

Chaminal to Danisas	Alternative Chemicals	Date to	Drac	Cons
Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
1,1,1-trichloroethane	Volatile Methyl Siloxanes (VMS)	decamethyltetrasiloxane.		Flammable Combustible Toxic
Acetone				
Accione				
	Aqueous surfactants and	1	Avoids volatile organic solvents, May	Workup and extraction procedures may
	macromolecular solutions	still solubilize organic reactions by forming micelles.	enhance chemical yield and selectivity	be tedious
		Oftentimes the use of a hazardous chemical, whether its		
		toxic or flammable, can be avoided simply by using		
	Cleaning detergents	commercially available cleaning detergents.		



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		Lactate esters (such as ethyl lactate) have shown		
		excellent solvent properties as safer, non-toxic, and		
		biodegradable chemical alternatives to several		
	Lactate esters (such as ethyl	halogenated compounds, making them viable		Solvent removal requires more energy
	lactate)	replacements in as cleaning agents or reaction solvents.	Biodegradable, Non-toxic	(boiling point: 154°C)
		Propylene carbonate (PC) is a safer, more environmenta		
		friendly alternative to chlorinated solvents and generic		
	Propylene carbonate	hazardous solvents used for cleaning, such as acetone.		
			Non-flammable, Tunable solvent	
			properties, Non-toxic, Easy removal fror	Vields not as high traditional solvents
				Reactivity with amines, although may
		Supercritical carbon dioxide(scCO2) has been used in the		reform amine after depressurization,
	Supercritical carbon	place of generic hazardous solvents. This includes but is	compounds and gases well, Critical	Safety and cost of high pressure
	dioxide(scCO2)	not limited to methylene chloride.	temperature low (Tc = 31.3°C)	equipment (Pc = 72.9 atm)
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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Acetonitrile				
		Different forms of alumina support, such as fluorided		
		silica-alumina catalysts, offer an alternative to using more		
	fluorided silica-alumina catalysts	hazardous catalysts in a number of chemical processes.		
		, i		
	Aqueous surfactants and	Aqueous surfactants and macromolecular solutions can	Avoids volatile organic solvents, May	Workup and extraction procedures may
	macromolecular solutions		enhance chemical yield and selectivity	be tedious
		, , ,	-	
		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 the		
		dangerous catalysts, such as hydrogen fluoride or sulfurion		
	catalytic systems	acid, are available.		
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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		Ethanol is a high volume chemical that is listed by the		
	Ethanol	EPA as an air contaminant.		
		El 71 do an an contaminant.		
		Fluorous solvents, such as the fluorous ether F-626,	Can dissolve both organic and fluorous	
		benzotrifluoride, fluorous dimethylformamide (F-DMF),	compounds, Easy to remove, Solvent	
	Fluorous ether F-626,	and perfluorohexanes (FC-72) are alternative chemicals		
	benzotrifluoride, fluorous	that have been used to replace a number of hazardous	point, Can form multi-phase reaction	
	dimethylformamide (F-DMF), and	chlorinated solvents in industry. Their unique properties		Yields almost comparable but not as high
	perfluorohexanes (FC-72)	have also caught the interest of organic chemists.	solubility of gases	as traditional solvents
			Non-volatile, Recyclable, Non	
				Some may be toxic to environment. 1,3-
			available in laboratory quantities, Tetrafluoroborate salts may have	dialkylimidazolium ionic liquids, for
		lonia liquido are tunically moltan calta that are liquid bala	1	instance, are antimicrobial depending on
		lonic liquids are typically molten salts that are liquid below 100°C and provide a less volatile and recyclable	bond acceptors and donors, Miscibility	require use of organic solvents in
	1 3-dialkylimidazolium cations with	alternative to many organic solvents such as methylene		preparation steps, High viscosity (can be
	tetrafluoroborate,	chloride. Some of the most popular ionic liquids use 1,3-		lowered if CO2 is dissolved in it), Anions
	hexaluorophosphate, or	dialkylimidazolium cations with tetrafluoroborate,	Can from one, two, or three-phase	of some ionic liquids may hydrolyze to
	trifluoromethane sulfonate anions	hexaluorophosphate, or trifluoromethane sulfonate anion		form undesirable products
		Troxardoropridate, or trinderentiatio sufferiate arifori	yr, 5, 51515	The second products



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Chemical to Replace Alternative Chemicals	Details	Pros	Cons
	Microwave irradiation has been increasingly used by both		
	academia and industry to reduce reaction times from day		
	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		
Microwave irradiation	product yields.		
			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
	Detective to a self-self-self-self-self-self-self-self-	_	esterified or etherified PEG may be
	Polyethylene glycol (PEG) is a water soluble solid that ca be used as a recyclable solvent medium in the place of	n Non-volatile, Inexpensive, Low toxicity	coextracted when using supercritical carbon dioxide, although PEG1500 is
Polyethylene glycol (PEG)		(approved for food industry)	significantly less likely to be coextracted
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	Different forms of alumina support, such as fluorided		
Benzene fluorided silica-alumina catalysts	silica-alumina catalysts, offer an alternative to using more hazardous catalysts in a number of chemical processes.		



Chemical to Replace	Alternative Chemicals	Detaile	Pros	Cons
Chemical to Replace	Alternative Chemicals	Details	Pros	Prepared industrially from toluen
			Less volatile	Solvent removal requires more energy
			Lower toxicity	(boiling point: 102°C)
			Relatively inert	Wet commercially
			Stable in strongly basic conditions	Hydrolyzes with acids at high
			Non-ozone depleter	temperatures
			Polarity between methylene chloride and	Reacts with strong Lewis acids
		Benzotrifluoride (BTF, C7H5F3) is a less toxic and more	ethyl acetate	May be sensitive to reducing conditions
		environmentally friendly alternative to tetrahydrofuran an	Dissolves organic compounds	involving electron transfer but compatible
	Benzotrifluoride (BTF, C7H5F3)		Miscible with organic solvents	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	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.		Miscible with water



Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		Ethanalia a high valuma abamical that is listed by the		
	Ethanol	Ethanol is a high volume chemical that is listed by the EPA as an air contaminant.		
		Glucose is a natural, biologically made sugar that has	Mild	
	Glucose	1	Renewable resource	
		Indium metal, a non-toxic metal often used in dental alloy	1	
	Indium metal	is a viable alternative for many hazardous catalyst systems.		



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
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		Microwave irradiation has been increasingly used by both		
		academia and industry to reduce reaction times from day	'S	
		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		
	Microwave irradiation	product yields.		
		Montmorillonite clay catalysts, which are composed of		
		octahedral and tetrahedral sheets of gibbsite and silicate		
		offer a safer and, in some cases, more effective alternative		
		to using more hazardous acids in catalyzing a number of		
	Montmorillonite clay catalysts	chemical reactions.		
			Non-flammable, Tunable solvent	
			properties, Non-toxic, Easy removal from	
				Reactivity with amines, although may
	Supercritical carbon	Supercritical carbon dioxide(scCO2) has been used in the place of generic hazardous solvents. This includes but is	ereactions, Dissolves permormated	reform amine after depressurization, Safety and cost of high pressure
	dioxide(scCO2)	not limited to methylene chloride.	temperature low (Tc = 31.3°C)	equipment (Pc = 72.9 atm)
	410/140(00002)	not innited to metrylene emonde.	tomporatoro low (10 = 01.0 0)	0401p.110111 (1 0 = 12.0 dtill)



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



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
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		Tetrabutylammonium tribromide (TBATB), a type of		
		organic ammonium tribromide (OATB), can be used to		
	Tetrabutylammonium tribromide	replace bromine in bromination reactions.		
	-	·		Prepared industrially from toluen
				Solvent removal requires more energy
			Lower toxicity	(boiling point: 102°C)
			Relatively inert	Wet commercially
				Hydrolyzes with acids at high
				temperatures
			Polarity between methylene chloride and	_
		Benzotrifluoride (BTF, C7H5F3) is a less toxic and more		May be sensitive to reducing conditions
		environmentally friendly alternative to tetrahydrofuran an	Dissolves organic compounds	involving electron transfer but compatible
Carbon Tetrachloride	Benzotrifluoride	methylene chloride.	Miscible with organic solvents	with hydride reductions and
		Coulab assess in listed an en ein anntaminant and		
		Cyclohexane is listed as an air contaminant and	Dialogtric constant and bailing point	Freezing point lower than carbon
	Cyclohexane	hazardous substance but in some instances can be used	= :	tetrachloride by 30 degrees
	Cyclonexalle	as a safer alternative to more hazardous chemicals.	Similar to Carbon tetrachionide	tetracinionae by 30 degrees



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
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		Methyl acetate, although regulated as an air contaminant		
	Methyl acetate	is a viable alternative for a number of more hazardous solvents.		
	Wetrryr acetate	solvents.		
		Titanosilicate molecular sieves can avoid the use of man	¥	
		hazardous chemicals and/or processes by effectively		
0-4	The second secon	catalyzing a number of reactions including the synthesis		
Carbon monoxide	Titanosilicate molecular sieves	of many carbonates and carbamates.		
		Zeolites are crystalline solids that can replace a number		
		hazardous catalysts used in traditional reactions such as		
		oxidation and reduction reactions, hydrogen-exchange		
	Zeolites	reactions, and the syntheses of carbamates		



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		1,1-Carbonylbisbenzotriazole is a chemical compound the		
Carbonyl chloride	1,1-Carbonylbisbenzotriazole	can be used in the place of phosgene in syntheses reactions.		
Cal Sorry Cilionae	i, i da sony isiasonizon idzole	i Cacilono.		
		1,1-Carbonylbisimidazole has been a viable chemical		
	1,1-Carbonylbisimidazole	alternative for phosgene in syntheses reactions.		
		Bis(4-nitrophenyl)carbonate is a safer chemical compoun		
	Bis(4-nitrophenyl)carbonate	that can be used in the place of phosgene in syntheses reactions.		
	Dia(+-introprietty)/carbonate	reactions.		



