Di-tert-butyl dicarbonate (BOC anhydride) is chemical compound often used in organic syntheses as a protecting agent or as a precursor in syntheses. It can be used in the place of phosgene in syntheses reactions.		
	Dimethyl carbonate (DMC)	Dimethyl carbonate (DMC) is a viable, green alternative f hazardous methylating agents such as dimethyl sulfate.	Non-toxic Non-mutagenic Methoxycarbonylating agent at 90°C Methylating agent at 160°C Avoids unwanted inorganic salt byproducts Only needs a catalytic amount of base	Requires pressure over 3 bars for batch processes because boiling point of DMC is 90°C Flammable

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	S,S-dimethyldithiocarbonate (DMDTC)	S,S-dimethyldithiocarbonate (DMDTC) is a milder chemical compound that can be used in the place of phosgene in syntheses reactions involving carbonylation.		
	Trihaloacetylchlorides	Trihaloacetylchlorides are safer chemical compounds that can be used in the place of phosgene in syntheses reactions.		
	Triphosgene	Triphosgene , though still hazardous, may be used as an easier to handle substitute for phosgene in chemical reactions.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Zeolites	Zeolites are crystalline solids that can replace a number of hazardous catalysts used in traditional reactions such as oxidation and reduction reactions, hydrogen-exchange reactions, and the syntheses of carbamates..		
Chromic Acid	Citranox Liquid Acid Detergent	Citranox Liquid Acid Detergent is a safer,biodegradable substitute for chromic acid in the cleaning of metals, grease, and solvents from hard surfaces.	Biodegradable	Foams
	Contrad 70 Liquid Detergent	Contrad 70 Liquid Detergent is a non-toxic substitute liquid detergent that can be used in the place of chromic acid for cleaning glass, plastic, ceramic, or metals to remove contaminants such as proteins or grease.	Biodegradable Phosphate-free	

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Liqui-Nox Detergent	Liqui-Nox Detergent for Critical Cleaning is a biodegradable, mild substitute for chromic acid in the cleaning of residue from analytical equipment.	Mild Ammonia-free	
	Nochromix Reagent	Nochromix Reagent is an inorganic oxidizer that can be used in solution with sulfuric acid to replace chromic acid in the cleaning of metals from glassware.	Avoids use of chromic acid	Used by mixing with sulfuric acid
Chromium(VI)	catalytic systems	Utilizing catalytic systems in any reaction promotes principles of Green Chemistry by improving the efficiency of a reaction. Many reactions, therefore, can be improve through the use of catalysts and/or using these catalysts in alternative solvents. The catalyst itself, however, may sometimes be very toxic and alternatives for many of thes dangerous catalysts, such as hydrogen fluoride or sulfuric acid, are available.		

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	2,2,6,6-tetramethylpiperidinyl-1-oxy (TEMPO)	2,2,6,6-tetramethylpiperidinyl-1-oxy (TEMPO) systems can be used to catalyze oxidation reactions while avoiding dangerous reagents and catalysts.		
Cyanomethane	fluorided silica-alumina catalysts	Different forms of alumina support, such as fluorided silica-alumina catalysts, offer an alternative to using more hazardous catalysts in a number of chemical processes.		
	Aqueous surfactants and macromolecular solutions	Aqueous surfactants and macromolecular solutions can still solubilize organic reactions by forming micelles.	Avoids volatile organic solvents, May enhance chemical yield and selectivity	Workup and extraction procedures may be tedious

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Ethanol	Ethanol is a high volume chemical that is listed by the EPA as an air contaminant.		
	catalytic systems	Utilizing catalytic systems in any reaction promotes principles of Green Chemistry by improving the efficiency of a reaction. Many reactions, therefore, can be improve through the use of catalysts and/or using these catalysts in alternative solvents. The catalyst itself, however, may sometimes be very toxic and alternatives for many of thes dangerous catalysts, such as hydrogen fluoride or sulfuric acid, are available.		
	fluorous ether F-626, benzotrifluoride, fluorous dimethylformamide (F-DMF), and perfluorohexanes (FC-72)	Fluorous solvents, such as the fluorous ether F-626, benzotrifluoride, fluorous dimethylformamide (F-DMF), and perfluorohexanes (FC-72) are alternative chemicals that have been used to replace a number of hazardous chlorinated solvents in industry. Their unique properties have also caught the interest of organic chemists.	Can dissolve both organic and fluorous compounds Easy to remove Solvent reusable without purification High boiling point Can form multi-phase reaction systems Relatively non-toxic High solubility of gases	Yields almost comparable but not as high as traditional solvents

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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Polyethylene glycol (PEG)	Polyethylene glycol (PEG) is a water soluble solid that can be used as a recyclable solvent medium in the place of volatile organic compounds.	Non-volatile, Inexpensive, Low toxicity (approved for food industry)	Viscous liquid at room temperature for PEG of molecular weights 300 and 600, Waxy solid for PEG 900, 1000, and 1500 which may become liquid under pressurized conditions (40°C at 90 bar), Terminal hydroxyl groups may be esterified or etherified PEG may be coextracted when using supercritical carbon dioxide, although PEG1500 is significantly less likely to be coextracted
	Gas-expanded liquids	Gas-expanded liquids can be used as solvents to increas yields.	Better solubility of gases Reduces viscosity of expanded solvent Enhances mass transfer Non-flammable Tunable solvent strength Suited for reactions already conducted under pressure Avoids unwanted secondary or tertiary amines when gas is CO2 (which forms carbamic acid or carbamates that revert	Liquid expanded may still be a hazardous solvent
	1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions	Ionic liquids are typically molten salts that are liquid below 100°C and provide a less volatile and recyclable alternative to many organic solvents such as methylene chloride. Some of the most popular ionic liquids use 1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions.	Non-volatile, Recyclable, Non explosiveNon-flammable, Commercially available in laboratory quantities, Tetrafluoroborate salts may have relatively low toxicity, Can have hydrogen bond acceptors and donors, Miscibility with water can be tuned by anions, alkyl groups, and sometimes temperature, Can from one, two, or three-phase catalytic systems	Some may be toxic to environment. 1,3-dialkylimidazolium ionic liquids, for instance, are antimicrobial depending on their N-alkyl group chain lengths, May require use of organic solvents in preparation steps, High viscosity (can be lowered if CO2 is dissolved in it), Anions of some ionic liquids may hydrolyze to form undesirable products

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Microwave irradiation	Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from days to minutes. Reactions performed in a microwave batch reactor, for instance, can be constantly monitored, and temperature and pressure can be manually controlled, often leading to more complete reactions and higher product yields.		
	solventless or solvent-free reactions	The use of hazardous chemicals can often be avoided without the addition of a reaction solvent in solventless or solvent-free reactions. Although a reactant may act as a solvent to still allow for a liquid reaction, other reactions can occur simply by crushing two solids together in the dry phase.		
	Supercritical carbon dioxide(scCO2)	Supercritical carbon dioxide(scCO2) has been used in the place of generic hazardous solvents. This includes but is not limited to methylene chloride.	Non-flammable, Tunable solvent properties, Non-toxic, Easy removal from product, Inert to oxidation and radical reactions, Dissolves perfluorinated compounds and gases well, Critical temperature low (Tc = 31.3°C)	Yields not as high traditional solvents, Reactivity with amines, although may reform amine after depressurization, Safety and cost of high pressure equipment (Pc = 72.9 atm)

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Dichloromethane	fluorided silica-alumina catalysts	Different forms of alumina support, such as fluorided silica-alumina catalysts, offer an alternative to using more hazardous catalysts in a number of chemical processes.		
	Benzotrifluoride	Benzotrifluoride (BTF, C7H5F3) is a less toxic and more environmentally friendly alternative to tetrahydrofuran and methylene chloride.	Less volatile Lower toxicity Relatively inert Stable in strongly basic conditions Non-ozone depleter Polarity between methylene chloride and ethyl acetate Dissolves organic compounds Miscible with organic solvents	Prepared industrially from toluen Solvent removal requires more energy (boiling point: 102°C) Wet commercially Hydrolyzes with acids at high temperatures Reacts with strong Lewis acids May be sensitive to reducing conditions involving electron transfer but compatible with hydride reductions and
	catalytic systems	Utilizing catalytic systems in any reaction promotes principles of Green Chemistry by improving the efficiency of a reaction. Many reactions, therefore, can be improve through the use of catalysts and/or using these catalysts in alternative solvents. The catalyst itself, however, may sometimes be very toxic and alternatives for many of thes dangerous catalysts, such as hydrogen fluoride or sulfuric acid, are available.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	d-Limonene	d-Limonene is a naturally derived citrus terpene or solvent that can be used to replace methylene chloride as a cleaning agent	Biodegradable	Solvent removal requires more energy (boiling point: 175.5-178°C) Suspected carcinogen Air oxidation of this chemical may create allergens.
	Dibasic esters	Dibasic esters (DBE) are by-products from the synthesis of adipic acid that are a less volatile and safer alternative to methylene chloride.	Biodegradable Solvent properties similar to methylene chloride Byproduct of current industrial processes	Solvent removal requires more energy (boiling point: 196-225°C) Incompatible with strong acids, bases, oxidants, and reducers Attracted to positively charged metal surfaces and may leave films
	Diethoxymethane (DEM or formaldehyde diethylactal)	Diethoxymethane (DEM or formaldehyde diethylactal) has been used as a good substitute for methylene chloride ar tetrahydrofuran.	Stable in aqueous acidic conditions and decomposes less than 1% Less likely to form peroxides than other ethers	Solvent removal requires more energy (boiling point: 88°C) Not stable under homgeneous acidic conditions and may liberate formaldehyde

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions	Ionic liquids are typically molten salts that are liquid below 100°C and provide a less volatile and recyclable alternative to many organic solvents such as methylene chloride. Some of the most popular ionic liquids use 1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions.	Non-volatile, Recyclable, Non explosiveNon-flammable, Commercially available in laboratory quantities, Tetrafluoroborate salts may have relatively low toxicity, Can have hydrogen bond acceptors and donors, Miscibility with water can be tuned by anions, alkyl groups, and sometimes temperature, Can from one, two, or three-phase catalytic systems	Some may be toxic to environment. 1,3-dialkylimidazolium ionic liquids, for instance, are antimicrobial depending on their N-alkyl group chain lengths, May require use of organic solvents in preparation steps, High viscosity (can be lowered if CO2 is dissolved in it), Anions of some ionic liquids may hydrolyze to form undesirable products
	Ethanol	Ethanol is a high volume chemical that is listed by the EPA as an air contaminant.		
	Lactate esters	Lactate esters (such as ethyl lactate) have shown excellent solvent properties as safer, non-toxic, and biodegradable chemical alternatives to several halogenated compounds, making them viable replacements in as cleaning agents or reaction solvents.	Biodegradable Non-toxic	Solvent removal requires more energy (boiling point: 154°C)

