Dr Emina Petrovic

PhD (Vic), MArch (Vic), dipl.ing.arh (Belgrade)

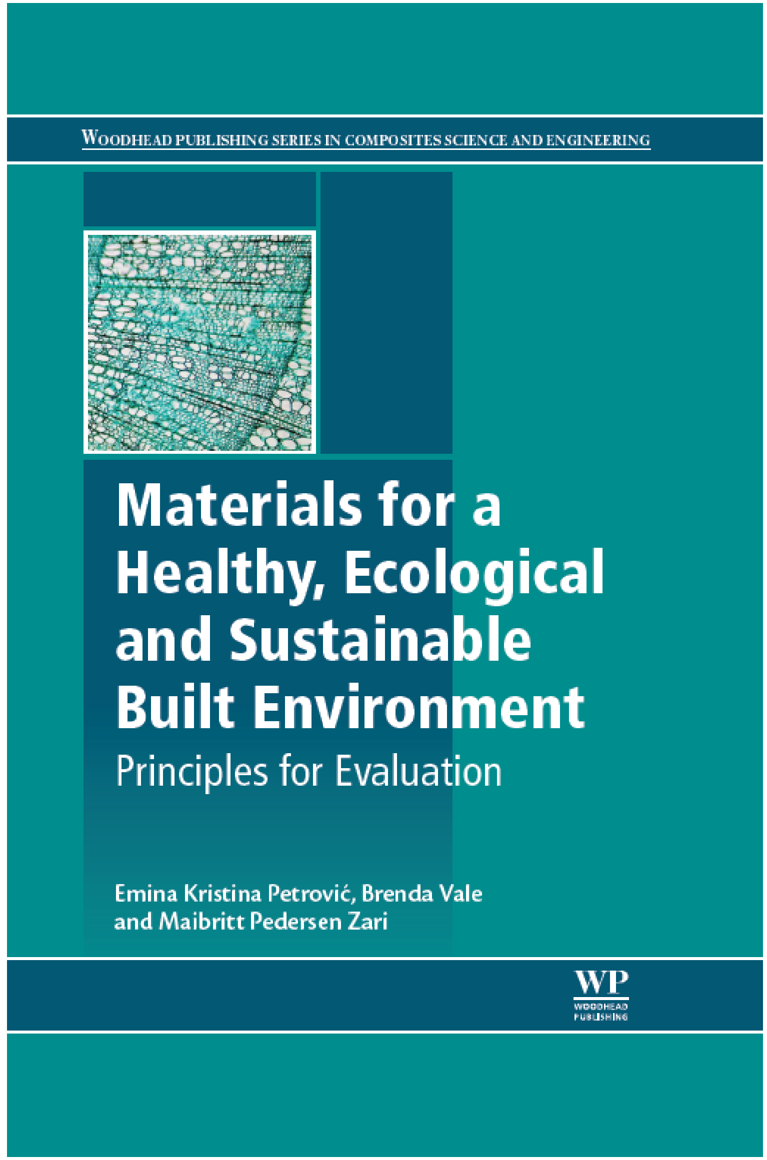
Victoria University of Wellington

ARE PLASTICS REALLY AN ISSUE IN SUSTAINABLE CONSTRUCTION?