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Alternative Chemicals	Details	Pros	Cons
Di-tert-butyl dicarbonate			
		Non-toxic	
			Requires pressure over 3 bars for batch
			processes because boiling point of DMC is 90°C
			Flammable
Dimethyl carbonate		Only needs a catalytic amount of base	i lammadio
	, , , , , , , , , , , , , , , , , , , ,	-	
	O O Provide Little and a value (DMDTO) in a 1111		
S,S-dimethyldithiocarbonate			
	Di-tert-butyl dicarbonate Dimethyl carbonate	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) is a viable, green alternative f hazardous methylating agents such as dimethyl sulfate. S,S-dimethyldithiocarbonate (DMDTC) is a milder chemical compound that can be used in the place of	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. Non-toxic Non-mutagenic Methoxycarbonylating agent at 90°C Methylating agent at 160°C Avoids unwanted inorganic salt byproducts Dimethyl carbonate Dimethyl carbonate Dimethyl carbonate (DMC) is a viable, green alternative following agent at 90°C Methylating agent at 160°C Avoids unwanted inorganic salt byproducts Only needs a catalytic amount of base S,S-dimethyldithiocarbonate (DMDTC) is a milder chemical compound that can be used in the place of



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



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
			Landa valadia	Prepared industrially from toluen
			Less volatile	Solvent removal requires more energy
			Lower toxicity	(boiling point: 102°C)
			Relatively inert	Wet commercially
			Stable in strongly basic conditions	Hydrolyzes with acids at high
			Non-ozone depleter Polarity between methylene chloride and	temperatures
				-
		Benzotrifluoride (BTF, C7H5F3) is a less toxic and more	Discolves organic compounds	May be sensitive to reducing conditions involving electron transfer but compatible
Chlorinated solvents	Benzotrifluoride	environmentally friendly alternative to tetrahydrofuran an	Miscible with organic solvents	with hydride reductions and
Chlorinated solvents	Benzotrinuoride	methylene chloride.	Miscible with organic solvents	with hydride reductions and
		d-Limonene is a naturally derived citrus terpene or solver that can be used to replace methylene chloride as a cleaning agent	t 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), 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



Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		Ethanol is a high volume chemical that is listed by the		
	Ethanol	EPA as an air contaminant.		
		Lactate esters (such as ethyl lactate) have shown excellent solvent properties as safer, non-toxic, and		
		biodegradable chemical alternatives to several		
	Lactate esters		Biodegradable	Solvent removal requires more energy (boiling point: 154°C)
	Lactate esters	replacements in as cleaning agents or reaction solvents.	NOTITIONIC	(bolling point: 134 C)
		Methyl acetate, although regulated as an air contaminant	t d	
	Methyl acetate	is a viable alternative for a number of more hazardous solvents.		



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
			Lower tovicity	
			Lower toxicity Non-irritant to eyes and skin	
			High flashpoint	
			Cleaning performance is similar to NMP	Solvent removal requires more energy
		Methyl soyate, a type of methyl ester, is a biodegradable		(boiling point: > 200°C)
		less toxic alternative that can replace methylene chloride	Riodegradable	Slow evaporation may leave film on
	Methyl soyate	as a cleaning agent.	Renewable	surfaces
	Metrlyr soyate	as a clearing agent.	Reflewable	Suraces
		N-methyl pyrrolidone (NMP) is a higher flashpoint solven	1	
		that can be used in the place of many chlorinated or		Regulated in California under the Known
		generic hazardous solvents used for cleaning, such as		Carcinogen and Reproductive Toxicants
	N-methyl pyrrolidone	acetone.		List
				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
		Polyethylene glycol (PEG) is a water soluble solid that ca		coextracted when using supercritical
		,	Non-volatile, Inexpensive, Low toxicity	carbon dioxide, although PEG1500 is
	Polyethylene glycol (PEG)	volatile organic compounds.	(approved for food industry)	significantly less likely to be coextracted



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
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		Propylene carbonate (PC) is a safer, more environmenta	Fairly biodegradable	High boiling point: 240°C
	Propylene carbonate (PC)	friendly alternative to chlorinated solvents and generic hazardous solvents used for cleaning, such as acetone.	Non-toxic	May decompose in aqueous environment
	ropyrene carbonate (1 0)	nazardous solvents used for cleaning, such as acetone.	THOTELOXIC	Iviay decompose in addeous environment
			Non-flammable, Tunable solvent	
			properties, Non-toxic, Easy removal fror	
				Reactivity with amines, although may
	Companyities I sould as	Supercritical carbon dioxide(scCO2) has been used in the	reactions, Dissolves perfluorinated	reform amine after depressurization,
	Supercritical carbon dioxide(scCO2)	place of generic hazardous solvents. This includes but is	temperature low (Tc = 31.3°C)	Safety and cost of high pressure equipment (Pc = 72.9 atm)
	dioxide(SCCO2)	not limited to methylene chloride.	temperature low (10 = 31.3 C)	equipment (FC = 72.9 atm)
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		Vertec Gold is a chemical combination of lactate esters		
		and methyl soyate that exhibits a higher evaporation rate		Not compatible with strong oxidizing
	Warten Call	than its components and may be a viable alternative for		agents
	Vertec Gold	many hazardous solvents.	Good solvency for cleaning	High boiling point: 144°C



Chamical to Banlage	Alternative Chemicals	D. (1)	Bree	Cons
Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
			Can dissolve both organic and fluorous	
			compounds	
			Easy to remove	
			Solvent reusable without purification	
	fluorous ether F-626,	and perfluorohexanes (FC-72) are alternative chemicals		
	benzotrifluoride, fluorous		Can form multi-phase reaction systems	
Oldson browns	dimethylformamide (F-DMF), and	chlorinated solvents in industry. Their unique properties		Yields almost comparable but not as high
Chlorobenzene	perfluorohexanes (FC-72)	have also caught the interest of organic chemists.	High solubility of gases	as traditional solvents
				Solvent removal requires more energy
				(boiling point: 175.5-178°C)
				Suspected carcinogen
		d-Limonene is a naturally derived citrus terpene or solver	t	Air oxidation of this chemical may create
		that can be used to replace methylene chloride as a		allergens.
Chlorofluorocarbons (CFCs)	d-Limonene	cleaning agent	Biodegradable	
		Lactate esters (such as ethyl lactate) have shown		
		excellent solvent properties as safer, non-toxic, and		
		biodegradable chemical alternatives to several		
			Biodegradable	Solvent removal requires more energy
	Lactate esters	replacements in as cleaning agents or reaction solvents.	Non-toxic	(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	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)	hexamethyldisiloxane, octamethyltrisiloxane, and		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.		Miscible with water



Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		Lactate esters (such as ethyl lactate) have shown		
		excellent solvent properties as safer, non-toxic, and		
		biodegradable chemical alternatives to several		
			Biodegradable	Solvent removal requires more energy
	Lactate esters	replacements in as cleaning agents or reaction solvents.	Non-toxic	(boiling point: 154°C)
	Methyl tert-butyl ether (MTBE) has			
	been used to replace			Groundwater contaminant after being
	dichloromethane in	Methyl tert-butyl ether (MTBE) has been used to replace		used as a fuel additive
	chromatography and extractions.	dichloromethane in chromatography and extractions.	Lower toxicity than halogenated solvents	Possible human carcinogen at high doses
	Mathadana ahlasida (DOM 5.5	Methylene chloride (DCM or dichloromethane) is a		
	Methylene chloride (DCM or	commonly used halogenated and volatile organic solvent		
	dichloromethane)	that is a suspected carcinogen.		



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
				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
		Polyethylene glycol (PEG) is a water soluble solid that ca	n	coextracted when using supercritical
			Non-volatile, Inexpensive, Low toxicity	carbon dioxide, although PEG1500 is
	Polyethylene glycol (PEG)		(approved for food industry)	significantly less likely to be coextracted
		1,1-Carbonylbisimidazole has been a viable chemical		
Chloroformyl chloride	1,1-Carbonylbisimidazole	alternative for phosgene in syntheses reactions.		
,	-,	anomalive for priorgene in dynamicocc reactions.		
		1,1-Carbonylbisbenzotriazole is a chemical compound the		
		can be used in the place of phosgene in syntheses		
	1,1-Carbonylbisbenzotriazole	reactions.		



Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Chemical to Replace	Alternative Chemicals	Details	1105	Cons
		Bis(4-nitrophenyl)carbonate is a safer chemical compoun	1	
		that can be used in the place of phosgene in syntheses		
	Bis(4-nitrophenyl)carbonate	reactions.		
		Di-tert-butyl dicarbonate (BOC anhydride) is chemical		
		compound often used in organic syntheses as a		
	Di-tert-butyl dicarbonate (BOC	protecting agent or as a precursor in syntheses. It can be		
	anhydride)	used in the place of phosgene in syntheses reactions.		
			Non-toxic	
			Non-mutagenic	
			Methoxycarbonylating agent at 90°C Methylating agent at 160°C	Requires pressure over 3 bars for batch processes because boiling point of DMC
				is 90°C
		Dimethyl carbonate (DMC) is a viable, green alternative f		Flammable
	Dimethyl carbonate (DMC)	hazardous methylating agents such as dimethyl sulfate.		



