An Investigation Into the Potential for PVC Reduction in Residential Building Drainage Lines

A Triple Bottom Line Analysis of PVC vs. HDPE

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Abstract

One of the most popular building materials in the world when looking for flexibility and cheap cost, PVC comes with numerous harmful side-effects to both the environment and the people surrounding it at various stages of its life cycle. One possible alternative is another plastic: HDPE. This study analyzes PVC's environmental and social effects from its production, to its implementation in the residential sector of UBC piping, and finally its disposal as either waste or recyclable material, while comparing it to HDPE. Multiple secondary sources, consisting of peer-reviewed journal articles and books, were consulted for research into both materials. Research revealed that the key harmful effects of PVC include the release of dust in production facilities, the leaching of its additives into the liquid it is transporting, and the release of chlorine toxins into the atmosphere during recycling and waste disposal. HDPE comes without any of PVC's harmful environmental and social side effects while at the same time providing better material properties, at the expense of a higher cost. It is recommended to switch to the use of HDPE piping when installing drainage lines and considering using HDPE for piping in the water system if UBC Technical Guidelines are changed to allow it in the future.

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Glossary

Plasticizer: Solvent added to a synthetic resin to produce plasticity and flexibility and to reduce brittleness

Stabilizer: Chemical substance added to another substance to prevent breakdown of emulsions

List of Abbreviations

HDPE: High-density Polyethylene

PBT: Persistent Bioaccumulation Toxins

PVC: Poly(vinyl chloride)

1.0 Introduction

PVC, or poly(vinyl chloride), is one of the most widely used plastics in the world with one of its uses being in piping. With the use of plasticizers it becomes a flexible material capable of filling many building needs while remaining cheap on the market due to mass production. Unfortunately, controversy surrounds it as it is known for leaving a footprint of numerous harmful effects on the environment during its production and disposal. Due to its low price, though, it continues to be used in a wide variety of applications despite its drawbacks. Its use will ultimately continue until a viable cheaper alternative is found.

PVC's closest competitor in the piping application is another plastic, HDPE, or high-density polyethylene. HDPE is already used in many piping systems requiring higher strength while maintaining the level of flexibility that PVC provides. However, it is more expensive and thus not used in less property-strict applications, like UBC's buildings. This report will focus on triple bottom line analyses of both PVC and HDPE with the purpose of deciding whether or not HDPE is a viable alternative to PVC as the main piping material used in UBC's residential buildings. Other alternatives, such as ductile iron, copper, and cement, were briefly researched though discarded when it became clear that HDPE likely be the best alternative moving forward.

Research was carried out using secondary sources including peer-reviewed journal articles and books. Due to limited time, primary data could not be obtained via tests by the group. Although it was discussed, the team concluded that a survey of UBC residents would not provide adequate results to the highly technical nature of the project. The secondary sources were used to evaluate PVC and HDPE in three key aspects: environmental, social, and economical. A final recommendation will be provided at the conclusion of this report.

2.0 <u>Environmental Analysis</u>

2.1 PVC

Polyvinyl Chloride (PVC) is used vastly in plastic piping. The PVC pipes are used for drainage in many cases, but the strong demand for PVC pipes has brought them to drinking water pipelines as well. The reasons for its popularity are mainly due its low cost and high strength. Vinyl Chloride (VC) is a proven human carcinogen, which is a substance capable of causing cancer in living tissue.

A test has been performed to find the VC accumulation from tap water out of the PVC pipes. The test was performed in a span of 715 days. VC accumulation from chlorinated tap water is shown in Figure 1 below:

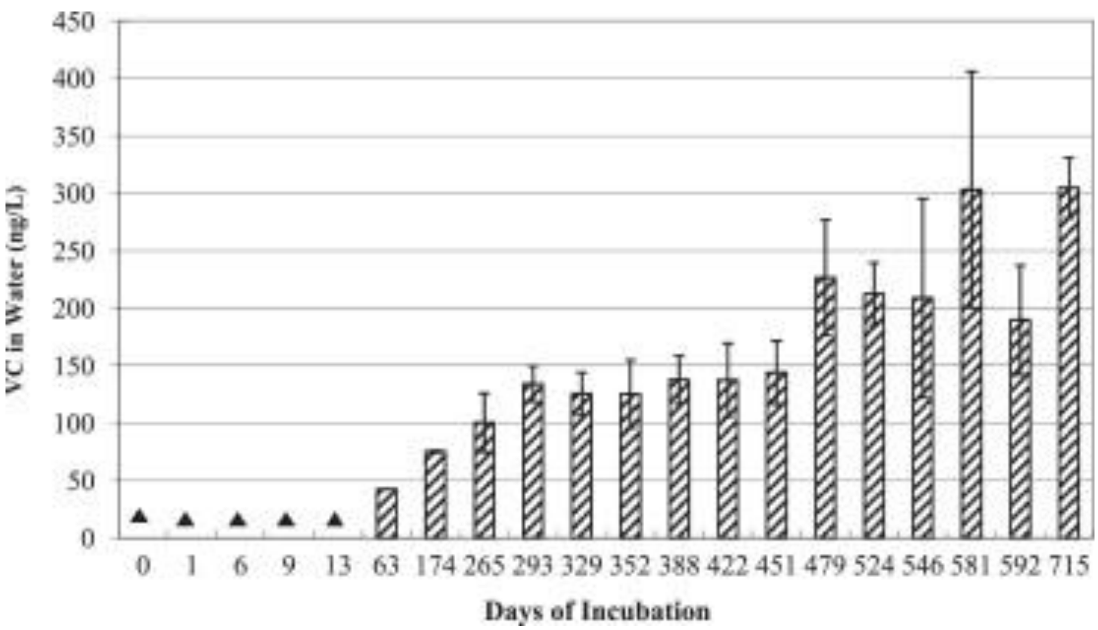

Figure 1: Time course of VC concentration found in chlorinated tap water. Water Research (2011), *Investigation of factors affecting the accumulation of vinyl chloride in polyvinyl chloride piping used in drinking water distribution systems*.

The chart in Figure 1 shows the amount of VC accumulated after specific days of incubation. The results show that the average amount of VC is approximately 130 ng/L after the first year. However, in the following months and especially on the 479th day of incubation, the amount of VC increases rapidly. This indicates a massive problem as the amount of VC more than doubles within a year. Although it may seem to accumulate by a consistent rate in the first year, the figure shows that it has the potential to grow exponentially. The error bars in Figure 1 represent the standard error between different numbers of tests. The black triangles indicated in the early stages of the test are the BDLs, which is below the detection limit. The reactors used for the measuring the accumulation could not detect the VC less than 30 ng/L.

As PVC is a commonly used thermoplastic material worldwide, the demand for PVC in the plastic industry is massive. The industry demands 35 million tons of PVC annually. In addition to its low cost and structural strength, PVC materials have great flexibility providing easy installation. The growing demand for PVC is also creating a problem for wastes. The used PVC materials that turn into waste create an environmental hazard with the chlorine content of the polymer. Recycling could be a solution to this matter, but the reality is that PVC materials are normally landfilled rather than being recycled. The landfilling method of disposing PVC wastes generates a high degree of pollution.

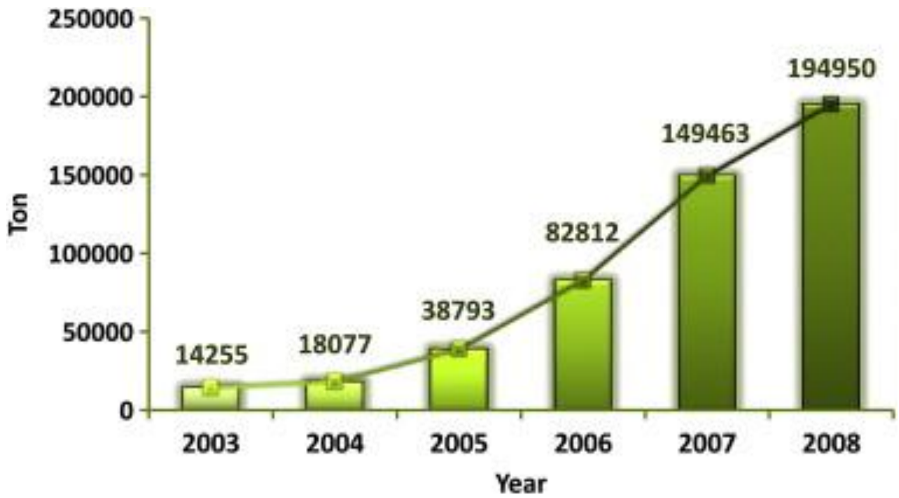

Figure 2: The tonnage of recycled PVC in Europe from 2003 until 2008. Polymer Degradation and Stability (2011), Recycling of PVC Wastes, 404-415.