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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Methyl soyate	Methyl soyate, a type of methyl ester, is a biodegradable, less toxic alternative that can replace methylene chloride as a cleaning agent.	Lower toxicity Non-irritant to eyes and skin High flashpoint Cleaning performance is similar to NMP and DMF Biodegradable Renewable	Solvent removal requires more energy (boiling point: > 200°C) Slow evaporation may leave film on surfaces
	Methyl tert-butyl ether (MTBE)	Methyl tert-butyl ether (MTBE) has been used to replace dichloromethane in chromatography and extractions.	Lower toxicity than halogenated solvents	Groundwater contaminant after being used as a fuel additive Possible human carcinogen at high doses
	N-methyl pyrrolidone (NMP)	N-methyl pyrrolidone (NMP) is a higher flashpoint solvent that can be used in the place of many chlorinated or generic hazardous solvents used for cleaning, such as acetone.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Supercritical fluids	Supercritical fluids have been used widely in industry to replace the use of organic solvents such as methylene chloride.	Non-flammable Tunable solvent properties Non-toxic Easy removal from product	Yields not as high traditional solvents Safety and cost of high pressure equipment
Diethyl Ether	Butyl diglyme, or diethylene glycol dibutyl ether	Butyl diglyme, or diethylene glycol dibutyl ether, is a viable alternative to many solvents often used in Grignard reactions.	Immiscible with water	Solvent removal requires more energy (boiling point: 256°C). Lower boiling point solvents that are similar but miscible with water are monoglyme (DME) and diglyme
	Indium metal	Indium metal, a non-toxic metal often used in dental alloy is a viable alternative for many hazardous catalyst systems.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions	Ionic liquids are typically molten salts that are liquid below 100°C and provide a less volatile and recyclable alternative to many organic solvents such as methylene chloride. Some of the most popular ionic liquids use 1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions.	Non-volatile, Recyclable, Non explosiveNon-flammable, Commercially available in laboratory quantities, Tetrafluoroborate salts may have relatively low toxicity, Can have hydrogen bond acceptors and donors, Miscibility with water can be tuned by anions, alkyl groups, and sometimes temperature, Can from one, two, or three-phase catalytic systems	Some may be toxic to environment. 1,3-dialkylimidazolium ionic liquids, for instance, are antimicrobial depending on their N-alkyl group chain lengths, May require use of organic solvents in preparation steps, High viscosity (can be lowered if CO2 is dissolved in it), Anions of some ionic liquids may hydrolyze to form undesirable products
	Methyl tert-butyl ether (MTBE)	Methyl tert-butyl ether (MTBE) has been used to replace dichloromethane in chromatography and extractions.	Lower toxicity than halogenated solvents	Groundwater contaminant after being used as a fuel additive Possible human carcinogen at high doses
	n-Octyl tetrahydrofurfuryl ether (n-OTE)	n-Octyl tetrahydrofurfuryl ether (n-OTE) is tetrahydrofuran derivative that can be used as an alternative solvent to tetrahydrofuran. This less water soluble replacement for THF offers a safer, more environmentally friendly alternative that avoids additional steps usually taken to remove water from THF.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Supercritical carbon dioxide(scCO2)	Supercritical carbon dioxide(scCO2) has been used in the place of generic hazardous solvents. This includes but is not limited to methylene chloride.	Non-flammable, Tunable solvent properties, Non-toxic, Easy removal from product, Inert to oxidation and radical reactions, Dissolves perfluorinated compounds and gases well, Critical temperature low (Tc = 31.3°C)	Yields not as high traditional solvents, Reactivity with amines, although may reform amine after depressurization, Safety and cost of high pressure equipment (Pc = 72.9 atm)
Dimethoxyethane (DME)	Diethoxymethane (DEM or formaldehyde diethylactal)	Diethoxymethane (DEM or formaldehyde diethylactal) has been used as a good substitute for methylene chloride ar tetrahydrofuran.	Diethoxymethane (DEM or formaldehyde diethylactal) has been used as a good substitute for methylene chloride and tetrahydrofuran.	Solvent removal requires more energy (boiling point: 88°C) Not stable under homgeneous acidic conditions and may liberate formaldehyde
Dimethyl Sulfate (DMS)	Dimethyl carbonate (DMC)	Dimethyl carbonate (DMC) is a viable, green alternative f hazardous methylating agents such as dimethyl sulfate.	Non-toxic Non-mutagenic Methoxycarbonylating agent at 90°C Methylating agent at 160°C Avoids unwanted inorganic salt byproducts Only needs a catalytic amount of base	Requires pressure over 3 bars for batch processes because boiling point of DMC is 90°C Flammable

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Dimethyl formamide (DMF)	fluorous ether F-626, benzotrifluoride, fluorous dimethylformamide (F-DMF), and perfluorohexanes (FC-72)	Fluorous solvents, such as the fluorous ether F-626, benzotrifluoride, fluorous dimethylformamide (F-DMF), and perfluorohexanes (FC-72) are alternative chemicals that have been used to replace a number of hazardous chlorinated solvents in industry. Their unique properties have also caught the interest of organic chemists.	Can dissolve both organic and fluorous compounds Easy to remove Solvent reusable without purification High boiling point Can form multi-phase reaction systems Relatively non-toxic High solubility of gases	Yields almost comparable but not as high as traditional solvents
	fluorided silica-alumina catalysts	Different forms of alumina support, such as fluorided silica-alumina catalysts, offer an alternative to using more hazardous catalysts in a number of chemical processes.		
	Glucose	Glucose is a natural, biologically made sugar that has proven to be a viable substitute for a number of more hazardous chemicals.	Mild, Renewable resource	

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Microwave irradiation	Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from days to minutes. Reactions performed in a microwave batch reactor, for instance, can be constantly monitored, and temperature and pressure can be manually controlled, often leading to more complete reactions and higher product yields.		
	N-methyl pyrrolidone (NMP)	N-methyl pyrrolidone (NMP) is a higher flashpoint solvent that can be used in the place of many chlorinated or generic hazardous solvents used for cleaning, such as acetone.		
	Polyethylene glycol (PEG)	Polyethylene glycol (PEG) is a water soluble solid that can be used as a recyclable solvent medium in the place of volatile organic compounds.	Non-volatile, Inexpensive, Low toxicity (approved for food industry)	Viscous liquid at room temperature for PEG of molecular weights 300 and 600, Waxy solid for PEG 900, 1000, and 1500 which may become liquid under pressurized conditions (40°C at 90 bar), Terminal hydroxyl groups may be esterified or etherified PEG may be coextracted when using supercritical carbon dioxide, although PEG1500 is significantly less likely to be coextracted

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	solventless or solvent-free reactions	The use of hazardous chemicals can often be avoided without the addition of a reaction solvent in solventless or solvent-free reactions. Although a reactant may act as a solvent to still allow for a liquid reaction, other reactions can occur simply by crushing two solids together in the dry phase.		
Dimethyl glycol	Diethoxymethane (DEM or formaldehyde diethylactal)	Diethoxymethane (DEM or formaldehyde diethylactal) has been used as a good substitute for methylene chloride ar tetrahydrofuran.	Diethoxymethane (DEM or formaldehyde diethylactal) has been used as a good substitute for methylene chloride and tetrahydrofuran.	Solvent removal requires more energy (boiling point: 88°C) Not stable under homgeneous acidic conditions and may liberate formaldehyde
Dimethyl sulfoxide (DMSO)	1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions	Ionic liquids are typically molten salts that are liquid below 100°C and provide a less volatile and recyclable alternative to many organic solvents such as methylene chloride. Some of the most popular ionic liquids use 1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions.	Non-volatile, Recyclable, Nor explosiveNon-flammable, Commercially available in laboratory quantities, Tetrafluoroborate salts may have relatively low toxicity, Can have hydrogen bond acceptors and donors, Miscibility with water can be tuned by anions, alkyl groups, and sometimes temperature, Can from one, two, or three-phase catalytic systems	Some may be toxic to environment. 1,3-dialkylimidazolium ionic liquids, for instance, are antimicrobial depending on their N-alkyl group chain lengths, May require use of organic solvents in preparation steps, High viscosity (can be lowered if CO2 is dissolved in it), Anions of some ionic liquids may hydrolyze to form undesirable products

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	n-Octyl tetrahydrofurfuryl ether (n-OTE)	n-Octyl tetrahydrofurfuryl ether (n-OTE) is tetrahydrofuran derivative that can be used as an alternative solvent to tetrahydrofuran. This less water soluble replacement for THF offers a safer, more environmentally friendly alternative that avoids additional steps usually taken to remove water from THF.		
	Polyethylene glycol (PEG)	Polyethylene glycol (PEG) is a water soluble solid that can be used as a recyclable solvent medium in the place of volatile organic compounds.	Non-volatile, Inexpensive, Low toxicity (approved for food industry)	Viscous liquid at room temperature for PEG of molecular weights 300 and 600, Waxy solid for PEG 900, 1000, and 1500 which may become liquid under pressurized conditions (40°C at 90 bar), Terminal hydroxyl groups may be esterified or etherified PEG may be coextracted when using supercritical carbon dioxide, although PEG1500 is significantly less likely to be coextracted
	solventless or solvent-free reactions	The use of hazardous chemicals can often be avoided without the addition of a reaction solvent in solventless or solvent-free reactions. Although a reactant may act as a solvent to still allow for a liquid reaction, other reactions can occur simply by crushing two solids together in the dry phase.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	fluorided silica-alumina catalysts	Different forms of alumina support, such as fluorided silica-alumina catalysts, offer an alternative to using more hazardous catalysts in a number of chemical processes.		
	Microwave irradiation	Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from days to minutes. Reactions performed in a microwave batch reactor, for instance, can be constantly monitored, and temperature and pressure can be manually controlled, often leading to more complete reactions and higher product yields.		
Ethanol	DNA extraction kits	Several companies now offer DNA extraction kits which can be used in the place of traditional DNA extraction methods to avoid the use of more hazardous substances and the generation of unnecessary wastes.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	catalytic systems	Utilizing catalytic systems in any reaction promotes principles of Green Chemistry by improving the efficiency of a reaction. Many reactions, therefore, can be improve through the use of catalysts and/or using these catalysts in alternative solvents. The catalyst itself, however, may sometimes be very toxic and alternatives for many of thes dangerous catalysts, such as hydrogen fluoride or sulfuric acid, are available.		
	Microwave irradiation	Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from days to minutes. Reactions performed in a microwave batch reactor, for instance, can be constantly monitored, and temperature and pressure can be manually controlled, often leading to more complete reactions and higher product yields.		
	Water	Water, the universal solvent, has been recognized as one of the safest and most environmentally friendly alternative to hazardous solvents. Several organic reactions, for instance, have been conducted quite successfully in aqueous instead of organic solutions.	Good for radical reactions (H abstraction from OH unlikely and no reactive multipl bonds) Non-flammable Can avoid tedious protection steps Solvent properties change with increasing temperature	Subsequent workup may be energy intensive and/or involve the use of organic solvents

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Ether	Butyl diglyme, or diethylene glycol dibutyl ether	Butyl diglyme, or diethylene glycol dibutyl ether, is a viable alternative to many solvents often used in Grignard reactions.	Immiscible with water	Solvent removal requires more energy (boiling point: 256°C). Lower boiling point solvents that are similar but miscible with water are monoglyme (DME) and diglyme
	Indium metal	Indium metal, a non-toxic metal often used in dental alloy is a viable alternative for many hazardous catalyst systems.		
	1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions	Ionic liquids are typically molten salts that are liquid below 100°C and provide a less volatile and recyclable alternative to many organic solvents such as methylene chloride. Some of the most popular ionic liquids use 1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions.	Non-volatile, Recyclable, Non explosiveNon-flammable, Commercially available in laboratory quantities, Tetrafluoroborate salts may have relatively low toxicity, Can have hydrogen bond acceptors and donors, Miscibility with water can be tuned by anions, alkyl groups, and sometimes temperature, Can from one, two, or three-phase catalytic systems	Some may be toxic to environment. 1,3-dialkylimidazolium ionic liquids, for instance, are antimicrobial depending on their N-alkyl group chain lengths, May require use of organic solvents in preparation steps, High viscosity (can be lowered if CO2 is dissolved in it), Anions of some ionic liquids may hydrolyze to form undesirable products

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Methyl tert-butyl ether (MTBE)	Methyl tert-butyl ether (MTBE) has been used to replace dichloromethane in chromatography and extractions.	Lower toxicity than halogenated solvents	Groundwater contaminant after being used as a fuel additive Possible human carcinogen at high doses
	n-Octyl tetrahydrofurfuryl ether (n-OTE)	n-Octyl tetrahydrofurfuryl ether (n-OTE) is tetrahydrofuran derivative that can be used as an alternative solvent to tetrahydrofuran. This less water soluble replacement for THF offers a safer, more environmentally friendly alternative that avoids additional steps usually taken to remove water from THF.		
	Supercritical carbon dioxide(scCO2)	Supercritical carbon dioxide(scCO2) has been used in the place of generic hazardous solvents. This includes but is not limited to methylene chloride.	Non-flammable, Tunable solvent properties, Non-toxic, Easy removal from product, Inert to oxidation and radical reactions, Dissolves perfluorinated compounds and gases well, Critical temperature low (Tc = 31.3°C)	Yields not as high traditional solvents, Reactivity with amines, although may reform amine after depressurization, Safety and cost of high pressure equipment (Pc = 72.9 atm)

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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Water	Water, the universal solvent, has been recognized as one of the safest and most environmentally friendly alternatives to hazardous solvents. Several organic reactions, for instance, have been conducted quite successfully in aqueous instead of organic solutions.	Good for radical reactions (H abstraction from OH unlikely and no reactive multipl bonds) Non-flammable Can avoid tedious protection steps Solvent properties change with increasing temperature	Subsequent workup may be energy intensive and/or involve the use of organic solvents
Ethidium Bromide	SybrSafe(TM)	SybrSafe(TM) have proven to be a safer and more effective DNA gel staining agent than ethidium bromide.	Less background and stronger fluorescence in DNA staining Lower disposal costs (approved for sewage disposal in MA)	Higher up-front cost
Ethoxyethane	Butyl diglyme, or diethylene glycol dibutyl ether	Butyl diglyme, or diethylene glycol dibutyl ether, is a viable alternative to many solvents often used in Grignard reactions.	Immiscible with water	Solvent removal requires more energy (boiling point: 256°C). Lower boiling point solvents that are similar but miscible with water are monoglyme (DME) and diglyme