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



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



Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Chambar to Hophace		Bottano		
		Liqui-Nox Detergent for Critical Cleaning is a		
	Liqui-Nox Detergent		Mild Ammonia-free	
		Nochromix Reagent is an inorganic oxidizer that can be		
	Nochromix Reagent	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
		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 other set in a character of the catalysts.		
		in alternative solvents. The catalyst itself, however, may sometimes be very toxic and alternatives for many of the	4	
Chromium(VI)	catalytic systems	dangerous catalysts, such as hydrogen fluoride or sulfuri acid, are available.	C	



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



Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
onemical to Replace		Ethanol is a high volume chemical that is listed by the	1103	0010
	Ethanol 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 the dangerous catalysts, such as hydrogen fluoride or sulfuri 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	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	



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
				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
		Polyethylene glycol (PEG) is a water soluble solid that ca	n en	coextracted when using supercritical
		be used as a recyclable solvent medium in the place of	Non-volatile, Inexpensive, Low toxicity	carbon dioxide, although PEG1500 is
	Polyethylene glycol (PEG)	volatile organic compounds.	(approved for food industry)	significantly less likely to be coextracted
			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	
		Gas-expanded liquids can be used as solvents to increas		Liquid expanded may still be a hazardous
	Gas-expanded liquids	yields.	carbamic acid or carbamates that revert	solvent
			Non-volatile, Recyclable, Non	
			1 .	Some may be toxic to environment. 1,3-
			available in laboratory quantities,	dialkylimidazolium ionic liquids, for
			Tetrafluoroborate salts may have	instance, are antimicrobial depending on
		lonic liquids are typically molten salts that are liquid below		
	4.2 dielladimidenelium esticus with	100°C and provide a less volatile and recyclable		require use of organic solvents in
		alternative to many organic solvents such as methylene		preparation steps, High viscosity (can be
	tetrafluoroborate,	chloride. Some of the most popular ionic liquids use 1,3-		lowered if CO2 is dissolved in it), Anions
	hexaluorophosphate, or	l ,	Can from one, two, or three-phase	of some ionic liquids may hydrolyze to
	trifluoromethane sulfonate anions	hexaluorophosphate, or trifluoromethane sulfonate anion	scatalytic systems	form undesirable products



				T
Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		Microwave irradiation has been increasingly used by both		
		academia and industry to reduce reaction times from day		
		to minutes. Reactions performed in a microwave batch		
		reactor, for instance, can be constantly monitored, and		
		temperature and pressure can be manually controlled,		
	Microwave irradiation	often leading to more complete reactions and higher		
	microwave irradiation	product yields.		
		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		
	solventless or solvent-free	can occur simply by crushing two solids together in the		
	reactions	dry phase.		
			Non-flammable, Tunable solvent	
			properties, Non-toxic, Easy removal fron product, Inert to oxidation and radical	Yields not as high traditional solvents, Reactivity with amines, although may
		Supercritical carbon dioxide(scCO2) has been used in the	[•	reform amine after depressurization,
	Supercritical carbon	place of generic hazardous solvents. This includes but is	compounds and gases well, Critical	Safety and cost of high pressure
	dioxide(scCO2)		temperature low (Tc = 31.3°C)	equipment (Pc = 72.9 atm)



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
·				
		Different forms of alumina support, such as fluorided		
		silica-alumina catalysts, offer an alternative to using more		
Dichloromethane	fluorided silica-alumina catalysts	hazardous catalysts in a number of chemical processes.		
				Prepared industrially from toluen
			Less volatile	Solvent removal requires more energy
			Lower toxicity	(boiling point: 102°C)
			Relatively inert	Wet commercially
			Stable in strongly basic conditions	Hydrolyzes with acids at high
			Non-ozone depleter	temperatures
			Polarity between methylene chloride and	_
		Benzotrifluoride (BTF, C7H5F3) is a less toxic and more	Piecely acetate	May be sensitive to reducing conditions
	Benzotrifluoride	environmentally friendly alternative to tetrahydrofuran an		involving electron transfer but compatible
	Benzotrinuoride	methylene chloride.	Miscible with organic solvents	with hydride reductions and
		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 the		
		dangerous catalysts, such as hydrogen fluoride or sulfurio		
	catalytic systems	acid, are available.		
	Catalytic Systems	acio, are available.		



Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	d-Limonene	d-Limonene is a naturally derived citrus terpene or solver that can be used to replace methylene chloride as a cleaning agent	t 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	chloride	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) ha been used as a good substitute for methylene chloride ar tetrahydrofuran.	Stable in aqueous acidic conditions and decomposes less than 1%	Not stable under homgeneous acidic



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
'			Non-volatile, Recyclable, Non	
			explosiveNon-flammable, Commercially	Some may be toxic to environment. 1,3-
			available in laboratory quantities,	dialkylimidazolium ionic liquids, for
			Tetrafluoroborate salts may have	instance, are antimicrobial depending on
		Ionic liquids are typically molten salts that are liquid below	relatively low toxicity, Can have hydroge	their N-alkyl group chain lengths, May
			bond acceptors and donors, Miscibility	require use of organic solvents in
	1,3-dialkylimidazolium cations with		with water can be tuned by anions, alkyl	preparation steps, High viscosity (can be
	tetrafluoroborate,	chloride. Some of the most popular ionic liquids use 1,3-	groups, and sometimes temperature,	lowered if CO2 is dissolved in it), Anions
	hexaluorophosphate, or	dialkylimidazolium cations with tetrafluoroborate,	Can from one, two, or three-phase	of some ionic liquids may hydrolyze to
	trifluoromethane sulfonate anions	hexaluorophosphate, or trifluoromethane sulfonate anions	catalytic systems	form undesirable products
		- a		
	Ethanal	Ethanol is a high volume chemical that is listed by the		
	Ethanol	EPA as an air contaminant.		
		Lactate esters (such as ethyl lactate) have shown		
		excellent solvent properties as safer, non-toxic, and		
		biodegradable chemical alternatives to several		
			Biodegradable	Solvent removal requires more energy
	Lactate esters	replacements in as cleaning agents or reaction solvents.	_	(boiling point: 154°C)
		- op. a some in a constanting agoing of reaction convents.		V 01 2 10.1 0/



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
			Lower toxicity	
			Non-irritant to eyes and skin	
			High flashpoint	
			Cleaning performance is similar to NMP	(boiling point: > 200°C)
		Methyl soyate, a type of methyl ester, is a biodegradable, less toxic alternative that can replace methylene chloride	Biodegradable	Slow evaporation may leave film on
	Methyl soyate		Renewable	surfaces
		Methyl tert-butyl ether (MTBE) has been used to replace		Groundwater contaminant after being used as a fuel additive
	Methyl tert-butyl ether (MTBE)		Lower toxicity than halogenated solvents	Possible human carcinogen at high doses
			, ,	3 5
		N-methyl pyrrolidone (NMP) is a higher flashpoint solvent		
		that can be used in the place of many chlorinated or		
	N-methyl pyrrolidone (NMP)	generic hazardous solvents used for cleaning, such as acetone.		
	it mount pyrrondono (timi)	accione.		<u>l</u>



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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	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, is a viab alternative to many solvents often used in Grignard reactions.	le 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.		



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



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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	reactions, Dissolves perfluorinated	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) ha been used as a good substitute for methylene chloride ar	Diethoxymethane (DEM or formaldehydediethylactal) has been used as a good	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)		Methylating agent at 160°C Avoids unwanted inorganic salt	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
One inical to Kepiace	Alternative offernicals	Details	1103	Oons
Directly of company ide (DME)	fluorous ether F-626, benzotrifluoride, fluorous dimethyloromamide (F-DMF), and	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	Can form multi-phase reaction systems Relatively non-toxic	Yields almost comparable but not as high
Dimethyl formamide (DMF)	perfluorohexanes (FC-72)	have also caught the interest of organic chemists.	High solubility of gases	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	



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		Microwave irradiation has been increasingly used by both		
		academia and industry to reduce reaction times from day to minutes. Reactions performed in a microwave batch	/S	
		reactor, for instance, can be constantly monitored, and		
		temperature and pressure can be manually controlled,		
		often leading to more complete reactions and higher		
	Microwave irradiation	product yields.		
		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		
	N-methyl pyrrolidone (NMP)	acetone.		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
		Polyethylene glycol (PEG) is a water soluble solid that ca	 am	coextracted when using supercritical
		be used as a recyclable solvent medium in the place of	Non-volatile, Inexpensive, Low toxicity	carbon dioxide, although PEG1500 is
	Polyethylene glycol (PEG)	volatile organic compounds.	(approved for food industry)	significantly less likely to be coextracted



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		The was of beautiful about the suited		
		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		
	solventless or solvent-free	can occur simply by crushing two solids together in the		
	reactions	dry phase.		
				Solvent removed requires more energy
			Diethoxymethane (DEM or formaldehyd	Solvent removal requires more energy
		Diethoxymethane (DEM or formaldehyde diethylactal) ha		Not stable under homgeneous acidic
	Diethoxymethane (DEM or	been used as a good substitute for methylene chloride ar	substitute for methylene chloride and	conditions and may liberate formaldehyde
Dimethyl glycol	formaldehyde diethylactal)		tetrahydrofuran.	, , , , , , , , , , , , , , , , , , , ,
			Non-volatile, Recyclable, Non	
				Some may be toxic to environment. 1,3-
			available in laboratory quantities,	dialkylimidazolium ionic liquids, for
			Tetrafluoroborate salts may have	instance, are antimicrobial depending on
		Ionic liquids are typically molten salts that are liquid below		
	1 2-dialkylimidazolium cations with		bond acceptors and donors, Miscibility	require use of organic solvents in preparation steps, High viscosity (can be
	tetrafluoroborate,	alternative to many organic solvents such as methylene chloride. Some of the most popular ionic liquids use 1,3-		lowered if CO2 is dissolved in it), Anions
	hexaluorophosphate, or		Can from one, two, or three-phase	of some ionic liquids may hydrolyze to
Dimethyl sulfoxide (DMSO)	trifluoromethane sulfonate anions	hexaluorophosphate, or trifluoromethane sulfonate anion		form undesirable products
		monard of the desired	yr, 5, 51515	The second products



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		n-Octyl tetrahydrofurfuryl ether (n-OTE) is tetrahydrofurai		
		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		
	OTE)	remove water from THF.		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
		Debugge and the second of the		esterified or etherified PEG may be coextracted when using supercritical
		Polyethylene glycol (PEG) is a water soluble solid that ca be used as a recyclable solvent medium in the place of	Non-volatile, Inexpensive, Low toxicity	carbon dioxide, although PEG1500 is
	Polyethylene glycol (PEG)	· · · · · · · · · · · · · · · · · · ·	(approved for food industry)	significantly less likely to be coextracted
	, , , , , , , , , , , , , , , , , , ,			3 1, 111 1, 111 111 111 111
		The use of herordeus shaminals can often be suited a		
		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		
	solventless or solvent-free	can occur simply by crushing two solids together in the		
	reactions	dry phase.		