2:00pm

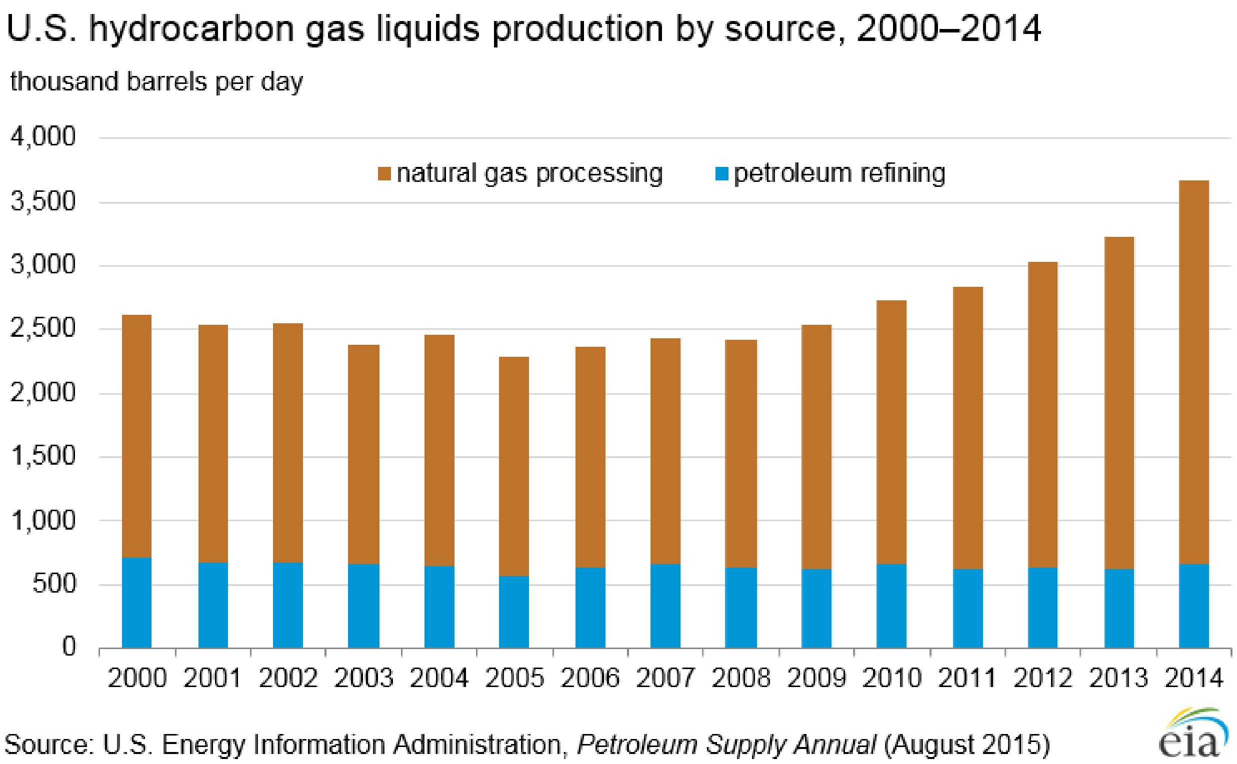
Are plastics really an issue in sustainable construction?

Dr Emina Kristina Petrović

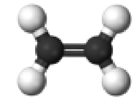
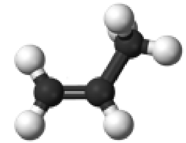
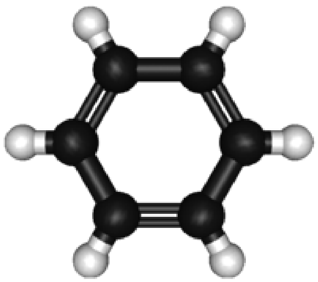
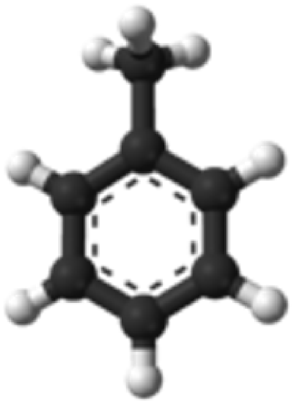

Woodhead Publishing Series in Composites Science and Engineering
Materials for a Healthy, Ecological and Sustainable Built Environment
Principles for Evaluation
Emina Kristina Petrović, Brenda Vale
and Maibritt Pedersen Zari
WP
WOODHEAD PUBLISHING