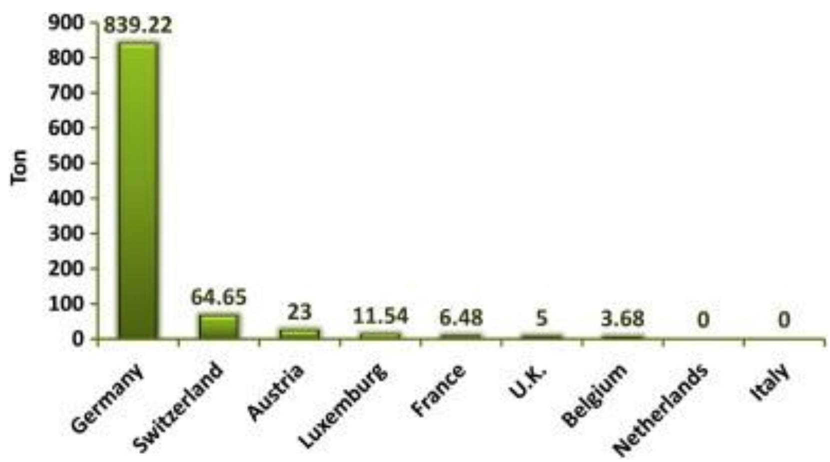

Figure 3: The tonnage of roofing materials recycled in Europe by country in 2008. Polymer Degradation and Stability (2011), Recycling of PVC Wastes, 404-415.

The amount of recycled PVC materials in Europe is shown in Figure 2. From 2003 to

2008, there has been a growth in the recycling rate of PVC materials. As awareness and concern for the environment grows, countries provide their best effort to recycle PVC despite the mid-high costs. In comparison, Figure 3 shows the amount of recycled PVC materials in 2008 by different countries in Europe. Many of the developing countries are struggling to take responsibility of the environment. The amount of recycling of the developing countries compared to Germany is a concern. It is a challenge to convince the developing countries to recycle.

2.2 HDPE

The alternative for PVC may be high-density polyethylene (HDPE) piping. In the environmental perspective, the HDPE material may be an economical material to be recycled. HDPE requires a short life cycle for recycling, and it is large constituent of milk, water, and detergent bottles. It does not have a high degree of pollution, but it does possess the potential to have higher cost for recycling than PVC.

2.3 Conclusion

PVC materials are usually landfilled, harming the environment, or recycled for new PVC materials at best. In contrast, HDPE materials can be recycled as constituents for other products for daily usage and bring health to both humans and the environment.

3.0 Social Analysis

3.1 Health Concerns

The social issues associated with plastics are currently being heavily examined by scientists and researchers due to their ubiquitous use and their still uncertain health effects. In an article by Myra Karstadt investigating the health effects of PVC, she states, "Total world employment in the PVC producing industries is likely to be well over 70,000 workers. Those employed in the industries which use PVC as a basic element are likely to total in the millions. Those who come in contact with PVC every day in some form or other probably make up at least one-third of the human race." (Karstadt, 1976). More importantly, modern PVC is synthesized of many additives to give it advantageous attributes. Pure PVC is characterized as brittle and difficult to work with. As a result, plasticizers and stabilizers are added to PVC to make it more practical.

PVC health side effects may be evident in both PVC production workers and individuals exposed to PVC through means such as PVC pipes. A number of clinical studies have demonstrated pulmonary abnormalities in PVC production workers. Further hazards to workers include the swallowing of PVC dust, as evidence exists that PVC particles may be persorbed from the intestine into the lymph or blood systems (Volkheimer, 1975). There is also the possibility of PVC serving as a skin irritant, allowing the PVC dust to serve as an efficient means for bringing sensitizing compounds to contact with the skin.