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		Different forms of alumina support, such as fluorided		
		silica-alumina catalysts, offer an alternative to using more		
	iluorided silica-alullillia catalysts	hazardous catalysts in a number of chemical processes.		
		Microwave irradiation has been increasingly used by both		
			' \$	
		often leading to more complete reactions and higher		
	Microwave irradiation	product yields.		
Ethanol				
	Microwave irradiation	academia and industry to reduce reaction times from day 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	5	



Chemical to Replace	Alternative Chemicals	Deteile	Pros	Cons
опеннов то керівсе		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 the dangerous catalysts, such as hydrogen fluoride or sulfuriacid, are available.		COIIS
	Microwave irradiation	Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from day 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		



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
				Solvent removal requires more energy
		Butyl diglyme, or diethylene glycol dibutyl ether, is a viab		(boiling point: 256°C). Lower boiling point
		alternative to many solvents often used in Grignard	ľ	solvents that are similar but miscible with
Ether	dibutyl ether		Immiscible with water	water are monoglyme (DME) and diglyme
		Indium metal, a non-toxic metal often used in dental alloy	J	
		is a viable alternative for many hazardous catalyst		
	Indium metal	systems.		
		-7	Non-volatile, Recyclable, Non	
				Some may be toxic to environment. 1,3-
			available in laboratory quantities,	dialkylimidazolium ionic liquids, for
			Tetrafluoroborate salts may have	instance, are antimicrobial depending on
		lonic liquids are typically molten salts that are liquid below		
	1 3-dialkylimidazolium cations with	-	bond acceptors and donors, Miscibility	require use of organic solvents in preparation steps, High viscosity (can be
	tetrafluoroborate,	chloride. Some of the most popular ionic liquids use 1,3-		lowered if CO2 is dissolved in it), Anions
	hexaluorophosphate, or		Can from one, two, or three-phase	of some ionic liquids may hydrolyze to
		hexaluorophosphate, or trifluoromethane sulfonate anion		form undesirable products
			k))	



		T	1	<u> </u>
Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
				Groundwater contaminant after being
		Methyl tert-butyl ether (MTBE) has been used to replace		used as a fuel additive
				Possible human carcinogen at high doses
		diomorometriane in dinomatography and extraorions.		a coolers mamman carolinegen at mgm acces
		n-Octyl tetrahydrofurfuryl ether (n-OTE) is tetrahydrofura	ή	
		derivative that can be used as an alternative solvent to		
		tetrahydrofuran. This less water soluble replacement for		
	n-Octyl totrahydrofurfuryl othor (n-	THF offers a safer, more environmentally friendly alternative that avoids additional steps usually taken to		
	OTE)	remove water from THF.		
	3.12)	Temove water from 1111 .		
			Non-flammable, Tunable solvent	
			properties, Non-toxic, Easy removal from	
			product, Inert to oxidation and radical	Reactivity with amines, although may
	Superoritical carbon	Supercritical carbon dioxide(scCO2) has been used in the	ereactions, Dissolves perfluorinated	reform amine after depressurization,
	Supercritical carbon dioxide(scCO2)	place of generic hazardous solvents. This includes but is	temperature low (Tc = 31.3°C)	Safety and cost of high pressure equipment (Pc = 72.9 atm)
	uloxide(SCCO2)	not limited to methylene chloride.	temperature low (10 = 31.3 C)	equipment (FC = 72.9 atm)



Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		Dotaile		
			Good for radical reactions (H abstraction	
			from OH unlikely and no reactive multip	
		Water, the universal solvent, has been recognized as one	bonds)	
		of the safest and most environmentally friendly alternative	Non-flammable	
			Can avoid tedious protection steps Solvent properties change with	Subsequent workup may be energy intensive and/or involve the use of organic
			increasing temperature	solvents
			5 1	
			Less background and stronger	
			fluorescence in DNA staining Lower disposal costs (approved for	
Ethidium Bromide		effective DNA gel staining agent than ethidium bromide.	sewage disposal in MA)	Higher up-front cost
			,	
				Solvent removal requires more energy
		Butyl diglyme, or diethylene glycol dibutyl ether, is a viab	l e	(boiling point: 256°C). Lower boiling point solvents that are similar but miscible with
Ethoxyethane	dibutyl ether	alternative to many solvents often used in Grignard reactions.	Immiscible with water	water are monoglyme (DME) and diglyme
Luioxyculalic	and tyr other	IGAGUOTIS.	minioodole with water	water are monoglyme (DIVIE) and digiyme



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



Observice Life Barriers	Alternative Objects		D	
Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		n-Octyl tetrahydrofurfuryl ether (n-OTE) is tetrahydrofural 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)		Non-flammable, Tunable solvent properties, Non-toxic, Easy removal fror 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, 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		



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
·				
			Distriction of the second seco	Solvent removal requires more energy
			Diethoxymethane (DEM or formaldehyd	
	Diethoxymethane (DEM or	Diethoxymethane (DEM or formaldehyde diethylactal) ha been used as a good substitute for methylene chloride ar	guernylacial) has been used as a good	Not stable under homgeneous acidic conditions and may liberate formaldehyde
Ethyl Acetate			tetrahydrofuran.	conditions and may liberate formalderryde
2,		tettarryurorurari.	tottariyarorarari.	
		Indian metal a non taxia metal often used in dental alle		
		Indium metal, a non-toxic metal often used in dental alloy is a viable alternative for many hazardous catalyst		
	Indium metal	systems.		
		eyeteme.		
				Groundwater contaminant after being
		Methyl tert-butyl ether (MTBE) has been used to replace		used as a fuel additive
			Lower toxicity than halogenated solvents	Possible human carcinogen at high doses
		distribution and in strictliategraphy and extractions.		Haman da.ddgd.r at riight doodd



			T	
Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
			Good for radical reactions (H abstraction	
			from OH unlikely and no reactive multipl	
		Water, the universal solvent, has been recognized as one of the safest and most environmentally friendly alternative	Non flammable	
			Can avoid tedious protection steps	Subsequent workup may be energy
			Solvent properties change with	intensive and/or involve the use of organic
	Water	· ·	increasing temperature	solvents
		and an analysis of a second se	, i	
		Ethanol is a high volume chemical that is listed by the		
	Ethanol	EPA as an air contaminant.		
		21 / t do di t di tottidi iliani		
				Columnt removal requires more
		Dutid dialyma or diathylana alygal dibytyl stranic a sich		Solvent removal requires more energy (boiling point: 256°C). Lower boiling point
		Butyl diglyme, or diethylene glycol dibutyl ether, is a viabl alternative to many solvents often used in Grignard		solvents that are similar but miscible with
Ethyl Ether	dibutyl ether		Immiscible with water	water are monoglyme (DME) and diglyme
Edity: Editor	andaty: otiloi	icaciions.	minisoloio with water	water are monogryme (DML) and digryme



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



Observice Life Barriers	Alternative Objects		D	
Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		n-Octyl tetrahydrofurfuryl ether (n-OTE) is tetrahydrofural 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)		Non-flammable, Tunable solvent properties, Non-toxic, Easy removal fror 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, 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		



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
			Diethoxymethane (DEM or formaldehyde	Solvent removal requires more energy
		Diethoxymethane (DEM or formaldehyde diethylactal) ha	` ` `	Not stable under homgeneous acidic
	Diethoxymethane (DEM or	been used as a good substitute for methylene chloride ar	substitute for methylene chloride and	conditions and may liberate formaldehyde
Ethylene glycol dimethyl ether	formaldehyde diethylactal)		tetrahydrofuran.	
				Solvent removal requires more energy
			Diethoxymethane (DEM or formaldehyde	1
		Diethoxymethane (DEM or formaldehyde diethylactal) ha	diethylactal) has been used as a good	Not stable under homgeneous acidic
	Diethoxymethane (DEM or	been used as a good substitute for methylene chloride a		conditions and may liberate formaldehyde
Formaldehyde	formaldehyde diethylactal)	tetrahydrofuran.	tetrahydrofuran.	
				Solvent removal requires more energy
			Diethoxymethane (DEM or formaldehyde	(boiling point: 88°C)
	5: 4	Diethoxymethane (DEM or formaldehyde diethylactal) ha	diethylactal) has been used as a good	Not stable under homgeneous acidic
Glyme	Diethoxymethane (DEM or formaldehyde diethylactal)	been used as a good substitute for methylene chloride at tetrahydrofuran.	substitute for methylene chloride and tetrahydrofuran.	conditions and may liberate formaldehyde
Glyffie	ioimaidenyde dietnylactai)	letranyuroruran.	tetranyururun.	



Alternative Chemicals	Details	Pros	Cons
	Dimethylpropyleneurea (DMPU) is a viable and safer		
	Cetyltrimethylammonium chloride (CTAC) is a cationic		
Aqueous surfactants and	Aqueous surfactants and macromolecular solutions can	Avoids volatile organic solvents, May	Workup and extraction procedures may
	•		be tedious
	imethylpropyleneurea (DMPU) etyltrimethylammonium chloride CTAC)	Dimethylpropyleneurea (DMPU) is a viable and safer chemical alternative for diprotic apolar solvents such as hexamethylphosphoramide (HMPA). Cetyltrimethylammonium chloride etyltrimethylammonium chloride reactions in water, including those reactions that normally run in organic solvents.	Dimethylpropyleneurea (DMPU) is a viable and safer chemical alternative for diprotic apolar solvents such as hexamethylphosphoramide (HMPA). Cetyltrimethylammonium chloride aqueous surfactant that can be used to accelerate reactions in water, including those reactions that normally run in organic solvents. Cetyltrimethylammonium chloride aqueous surfactant that can be used to accelerate reactions in water, including those reactions that normally run in organic solvents. Aqueous surfactants and Aqueous surfactants and macromolecular solutions can Avoids volatile organic solvents, May



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



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Volatile methyl siloxanes (VMS)	, , ,		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	Non-flammable, Tunable solvent properties, Non-toxic, Easy removal fron 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 day 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
		, 20 ta0		
		Different forms of alumina support, such as fluorided		
		silica-alumina catalysts, offer an alternative to using more		
	fluorided silica-alumina catalysts	hazardous catalysts in a number of chemical processes.		
			Better solubility of gases	
			Reduces viscosity of expanded solvent	
			Enhances mass transfer	
			Non-flammable	
			Tunable solvent strength	
			Suited for reactions already conducted	
			under pressure	
		0	Avoids unwanted secondary or tertiary	Liquid avecaded may still be a becarded
		Gas-expanded liquids can be used as solvents to increas		
	Gas-expanded liquids	yields.	carbamic acid or carbamates that revert	solveni
		Solid acid catalysts can be used in the place of a number		
		of hazardous strong acids traditionally used in chemical		
	Solid acid catalysts	reactions.		
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Ohamiaal (a Bantaa	Alta-marker Observing to		Barra	
Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		The use of hazardous chemicals can often be avoided		
		without the addition of a reaction solvent in solventless of	r	
		solvent-free reactions. Although a reactant may act as a		
		solvent to still allow for a liquid reaction, other reactions		
	solventless or solvent-free	can occur simply by crushing two solids together in the		
	reactions	dry phase.		
		Sulfated zirconia is a solid acid catalyst that can be used		
	Sulfated zirconia	in a number of reactions to avoid the use of strong acids		
	Suirated zirconia	such as hydrofluoric acid and other strong Lewis acids.		
			Non-flammable, Tunable solvent	
			properties, Non-toxic, Easy removal from	
			product, Inert to oxidation and radical	Reactivity with amines, although may
	Supercritical carbon	Supercritical carbon dioxide(scCO2) has been used in the place of generic hazardous solvents. This includes but is	ereactions, Dissolves peritioninated	reform amine after depressurization, Safety and cost of high pressure
	dioxide(scCO2)		temperature low (Tc = 31.3°C)	equipment (Pc = 72.9 atm)
	dioxido(3000L)	not innited to metrylene chloride.	temperature low (10 = 51.5 O)	equipment (1 6 = 72.5 atm)



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Chomical to Hopiaco	r morriadivo Grionnicale	Details		90110
		Zeolites are crystalline solids that can replace a number of		
		hazardous catalysts used in traditional reactions such as oxidation and reduction reactions, hydrogen-exchange		
	Zeolites	reactions, and the syntheses of carbamates		
		Microwave irradiation has been increasingly used by both		
		academia and industry to reduce reaction times from day	's	
		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		
Hydrogen Fluoride	Microwave irradiation	product yields.		
		Different forms of alumina support, such as fluorided		
		silica-alumina catalysts, offer an alternative to using more		
	nuonueu Sinca-aiumma CalaiyStS	hazardous catalysts in a number of chemical processes.		