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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Indium metal	Indium metal, a non-toxic metal often used in dental alloy is a viable alternative for many hazardous catalyst systems.		
	1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions	Ionic liquids are typically molten salts that are liquid below 100°C and provide a less volatile and recyclable alternative to many organic solvents such as methylene chloride. Some of the most popular ionic liquids use 1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions.	Non-volatile, Recyclable, Non explosiveNon-flammable, Commercially available in laboratory quantities, Tetrafluoroborate salts may have relatively low toxicity, Can have hydrogen bond acceptors and donors, Miscibility with water can be tuned by anions, alkyl groups, and sometimes temperature, Can from one, two, or three-phase catalytic systems	Some may be toxic to environment. 1,3-dialkylimidazolium ionic liquids, for instance, are antimicrobial depending on their N-alkyl group chain lengths, May require use of organic solvents in preparation steps, High viscosity (can be lowered if CO2 is dissolved in it), Anions of some ionic liquids may hydrolyze to form undesirable products
	Methyl tert-butyl ether (MTBE)	Methyl tert-butyl ether (MTBE) has been used to replace dichloromethane in chromatography and extractions.	Lower toxicity than halogenated solvents	Groundwater contaminant after being used as a fuel additive Possible human carcinogen at high doses

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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	n-Octyl tetrahydrofurfuryl ether (n-OTE)	n-Octyl tetrahydrofurfuryl ether (n-OTE) is tetrahydrofuran derivative that can be used as an alternative solvent to tetrahydrofuran. This less water soluble replacement for THF offers a safer, more environmentally friendly alternative that avoids additional steps usually taken to remove water from THF.		
	Supercritical carbon dioxide(scCO2)	Supercritical carbon dioxide(scCO2) has been used in the place of generic hazardous solvents. This includes but is not limited to methylene chloride.	Non-flammable, Tunable solvent properties, Non-toxic, Easy removal from product, Inert to oxidation and radical reactions, Dissolves perfluorinated compounds and gases well, Critical temperature low (Tc = 31.3°C)	Yields not as high traditional solvents, Reactivity with amines, although may reform amine after depressurization, Safety and cost of high pressure equipment (Pc = 72.9 atm)
	Water	Water, the universal solvent, has been recognized as one of the safest and most environmentally friendly alternative to hazardous solvents. Several organic reactions, for instance, have been conducted quite successfully in aqueous instead of organic solutions.	Good for radical reactions (H abstraction from OH unlikely and no reactive multipl bonds) Non-flammable Can avoid tedious protection steps Solvent properties change with increasing temperature	Subsequent workup may be energy intensive and/or involve the use of organic solvents

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Ethyl Acetate	Diethoxymethane (DEM or formaldehyde diethylactal)	Diethoxymethane (DEM or formaldehyde diethylactal) has been used as a good substitute for methylene chloride ar tetrahydrofuran.	Diethoxymethane (DEM or formaldehyde diethylactal) has been used as a good substitute for methylene chloride and tetrahydrofuran.	Solvent removal requires more energy (boiling point: 88°C) Not stable under homgeneous acidic conditions and may liberate formaldehyde
	Indium metal	Indium metal, a non-toxic metal often used in dental alloy is a viable alternative for many hazardous catalyst systems.		
	Methyl tert-butyl ether (MTBE)	Methyl tert-butyl ether (MTBE) has been used to replace dichloromethane in chromatography and extractions.	Lower toxicity than halogenated solvents	Groundwater contaminant after being used as a fuel additive Possible human carcinogen at high doses

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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Water	Water, the universal solvent, has been recognized as one of the safest and most environmentally friendly alternative to hazardous solvents. Several organic reactions, for instance, have been conducted quite successfully in aqueous instead of organic solutions.	Good for radical reactions (H abstraction from OH unlikely and no reactive multipl bonds) Non-flammable Can avoid tedious protection steps Solvent properties change with increasing temperature	Subsequent workup may be energy intensive and/or involve the use of organic solvents
	Ethanol	Ethanol is a high volume chemical that is listed by the EPA as an air contaminant.		
Ethyl Ether	Butyl diglyme, or diethylene glycol dibutyl ether	Butyl diglyme, or diethylene glycol dibutyl ether, is a viable alternative to many solvents often used in Grignard reactions.	Immiscible with water	Solvent removal requires more energy (boiling point: 256°C). Lower boiling point solvents that are similar but miscible with water are monoglyme (DME) and diglyme

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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Indium metal	Indium metal, a non-toxic metal often used in dental alloy is a viable alternative for many hazardous catalyst systems.		
	1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions	Ionic liquids are typically molten salts that are liquid below 100°C and provide a less volatile and recyclable alternative to many organic solvents such as methylene chloride. Some of the most popular ionic liquids use 1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions.	Non-volatile, Recyclable, Non explosiveNon-flammable, Commercially available in laboratory quantities, Tetrafluoroborate salts may have relatively low toxicity, Can have hydrogen bond acceptors and donors, Miscibility with water can be tuned by anions, alkyl groups, and sometimes temperature, Can from one, two, or three-phase catalytic systems	Some may be toxic to environment. 1,3-dialkylimidazolium ionic liquids, for instance, are antimicrobial depending on their N-alkyl group chain lengths, May require use of organic solvents in preparation steps, High viscosity (can be lowered if CO2 is dissolved in it), Anions of some ionic liquids may hydrolyze to form undesirable products
	Methyl tert-butyl ether (MTBE)	Methyl tert-butyl ether (MTBE) has been used to replace dichloromethane in chromatography and extractions.	Lower toxicity than halogenated solvents	Groundwater contaminant after being used as a fuel additive Possible human carcinogen at high doses

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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	n-Octyl tetrahydrofurfuryl ether (n-OTE)	n-Octyl tetrahydrofurfuryl ether (n-OTE) is tetrahydrofuran derivative that can be used as an alternative solvent to tetrahydrofuran. This less water soluble replacement for THF offers a safer, more environmentally friendly alternative that avoids additional steps usually taken to remove water from THF.		
	Supercritical carbon dioxide(scCO2)	Supercritical carbon dioxide(scCO2) has been used in the place of generic hazardous solvents. This includes but is not limited to methylene chloride.	Non-flammable, Tunable solvent properties, Non-toxic, Easy removal from product, Inert to oxidation and radical reactions, Dissolves perfluorinated compounds and gases well, Critical temperature low (Tc = 31.3°C)	Yields not as high traditional solvents, Reactivity with amines, although may reform amine after depressurization, Safety and cost of high pressure equipment (Pc = 72.9 atm)
	Water	Water, the universal solvent, has been recognized as one of the safest and most environmentally friendly alternative to hazardous solvents. Several organic reactions, for instance, have been conducted quite successfully in aqueous instead of organic solutions.	Good for radical reactions (H abstraction from OH unlikely and no reactive multipl bonds) Non-flammable Can avoid tedious protection steps Solvent properties change with increasing temperature	Subsequent workup may be energy intensive and/or involve the use of organic solvents

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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Ethylene glycol dimethyl ether	Diethoxymethane (DEM or formaldehyde diethylactal)	Diethoxymethane (DEM or formaldehyde diethylactal) has been used as a good substitute for methylene chloride ar tetrahydrofuran.	Diethoxymethane (DEM or formaldehyde diethylactal) has been used as a good substitute for methylene chloride and tetrahydrofuran.	Solvent removal requires more energy (boiling point: 88°C) Not stable under homgeneous acidic conditions and may liberate formaldehyde
Formaldehyde	Diethoxymethane (DEM or formaldehyde diethylactal)	Diethoxymethane (DEM or formaldehyde diethylactal) has been used as a good substitute for methylene chloride ar tetrahydrofuran.	Diethoxymethane (DEM or formaldehyde diethylactal) has been used as a good substitute for methylene chloride and tetrahydrofuran.	Solvent removal requires more energy (boiling point: 88°C) Not stable under homgeneous acidic conditions and may liberate formaldehyde
Glyme	Diethoxymethane (DEM or formaldehyde diethylactal)	Diethoxymethane (DEM or formaldehyde diethylactal) has been used as a good substitute for methylene chloride ar tetrahydrofuran.	Diethoxymethane (DEM or formaldehyde diethylactal) has been used as a good substitute for methylene chloride and tetrahydrofuran.	Solvent removal requires more energy (boiling point: 88°C) Not stable under homgeneous acidic conditions and may liberate formaldehyde

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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Hexamethylphosphoramide (HMPA)	Dimethylpropyleneurea (DMPU)	Dimethylpropyleneurea (DMPU) is a viable and safer chemical alternative for diprotic apolar solvents such as hexamethylphosphoramide (HMPA).		
Hexane	Cetyltrimethylammonium chloride (CTAC)	Cetyltrimethylammonium chloride (CTAC) is a cationic aqueous surfactant that can be used to accelerate reactions in water, including those reactions that normally run in organic solvents.		
	Aqueous surfactants and macromolecular solutions	Aqueous surfactants and macromolecular solutions can still solubilize organic reactions by forming micelles.	Avoids volatile organic solvents, May enhance chemical yield and selectivity	Workup and extraction procedures may be tedious

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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Dimethyldodecylamine oxide (DDAO)	Dimethyldodecylamine oxide (DDAO) is a non-ionic aqueous surfactant that can be used to accelerate reactions in water, including those reactions that normally run in organic solvents.		
	Sodium dodecyl sulfate (SDS)	Sodium dodecyl sulfate (SDS) is a an anionic surfactant that can be used to accelerate reactions in water, including those reactions that normally run in organic solvents.		
	Tetrabutylammonium bromide (TBAB)	Tetrabutylammonium bromide (TBAB) is a chemical that can be used as a phase-transfer catalyst and can be used to replace bromine in bromination reactions.	Good brominating and oxidizing agent	Some syntheses of this reagent may involve hazardous conditions and/or chemicals

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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Volatile methyl siloxanes (VMS)	Volatile methyl siloxanes (VMS), which have been formally ruled by the EPA to be exempt from VOC or Hazardous Air Pollutant regulation, are low molecular weight silicone fluids that provide a less toxic alternative to several hazardous organic solvents. Examples of VMS include hexamethyldisiloxane, octamethyltrisiloxane, and decamethyltetrasiloxane.	Rapidly dries without leaving residue Cleans a variety of contaminants Can be distilled for reuse	Flammable Combustible Toxic
	Supercritical carbon dioxide(scCO2)	Supercritical carbon dioxide(scCO2) has been used in the place of generic hazardous solvents. This includes but is not limited to methylene chloride.	Non-flammable, Tunable solvent properties, Non-toxic, Easy removal from product, Inert to oxidation and radical reactions, Dissolves perfluorinated compounds and gases well, Critical temperature low (Tc = 31.3°C)	Yields not as high traditional solvents, Reactivity with amines, although may reform amine after depressurization, Safety and cost of high pressure equipment (Pc = 72.9 atm)
Hydrofluoric Acid	Microwave irradiation	Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from days to minutes. Reactions performed in a microwave batch reactor, for instance, can be constantly monitored, and temperature and pressure can be manually controlled, often leading to more complete reactions and higher product yields.		

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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	fluorided silica-alumina catalysts	Different forms of alumina support, such as fluorided silica-alumina catalysts, offer an alternative to using more hazardous catalysts in a number of chemical processes.		
	Gas-expanded liquids	Gas-expanded liquids can be used as solvents to increas yields.	Better solubility of gase Reduces viscosity of expanded solvent Enhances mass transfer Non-flammable Tunable solvent strength Suited for reactions already conducted under pressure Avoids unwanted secondary or tertiary amines when gas is CO2 (which forms carbamic acid or carbamates that revert	Liquid expanded may still be a hazardous solvent
	Solid acid catalysts	Solid acid catalysts can be used in the place of a number of hazardous strong acids traditionally used in chemical reactions.		