95% of all synthetic chemicals are presently manufactured from fossil resources

About 10% of all fossil fuels are used for synthetic chemicals



https://www.eia.gov/energyexplained/index.cfm?page=hgls_home

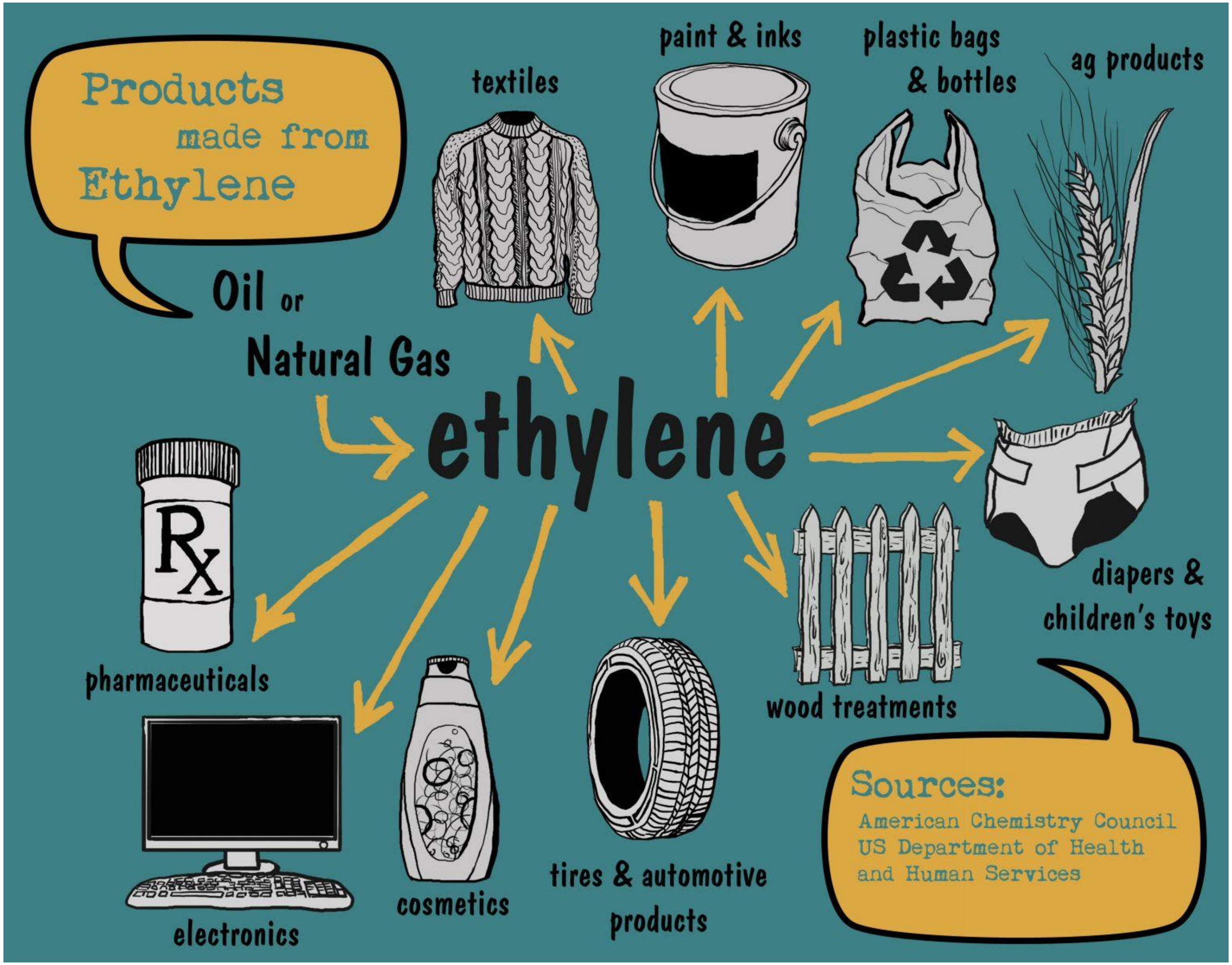
C2	**Ethylene**	
C3	**Propylene**	
C4	**Olefins** or **hydrocarbons C4**	
C6	**Benzene**	
C7	**Toluene**	
C8	**Xylenes**	