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
			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	
		Gas-expanded liquids can be used as solvents to increase		
	Gas-expanded liquids	yields.	carbamic acid or carbamates that revert	solvent
		Solid acid catalysts can be used in the place of a numbe	r 	
	Solid soid sotalysts	of hazardous strong acids traditionally used in chemical		
	Solid acid catalysts	reactions.		
		The use of hazardous chemicals can often be avoided		
		without the addition of a reaction solvent in solventless o	,	
		solvent-free reactions. Although a reactant may act as a		
		solvent to still allow for a liquid reaction, other reactions		
	solventless or solvent-free	can occur simply by crushing two solids together in the		
	reactions	dry phase.		
	100010110	ury pridoc.	J]



Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Chemical to Replace	Atternative Orienticals	Details	1103	00113
		Sulfated zirconia is a solid acid catalyst that can be used		
	Sulfated zirconia	in a number of reactions to avoid the use of strong acids		
	Sunated zircoma	such as hydrofluoric acid and other strong Lewis acids.		
			Non-flammable, Tunable solvent	
			properties, Non-toxic, Easy removal from	Yields not as high traditional solvents.
				Reactivity with amines, although may
		Supercritical carbon dioxide(scCO2) has been used in the	reactions, Dissolves perfluorinated	reform amine after depressurization,
	Supercritical carbon	place of generic hazardous solvents. This includes but is		Safety and cost of high pressure
	dioxide(scCO2)	not limited to methylene chloride.	temperature low (Tc = 31.3°C)	equipment (Pc = 72.9 atm)
		Zeolites are crystalline solids that can replace a number	↓ ∳f	
		hazardous catalysts used in traditional reactions such as		
	7	oxidation and reduction reactions, hydrogen-exchange		
	Zeolites	reactions, and the syntheses of carbamates		



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		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		
Hydroxybenzene	DNA extraction kits	and the generation of unnecessary wastes.		
		Traditional DNA extraction procedures can avoid the use		
	DNA Extraction with Polycarbonate	of dangerous and hazardous chemicals by performing		
	Filters	DNA extraction with polycarbonate filters.		
		Traditional DNA extraction procedures can be replaced b	V	
		alternative processes such as DNA extraction with		
	Glycol	polethylene glycol and simple salts.		



	1			
Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
				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
		Polyethylene glycol (PEG) is a water soluble solid that ca	n	coextracted when using supercritical
			Non-volatile, Inexpensive, Low toxicity	carbon dioxide, although PEG1500 is
	Polyethylene glycol (PEG)		(approved for food industry)	significantly less likely to be coextracted
		Titanosilicate molecular sieves can avoid the use of many	y	
		hazardous chemicals and/or processes by effectively		
		catalyzing a number of reactions including the synthesis		
Isocyanates		of many carbonates and carbamates.		
		7lites and amountables a clied the transport and a community	,	
		Zeolites are crystalline solids that can replace a number of hazardous catalysts used in traditional reactions such as		
		oxidation and reduction reactions, hydrogen-exchange		
	Zeolites	reactions, and the syntheses of carbamates		
<u> </u>	l .	in the same of the same and the	l .	



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Chemical to Replace Alternative	Chemicals De	etails	Pros	Cons
		lectrodes using mercury to detect trace metals can be		
Mercury	re	eplaced with non-mercury electrodes.		
	Δ1	Icohol thermometers		
	Al	iconor thermometers		
				Oal and an arrandom in a second
				Solvent removal requires more energy
	l _D	riethoxymethane (DEM or formaldehyde diethylactal) ha	Diethoxymethane (DEM or formaldehyde	Not stable under homgeneous acidic
Diethoxyme	ethane (DEM or be	een used as a good substitute for methylene chloride ar	substitute for methylene chloride and	conditions and may liberate formaldehyde
	de diethylactal) tei	etrahydrofuran.	tetrahydrofuran.	land the second



Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		Different forms of alumina support, such as fluorided silica-alumina catalysts, offer an alternative to using more		
Methanol	fluorided silica-alumina catalysts	hazardous catalysts in a number of chemical processes.		
	Aqueous surfactants and	Aqueous surfactants and macromolecular solutions can	Avoids volatile organic solvents, May	Workup and extraction procedures may
	macromolecular solutions	1		be tedious
		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 the dangerous catalysts, such as hydrogen fluoride or sulfurions.		
	catalytic systems	acid, are available.		



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		Combined (A guarater®) is a loss toxic and more		
		Combisolven t(Aquastar®) is a less toxic and more environmentally friendly chemical currently available to u		
	Combisolven t(Aquastar®)	in the place of methanol in Karl Fischer titrations.		
	Combisorven (Aquastare)	In the place of methanorin Kan Fischer unations.		
		Ethanol is a high volume chemical that is listed by the		
	Ethanol	EPA as an air contaminant.		
			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	Line in the second of the second in the second
		Gas-expanded liquids can be used as solvents to increas	amines when gas is CO2 (which forms	Liquid expanded may still be a hazardous
	Gas-expanded liquids	yields.	carbamic acid or carbamates that revert	solvent



Chemical to Replace	Alternative Chemicals	2	Pros	Cons
			Non-volatile, Recyclable, Non	C
			,	Some may be toxic to environment. 1,3-
			available in laboratory quantities,	dialkylimidazolium ionic liquids, for
		lonic liquids are typically molten salts that are liquid below	Tetrafluoroborate salts may have	instance, are antimicrobial depending on
			bond acceptors and donors, Miscibility	require use of organic solvents in
	1 3-dialkylimidazolium cations with	1		preparation steps, High viscosity (can be
	tetrafluoroborate,	chloride. Some of the most popular ionic liquids use 1,3-		lowered if CO2 is dissolved in it), Anions
	hexaluorophosphate, or		Can from one, two, or three-phase	of some ionic liquids may hydrolyze to
		hexaluorophosphate, or trifluoromethane sulfonate anions		form undesirable products
	timuoromethane sunonate amons	Inexaluoropriospriate, or trilluorometriane sullonate anions	catalytic systems	Tom undesirable products
		Isopropanol, the chemical used as rubbing alcohol, can b	Less toxic than methanol	Still a volatile organic compound
	Isopropanol	used as an alternative for more hazardous chemicals.	Non-halogenated	Flammable
		The use of a semi dry apparatus in westers blottless as		
		The use of a semi-dry apparatus in western blotting or		
	semi-dry apparatus	other drying techniques can help to minimize the use of		
	semi-ury apparatus	hazardous solvents, such as methanol.		



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		Microwave irradiation has been increasingly used by both		
		academia and industry to reduce reaction times from day		
		to minutes. Reactions performed in a microwave batch		
		reactor, for instance, can be constantly monitored, and		
		temperature and pressure can be manually controlled,		
	Microwave irradiation	often leading to more complete reactions and higher		
	microwave irradiation	product yields.		
		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		
	solventless or solvent-free	can occur simply by crushing two solids together in the		
	reactions	dry phase.		
			Non-flammable, Tunable solvent	
			properties, Non-toxic, Easy removal fron product, Inert to oxidation and radical	Yields not as high traditional solvents, Reactivity with amines, although may
		Supercritical carbon dioxide(scCO2) has been used in the	[•	reform amine after depressurization,
	Supercritical carbon	place of generic hazardous solvents. This includes but is	compounds and gases well, Critical	Safety and cost of high pressure
	dioxide(scCO2)		temperature low (Tc = 31.3°C)	equipment (Pc = 72.9 atm)



Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Спетісаї то керіасе		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	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	
Methyl Chloroform	Volatile Methyl Siloxanes (VMS)		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 day 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
·				
		Different forms of alumina support, such as fluorided		
		silica-alumina catalysts, offer an alternative to using more	1	
	fluorided silica-alumina catalysts	hazardous catalysts in a number of chemical processes.	Detten eelubilitus faceas	
			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	
		Gas-expanded liquids can be used as solvents to increas		Liquid expanded may still be a hazardous
	Gas-expanded liquids	yields.	carbamic acid or carbamates that revert	solvent
			Non-volatile, Recyclable, Non	
				Some may be toxic to environment. 1,3-
			available in laboratory quantities,	dialkylimidazolium ionic liquids, for
			Tetrafluoroborate salts may have	instance, are antimicrobial depending on
		Ionic liquids are typically molten salts that are liquid below		
		100°C and provide a less volatile and recyclable		require use of organic solvents in
				preparation steps, High viscosity (can be
	tetrafluoroborate,	chloride. Some of the most popular ionic liquids use 1,3-		lowered if CO2 is dissolved in it), Anions
	hexaluorophosphate, or	dialkylimidazolium cations with tetrafluoroborate,	Can from one, two, or three-phase	of some ionic liquids may hydrolyze to
	trifluoromethane sulfonate anions	hexaluorophosphate, or trifluoromethane sulfonate anion	scatalytic systems	form undesirable products



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Chaminal to Danlage	Alternative Chemicals	Part 11.	Bree	Sama
Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Aqueous surfactants and	Aqueous surfactants and macromolecular solutions can	Avoids volatile organic solvents, May	Workup and extraction procedures may
	macromolecular solutions	· '	<u> </u>	be tedious
		oth coldonize organic reactions by forming finectics.	ormanise enemies yiers and eeleeming	
		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 the		
		dangerous catalysts, such as hydrogen fluoride or sulfuri		
	catalytic systems	acid, are available.		
		Ethanol is a high volume chemical that is listed by the		
	Ethanol	EPA as an air contaminant.		