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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	solventless or solvent-free reactions	The use of hazardous chemicals can often be avoided without the addition of a reaction solvent in solventless or solvent-free reactions. Although a reactant may act as a solvent to still allow for a liquid reaction, other reactions can occur simply by crushing two solids together in the dry phase.		
	Sulfated zirconia	Sulfated zirconia is a solid acid catalyst that can be used in a number of reactions to avoid the use of strong acids such as hydrofluoric acid and other strong Lewis acids.		
	Supercritical carbon dioxide(scCO2)	Supercritical carbon dioxide(scCO2) has been used in the place of generic hazardous solvents. This includes but is not limited to methylene chloride.	Non-flammable, Tunable solvent properties, Non-toxic, Easy removal from product, Inert to oxidation and radical reactions, Dissolves perfluorinated compounds and gases well, Critical temperature low (Tc = 31.3°C)	Yields not as high traditional solvents, Reactivity with amines, although may reform amine after depressurization, Safety and cost of high pressure equipment (Pc = 72.9 atm)

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Zeolites	Zeolites are crystalline solids that can replace a number of hazardous catalysts used in traditional reactions such as oxidation and reduction reactions, hydrogen-exchange reactions, and the syntheses of carbamates..		
Hydrogen Fluoride	Microwave irradiation	Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from days to minutes. Reactions performed in a microwave batch reactor, for instance, can be constantly monitored, and temperature and pressure can be manually controlled, often leading to more complete reactions and higher product yields.		
	fluorided silica-alumina catalysts	Different forms of alumina support, such as fluorided silica-alumina catalysts, offer an alternative to using more hazardous catalysts in a number of chemical processes.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Gas-expanded liquids	Gas-expanded liquids can be used as solvents to increas yields.	Better solubility of gases Reduces viscosity of expanded solvent Enhances mass transfer Non-flammable Tunable solvent strength Suited for reactions already conducted under pressure Avoids unwanted secondary or tertiary amines when gas is CO2 (which forms carbamic acid or carbamates that revert	Liquid expanded may still be a hazardous solvent
	Solid acid catalysts	Solid acid catalysts can be used in the place of a number of hazardous strong acids traditionally used in chemical reactions.		
	solventless or solvent-free reactions	The use of hazardous chemicals can often be avoided without the addition of a reaction solvent in solventless or solvent-free reactions. Although a reactant may act as a solvent to still allow for a liquid reaction, other reactions can occur simply by crushing two solids together in the dry phase.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Sulfated zirconia	Sulfated zirconia is a solid acid catalyst that can be used in a number of reactions to avoid the use of strong acids such as hydrofluoric acid and other strong Lewis acids.		
	Supercritical carbon dioxide(scCO2)	Supercritical carbon dioxide(scCO2) has been used in the place of generic hazardous solvents. This includes but is not limited to methylene chloride.	Non-flammable, Tunable solvent properties, Non-toxic, Easy removal from product, Inert to oxidation and radical reactions, Dissolves perfluorinated compounds and gases well, Critical temperature low (Tc = 31.3°C)	Yields not as high traditional solvents, Reactivity with amines, although may reform amine after depressurization, Safety and cost of high pressure equipment (Pc = 72.9 atm)
	Zeolites	Zeolites are crystalline solids that can replace a number of hazardous catalysts used in traditional reactions such as oxidation and reduction reactions, hydrogen-exchange reactions, and the syntheses of carbamates..		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Hydroxybenzene	DNA extraction kits	Several companies now offer DNA extraction kits which can be used in the place of traditional DNA extraction methods to avoid the use of more hazardous substances and the generation of unnecessary wastes.		
	DNA Extraction with Polycarbonate Filters	Traditional DNA extraction procedures can avoid the use of dangerous and hazardous chemicals by performing DNA extraction with polycarbonate filters.		
	DNA Extraction with Polyethylene Glycol	Traditional DNA extraction procedures can be replaced by alternative processes such as DNA extraction with polethylene glycol and simple salts.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Polyethylene glycol (PEG)	Polyethylene glycol (PEG) is a water soluble solid that can be used as a recyclable solvent medium in the place of volatile organic compounds.	Non-volatile, Inexpensive, Low toxicity (approved for food industry)	Viscous liquid at room temperature for PEG of molecular weights 300 and 600, Waxy solid for PEG 900, 1000, and 1500 which may become liquid under pressurized conditions (40°C at 90 bar), Terminal hydroxyl groups may be esterified or etherified PEG may be coextracted when using supercritical carbon dioxide, although PEG1500 is significantly less likely to be coextracted
Isocyanates		Titanosilicate molecular sieves can avoid the use of many hazardous chemicals and/or processes by effectively catalyzing a number of reactions including the synthesis of many carbonates and carbamates.		
	Zeolites	Zeolites are crystalline solids that can replace a number of hazardous catalysts used in traditional reactions such as oxidation and reduction reactions, hydrogen-exchange reactions, and the syntheses of carbamates..		

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Mercury		Electrodes using mercury to detect trace metals can be replaced with non-mercury electrodes.		
		Alcohol thermometers		
Methanal	Diethoxymethane (DEM or formaldehyde diethylactal)	Diethoxymethane (DEM or formaldehyde diethylactal) has been used as a good substitute for methylene chloride ar tetrahydrofuran.	Diethoxymethane (DEM or formaldehyde diethylactal) has been used as a good substitute for methylene chloride and tetrahydrofuran.	Solvent removal requires more energy (boiling point: 88°C) Not stable under homgeneous acidic conditions and may liberate formaldehyde

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Methanol	fluorided silica-alumina catalysts	Different forms of alumina support, such as fluorided silica-alumina catalysts, offer an alternative to using more hazardous catalysts in a number of chemical processes.		
	Aqueous surfactants and macromolecular solutions	Aqueous surfactants and macromolecular solutions can still solubilize organic reactions by forming micelles.	Avoids volatile organic solvents, May enhance chemical yield and selectivity	Workup and extraction procedures may be tedious
	catalytic systems	Utilizing catalytic systems in any reaction promotes principles of Green Chemistry by improving the efficiency of a reaction. Many reactions, therefore, can be improve through the use of catalysts and/or using these catalysts in alternative solvents. The catalyst itself, however, may sometimes be very toxic and alternatives for many of thes dangerous catalysts, such as hydrogen fluoride or sulfuric acid, are available.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Combisolven t(Aquastar®)	Combisolven t(Aquastar®) is a less toxic and more environmentally friendly chemical currently available to us in the place of methanol in Karl Fischer titrations.		
	Ethanol	Ethanol is a high volume chemical that is listed by the EPA as an air contaminant.		
	Gas-expanded liquids	Gas-expanded liquids can be used as solvents to increas yields.	Better solubility of gases Reduces viscosity of expanded solvent Enhances mass transfer Non-flammable Tunable solvent strength Suited for reactions already conducted under pressure Avoids unwanted secondary or tertiary amines when gas is CO2 (which forms carbamic acid or carbamates that revert	Liquid expanded may still be a hazardous solvent

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions	Ionic liquids are typically molten salts that are liquid below 100°C and provide a less volatile and recyclable alternative to many organic solvents such as methylene chloride. Some of the most popular ionic liquids use 1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions.	Non-volatile, Recyclable, Non explosiveNon-flammable, Commercially available in laboratory quantities, Tetrafluoroborate salts may have relatively low toxicity, Can have hydrogen bond acceptors and donors, Miscibility with water can be tuned by anions, alkyl groups, and sometimes temperature, Can from one, two, or three-phase catalytic systems	Some may be toxic to environment. 1,3-dialkylimidazolium ionic liquids, for instance, are antimicrobial depending on their N-alkyl group chain lengths, May require use of organic solvents in preparation steps, High viscosity (can be lowered if CO2 is dissolved in it), Anions of some ionic liquids may hydrolyze to form undesirable products
	Isopropanol	Isopropanol, the chemical used as rubbing alcohol, can b used as an alternative for more hazardous chemicals.	Less toxic than methanol Non-halogenated	Still a volatile organic compound Flammable
	semi-dry apparatus	The use of a semi-dry apparatus in western blotting or other drying techniques can help to minimize the use of hazardous solvents, such as methanol.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Microwave irradiation	Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from days to minutes. Reactions performed in a microwave batch reactor, for instance, can be constantly monitored, and temperature and pressure can be manually controlled, often leading to more complete reactions and higher product yields.		
	solventless or solvent-free reactions	The use of hazardous chemicals can often be avoided without the addition of a reaction solvent in solventless or solvent-free reactions. Although a reactant may act as a solvent to still allow for a liquid reaction, other reactions can occur simply by crushing two solids together in the dry phase.		
	Supercritical carbon dioxide(scCO2)	Supercritical carbon dioxide(scCO2) has been used in the place of generic hazardous solvents. This includes but is not limited to methylene chloride.	Non-flammable, Tunable solvent properties, Non-toxic, Easy removal from product, Inert to oxidation and radical reactions, Dissolves perfluorinated compounds and gases well, Critical temperature low (Tc = 31.3°C)	Yields not as high traditional solvents, Reactivity with amines, although may reform amine after depressurization, Safety and cost of high pressure equipment (Pc = 72.9 atm)

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Water	Water, the universal solvent, has been recognized as one of the safest and most environmentally friendly alternatives to hazardous solvents. Several organic reactions, for instance, have been conducted quite successfully in aqueous instead of organic solutions.	Good for radical reactions (H abstraction from OH unlikely and no reactive multipl bonds) Non-flammable Can avoid tedious protection steps Solvent properties change with increasing temperature	Subsequent workup may be energy intensive and/or involve the use of organic solvents
Methyl Chloroform	Volatile Methyl Siloxanes (VMS)	Volatile methyl siloxanes (VMS), which have been formally ruled by the EPA to be exempt from VOC or Hazardous Air Pollutant regulation, are low molecular weight silicone fluids that provide a less toxic alternative to several hazardous organic solvents. Examples of VMS include hexamethyldisiloxane, octamethyltrisiloxane, and decamethyltetrasiloxane.	Rapidly dries without leaving residue, Cleans a variety of contaminants, Can b distilled for reuse	Flammable Combustible Toxic
Methyl Cyanide	Microwave irradiation	Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from days to minutes. Reactions performed in a microwave batch reactor, for instance, can be constantly monitored, and temperature and pressure can be manually controlled, often leading to more complete reactions and higher product yields.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	fluorided silica-alumina catalysts	Different forms of alumina support, such as fluorided silica-alumina catalysts, offer an alternative to using more hazardous catalysts in a number of chemical processes.		
	Gas-expanded liquids	Gas-expanded liquids can be used as solvents to increas yields.	Better solubility of gases Reduces viscosity of expanded solvent Enhances mass transfer Non-flammable Tunable solvent strength Suited for reactions already conducted under pressure Avoids unwanted secondary or tertiary amines when gas is CO2 (which forms carbamic acid or carbamates that revert	Liquid expanded may still be a hazardous solvent
	1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions	Ionic liquids are typically molten salts that are liquid below 100°C and provide a less volatile and recyclable alternative to many organic solvents such as methylene chloride. Some of the most popular ionic liquids use 1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions.	Non-volatile, Recyclable, Non explosiveNon-flammable, Commercially available in laboratory quantities, Tetrafluoroborate salts may have relatively low toxicity, Can have hydrogen bond acceptors and donors, Miscibility with water can be tuned by anions, alkyl groups, and sometimes temperature, Can from one, two, or three-phase catalytic systems	Some may be toxic to environment. 1,3-dialkylimidazolium ionic liquids, for instance, are antimicrobial depending on their N-alkyl group chain lengths, May require use of organic solvents in preparation steps, High viscosity (can be lowered if CO2 is dissolved in it), Anions of some ionic liquids may hydrolyze to form undesirable products