	Gr	Name	Carbon content	Description
C1		**Syngas** (synthesis gas)	C1 H, CO andCO_2	Hydrogen, carbon monoxide, and carbon dioxide
C2	**Olefins**	**Ethylene** (or ethene)	C2 C_2H_4 or $CH_2{=}CH_2$	Colourless gas with a sweet odour and taste, lighter than air. Extremely flammable, requires pressurised storage.
C3	**Olefins**	**Propylene** (old propene) (Other C3 hydrocarbons of C3, such as propane (C_3H_8) can be included.)	C3 C_3H_6 or CH_2CHCH_3	Propylene is colourless gas with faint petroleum like odour and is heavier than air. Extremely flammable, requires pressurised storage, very volatile organic compound (VVOC).
C4	**Olefins**	**Olefins** or **hydrocarbons C4**, or 1,3-butadiene, butadiene, divinyl, vinylethylene, biethylene, etc.	C4 C_4H_6 or $CH_2{=}(CH)_2{=}CH_2$ or $CH_2{=}CHCH{=}CH_2$	A set of synthetic colourless gases. Extremely flammable; very volatile organic compounds (VVOC).
C6	**Aromatics**	**Benzene** (or benzol)	C6 C_6H_6	Volatile, clear, colourless, gas with petrol like, sweet odour. Highly flammable; volatile organic compound (VOC).
C7	**Aromatics**	**Toluene**	C7 C_7H_8 or $C_6H_5CH_3$	Clear colourless liquid with a distinctive aromatic odour. Highly flammable liquid and vapor; volatile organic compound (VOC) with vapours heavier than air.
C8	**Aromatics**	**Xylenes** (a group of chemicals: o- Xylene, m- Xylene, p- Xylene, etc.)	C8 C_8H_{10} or $C_6H_4(CH_3)_2$	o-Xylene, m- Xylene, and p-Xylene are colourless watery liquids with a sweet odour and irritating vapour (less dense than water). Flammable liquid and vapour; volatile organic compound (VOC).

A view of the steam crackers at Ludwigshafen in Germany. The whole site is the largest continuous chemical site in the world. The steam crackers alone occupy 64 000 m^2, which is about the size of 13 football fields. Naphtha is the feedstock and the main products are ethene and propene, used to make polymers.

http://www.essentialchemicalindustry.org/processes/cracking-isomerisation-and-reforming.html

	Gr	Name	Background
C1		**Syngas** (synthesis gas)	
C2	Olefins	**Ethylene** (or ethene)	Over 130 million metric tons produced in 2013. Mainly used in the production of polyethylene (PE). An important natural plant hormone, used to force the ripening of fruit. Normally produced for industrial use by energy intensive steam cracking of crude oil. In 2013, about 63% of global demand for ethylene was for producing HDPE, LLDPE, LDPE.
C3	Olefins	**Propylene** (old propene)	Found in nature as a by-product of vegetation and fermentation processes. Normally produced for industrial use by steam cracking of crude oil. Total production of propylene is about half of that of ethylene, or about 85 million metric tons in 2013.
C4	Olefins	**Olefins** or **hydrocarbons C4**, or 1,3-butadiene, butadiene, divinyl, vinylethylene, biethylene, etc.	A family of chemicals based on C_4 which are by-products of steam cracking used to produce ethylene and other olefins. Mainly unstable and highly reactive. 1,3-butadiene is usually found in urban air from vehicle exhausts. It breaks down quickly in the atmosphere. In 2020, about 13.7 million metric tons of butadiene will be industrially processed globally.
C6	Aromatics	**Benzene** (or benzol)	By-product of coal distillation and crude oil refining processes. Used as a solvent, a chemical intermediate and in petrol. Formerly used as parasiticide. Found in air from burning fossil fuels, and in cigarette smoke. Used to make plastics including resins, nylon and synthetic fibres, and also rubbers, lubricants, dyes, detergents, drugs and pesticides. In 2012, the total market for benzene was approx. US$69 billion.
C7	Aromatics	**Toluene**	Toluene mainly occurs as a by-product in steam cracking or catalytic reforming. Most toluene is processed into benzene and xylene, and from there into fuels. In addition, it is used in lubricants and greases, anti-freeze products, biocides, non-metal surface treatments, inks and toners, leather treatment, polishes and waxes, textile dyes, adhesives and sealants. In 2013, US$24.5 billion was generated globally from sales of toluene.
C8	Aromatics	**Xylenes** (a group of chemicals: o- Xylene, m- Xylene, p- Xylene, etc.)	Xylenes are used in the production of plastics (PET), plasticisers (phthalate anhydride), fuels and solvents. The main application of xylenes is use in the production of paraxylene, which is processed into terephthalic acid (TPA) and used in manufacture of PET. In 2013 this process generated US$51 billion globally. TPA is a substitute for dimethyl terephthalate (DMT).