			Γ	1
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 fror product, Inert to oxidation and radical ereactions, 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			



Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
onemical to Replace	Polyethylene glycol (PEG)	Polyethylene glycol (PEG) is a water soluble solid that ca be used as a recyclable solvent medium in the place of		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 day 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.		



Chamical to Poplace	Alternative Chemicals	Dataila	Dree	Cono
Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Dimethyl carbonate (DMC)		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 of 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 lodide	Microwave irradiation	Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from day 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
Chemical to Replace	Alternative Chemicals	Details	103	Colis
			Non-toxic	
			Non-mutagenic	
			Methoxycarbonylating agent at 90°C	Requires pressure over 3 bars for batch
			Methylating agent at 160°C	processes because boiling point of DMC
			Avoids unwanted inorganic salt	is 90°C
		Dimethyl carbonate (DMC) is a viable, green alternative f	byproducts	Flammable
	Dimethyl carbonate (DMC)	hazardous methylating agents such as dimethyl sulfate.	Only needs a catalytic amount of base	
		Microwave irradiation has been increasingly used by both		
		academia and industry to reduce reaction times from day	/B	
		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		
	Microwave irradiation	product yields.		
	more trave irradiation	product yields.	Non-volatile, Recyclable, Non	
				Some may be toxic to environment. 1,3-
			available in laboratory quantities,	dialkylimidazolium ionic liquids, for
			Tetrafluoroborate salts may have	instance, are antimicrobial depending on
		Ionic liquids are typically molten salts that are liquid below	relatively low toxicity, Can have hydroge	their N-alkyl group chain lengths, May
		100°C and provide a less volatile and recyclable	bond acceptors and donors, Miscibility	require use of organic solvents in
		alternative to many organic solvents such as methylene		preparation steps, High viscosity (can be
	tetrafluoroborate,	chloride. Some of the most popular ionic liquids use 1,3-		lowered if CO2 is dissolved in it), Anions
	hexaluorophosphate, or	, . ,	Can from one, two, or three-phase	of some ionic liquids may hydrolyze to
	trifluoromethane sulfonate anions	hexaluorophosphate, or trifluoromethane sulfonate anion	catalytic systems	form undesirable products



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		Dotailo		
		Different forms of alumina support, such as fluorided		
		silica-alumina catalysts, offer an alternative to using more		
	fluorided silica-alumina catalysts	hazardous catalysts in a number of chemical processes.		
		·		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
		Polyethylene glycol (PEG) is a water soluble solid that ca		coextracted when using supercritical
			Non-volatile, Inexpensive, Low toxicity	carbon dioxide, although PEG1500 is
	Polyethylene glycol (PEG)	volatile organic compounds.	(approved for food industry)	significantly less likely to be coextracted
		n Ootel totrobudrofurfurd other (n OTE) is total-budrofur-		
		n-Octyl tetrahydrofurfuryl ether (n-OTE) is tetrahydrofural 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		
	OTE)	remove water from THF.		
	V1L)	remove water nom the.		



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		The way of beautiful about the beautiful and		
		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		
	solventless or solvent-free	can occur simply by crushing two solids together in the		
	reactions	dry phase.		
				Solvent removal requires more energy
			Diethoxymethane (DEM or formaldehyde	
	Diethoxymethane (DEM or	Diethoxymethane (DEM or formaldehyde diethylactal) ha been used as a good substitute for methylene chloride ar	substitute for methylone chloride and	Not stable under homgeneous acidic conditions and may liberate formaldehyde
Methyl tert-butyl ether (MTBE)		tetrahydrofuran.	tetrahydrofuran.	conditions and may liberate formalderlyde
monty: tore busy: onio: (m: 22)	iomaidonydd diomylddiai,	ichanyuronan.	tottariyarorarari.	
			Good for radical reactions (H abstraction	
		Water, the universal solvent, has been recognized as one	from OH unlikely and no reactive multipl	
		of the safest and most environmentally friendly alternative		
		to hazardous solvents. Several organic reactions, for	Can avoid tedious protection steps	Subsequent workup may be energy
		instance, have been conducted quite successfully in	Solvent properties change with	intensive and/or involve the use of organic
	Water	aqueous instead of organic solutions.	increasing temperature	solvents



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		Utilizing antalytic avatama in any regation promotes		
		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 the		
		dangerous catalysts, such as hydrogen fluoride or sulfuri		
Methylbenzene	catalytic systems	acid, are available.		
				California de la constitución de
				Solvent removal requires more energy (boiling point: 175.5-178°C)
				Suspected carcinogen
		d-Limonene is a naturally derived citrus terpene or solver	1	Air oxidation of this chemical may create
		that can be used to replace methylene chloride as a	ľ	allergens.
	d-Limonene	· · · · · · · · · · · · · · · · · · ·	Biodegradable	3
		3 - 3 - 3 - 3 - 3 - 3 - 3 - 3 - 3 - 3 -	<u> </u>	
				0.1
			Diethovymethone (DEM or formaldahyd	Solvent removal requires more energy
		Diethoxymethane (DEM or formaldehyde diethylactal) ha	Diethoxymethane (DEM or formaldehyd	Not stable under homgeneous acidic
	Diethoxymethane (DEM or	been used as a good substitute for methylene chloride ar	substitute for methylene chloride and	conditions and may liberate formaldehyde
	formaldehyde diethylactal)		tetrahydrofuran.	conditions and may insorate formalderryde
	iormalaony ao alothy laotaly	totianyarorani.	tottati) di oratati.	



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
				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
		Polyethylene glycol (PEG) is a water soluble solid that ca		coextracted when using supercritical
			Non-volatile, Inexpensive, Low toxicity	carbon dioxide, although PEG1500 is
	Polyethylene glycol (PEG)	volatile organic compounds.	(approved for food industry)	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	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 day 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.		



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



Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		Dotaile		
			Non-flammable, Tunable solvent properties, Non-toxic, Easy removal fror	
	Supercritical carbon dioxide(scCO2)	Supercritical carbon dioxide(scCO2) has been used in the place of generic hazardous solvents. This includes but is	reactions, Dissolves perfluorinated	Reactivity with amines, although may reform amine after depressurization, Safety and cost of high pressure equipment (Pc = 72.9 atm)
	Volatile Methyl Siloxanes (VMS)			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		



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		Envirocat catalysts, provided by Contract Chemicals Ltd	,	
		are more environmentally friendly catalysts that have bee	n en	
		used to replace hazardous substances in a variety of		
	Envirocat catalysts	reactions.		
				Prepared industrially from toluen
			Less volatile	Solvent removal requires more energy
			Lower toxicity	(boiling point: 102°C)
			Relatively inert	Wet commercially
			Stable in strongly basic conditions	Hydrolyzes with acids at high
			Non-ozone depleter	temperatures
			Polarity between methylene chloride and	
		Benzotrifluoride (BTF, C7H5F3) is a less toxic and more	Piecely accepted accepted	May be sensitive to reducing conditions
Methylene Chloride (DCM)	Populatificatida (BTC C7UEC2)	environmentally friendly alternative to tetrahydrofuran an		involving electron transfer but compatible
Methylene Chloride (DCM)	Benzotrifluoride (BTF, C7H5F3)	methylene chloride.	Miscible with organic solvents	with hydride reductions and
				Solvent removal requires more energy
				(boiling point: 175.5-178°C)
				Suspected carcinogen
		d-Limonene is a naturally derived citrus terpene or solver	dt	Air oxidation of this chemical may create
		that can be used to replace methylene chloride as a		allergens.
	d-Limonene	· · · · · · · · · · · · · · · · · · ·	Biodegradable	-
	u-Limonette	cleaning agent	Biodegradable	



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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.	Solvent properties similar to methylene chloride	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) ha been used as a good substitute for methylene chloride ar tetrahydrofuran.	Diethoxymethane (DEM or formaldehyd gdiethylactal) 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.		



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
-			Non-volatile, Recyclable, Non	
			explosiveNon-flammable, Commercially	Some may be toxic to environment. 1,3-
			available in laboratory quantities,	dialkylimidazolium ionic liquids, for
			Tetrafluoroborate salts may have	instance, are antimicrobial depending on
		Ionic liquids are typically molten salts that are liquid below		
				require use of organic solvents in
				preparation steps, High viscosity (can be
	tetrafluoroborate,	chloride. Some of the most popular ionic liquids use 1,3-		lowered if CO2 is dissolved in it), Anions
	hexaluorophosphate, or	dialkylimidazolium cations with tetrafluoroborate,	Can from one, two, or three-phase	of some ionic liquids may hydrolyze to
	trifluoromethane sulfonate anions	hexaluorophosphate, or trifluoromethane sulfonate anion	catalytic systems	form undesirable products
		Lactate esters (such as ethyl lactate) have shown		
		excellent solvent properties as safer, non-toxic, and		
		biodegradable chemical alternatives to several		
	Lactate esters (such as ethyl	halogenated compounds, making them viable		Solvent removal requires more energy
	lactate)	replacements in as cleaning agents or reaction solvents.	Biodegradable Non-toxic	(boiling point: 154°C)
		replacements in as slearning agents of reaction solvents.	2.000g.uuusis, 1.to.i. toxiis	(coming points for c)
			Lower toxicity	
			Non-irritant to eyes and skin	
			High flashpoint	
			Cleaning performance is similar to NMP	Solvent removal requires more energy
		Methyl soyate, a type of methyl ester, is a biodegradable	and DMF	(boiling point: > 200°C)
		less toxic alternative that can replace methylene chloride	Biodegradable	Slow evaporation may leave film on
	Methyl soyate	as a cleaning agent.	Renewable	surfaces