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Aqueous surfactants and macromolecular solutions	Aqueous surfactants and macromolecular solutions can still solubilize organic reactions by forming micelles.	Avoids volatile organic solvents, May enhance chemical yield and selectivity	Workup and extraction procedures may be tedious
	catalytic systems	Utilizing catalytic systems in any reaction promotes principles of Green Chemistry by improving the efficiency of a reaction. Many reactions, therefore, can be improve through the use of catalysts and/or using these catalysts in alternative solvents. The catalyst itself, however, may sometimes be very toxic and alternatives for many of thes dangerous catalysts, such as hydrogen fluoride or sulfuric acid, are available.		
	Ethanol	Ethanol is a high volume chemical that is listed by the EPA as an air contaminant.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	fluorous ether F-626, benzotrifluoride, fluorous dimethylformamide (F-DMF), and perfluorohexanes (FC-72)	Fluorous solvents, such as the fluorous ether F-626, benzotrifluoride, fluorous dimethylformamide (F-DMF), and perfluorohexanes (FC-72) are alternative chemicals that have been used to replace a number of hazardous chlorinated solvents in industry. Their unique properties have also caught the interest of organic chemists.	Can dissolve both organic and fluorous compounds Easy to remove Solvent reusable without purification High boiling point Can form multi-phase reaction systems Relatively non-toxic High solubility of gases	Yields almost comparable but not as high as traditional solvents
	Supercritical carbon dioxide(scCO2)	Supercritical carbon dioxide(scCO2) has been used in the place of generic hazardous solvents. This includes but is not limited to methylene chloride.	Non-flammable, Tunable solvent properties, Non-toxic, Easy removal from product, Inert to oxidation and radical reactions, Dissolves perfluorinated compounds and gases well, Critical temperature low (Tc = 31.3°C)	Yields not as high traditional solvents, Reactivity with amines, although may reform amine after depressurization, Safety and cost of high pressure equipment (Pc = 72.9 atm)
	Water	Water, the universal solvent, has been recognized as one of the safest and most environmentally friendly alternative to hazardous solvents. Several organic reactions, for instance, have been conducted quite successfully in aqueous instead of organic solutions.	Good for radical reactions (H abstraction from OH unlikely and no reactive multipl bonds) Non-flammable Can avoid tedious protection steps Solvent properties change with increasing temperature	Subsequent workup may be energy intensive and/or involve the use of organic solvents

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Polyethylene glycol (PEG)	Polyethylene glycol (PEG) is a water soluble solid that can be used as a recyclable solvent medium in the place of volatile organic compounds.	Non-volatile, Inexpensive, Low toxicity (approved for food industry)	Viscous liquid at room temperature for PEG of molecular weights 300 and 600, Waxy solid for PEG 900, 1000, and 1500 which may become liquid under pressurized conditions (40°C at 90 bar), Terminal hydroxyl groups may be esterified or etherified PEG may be coextracted when using supercritical carbon dioxide, although PEG1500 is significantly less likely to be coextracted
	solventless or solvent-free reactions	The use of hazardous chemicals can often be avoided without the addition of a reaction solvent in solventless or solvent-free reactions. Although a reactant may act as a solvent to still allow for a liquid reaction, other reactions can occur simply by crushing two solids together in the dry phase.		
Methyl Halides	Microwave irradiation	Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from days to minutes. Reactions performed in a microwave batch reactor, for instance, can be constantly monitored, and temperature and pressure can be manually controlled, often leading to more complete reactions and higher product yields.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Dimethyl carbonate (DMC)	Dimethyl carbonate (DMC) is a viable, green alternative f hazardous methylating agents such as dimethyl sulfate.	Non-toxic Non-mutagenic Methoxycarbonylating agent at 90°C Methylating agent at 160°C Avoids unwanted inorganic salt byproducts Only needs a catalytic amount of base	Requires pressure over 3 bars for batch processes because boiling point of DMC is 90°C Flammable
	solventless or solvent-free reactions	The use of hazardous chemicals can often be avoided without the addition of a reaction solvent in solventless or solvent-free reactions. Although a reactant may act as a solvent to still allow for a liquid reaction, other reactions can occur simply by crushing two solids together in the dry phase.		
Methyl Iodide	Microwave irradiation	Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from days to minutes. Reactions performed in a microwave batch reactor, for instance, can be constantly monitored, and temperature and pressure can be manually controlled, often leading to more complete reactions and higher product yields.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Dimethyl carbonate (DMC)	Dimethyl carbonate (DMC) is a viable, green alternative f hazardous methylating agents such as dimethyl sulfate.	Non-toxic Non-mutagenic Methoxycarbonylating agent at 90°C Methylating agent at 160°C Avoids unwanted inorganic salt byproducts Only needs a catalytic amount of base	Requires pressure over 3 bars for batch processes because boiling point of DMC is 90°C Flammable
	Microwave irradiation	Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from days to minutes. Reactions performed in a microwave batch reactor, for instance, can be constantly monitored, and temperature and pressure can be manually controlled, often leading to more complete reactions and higher product yields.		
	1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions	Ionic liquids are typically molten salts that are liquid below 100°C and provide a less volatile and recyclable alternative to many organic solvents such as methylene chloride. Some of the most popular ionic liquids use 1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions.	Non-volatile, Recyclable, Non explosiveNon-flammable, Commercially available in laboratory quantities, Tetrafluoroborate salts may have relatively low toxicity, Can have hydrogen bond acceptors and donors, Miscibility with water can be tuned by anions, alkyl groups, and sometimes temperature, Can from one, two, or three-phase catalytic systems	Some may be toxic to environment. 1,3-dialkylimidazolium ionic liquids, for instance, are antimicrobial depending on their N-alkyl group chain lengths, May require use of organic solvents in preparation steps, High viscosity (can be lowered if CO2 is dissolved in it), Anions of some ionic liquids may hydrolyze to form undesirable products

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	fluorided silica-alumina catalysts	Different forms of alumina support, such as fluorided silica-alumina catalysts, offer an alternative to using more hazardous catalysts in a number of chemical processes.		
	Polyethylene glycol (PEG)	Polyethylene glycol (PEG) is a water soluble solid that can be used as a recyclable solvent medium in the place of volatile organic compounds.	Non-volatile, Inexpensive, Low toxicity (approved for food industry)	Viscous liquid at room temperature for PEG of molecular weights 300 and 600, Waxy solid for PEG 900, 1000, and 1500 which may become liquid under pressurized conditions (40°C at 90 bar), Terminal hydroxyl groups may be esterified or etherified PEG may be coextracted when using supercritical carbon dioxide, although PEG1500 is significantly less likely to be coextracted
	n-Octyl tetrahydrofurfuryl ether (n-OTE)	n-Octyl tetrahydrofurfuryl ether (n-OTE) is tetrahydrofuran derivative that can be used as an alternative solvent to tetrahydrofuran. This less water soluble replacement for THF offers a safer, more environmentally friendly alternative that avoids additional steps usually taken to remove water from THF.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	solventless or solvent-free reactions	The use of hazardous chemicals can often be avoided without the addition of a reaction solvent in solventless or solvent-free reactions. Although a reactant may act as a solvent to still allow for a liquid reaction, other reactions can occur simply by crushing two solids together in the dry phase.		
Methyl tert-butyl ether (MTBE)	Diethoxymethane (DEM or formaldehyde diethylactal)	Diethoxymethane (DEM or formaldehyde diethylactal) has been used as a good substitute for methylene chloride ar tetrahydrofuran.	Diethoxymethane (DEM or formaldehyde diethylactal) has been used as a good substitute for methylene chloride and tetrahydrofuran.	Solvent removal requires more energy (boiling point: 88°C) Not stable under homgeneous acidic conditions and may liberate formaldehyde
	Water	Water, the universal solvent, has been recognized as one of the safest and most environmentally friendly alternative to hazardous solvents. Several organic reactions, for instance, have been conducted quite successfully in aqueous instead of organic solutions.	Good for radical reactions (H abstraction from OH unlikely and no reactive multipl bonds) Non-flammable Can avoid tedious protection steps Solvent properties change with increasing temperature	Subsequent workup may be energy intensive and/or involve the use of organic solvents

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Methylbenzene	catalytic systems	Utilizing catalytic systems in any reaction promotes principles of Green Chemistry by improving the efficiency of a reaction. Many reactions, therefore, can be improve through the use of catalysts and/or using these catalysts in alternative solvents. The catalyst itself, however, may sometimes be very toxic and alternatives for many of thes dangerous catalysts, such as hydrogen fluoride or sulfuric acid, are available.		
	d-Limonene	d-Limonene is a naturally derived citrus terpene or solvent that can be used to replace methylene chloride as a cleaning agent	Biodegradable	Solvent removal requires more energy (boiling point: 175.5-178°C) Suspected carcinogen Air oxidation of this chemical may create allergens.
	Diethoxymethane (DEM or formaldehyde diethylactal)	Diethoxymethane (DEM or formaldehyde diethylactal) has been used as a good substitute for methylene chloride ar tetrahydrofuran.	Diethoxymethane (DEM or formaldehyde diethylactal) has been used as a good substitute for methylene chloride and tetrahydrofuran.	Solvent removal requires more energy (boiling point: 88°C) Not stable under homgeneous acidic conditions and may liberate formaldehyde

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Polyethylene glycol (PEG)	Polyethylene glycol (PEG) is a water soluble solid that can be used as a recyclable solvent medium in the place of volatile organic compounds.	Non-volatile, Inexpensive, Low toxicity (approved for food industry)	Viscous liquid at room temperature for PEG of molecular weights 300 and 600, Waxy solid for PEG 900, 1000, and 1500 which may become liquid under pressurized conditions (40°C at 90 bar), Terminal hydroxyl groups may be esterified or etherified PEG may be coextracted when using supercritical carbon dioxide, although PEG1500 is significantly less likely to be coextracted
	Methyl soyate	Methyl soyate, a type of methyl ester, is a biodegradable, less toxic alternative that can replace methylene chloride as a cleaning agent.	Lower toxicity Non-irritant to eyes and skin High flashpoint Cleaning performance is similar to NMP and DMF Biodegradable Renewable	Solvent removal requires more energy (boiling point: > 200°C) Slow evaporation may leave film on surfaces
	Microwave irradiation	Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from days to minutes. Reactions performed in a microwave batch reactor, for instance, can be constantly monitored, and temperature and pressure can be manually controlled, often leading to more complete reactions and higher product yields.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Montmorillonite clay catalysts	Montmorillonite clay catalysts, which are composed of octahedral and tetrahedral sheets of gibbsite and silicate, offer a safer and, in some cases, more effective alternativ to using more hazardous acids in catalyzing a number of chemical reactions.		
	Poly(propylene glycol) or PPG 4025	Poly(propylene glycol) or PPG 4025 is an alternative chemical that may be used in the place of more hazardou solvents, such as toluene.	Low corrosive activity Toxicity decreases with increasing molecular weight	Viscous liquid at room temperature
	solventless or solvent-free reactions	The use of hazardous chemicals can often be avoided without the addition of a reaction solvent in solventless or solvent-free reactions. Although a reactant may act as a solvent to still allow for a liquid reaction, other reactions can occur simply by crushing two solids together in the dry phase.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Supercritical carbon dioxide(scCO2)	Supercritical carbon dioxide(scCO2) has been used in the place of generic hazardous solvents. This includes but is not limited to methylene chloride.	Non-flammable, Tunable solvent properties, Non-toxic, Easy removal from product, Inert to oxidation and radical reactions, Dissolves perfluorinated compounds and gases well, Critical temperature low (Tc = 31.3°C)	Yields not as high traditional solvents, Reactivity with amines, although may reform amine after depressurization, Safety and cost of high pressure equipment (Pc = 72.9 atm)
	Volatile Methyl Siloxanes (VMS)	Volatile methyl siloxanes (VMS), which have been formally ruled by the EPA to be exempt from VOC or Hazardous Air Pollutant regulation, are low molecular weight silicone fluids that provide a less toxic alternative to several hazardous organic solvents. Examples of VMS include hexamethyldisiloxane, octamethyltrisiloxane, and decamethyltetrasiloxane.	Rapidly dries without leaving residue, Cleans a variety of contaminants, Can b distilled for reuse	Flammable Combustible Toxic
	Water	Water, the universal solvent, has been recognized as one of the safest and most environmentally friendly alternative to hazardous solvents. Several organic reactions, for instance, have been conducted quite successfully in aqueous instead of organic solutions.	Good for radical reactions (H abstraction from OH unlikely and no reactive multipl bonds) Non-flammable Can avoid tedious protection steps Solvent properties change with increasing temperature	Subsequent workup may be energy intensive and/or involve the use of organic solvents

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Envirocat catalysts	Envirocat catalysts, provided by Contract Chemicals Ltd., are more environmentally friendly catalysts that have been used to replace hazardous substances in a variety of reactions.		
Methylene Chloride (DCM)	Benzotrifluoride (BTF, C7H5F3)	Benzotrifluoride (BTF, C7H5F3) is a less toxic and more environmentally friendly alternative to tetrahydrofuran and methylene chloride.	Less volatile Lower toxicity Relatively inert Stable in strongly basic conditions Non-ozone depleter Polarity between methylene chloride and ethyl acetate Dissolves organic compounds Miscible with organic solvents	Prepared industrially from toluen Solvent removal requires more energy (boiling point: 102°C) Wet commercially Hydrolyzes with acids at high temperatures Reacts with strong Lewis acids May be sensitive to reducing conditions involving electron transfer but compatible with hydride reductions and
	d-Limonene	d-Limonene is a naturally derived citrus terpene or solvent that can be used to replace methylene chloride as a cleaning agent	Biodegradable	Solvent removal requires more energy (boiling point: 175.5-178°C) Suspected carcinogen Air oxidation of this chemical may create allergens.