http://archive.alleghenyfront.org/products-made-ethylene/full.html

	Gr	Name	Based on official wordings from PubChem and ECHA	
			Health impact	Disposal
C2	**Olefins**	**Ethylene**	May cause drowsiness or dizziness; known for specific target organ toxicity from single exposure. Harmful to aquatic life with long lasting effects. Inadequate evidence that it is carcinogenic – IARC class 3 carcinogen.	Should not be released into the environment.
C3	**Olefins**	**Propylene**	May cause drowsiness or dizziness; known for specific target organ toxicity from single exposure. If released indoors during production, it can cause suffocation. May damage fertility or the unborn child. Harmful to aquatic life with long lasting effects. Inadequate evidence that it is carcinogenic – IARC class 3 carcinogen.	Should not be released into the environment, but ECHA comments that release is likely to occur from industrial use. Registration under REACH is required in Europe.
C4	**Olefins**	**1,3-butadiene**	1,3-butadiene is carcinogenic to humans by inhalation – IARC class 1 (eye, nose, throat). It may cause central nervous system disturbances; may cause genetic defects (skeletal abnormalities, decreased foetal weight and reproductive effects). May cause drowsiness or dizziness; known for specific target organ toxicity from single exposure. Causes damage to organs through prolonged or repeated exposure.	Registration under REACH is required in Europe. Environmental regulatory agencies to be contacted before any disposal. Keep materials out of water sources and sewers.
C6	**Aromatics**	**Benzene**	Causes central nervous system and bone marrow damage, and is carcinogenic. May be fatal if swallowed or enters airways. May cause genetic defects (germ cell mutagenicity). Known carcinogenic – IARC class 1. Causes damage to organs through prolonged or repeated exposure. Harmful to aquatic life with long lasting effects.	There is no proven method of disposal for carcinogenic compounds, Destruction, by incineration may be the best option.
C7	**Aromatics**	**Toluene**	May be fatal if swallowed and enters airways. Causes skin and eye irritation. May damage fertility or foetuses. Causes damage to organs (specific organ toxicity from single exposure), and damage through prolonged or repeated exposure. Toxic to aquatic life, with long lasting effects. (For more detail, see table 8.1.)	Toluene may be disposed of by controlled incineration. It should not be put in sewers because of possibility of exposition.
C8	**Aromatics**	**Xylenes**	o-Xylene, m- Xylene, and p-Xylene have similar health impacts which include acute toxicity if inhaled and damage to organs. Toxic to aquatic life with long lasting effects.	Used in production of fuels, which is their effective disposal.