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. Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from day	Lower toxicity than halogenated solvent	Groundwater contaminant after being used as a fuel additive Possible human carcinogen at high doses
	Microwave irradiation	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 solven 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.		
		The use of hazardous chemicals can often be avoided		
		without the addition of a reaction solvent in solventless or	n d	
		solvent-free reactions. Although a reactant may act as a		
	ashanda as an ashand for a	solvent to still allow for a liquid reaction, other reactions		
	solventless or solvent-free reactions	can occur simply by crushing two solids together in the		
	reactions	dry phase.		
			Non-flammable, Tunable solvent	
			properties, Non-toxic, Easy removal from	
			product, Inert to oxidation and radical	Reactivity with amines, although may
	Supercritical carbon	Supercritical carbon dioxide(scCO2) has been used in the place of generic hazardous solvents. This includes but is	ereactions, Dissolves permuorinated	reform amine after depressurization, Safety and cost of high pressure
	dioxide(scCO2)		temperature low (Tc = 31.3°C)	equipment (Pc = 72.9 atm)
		not minica to motifyione oriionae.	(10 = 01.0 0)	



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



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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	Good for radical reactions (H abstraction from OH unlikely and no reactive multiplebonds) Non-flammable Can avoid tedious protection steps Solvent properties change with increasing temperature	
	avate:	aqueous instead of organic solutions.	increasing temperature	Solvents
		Different forms of alumina support, such as fluorided silica-alumina catalysts, offer an alternative to using more		
N,N-dimethylformamide	fluorided silica-alumina catalysts	hazardous catalysts in a number of chemical processes.		
	Fluorous ether F-626, benzotrifluoride, fluorous	benzotrifluoride, fluorous dimethylformamide (F-DMF), and perfluorohexanes (FC-72) are alternative chemicals that have been used to replace a number of hazardous	point, Can form multi-phase reaction	
	dimethylformamide (F-DMF), and perfluorohexanes (FC-72)	chlorinated solvents in industry. Their unique properties have also caught the interest of organic chemists.	systems, Relatively non-toxic, High solubility of gases	Yields almost comparable but not as high as traditional solvents



Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		l'.	Mild	
	Glucose	hazardous chemicals.	Renewable resource	
		Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from day 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) is a higher flashpoint solven that can be used in the place of many chlorinated or generic hazardous solvents used for cleaning, such as acetone.		



Chamical to Danlage	Alternative Chemicals	Date lle	Bree	Cons
Chemical to Replace	Alternative Chemicals	Details	Pros	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
		Polyethylene glycol (PEG) is a water soluble solid that ca	an	coextracted when using supercritical
			Non-volatile, Inexpensive, Low toxicity	carbon dioxide, although PEG1500 is
	Polyethylene glycol (PEG)	volatile organic compounds.	(approved for food industry)	significantly less likely to be coextracted
		The use of hazardous chemicals can often be avoided		
		without the addition of a reaction solvent in solventless of		
		solvent-free reactions. Although a reactant may act as a		
		solvent to still allow for a liquid reaction, other reactions		
	solventless or solvent-free	can occur simply by crushing two solids together in the		
	reactions	dry phase.		!
		. 71		
				1
			Good for radical reactions (H abstraction	
			from OH unlikely and no reactive multip	1
		Water, the universal solvent, has been recognized as one	(DONGS)	
		of the safest and most environmentally friendly alternative		Subaggiant working may be energy
			Can avoid tedious protection steps Solvent properties change with	Subsequent workup may be energy intensive and/or involve the use of organic
	Water	, , ,	increasing temperature	solvents
	Tratei	aqueous instead of organic solutions.	moreasing temperature	SOLVOIRS



Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
- Charles to Hophuso		Details		00.10
		<u>.</u>		
		Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from day		
		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		
N-methyl pyrrolidone (NMP)	Microwave irradiation	product yields.		
		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		
	solventless or solvent-free	can occur simply by crushing two solids together in the		
	reactions	dry phase.		
				Solvent removal requires more energy
				(boiling point: 175.5-178°C)
		l		Suspected carcinogen
		d-Limonene is a naturally derived citrus terpene or solver	lt l	Air oxidation of this chemical may create
Perchloroethylene	d-Limonene	that can be used to replace methylene chloride as a cleaning agent	Biodegradable	allergens.
i cromorocaryiene	a Elifonolic	localling agent	Diodogiadabio	<u> </u>



Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Chambal to Replace	, mornauve onemicals	Details		
		Lactate esters (such as ethyl lactate) have shown		
		excellent solvent properties as safer, non-toxic, and		
	Lactate esters (such as ethyl	biodegradable chemical alternatives to several halogenated compounds, making them viable		Solvent removal requires more energy
	lactate)	replacements in as cleaning agents or reaction solvents.	Biodegradable, Non-toxic	(boiling point: 154°C)
	,	3.3		,
			Lower toxicity	
			Non-irritant to eyes and skin	
			High flashpoint	
		Methyl soyate, a type of methyl ester, is a biodegradable	Cleaning performance is similar to NMP	(boiling point: > 200°C)
		less toxic alternative that can replace methylene chloride	Biodegradable	Slow evaporation may leave film on
	Methyl soyate		Renewable	surfaces
		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		
Phenol	DNA extraction kits	and the generation of unnecessary wastes.		



Chemical to Replace	Alternative Chemicals	Detaile	Pros	Cons
Chemical to Replace	Alternative Chemicals	Details	105	Cons
		Traditional DNA extraction procedures can avoid the use		
	DNA Extraction with Polycarbonate	of dangerous and hazardous chemicals by performing		
	Filters	DNA extraction with polycarbonate filters.		
		Traditional DNA extraction procedures can be replaced b		
	DNA Extraction with Polyethylene	alternative processes such as DNA extraction with	ĺ	
	Glycol	polethylene glycol and simple salts.		
				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
		Polyethylene glycol (PEG) is a water soluble solid that ca		coextracted when using supercritical
			Non-volatile, Inexpensive, Low toxicity	carbon dioxide, although PEG1500 is
	Polyethylene glycol (PEG)		(approved for food industry)	significantly less likely to be coextracted
		1 0 1 1 1 1 1 1		



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		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		
Phenyl alcohol	DNA extraction kits	and the generation of unnecessary wastes.		
		Traditional DNA extraction procedures can avoid the use		
	DNA Extraction with Polycarbonate	of dangerous and hazardous chemicals by performing		
	Filters	DNA extraction with polycarbonate filters.		
		Traditional DNA extraction procedures can be replaced b		
	DNA Extraction with Polyethylene	alternative processes such as DNA extraction with	ĺ	
	Glycol	polethylene glycol and simple salts.		



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
				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
		Delivestavilene aliveel (DEC) is a water calculate colid that as		esterified or etherified PEG may be coextracted when using supercritical
		Polyethylene glycol (PEG) is a water soluble solid that ca be used as a recyclable solvent medium in the place of	Non-volatile, Inexpensive, Low toxicity	carbon dioxide, although PEG1500 is
	Polyethylene glycol (PEG)	,	(approved for food industry)	significantly less likely to be coextracted
	i olyomylono glycol (i 20)	voianie organie compounds.	(approved for food industry)	organical trape in contraction
		1,1-Carbonylbisbenzotriazole is a chemical compound the		
Phase range (CC)		can be used in the place of phosgene in syntheses		
Phosgene(CG)	1,1-Carbonylbisbenzotriazole	reactions.		
		1,1-Carbonylbisimidazole has been a viable chemical		
	1,1-Carbonylbisimidazole	alternative for phosgene in syntheses reactions.		



Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Chemical to Replace	Alternative orientedis	Details	1100	00113
	1,1-Carbonylbisimidazole	1,1-Carbonylbisimidazole has been a viable chemical		
	1,1-Carbonyibisimidazole	alternative for phosgene in syntheses reactions.		
		Di-tert-butyl dicarbonate (BOC anhydride) is chemical		
		compound often used in organic syntheses as a		
	Di-tert-butyl dicarbonate (BOC anhydride)	protecting agent or as a precursor in syntheses. It can be used in the place of phosgene in syntheses reactions.		
	amyunue)	used in the place of phosgene in syntheses reactions.		
			New York	
			Non-toxic Non-mutagenic	
				Requires pressure over 3 bars for batch
			Methylating agent at 160°C	processes because boiling point of DMC
				is 90°C
	Dimethyl carbonate (DMC)	Dimethyl carbonate (DMC) is a viable, green alternative f		Flammable
	Difficulty Carbonate (DIVIC)	hazardous methylating agents such as dimethyl sulfate.	Only needs a catalytic amount of base	



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



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



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
-				
		Isopropanol, the chemical used as rubbing alcohol, can b	Less toxic than methanol	Still a volatile organic compound
Pyridine	Isopropanol		Non-halogenated	Flammable
	Гооргорино	doct do an alternative for more nazaraous orienticals.	The Hallege Halle	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
		Delicate les estables (PEO) is a section of the self-little of		esterified or etherified PEG may be
		Polyethylene glycol (PEG) is a water soluble solid that ca be used as a recyclable solvent medium in the place of	n Non-volatile, Inexpensive, Low toxicity	coextracted when using supercritical carbon dioxide, although PEG1500 is
	Polyethylene glycol (PEG)	· · · · · · · · · · · · · · · · · · ·	(approved for food industry)	significantly less likely to be coextracted
	l olyculyiche giyeer (i 20)	voiatile organic compounds.	(approved for food industry)	significantly less likely to be econtracted
		Microwave irradiation has been increasingly used by both		
		academia and industry to reduce reaction times from day	5	
		to minutes. Reactions performed in a microwave batch		
		reactor, for instance, can be constantly monitored, and		
		temperature and pressure can be manually controlled,		
	Microwave irradiation	often leading to more complete reactions and higher		
	wildiowave irradiation	product yields.		