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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Dibasic esters	Dibasic esters (DBE) are by-products from the synthesis of adipic acid that are a less volatile and safer alternative to methylene chloride.	Biodegradable Solvent properties similar to methylene chloride Byproduct of current industrial processes	Solvent removal requires more energy (boiling point: 196-225°C) Incompatible with strong acids, bases, oxidants, and reducers Attracted to positively charged metal surfaces and may leave films
	Diethoxymethane (DEM or formaldehyde diethylactal)	Diethoxymethane (DEM or formaldehyde diethylactal) has been used as a good substitute for methylene chloride ar tetrahydrofuran.	Diethoxymethane (DEM or formaldehyde diethylactal) has been used as a good substitute for methylene chloride and tetrahydrofuran.	Solvent removal requires more energy (boiling point: 88°C) Not stable under homgeneous acidic conditions and may liberate formaldehyde
	Ethanol	Ethanol is a high volume chemical that is listed by the EPA as an air contaminant.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions	Ionic liquids are typically molten salts that are liquid below 100°C and provide a less volatile and recyclable alternative to many organic solvents such as methylene chloride. Some of the most popular ionic liquids use 1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions.	Non-volatile, Recyclable, Non explosiveNon-flammable, Commercially available in laboratory quantities, Tetrafluoroborate salts may have relatively low toxicity, Can have hydrogen bond acceptors and donors, Miscibility with water can be tuned by anions, alkyl groups, and sometimes temperature, Can from one, two, or three-phase catalytic systems	Some may be toxic to environment. 1,3-dialkylimidazolium ionic liquids, for instance, are antimicrobial depending on their N-alkyl group chain lengths, May require use of organic solvents in preparation steps, High viscosity (can be lowered if CO2 is dissolved in it), Anions of some ionic liquids may hydrolyze to form undesirable products
	Lactate esters (such as ethyl lactate)	Lactate esters (such as ethyl lactate) have shown excellent solvent properties as safer, non-toxic, and biodegradable chemical alternatives to several halogenated compounds, making them viable replacements in as cleaning agents or reaction solvents.	Biodegradable, Non-toxic	Solvent removal requires more energy (boiling point: 154°C)
	Methyl soyate	Methyl soyate, a type of methyl ester, is a biodegradable, less toxic alternative that can replace methylene chloride as a cleaning agent.	Lower toxicity Non-irritant to eyes and skin High flashpoint Cleaning performance is similar to NMP and DMF Biodegradable Renewable	Solvent removal requires more energy (boiling point: > 200°C) Slow evaporation may leave film on surfaces

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Methyl tert-butyl ether (MTBE)	Methyl tert-butyl ether (MTBE) has been used to replace dichloromethane in chromatography and extractions.	Lower toxicity than halogenated solvents	Groundwater contaminant after being used as a fuel additive Possible human carcinogen at high doses
	Microwave irradiation	Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from days to minutes. Reactions performed in a microwave batch reactor, for instance, can be constantly monitored, and temperature and pressure can be manually controlled, often leading to more complete reactions and higher product yields.		
	N-methyl pyrrolidone (NMP)	N-methyl pyrrolidone (NMP) is a higher flashpoint solvent that can be used in the place of many chlorinated or generic hazardous solvents used for cleaning, such as acetone.		

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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		A new process for polycarbonate synthesis without the use of phosgene, a poisonous gas, or methylene chloride, a suspected carcinogen, has been developed.		
	solventless or solvent-free reactions	The use of hazardous chemicals can often be avoided without the addition of a reaction solvent in solventless or solvent-free reactions. Although a reactant may act as a solvent to still allow for a liquid reaction, other reactions can occur simply by crushing two solids together in the dry phase.		
	Supercritical carbon dioxide(scCO2)	Supercritical carbon dioxide(scCO2) has been used in the place of generic hazardous solvents. This includes but is not limited to methylene chloride.	Non-flammable, Tunable solvent properties, Non-toxic, Easy removal from product, Inert to oxidation and radical reactions, Dissolves perfluorinated compounds and gases well, Critical temperature low (Tc = 31.3°C)	Yields not as high traditional solvents, Reactivity with amines, although may reform amine after depressurization, Safety and cost of high pressure equipment (Pc = 72.9 atm)

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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Supercritical fluids	Supercritical fluids have been used widely in industry to replace the use of organic solvents such as methylene chloride.	Non-flammable Tunable solvent properties Non-toxic Easy removal from product	Yields not as high traditional solvents Safety and cost of high pressure equipment
	2,2,6,6-tetramethylpiperidinyl-1-oxy (TEMPO)	2,2,6,6-tetramethylpiperidinyl-1-oxy (TEMPO) systems can be used to catalyze oxidation reactions while avoiding dangerous reagents and catalysts.		
	Vertec Gold	Vertec Gold is a chemical combination of lactate esters and methyl soyate that exhibits a higher evaporation rate than its components and may be a viable alternative for many hazardous solvents.	Good solvency for cleaning	Not compatible with strong oxidizing agents High boiling point: 144°C

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Water	Water, the universal solvent, has been recognized as one of the safest and most environmentally friendly alternative to hazardous solvents. Several organic reactions, for instance, have been conducted quite successfully in aqueous instead of organic solutions.	Good for radical reactions (H abstraction from OH unlikely and no reactive multipl bonds) Non-flammable Can avoid tedious protection steps Solvent properties change with increasing temperature	Subsequent workup may be energy intensive and/or involve the use of organic solvents
N,N-dimethylformamide	fluorided silica-alumina catalysts	Different forms of alumina support, such as fluorided silica-alumina catalysts, offer an alternative to using more hazardous catalysts in a number of chemical processes.		
	Fluorous ether F-626, benzotrifluoride, fluorous dimethylformamide (F-DMF), and perfluorohexanes (FC-72)	Fluorous solvents, such as the fluorous ether F-626, benzotrifluoride, fluorous dimethylformamide (F-DMF), and perfluorohexanes (FC-72) are alternative chemicals that have been used to replace a number of hazardous chlorinated solvents in industry. Their unique properties have also caught the interest of organic chemists.	Can dissolve both organic and fluorous compounds, Easy to remove, Solvent reusable without purification, High boilin point, Can form multi-phase reaction systems, Relatively non-toxic, High solubility of gases	Yields almost comparable but not as high as traditional solvents

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Glucose	Glucose is a natural, biologically made sugar that has proven to be a viable substitute for a number of more hazardous chemicals.	Mild Renewable resource	
	Microwave irradiation	Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from days to minutes. Reactions performed in a microwave batch reactor, for instance, can be constantly monitored, and temperature and pressure can be manually controlled, often leading to more complete reactions and higher product yields.		
	N-methyl pyrrolidone (NMP)	N-methyl pyrrolidone (NMP) is a higher flashpoint solvent that can be used in the place of many chlorinated or generic hazardous solvents used for cleaning, such as acetone.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Polyethylene glycol (PEG)	Polyethylene glycol (PEG) is a water soluble solid that can be used as a recyclable solvent medium in the place of volatile organic compounds.	Non-volatile, Inexpensive, Low toxicity (approved for food industry)	Viscous liquid at room temperature for PEG of molecular weights 300 and 600, Waxy solid for PEG 900, 1000, and 1500 which may become liquid under pressurized conditions (40°C at 90 bar), Terminal hydroxyl groups may be esterified or etherified PEG may be coextracted when using supercritical carbon dioxide, although PEG1500 is significantly less likely to be coextracted
	solventless or solvent-free reactions	The use of hazardous chemicals can often be avoided without the addition of a reaction solvent in solventless or solvent-free reactions. Although a reactant may act as a solvent to still allow for a liquid reaction, other reactions can occur simply by crushing two solids together in the dry phase.		
	Water	Water, the universal solvent, has been recognized as one of the safest and most environmentally friendly alternatives to hazardous solvents. Several organic reactions, for instance, have been conducted quite successfully in aqueous instead of organic solutions.	Good for radical reactions (H abstraction from OH unlikely and no reactive multiple bonds) Non-flammable Can avoid tedious protection steps Solvent properties change with increasing temperature	Subsequent workup may be energy intensive and/or involve the use of organic solvents

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
N-methyl pyrrolidone (NMP)	Microwave irradiation	Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from days to minutes. Reactions performed in a microwave batch reactor, for instance, can be constantly monitored, and temperature and pressure can be manually controlled, often leading to more complete reactions and higher product yields.		
	solventless or solvent-free reactions	The use of hazardous chemicals can often be avoided without the addition of a reaction solvent in solventless or solvent-free reactions. Although a reactant may act as a solvent to still allow for a liquid reaction, other reactions can occur simply by crushing two solids together in the dry phase.		
Perchloroethylene	d-Limonene	d-Limonene is a naturally derived citrus terpene or solvent that can be used to replace methylene chloride as a cleaning agent	Biodegradable	Solvent removal requires more energy (boiling point: 175.5-178°C) Suspected carcinogen Air oxidation of this chemical may create allergens.

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Lactate esters (such as ethyl lactate)	Lactate esters (such as ethyl lactate) have shown excellent solvent properties as safer, non-toxic, and biodegradable chemical alternatives to several halogenated compounds, making them viable replacements in as cleaning agents or reaction solvents.	Biodegradable, Non-toxic	Solvent removal requires more energy (boiling point: 154°C)
	Methyl soyate	Methyl soyate, a type of methyl ester, is a biodegradable, less toxic alternative that can replace methylene chloride as a cleaning agent.	Lower toxicity Non-irritant to eyes and skin High flashpoint Cleaning performance is similar to NMP and DMF Biodegradable Renewable	Solvent removal requires more energy (boiling point: > 200°C) Slow evaporation may leave film on surfaces
Phenol	**DNA extraction kits**	Several companies now offer DNA extraction kits which can be used in the place of traditional DNA extraction methods to avoid the use of more hazardous substances and the generation of unnecessary wastes.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	DNA Extraction with Polycarbonate Filters	Traditional DNA extraction procedures can avoid the use of dangerous and hazardous chemicals by performing DNA extraction with polycarbonate filters.		
	DNA Extraction with Polyethylene Glycol	Traditional DNA extraction procedures can be replaced by alternative processes such as DNA extraction with polethylene glycol and simple salts.		
	Polyethylene glycol (PEG)	Polyethylene glycol (PEG) is a water soluble solid that can be used as a recyclable solvent medium in the place of volatile organic compounds.	Non-volatile, Inexpensive, Low toxicity (approved for food industry)	Viscous liquid at room temperature for PEG of molecular weights 300 and 600, Waxy solid for PEG 900, 1000, and 1500 which may become liquid under pressurized conditions (40°C at 90 bar), Terminal hydroxyl groups may be esterified or etherified PEG may be coextracted when using supercritical carbon dioxide, although PEG1500 is significantly less likely to be coextracted

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Phenyl alcohol	DNA extraction kits	Several companies now offer DNA extraction kits which can be used in the place of traditional DNA extraction methods to avoid the use of more hazardous substances and the generation of unnecessary wastes.		
	DNA Extraction with Polycarbonate Filters	Traditional DNA extraction procedures can avoid the use of dangerous and hazardous chemicals by performing DNA extraction with polycarbonate filters.		
	DNA Extraction with Polyethylene Glycol	Traditional DNA extraction procedures can be replaced by alternative processes such as DNA extraction with polethylene glycol and simple salts.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Polyethylene glycol (PEG)	Polyethylene glycol (PEG) is a water soluble solid that can be used as a recyclable solvent medium in the place of volatile organic compounds.	Non-volatile, Inexpensive, Low toxicity (approved for food industry)	Viscous liquid at room temperature for PEG of molecular weights 300 and 600, Waxy solid for PEG 900, 1000, and 1500 which may become liquid under pressurized conditions (40°C at 90 bar), Terminal hydroxyl groups may be esterified or etherified PEG may be coextracted when using supercritical carbon dioxide, although PEG1500 is significantly less likely to be coextracted
Phosgene(CG)	1,1-Carbonylbisbenzotriazole	1,1-Carbonylbisbenzotriazole is a chemical compound that can be used in the place of phosgene in syntheses reactions.		
	1,1-Carbonylbisimidazole	1,1-Carbonylbisimidazole has been a viable chemical alternative for phosgene in syntheses reactions.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	1,1-Carbonylbisimidazole	1,1-Carbonylbisimidazole has been a viable chemical alternative for phosgene in syntheses reactions.		
	Di-tert-butyl dicarbonate (BOC anhydride)	Di-tert-butyl dicarbonate (BOC anhydride) is chemical compound often used in organic syntheses as a protecting agent or as a precursor in syntheses. It can be used in the place of phosgene in syntheses reactions.		
	Dimethyl carbonate (DMC)	Dimethyl carbonate (DMC) is a viable, green alternative f hazardous methylating agents such as dimethyl sulfate.	Non-toxic Non-mutagenic Methoxycarbonylating agent at 90°C Methylating agent at 160°C Avoids unwanted inorganic salt byproducts Only needs a catalytic amount of base	Requires pressure over 3 bars for batch processes because boiling point of DMC is 90°C Flammable