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C4	Olefins	1,3-butadiene	1,3-butadiene is carcinogenic to humans by inhalation – IARC class 1 (eye, nose, throat). It may cause central nervous system disturbances; may cause genetic defects (skeletal abnormalities, decreased foetal weight and reproductive effects). May cause drowsiness or dizziness; known for specific target organ toxicity from single exposure. Causes damage to organs through prolonged or repeated exposure.	Registration under REACH is required in Europe. Environmental regulatory agencies to be contacted before any disposal. Keep materials out of water sources and sewers.
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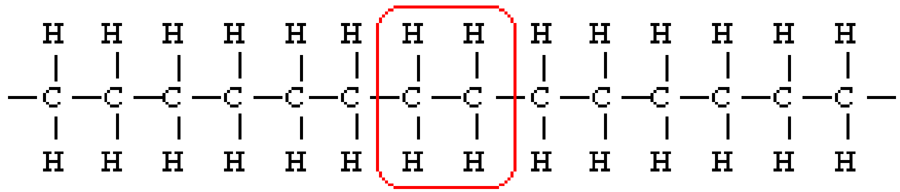
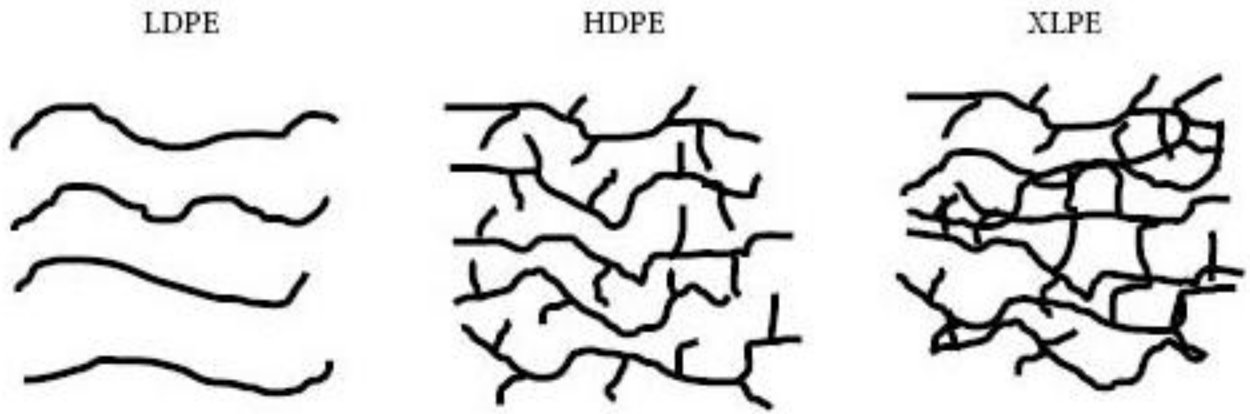
http://www.csb.gov/formosa-plastics-propylene-explosion/

Polyethylene (PE) (previously polyolefin) – polymer of ethylene





Polymer	Construction application	Recycling No. Level of recycling
Polyethylene (PE) HDPE (no. 2) LDPE (no. 4)		No. 2 - 30% No. 4 - 6%
Poly(ethylene terephthalate) (PET) or Polyesters	Polyester insulation, carpets, and as a substrate in thin film solar cells	No. 1 - 31-52%
Polypropylene (PP)	Plumbing supplies and indoor/outdoor carpeting, especially close to pools as it does not absorb water	No. 5 - 3%
Polycarbonate	Transparent roof covering for indoor-outdoor areas, and other large transparent sheets; one of the common components in two pot epoxy resins	-
Polystyrene	Expanded polystyrene insulation	No. 6 - 1%
Poly(styrene-butadiene) SBR rubber and Poly(styrene-butadiene-styrene) SBS rubber	Used in some carpet backing	-
Poly(styrene-co-acrylonitrile) (SAN), and poly(acrylonitrile-co-butadiene-co-styrene) (ABS)	Plumbing fixtures and pipes and the faces of electric sockets	-
Poly(vinyl chloride) (PVC)	Plumbing pipes and fixtures, vinyl flooring, window frames, electrical cable covering	No. 3 <1% Dangerous to recycle