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 of 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, 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	Non-flammable	
Sodium Azide	Microwave irradiation	Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from day 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
·				
		The use of hazardous chemicals can often be avoided		
		without the addition of a reaction solvent in solventless of		
		solvent-free reactions. Although a reactant may act as a		
	solventless or solvent-free	solvent to still allow for a liquid reaction, other reactions		
		can occur simply by crushing two solids together in the dry phase.		
	i odotiono	ury pridoc.		
		Different forms of alumina support, such as fluorided		
	fluoridad allica alcunina actalusta	silica-alumina catalysts, offer an alternative to using more	1	
	fluorided silica-alumina catalysts	hazardous catalysts in a number of chemical processes.		
		Glucose is a natural, biologically made sugar that has		
			Mild	
Sodium Borohydride	Glucose	hazardous chemicals.	Renewable resource	



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		Glucose is a natural, biologically made sugar that has		
			Mild	
Sodium tetrahydroborate	Glucose	1	Renewable resource	
				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
		Polyethylene glycol (PEG) is a water soluble solid that ca	n	coextracted when using supercritical
			Non-volatile, Inexpensive, Low toxicity	carbon dioxide, although PEG1500 is
Sulfinylbismethane	Polyethylene glycol (PEG)	· · · · · · · · · · · · · · · · · · ·	(approved for food industry)	significantly less likely to be coextracted
		5	*/	
		· · · · · · · · · · · · · · · · · · ·	/B	
	Microwave irradiation	product yields.		
		Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from day 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	(approved for food industry)	



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
·				
		The use of hazardous chemicals can often be avoided		
		without the addition of a reaction solvent in solventless of		
		solvent-free reactions. Although a reactant may act as a		
		solvent to still allow for a liquid reaction, other reactions		
	solventless or solvent-free	can occur simply by crushing two solids together in the		
	reactions	dry phase.		
		Different forms of alumina support, such as fluorided		
		silica-alumina catalysts, offer an alternative to using more		
	fluorided silica-alumina catalysts	hazardous catalysts in a number of chemical processes.		
		,	Non-volatile, Recyclable, Non	
			explosiveNon-flammable, Commercially	Some may be toxic to environment. 1,3-
			available in laboratory quantities,	dialkylimidazolium ionic liquids, for
			Tetrafluoroborate salts may have	instance, are antimicrobial depending on
		Ionic liquids are typically molten salts that are liquid below		
		-		require use of organic solvents in
		alternative to many organic solvents such as methylene		preparation steps, High viscosity (can be
		chloride. Some of the most popular ionic liquids use 1,3-		lowered if CO2 is dissolved in it), Anions
		,	•	of some ionic liquids may hydrolyze to
	trifluoromethane sulfonate anions	hexaluorophosphate, or trifluoromethane sulfonate anion	catalytic systems	form undesirable products



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	n-Octyl tetrahydrofurfuryl ether (n-	n-Octyl tetrahydrofurfuryl ether (n-OTE) is tetrahydrofural 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		
	OTE)	remove water from THF.		
Sulphuric acid dimethyl ester		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 the dangerous catalysts, such as hydrogen fluoride or sulfuri acid, are available.		
	Dimethyl carbonate (DMC)		Methylating agent at 160°C Avoids unwanted inorganic salt	Requires pressure over 3 bars for batch processes because boiling point of DMC is 90°C Flammable



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
Tetrachloroethylene	d-Limonene	d-Limonene is a naturally derived citrus terpene or solver that can be used to replace methylene chloride as a cleaning agent	t 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	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



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
				Prepared industrially from toluen
			Less volatile	Solvent removal requires more energy
			Lower toxicity	(boiling point: 102°C)
			Relatively inert	Wet commercially
			Stable in strongly basic conditions	Hydrolyzes with acids at high
			Non-ozone depleter	temperatures
			Polarity between methylene chloride and	
		Benzotrifluoride (BTF, C7H5F3) is a less toxic and more	ethyl acetate	May be sensitive to reducing conditions
		environmentally friendly alternative to tetrahydrofuran an		involving electron transfer but compatible
Tetrachloromethane	Benzotrifluoride (BTF, C7H5F3)	methylene chloride.	Miscible with organic solvents	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.		



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from day 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	Non-flammable	
Tetrahydrofuran (THF)	Alkoxyethanols	Alkoxyethanols, such as 2-methoxyethanol and 2- ethoxyethanol, can be used as less flammable alternative to organic solvents such as tetrahydrofuran.	as	



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.		
				Solvent removal requires more energy
		Butyl diglyme, or diethylene glycol dibutyl ether, is a viab alternative to many solvents often used in Grignard reactions.	e Immiscible with water	(boiling point: 256°C). Lower boiling point solvents that are similar but miscible with water are monoglyme (DME) and diglyme
		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		
	catalytic systems	sometimes be very toxic and alternatives for many of the dangerous catalysts, such as hydrogen fluoride or sulfuri acid, are available.		



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
	Diethoxymethane (DEM or	Diethoxymethane (DEM or formaldehyde diethylactal) habeen used as a good substitute for methylene chloride at	Less likely to form peroxides than other	Not stable under homgeneous acidic
	formaldehyde diethylactal)	tetrahydrofuran.	ethers	
	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	alternative to many organic solvents such as methylene chloride. Some of the most popular ionic liquids use 1,3-	available in laboratory quantities, Tetrafluoroborate salts may have relatively low toxicity, Can have hydroge bond acceptors and donors, Miscibility with water can be tuned by anions, alkyl groups, and sometimes temperature, Can from one, two, or three-phase	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



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.	h	
	n-Octyl tetrahydrofurfuryl ether (n- OTE)	n-Octyl tetrahydrofurfuryl ether (n-OTE) is tetrahydrofurar 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 day 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.		



Chamical to Danies	Alta mantina Chaminala		Bree	Sama
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 of 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	Non-flammable, Tunable solvent properties, Non-toxic, Easy removal fror 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, 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		



Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		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 the		
		dangerous catalysts, such as hydrogen fluoride or sulfurion	¢	
Toluene	catalytic systems	acid, are available.		
				Solvent removal requires more energy
				(boiling point: 175.5-178°C)
				Suspected carcinogen
		d-Limonene is a naturally derived citrus terpene or solver	t	Air oxidation of this chemical may create
		that can be used to replace methylene chloride as a		allergens.
	d-Limonene	cleaning agent	Biodegradable	
			Lower toxicity	
			Non-irritant to eyes and skin	
			High flashpoint	
			Cleaning performance is similar to NMP	Solvent removal requires more energy
		Methyl soyate, a type of methyl ester, is a biodegradable	0 1	(boiling point: > 200°C)
		less toxic alternative that can replace methylene chloride	Biodegradable	Slow evaporation may leave film on
	Methyl soyate		Renewable	surfaces



Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
			Non toxic	
			Non-toxic	
			Non-mutagenic	Deguires pressure over 2 here for botch
			Methoxycarbonylating agent at 90°C Methylating agent at 160°C	Requires pressure over 3 bars for batch processes because boiling point of DMC
			Avoids unwanted inorganic salt	is 90°C
				Flammable
	Dimethyl carbonate (DMC)	Dimethyl carbonate (DMC) is a viable, green alternative f hazardous methylating agents such as dimethyl sulfate.	Only needs a catalytic amount of base	Fiammable
	Difficulty Carbonate (Divic)	nazardous metnyiating agents such as dimetnyi sullate.	Only needs a catalytic amount of base	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
		Polyethylene glycol (PEG) is a water soluble solid that ca	an e	coextracted when using supercritical
		be used as a recyclable solvent medium in the place of	Non-volatile, Inexpensive, Low toxicity	carbon dioxide, although PEG1500 is
	Polyethylene glycol (PEG)	volatile organic compounds.	(approved for food industry)	significantly less likely to be coextracted
		B L (l	
			Low corrosive activity	
	Poly(propylene glycol) or PPG 4025	chemical that may be used in the place of more hazardou		Viacous liquid at room tomporature
	4020	solvents, such as toluene.	molecular weight	Viscous liquid at room temperature



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 of 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	reactions, Dissolves perfluorinated compounds and gases well, Critical	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)			Flammable Combustible Toxic



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	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	
Trichloroethylene (TCE)	d-Limonene	d-Limonene is a naturally derived citrus terpene or solver that can be used to replace methylene chloride as a cleaning agent	t 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



Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
		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		
	DNA extraction kits	and the generation of unnecessary wastes.		
		,		
		Traditional DNA extraction procedures can avoid the use		
	DNA Extraction with Polycarbonate	of dangerous and hazardous chemicals by performing		
		DNA extraction with polycarbonate filters.		
		510 Community Polycarbonate Interes.		
	DNA Federal and the Balance	Traditional DNA extraction procedures can be replaced b	y	
	DNA Extraction with Polyethylene	alternative processes such as DNA extraction with		
	Glycol	polethylene glycol and simple salts.		



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
·				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
		Polyethylene glycol (PEG) is a water soluble solid that ca		coextracted when using supercritical
	Debugglere alvest (DEC)	· · · · · · · · · · · · · · · · · · ·	Non-volatile, Inexpensive, Low toxicity	carbon dioxide, although PEG1500 is
	Polyethylene glycol (PEG)	volatile organic compounds.	(approved for food industry)	significantly less likely to be coextracted
		Lactate esters (such as ethyl lactate) have shown		
		excellent solvent properties as safer, non-toxic, and		
		biodegradable chemical alternatives to several		
	Lactate esters (such as ethyl	halogenated compounds, making them viable		Solvent removal requires more energy
	lactate)	replacements in as cleaning agents or reaction solvents.	Biodegradable, Non-toxic	(boiling point: 154°C)
				Groundwater contaminant after being
		Methyl tert-butyl ether (MTBE) has been used to replace		used as a fuel additive
	Methyl tert-butyl ether (MTBE)			sPossible human carcinogen at high doses
L			, , ,	. , , , , , , , , , , , , , , , , , , ,



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



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Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
			Can dissolve both organic and fluorous	
	Fluores of the F CCC		compounds, Easy to remove, Solvent	
	Fluorous ether F-626, benzotrifluoride, fluorous	and perfluorohexanes (FC-72) are alternative chemicals that have been used to replace a number of hazardous	point, Can form multi-phase reaction	
	dimethylformamide (F-DMF), and		systems, Relatively non-toxic, High	Yields almost comparable but not as high
	perfluorohexanes (FC-72)		solubility of gases	as traditional solvents
				May still need a reduced amount of
		HistoSolve is a less toxic alternative available to replace	br	conventional solvents, i.e. xylene, for
	HistoSolve	minimize the use of xylenes in preparing histology slides.		effective drying
		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		
	solventless or solvent-free	solvent to still allow for a liquid reaction, other reactions can occur simply by crushing two solids together in the		
	reactions	dry phase.		
<u> </u>		I / L		l



Chemical to Replace	Alternative Chemicals	Details	Pros	Cons
one mount of replace		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	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	
	Volatile Methyl Siloxanes (VMS)	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		Flammable Combustible Toxic
	Microwave irradiation	Microwave irradiation has been increasingly used by both academia and industry to reduce reaction times from day 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