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	urethane synthesis	Monsanto has designed a new urethane synthesis, such as the synthesis of carbamate esters, that avoids the use of phosgene.		
	S,S-dimethyldithiocarbonate (DMDTC)	S,S-dimethyldithiocarbonate (DMDTC) is a milder chemical compound that can be used in the place of phosgene in syntheses reactions involving carbonylation.		
	Titanosilicate molecular sieves	Titanosilicate molecular sieves can avoid the use of many hazardous chemicals and/or processes by effectively catalyzing a number of reactions including the synthesis of many carbonates and carbamates.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Trihaloacetylchlorides	Trihaloacetylchlorides are safer chemical compounds that can be used in the place of phosgene in syntheses reactions.		
	Triphosgene	Triphosgene , though still hazardous, may be used as an easier to handle substitute for phosgene in chemical reactions.		
	Zeolites	Zeolites are crystalline solids that can replace a number of hazardous catalysts used in traditional reactions such as oxidation and reduction reactions, hydrogen-exchange reactions, and the syntheses of carbamates..		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Pyridine	Isopropanol	Isopropanol, the chemical used as rubbing alcohol, can b used as an alternative for more hazardous chemicals.	Less toxic than methanol Non-halogenated	Still a volatile organic compound Flammable
	Polyethylene glycol (PEG)	Polyethylene glycol (PEG) is a water soluble solid that can be used as a recyclable solvent medium in the place of volatile organic compounds.	Non-volatile, Inexpensive, Low toxicity (approved for food industry)	Viscous liquid at room temperature for PEG of molecular weights 300 and 600, Waxy solid for PEG 900, 1000, and 1500 which may become liquid under pressurized conditions (40°C at 90 bar), Terminal hydroxyl groups may be esterified or etherified PEG may be coextracted when using supercritical carbon dioxide, although PEG1500 is significantly less likely to be coextracted
	Microwave irradiation	Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from days to minutes. Reactions performed in a microwave batch reactor, for instance, can be constantly monitored, and temperature and pressure can be manually controlled, often leading to more complete reactions and higher product yields.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	solventless or solvent-free reactions	The use of hazardous chemicals can often be avoided without the addition of a reaction solvent in solventless or solvent-free reactions. Although a reactant may act as a solvent to still allow for a liquid reaction, other reactions can occur simply by crushing two solids together in the dry phase.		
	Water	Water, the universal solvent, has been recognized as one of the safest and most environmentally friendly alternatives to hazardous solvents. Several organic reactions, for instance, have been conducted quite successfully in aqueous instead of organic solutions.	Good for radical reactions (H abstraction from OH unlikely and no reactive multipl bonds) Non-flammable Can avoid tedious protection steps Solvent properties change with increasing temperature	Subsequent workup may be energy intensive and/or involve the use of organic solvents
Sodium Azide	**Microwave irradiation**	Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from days to minutes. Reactions performed in a microwave batch reactor, for instance, can be constantly monitored, and temperature and pressure can be manually controlled, often leading to more complete reactions and higher product yields.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	solventless or solvent-free reactions	The use of hazardous chemicals can often be avoided without the addition of a reaction solvent in solventless or solvent-free reactions. Although a reactant may act as a solvent to still allow for a liquid reaction, other reactions can occur simply by crushing two solids together in the dry phase.		
	fluorided silica-alumina catalysts	Different forms of alumina support, such as fluorided silica-alumina catalysts, offer an alternative to using more hazardous catalysts in a number of chemical processes.		
Sodium Borohydride	Glucose	Glucose is a natural, biologically made sugar that has proven to be a viable substitute for a number of more hazardous chemicals.	Mild Renewable resource	

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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Sodium tetrahydroborate	Glucose	Glucose is a natural, biologically made sugar that has proven to be a viable substitute for a number of more hazardous chemicals.	Mild Renewable resource	
Sulfinylbismethane	Polyethylene glycol (PEG)	Polyethylene glycol (PEG) is a water soluble solid that can be used as a recyclable solvent medium in the place of volatile organic compounds.	Non-volatile, Inexpensive, Low toxicity (approved for food industry)	Viscous liquid at room temperature for PEG of molecular weights 300 and 600, Waxy solid for PEG 900, 1000, and 1500 which may become liquid under pressurized conditions (40°C at 90 bar), Terminal hydroxyl groups may be esterified or etherified PEG may be coextracted when using supercritical carbon dioxide, although PEG1500 is significantly less likely to be coextracted
	Microwave irradiation	Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from days to minutes. Reactions performed in a microwave batch reactor, for instance, can be constantly monitored, and temperature and pressure can be manually controlled, often leading to more complete reactions and higher product yields.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	solventless or solvent-free reactions	The use of hazardous chemicals can often be avoided without the addition of a reaction solvent in solventless or solvent-free reactions. Although a reactant may act as a solvent to still allow for a liquid reaction, other reactions can occur simply by crushing two solids together in the dry phase.		
	fluorided silica-alumina catalysts	Different forms of alumina support, such as fluorided silica-alumina catalysts, offer an alternative to using more hazardous catalysts in a number of chemical processes.		
	1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions	Ionic liquids are typically molten salts that are liquid below 100°C and provide a less volatile and recyclable alternative to many organic solvents such as methylene chloride. Some of the most popular ionic liquids use 1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions.	Non-volatile, Recyclable, Non explosiveNon-flammable, Commercially available in laboratory quantities, Tetrafluoroborate salts may have relatively low toxicity, Can have hydrogen bond acceptors and donors, Miscibility with water can be tuned by anions, alkyl groups, and sometimes temperature, Can from one, two, or three-phase catalytic systems	Some may be toxic to environment. 1,3-dialkylimidazolium ionic liquids, for instance, are antimicrobial depending on their N-alkyl group chain lengths, May require use of organic solvents in preparation steps, High viscosity (can be lowered if CO2 is dissolved in it), Anions of some ionic liquids may hydrolyze to form undesirable products

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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	n-Octyl tetrahydrofurfuryl ether (n-OTE)	n-Octyl tetrahydrofurfuryl ether (n-OTE) is tetrahydrofuran derivative that can be used as an alternative solvent to tetrahydrofuran. This less water soluble replacement for THF offers a safer, more environmentally friendly alternative that avoids additional steps usually taken to remove water from THF.		
Sulphuric acid dimethyl ester	catalytic systems	Utilizing catalytic systems in any reaction promotes principles of Green Chemistry by improving the efficiency of a reaction. Many reactions, therefore, can be improve through the use of catalysts and/or using these catalysts in alternative solvents. The catalyst itself, however, may sometimes be very toxic and alternatives for many of thes dangerous catalysts, such as hydrogen fluoride or sulfuric acid, are available.		
	Dimethyl carbonate (DMC)	Dimethyl carbonate (DMC) is a viable, green alternative f hazardous methylating agents such as dimethyl sulfate.	Non-toxic Non-mutagenic Methoxycarbonylating agent at 90°C Methylating agent at 160°C Avoids unwanted inorganic salt byproducts Only needs a catalytic amount of base	Requires pressure over 3 bars for batch processes because boiling point of DMC is 90°C Flammable

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Tetrachloroethylene	d-Limonene	d-Limonene is a naturally derived citrus terpene or solvent that can be used to replace methylene chloride as a cleaning agent	Biodegradable	Solvent removal requires more energy (boiling point: 175.5-178°C) Suspected carcinogen Air oxidation of this chemical may create allergens.
	Lactate esters (such as ethyl lactate)	Lactate esters (such as ethyl lactate) have shown excellent solvent properties as safer, non-toxic, and biodegradable chemical alternatives to several halogenated compounds, making them viable replacements in as cleaning agents or reaction solvents.	Biodegradable, Non-toxic	Solvent removal requires more energy (boiling point: 154°C)
	Methyl soyate	Methyl soyate, a type of methyl ester, is a biodegradable, less toxic alternative that can replace methylene chloride as a cleaning agent.	Lower toxicity Non-irritant to eyes and skin High flashpoint Cleaning performance is similar to NMP and DMF Biodegradable Renewable	Solvent removal requires more energy (boiling point: > 200°C) Slow evaporation may leave film on surfaces

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Tetrachloromethane	Benzotrifluoride (BTF, C7H5F3)	Benzotrifluoride (BTF, C7H5F3) is a less toxic and more environmentally friendly alternative to tetrahydrofuran and methylene chloride.	Less volatile Lower toxicity Relatively inert Stable in strongly basic conditions Non-ozone depleter Polarity between methylene chloride and ethyl acetate Dissolves organic compounds Miscible with organic solvents	Prepared industrially from toluen Solvent removal requires more energy (boiling point: 102°C) Wet commercially Hydrolyzes with acids at high temperatures Reacts with strong Lewis acids May be sensitive to reducing conditions involving electron transfer but compatible with hydride reductions and
	Cyclohexane	Cyclohexane is listed as an air contaminant and hazardous substance but in some instances can be used as a safer alternative to more hazardous chemicals.	Dielectric constant and boiling point similar to carbon tetrachloride	Freezing point lower than carbon tetrachloride by 30 degrees
	Methyl acetate	Methyl acetate, although regulated as an air contaminant, is a viable alternative for a number of more hazardous solvents.		

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Microwave irradiation	Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from days to minutes. Reactions performed in a microwave batch reactor, for instance, can be constantly monitored, and temperature and pressure can be manually controlled, often leading to more complete reactions and higher product yields.		
	Water	Water, the universal solvent, has been recognized as one of the safest and most environmentally friendly alternatives to hazardous solvents. Several organic reactions, for instance, have been conducted quite successfully in aqueous instead of organic solutions.	Good for radical reactions (H abstraction from OH unlikely and no reactive multipl bonds) Non-flammable Can avoid tedious protection steps Solvent properties change with increasing temperature	Subsequent workup may be energy intensive and/or involve the use of organic solvents
Tetrahydrofuran (THF)	Alkoxyethanols	Alkoxyethanols, such as 2-methoxyethanol and 2-ethoxyethanol, can be used as less flammable alternatives to organic solvents such as tetrahydrofuran.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	fluorided silica-alumina catalysts	Different forms of alumina support, such as fluorided silica-alumina catalysts, offer an alternative to using more hazardous catalysts in a number of chemical processes.		
	Butyl diglyme, or diethylene glycol dibutyl ether	Butyl diglyme, or diethylene glycol dibutyl ether, is a viable alternative to many solvents often used in Grignard reactions.	Immiscible with water	Solvent removal requires more energy (boiling point: 256°C). Lower boiling point solvents that are similar but miscible with water are monoglyme (DME) and diglyme
	catalytic systems	Utilizing catalytic systems in any reaction promotes principles of Green Chemistry by improving the efficiency of a reaction. Many reactions, therefore, can be improve through the use of catalysts and/or using these catalysts in alternative solvents. The catalyst itself, however, may sometimes be very toxic and alternatives for many of thes dangerous catalysts, such as hydrogen fluoride or sulfuric acid, are available.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Diethoxymethane (DEM or formaldehyde diethylactal)	Diethoxymethane (DEM or formaldehyde diethylactal) has been used as a good substitute for methylene chloride ar tetrahydrofuran.	Stable in aqueous acidic conditions and decomposes less than 1% Less likely to form peroxides than other ethers	Solvent removal requires more energy (boiling point: 88°C) Not stable under homgeneous acidic conditions and may liberate formaldehyde
	Indium metal	Indium metal, a non-toxic metal often used in dental alloy is a viable alternative for many hazardous catalyst systems.		
	1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions	Ionic liquids are typically molten salts that are liquid below 100°C and provide a less volatile and recyclable alternative to many organic solvents such as methylene chloride. Some of the most popular ionic liquids use 1,3-dialkylimidazolium cations with tetrafluoroborate, hexaluorophosphate, or trifluoromethane sulfonate anions.	Non-volatile, Recyclable, Nor explosiveNon-flammable, Commercially available in laboratory quantities, Tetrafluoroborate salts may have relatively low toxicity, Can have hydrogen bond acceptors and donors, Miscibility with water can be tuned by anions, alkyl groups, and sometimes temperature, Can from one, two, or three-phase catalytic systems	Some may be toxic to environment. 1,3-dialkylimidazolium ionic liquids, for instance, are antimicrobial depending on their N-alkyl group chain lengths, May require use of organic solvents in preparation steps, High viscosity (can be lowered if CO2 is dissolved in it), Anions of some ionic liquids may hydrolyze to form undesirable products

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Microreaction technology (MRT)	Microreaction technology (MRT) conducts reactions on the microscale and has been used to minimize the dangers associated with highly exothermic reactions, high temperature reactions, or reactions with unstable intermediates. This technology is being investigated by both members in academia and industry and also represents a safer way of avoiding scale effects in the mass production of chemical compounds.		
	n-Octyl tetrahydrofurfuryl ether (n-OTE)	n-Octyl tetrahydrofurfuryl ether (n-OTE) is tetrahydrofuran derivative that can be used as an alternative solvent to tetrahydrofuran. This less water soluble replacement for THF offers a safer, more environmentally friendly alternative that avoids additional steps usually taken to remove water from THF.		
	Microwave irradiation	Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from days to minutes. Reactions performed in a microwave batch reactor, for instance, can be constantly monitored, and temperature and pressure can be manually controlled, often leading to more complete reactions and higher product yields.		