Polymer	Construction application	Health impact
Polyethylene (PE) HDPE (no. 2) LDPE (no. 4)		Appears to be safe, not known to leach.
Poly(ethylene terephthalate) (PET) or Polyesters	Polyester insulation, carpets, and as a substrate in thin film solar cells	Appears to be safe for short term use – designed for single use only, extended life can increase the risk of leaching and bacterial growth. Appears to leach under extreme conditions.
Polypropylene (PP)	Plumbing supplies and indoor/outdoor carpeting, especially close to pools as it does not absorb water	Because of hazardousness of propylene, hazardous during production, but appears to be safe in use. Not known to leach harmful chemicals.
Polycarbonate	Transparent roof covering for indoor-outdoor areas, and other large transparent sheets; one of the common components in two pot epoxy resins	Avoid – contains hormone disruptor BPA with oestrogenic activity; may cause chromosomal damage, can leach into food, especially as the product ages.
Polystyrene	Expanded polystyrene insulation	Avoid. Benzene (used in production of styrene) is a known human carcinogen. May leach harmful substances (possible carcinogens and hormone disruptors). Persistent in the environment. Energy intensive.
Poly(styrene-butadiene) SBR rubber and Poly(styrene-butadiene-styrene) SBS rubber	Used in some carpet backing	SBR is harmful to aquatic life with long lasting effects. It may cause an allergic skin reaction. It is manufactured using toxic chemicals.
Poly(vinyl chloride) (PVC)	Plumbing pipes and fixtures, vinyl flooring, window frames, electrical cable covering	Toxic in production and disposal. Plasticisers added for flexible applications can leach and be harmful.

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Polypropylene (PP)	Plumbing supplies and indoor/outdoor carpeting, especially close to pools as it does not absorb water	Because of hazardousness of propylene, hazardous during production, but appears to be safe in use. Not known to leach harmful chemicals.
Polycarbonate	Transparent roof covering for indoor-outdoor areas, and other large transparent sheets; one of the common components in two pot epoxy resins	Avoid – contains hormone disruptor BPA with oestrogenic activity; may cause chromosomal damage, can leach into food, especially as the product ages.
Polystyrene	Expanded polystyrene insulation	Avoid. Benzene (used in production of styrene) is a known human carcinogen. May leach harmful substances (possible carcinogens and hormone disruptors). Persistent in the environment. Energy intensive.
Poly(styrene-butadiene) SBR rubber and Poly(styrene-butadiene-styrene) SBS rubber	Used in some carpet backing	SBR is harmful to aquatic life with long lasting effects. It may cause an allergic skin reaction. It is manufactured using toxic chemicals.
Poly(vinyl chloride) (PVC)	Plumbing pipes and fixtures, vinyl flooring, window frames, electrical cable covering	Toxic in production and disposal. Plasticisers added for flexible applications can leach and be harmful.

Disposal of plastics

Many plastics can be incinerated – but this might release toxic gases into the environment

Biodegradation is theoretically possible. It takes places in two steps:

1. Fragmentation of the polymer
2. Bio-assimilation of the polymer fragments by microorganisms and their mineralisation

This takes very long time – often hundreds of years

Film-forming finishes: paints, varnishes, and oils

Polymer surface formed on the installation site, and this process is described as drying.

Such process has direct potential to adversely impact indoor air quality.

Many older paints relied heavily on the use of organic solvents – solvent has to evaporate before the curing chemical reaction would occur.

Several families of polymers are included here:

- Acrylic polymer emulsions
- Polyvinyl acetate (PVA) emulsions, and
- Reaction polymers

Acrylic paints

Since the WW2 rapid development of acrylic or latex paint – then also called 'rubber-based paints' Acrylic polymer emulsions are currently the dominant technology in paints.

Emulsions are designed to prevent polymerisation before application by using water-soluble surfactants to physically separate small monomer droplets from each other. The emulsion contains: monomer droplets, surfactants and water-soluble initiators of the process.

Acrylic monomers suitable for the development of paints are esters of acrylic and methacrylic acid and include: methyl, ethyl, isobutyl, *n*-butyl, 2-ethylhexyl, octyl, lauryl, and stearyl.