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	solventless or solvent-free reactions	The use of hazardous chemicals can often be avoided without the addition of a reaction solvent in solventless or solvent-free reactions. Although a reactant may act as a solvent to still allow for a liquid reaction, other reactions can occur simply by crushing two solids together in the dry phase.		
	Supercritical carbon dioxide(scCO2)	Supercritical carbon dioxide(scCO2) has been used in the place of generic hazardous solvents. This includes but is not limited to methylene chloride.	Non-flammable, Tunable solvent properties, Non-toxic, Easy removal from product, Inert to oxidation and radical reactions, Dissolves perfluorinated compounds and gases well, Critical temperature low (Tc = 31.3°C)	Yields not as high traditional solvents, Reactivity with amines, although may reform amine after depressurization, Safety and cost of high pressure equipment (Pc = 72.9 atm)
	Water	Water, the universal solvent, has been recognized as one of the safest and most environmentally friendly alternative to hazardous solvents. Several organic reactions, for instance, have been conducted quite successfully in aqueous instead of organic solutions.	Good for radical reactions (H abstraction from OH unlikely and no reactive multipl bonds) Non-flammable Can avoid tedious protection steps Solvent properties change with increasing temperature	Subsequent workup may be energy intensive and/or involve the use of organic solvents

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Toluene	catalytic systems	Utilizing catalytic systems in any reaction promotes principles of Green Chemistry by improving the efficiency of a reaction. Many reactions, therefore, can be improve through the use of catalysts and/or using these catalysts in alternative solvents. The catalyst itself, however, may sometimes be very toxic and alternatives for many of thes dangerous catalysts, such as hydrogen fluoride or sulfuric acid, are available.		
	d-Limonene	d-Limonene is a naturally derived citrus terpene or solvent that can be used to replace methylene chloride as a cleaning agent	Biodegradable	Solvent removal requires more energy (boiling point: 175.5-178°C) Suspected carcinogen Air oxidation of this chemical may create allergens.
	Methyl soyate	Methyl soyate, a type of methyl ester, is a biodegradable, less toxic alternative that can replace methylene chloride as a cleaning agent.	Lower toxicity Non-irritant to eyes and skin High flashpoint Cleaning performance is similar to NMP and DMF Biodegradable Renewable	Solvent removal requires more energy (boiling point: > 200°C) Slow evaporation may leave film on surfaces

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Dimethyl carbonate (DMC)	Dimethyl carbonate (DMC) is a viable, green alternative f hazardous methylating agents such as dimethyl sulfate.	Non-toxic Non-mutagenic Methoxycarbonylating agent at 90°C Methylating agent at 160°C Avoids unwanted inorganic salt byproducts Only needs a catalytic amount of base	Requires pressure over 3 bars for batch processes because boiling point of DMC is 90°C Flammable
	Polyethylene glycol (PEG)	Polyethylene glycol (PEG) is a water soluble solid that can be used as a recyclable solvent medium in the place of volatile organic compounds.	Non-volatile, Inexpensive, Low toxicity (approved for food industry)	Viscous liquid at room temperature for PEG of molecular weights 300 and 600, Waxy solid for PEG 900, 1000, and 1500 which may become liquid under pressurized conditions (40°C at 90 bar), Terminal hydroxyl groups may be esterified or etherified PEG may be coextracted when using supercritical carbon dioxide, although PEG1500 is significantly less likely to be coextracted
	Poly(propylene glycol) or PPG 4025	Poly(propylene glycol) or PPG 4025 is an alternative chemical that may be used in the place of more hazardou solvents, such as toluene.	Low corrosive activity Toxicity decreases with increasing molecular weight	Viscous liquid at room temperature

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	solventless or solvent-free reactions	The use of hazardous chemicals can often be avoided without the addition of a reaction solvent in solventless or solvent-free reactions. Although a reactant may act as a solvent to still allow for a liquid reaction, other reactions can occur simply by crushing two solids together in the dry phase.		
	Supercritical carbon dioxide(scCO2)	Supercritical carbon dioxide(scCO2) has been used in the place of generic hazardous solvents. This includes but is not limited to methylene chloride.	Non-flammable, Tunable solvent properties, Non-toxic, Easy removal from product, Inert to oxidation and radical reactions, Dissolves perfluorinated compounds and gases well, Critical temperature low (Tc = 31.3°C)	Yields not as high traditional solvents, Reactivity with amines, although may reform amine after depressurization, Safety and cost of high pressure equipment (Pc = 72.9 atm)
	Volatile Methyl Siloxanes (VMS)	Volatile methyl siloxanes (VMS), which have been formally ruled by the EPA to be exempt from VOC or Hazardous Air Pollutant regulation, are low molecular weight silicone fluids that provide a less toxic alternative to several hazardous organic solvents. Examples of VMS include hexamethyldisiloxane, octamethyltrisiloxane, and decamethyltetrasiloxane.	Rapidly dries without leaving residue, Cleans a variety of contaminants, Can b distilled for reuse	Flammable Combustible Toxic

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Water	Water, the universal solvent, has been recognized as one of the safest and most environmentally friendly alternatives to hazardous solvents. Several organic reactions, for instance, have been conducted quite successfully in aqueous instead of organic solutions.	Good for radical reactions (H abstraction from OH unlikely and no reactive multipl bonds) Non-flammable Can avoid tedious protection steps Solvent properties change with increasing temperature	Subsequent workup may be energy intensive and/or involve the use of organic solvents
Trichloroethylene (TCE)	d-Limonene	d-Limonene is a naturally derived citrus terpene or solvent that can be used to replace methylene chloride as a cleaning agent	Biodegradable	Solvent removal requires more energy (boiling point: 175.5-178°C) Suspected carcinogen Air oxidation of this chemical may create allergens.
Trichloromethane	Dimethoxyethane (DME)	Dimethoxyethane (DME) is a colorless liquid that may be used a substitute for more hazardous chemicals such as chloroform. DME is miscible with water.	Similar dieletric constant to chloroform	Miscible with water

Fisher Science Education

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	DNA extraction kits	Several companies now offer DNA extraction kits which can be used in the place of traditional DNA extraction methods to avoid the use of more hazardous substances and the generation of unnecessary wastes.		
	DNA Extraction with Polycarbonate Filters	Traditional DNA extraction procedures can avoid the use of dangerous and hazardous chemicals by performing DNA extraction with polycarbonate filters.		
	DNA Extraction with Polyethylene Glycol	Traditional DNA extraction procedures can be replaced by alternative processes such as DNA extraction with polethylene glycol and simple salts.		

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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Polyethylene glycol (PEG)	Polyethylene glycol (PEG) is a water soluble solid that can be used as a recyclable solvent medium in the place of volatile organic compounds.	Non-volatile, Inexpensive, Low toxicity (approved for food industry)	Viscous liquid at room temperature for PEG of molecular weights 300 and 600, Waxy solid for PEG 900, 1000, and 1500 which may become liquid under pressurized conditions (40°C at 90 bar), Terminal hydroxyl groups may be esterified or etherified PEG may be coextracted when using supercritical carbon dioxide, although PEG1500 is significantly less likely to be coextracted
	Lactate esters (such as ethyl lactate)	Lactate esters (such as ethyl lactate) have shown excellent solvent properties as safer, non-toxic, and biodegradable chemical alternatives to several halogenated compounds, making them viable replacements in as cleaning agents or reaction solvents.	Biodegradable, Non-toxic	Solvent removal requires more energy (boiling point: 154°C)
	Methyl tert-butyl ether (MTBE)	Methyl tert-butyl ether (MTBE) has been used to replace dichloromethane in chromatography and extractions.	Lower toxicity than halogenated solvents	Groundwater contaminant after being used as a fuel additive Possible human carcinogen at high doses

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	Methylene chloride (DCM or dichloromethane)	Methylene chloride (DCM or dichloromethane) is a commonly used halogenated and volatile organic solvent that is a suspected carcinogen.		
	solventless or solvent-free reactions	The use of hazardous chemicals can often be avoided without the addition of a reaction solvent in solventless or solvent-free reactions. Although a reactant may act as a solvent to still allow for a liquid reaction, other reactions can occur simply by crushing two solids together in the dry phase.		
Xylenes	Ethanol	Ethanol is a high volume chemical that is listed by the EPA as an air contaminant.		

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	Fluorous ether F-626, benzotrifluoride, fluorous dimethylformamide (F-DMF), and perfluorohexanes (FC-72)	Fluorous solvents, such as the fluorous ether F-626, benzotrifluoride, fluorous dimethylformamide (F-DMF), and perfluorohexanes (FC-72) are alternative chemicals that have been used to replace a number of hazardous chlorinated solvents in industry. Their unique properties have also caught the interest of organic chemists.	Can dissolve both organic and fluorous compounds, Easy to remove, Solvent reusable without purification, High boilin point, Can form multi-phase reaction systems, Relatively non-toxic, High solubility of gases	Yields almost comparable but not as high as traditional solvents
	HistoSolve	HistoSolve is a less toxic alternative available to replace or minimize the use of xylenes in preparing histology slides.	Less toxic	May still need a reduced amount of conventional solvents, i.e. xylene, for effective drying
	solventless or solvent-free reactions	The use of hazardous chemicals can often be avoided without the addition of a reaction solvent in solventless or solvent-free reactions. Although a reactant may act as a solvent to still allow for a liquid reaction, other reactions can occur simply by crushing two solids together in the dry phase.		

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	Water	Water, the universal solvent, has been recognized as one of the safest and most environmentally friendly alternatives to hazardous solvents. Several organic reactions, for instance, have been conducted quite successfully in aqueous instead of organic solutions.	Good for radical reactions (H abstraction from OH unlikely and no reactive multipl bonds) Non-flammable Can avoid tedious protection steps Solvent properties change with increasing temperature	Subsequent workup may be energy intensive and/or involve the use of organic solvents
	Volatile Methyl Siloxanes (VMS)	Volatile methyl siloxanes (VMS), which have been formally ruled by the EPA to be exempt from VOC or Hazardous Air Pollutant regulation, are low molecular weight silicone fluids that provide a less toxic alternative to several hazardous organic solvents. Examples of VMS include hexamethyldisiloxane, octamethyltrisiloxane, and decamethyltetrasiloxane.	Rapidly dries without leaving residue, Cleans a variety of contaminants, Can b distilled for reuse	Flammable Combustible Toxic
	Microwave irradiation	Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from days to minutes. Reactions performed in a microwave batch reactor, for instance, can be constantly monitored, and temperature and pressure can be manually controlled, often leading to more complete reactions and higher product yields.		

Chemical to Replace	Alternative Chemicals	Details	Pros	Cons

Source: Massachusetts Institute of Technology