For example: a paint might contain butyl acrylate or 2-ethyl hexylacrylate to give the acrylic paint adhesive strength, combined with methyl methacrylate and methyl acrylate to give it cohesive strength. (Unfortunately, each of those is classified by ECHA as a serious irritant for humans and also harmful to aquatic life.)

Reaction polymers: epoxies, phenolic and polyurethanes

Epoxy

Epoxy – two pot systems generally containing base resin (epoxy monomer), curing agents, reaction adjusters (possibly fibre and fillers)

75-90% of epoxy resins are based on combination of epichlorohydrin and bisphenol A (BPA)

This chemistry can cause allergic dermatitis and be sensitizer for many users during installation, but generally not a risk once it is fully reacted

Phenolic reaction polymers

Urea-formaldehyde, melamine-formaldehyde and phenol-formaldehyde

Used as hardeners of epoxy and as durable paints

Phenol-formaldehyde is used in manufacture of laminate products such as Formica: several layers of kraft paper with phenol-formaldehyde resin, exposed to compression and cured with heat. The same is possible using melamine-formaldehyde.

These are all toxic during their manufacture, but currently considered to be stable when fully reacted. (Phenol is toxic if swallowed, inhaled, or in contact with skin, and is suspected to be causing genetic defects and demanding organs with prolonged or repeat exposure. It is also harmful to aquatic life with long-lasting effects.)

Polyurethane varnish systems

Urethanes are known for chemical, water and abrasion resistance with high tensile and impact strength. Generally made using a variety of polyos and isocyanates. For a long time used organic solvents to support reaction.

The most common isocyanates used in polyurethanes are:

- Toluene-2,6-diisocyanate is fatal if directly inhaled. It is an irritant, may cause allergic reactions, is suspected of causing cancer (IARC Group 2B), and is harmful to aquatic life with long lasting effects (PubChem, 2016).
- 4,4'- diphenylmethane diisocyanate (MDI) is fatal if directly inhaled, is an irritant, may cause allergic reactions, and causes damage to organs through prolonged or repeated exposure (PubChem, 2016).
- 1,6-diisocyanatohexane is known as a severe irritant which can cause chronic lung problems after long term exposure. No information is currently available on its long term health impacts (PubChem, 2016).
- Isophorone diisocyanate (IPDI) is toxic when inhaled (fatal if directly inhaled), toxic when absorbed through the skin, is a strong skin irritant, and is toxic to aquatic life with long lasting effects (PubChem, 2016).

Natural oil varnishes

Traditional wood oil systems relied on oils such as linseed and tung oil in order to cure through a reaction of their polyunsaturated oils with oxygen in the air – can take a long time

Solvent can be used to accelerate this

More recently, new developments based on old

Biopolimers

Use grown materials for generating polymers

Can be done by extracting the same key hydrocarbons from grown bioresources using: ethanol C_2H_5OH, glycerol $C_3H_8O_3$, xylose $C_5H_{10}O_5$, fructose $C_6H_{12}O_6$, and glucose $C_6H_{12}O_6$

Or

Production of olefins using more directly suited processes such as bioethanol dehydration, methanol-to-olefins, catalytic fast pyrolysis of lignocellulosic biomass, and bio-oil upgrading. In recent years real increase of production of ethanol using biomass fermentation.

Or

Fluid catalyst cracking of hydrodeoxygenated vegetable oils using wood pulping

Biopolimers

Development of completely new polymers based around the chemicals commonly found in bioresources without mimicking the existing petrochemical industry

Poly(lactic acid) PLA is one such example already on the market

PLA is recyclable, biodegradable and compostable alternative to more robust and durable plastics

Lactic acid, monomer of PLA, is produced by bacterial fermentation of corn starch or sugar. Wood dust can be added as a stabiliser and filler.

Still, it requires very special conditions for biodegradation and not yet readily accepted for recycling.

Biofuels compete with the foodchain

Thank you.