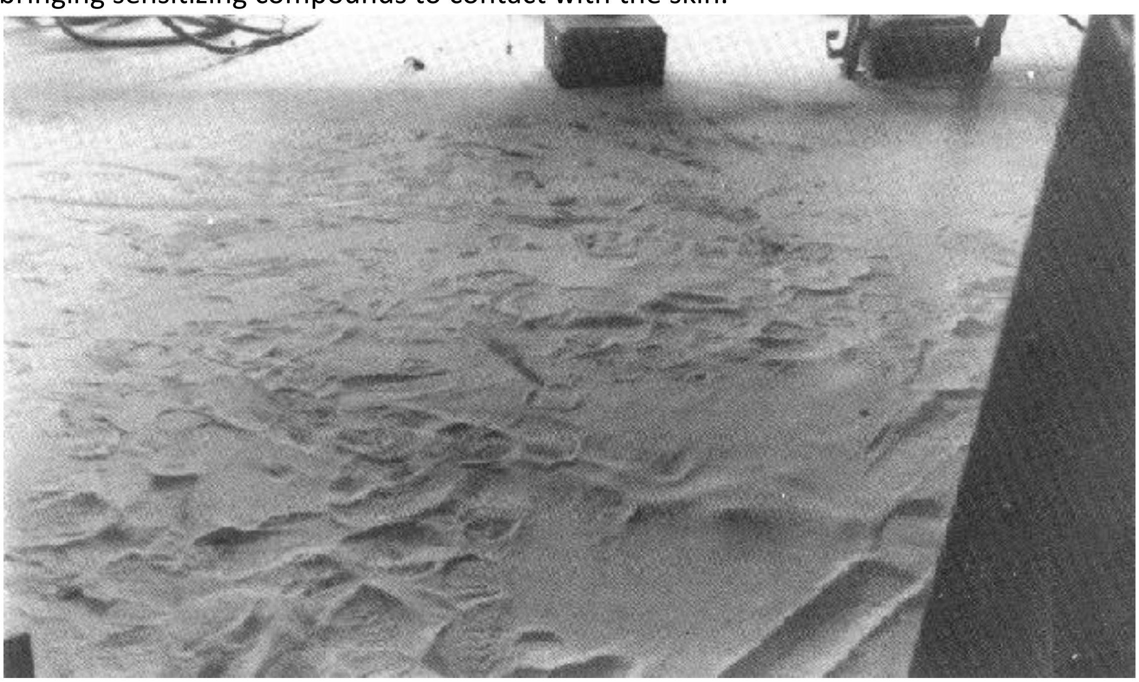

Figure 4: Floor of PVC manufacturing plant. Karstadt, 1976.

As consumers of PVC, or users of PVC pipes, other serious potential risks are present. Because PVC is rigid and brittle without the addition of additives, a significant amount of toxic chemical plasticizers and stabilizers are included such as lead, cadmium, and organotins. These additives make PVC pipes especially dangerous because chemically, they are not covalently bonded to the polymer matrix and are therefore highly susceptible to leaching (Thornton, 2002). In addition, several major toxic manufacturing by-products are unavoidably created during the production of PVC material, including dioxin, ethylene dichloride, and vinyl chloride which may potentially cause cancer, neurological damage, birth defects, and impaired child development (Karstadt, 1976). PVC manufacturing plants have a further detrimental impact as they pollute their surroundings with these by-products, most notably dioxin. Dioxin is a persistent bioaccumulation toxin (PBT); it is not broken down rapidly and is stored in fatty tissue. Worldwide concentration levels of dioxin increase as the toxin is accumulated up the food chain (Stephens, 1990).

3.2 Material Versatility and Properties

Unlike its competitor, HDPE is non-chlorinated, making it more readily recyclable. It also has no added plasticizers, therefore meaning HDPE is not subject to the embrittlement that can occur when plasticisers leach out. HDPE is significantly more resistant to several solvents and can operate at a higher maximum temperature than PVC, evident in Table 1. Due to this resilience from solvents and ability to operate at higher temperatures, HDPE is an ideal choice for piping. From a durability standpoint, HDPE is again preferred. Evident in Table 1, HDPE has a greater range of elongation; this allows the pipe to be more flexible and compatible with a wider range of piping designs. PVC, in contrast, is more brittle and therefore less ideal to use as underground piping material. HDPE is convenient to use in underground piping because it is known to absorb shock waves and minimize the effect of instability to the system (GSE, 2009).

Property	HDPE (GSE HD)	PVC
Maximum Temperature*	160° F	140° F
Acid Resistance	Excellent	Poor to good
Alkali Resistance	Excellent	Good
Chlorinated Hydrocarbon Resistance	Very Good	Poor
Aromatic Hydrocarbon Resistance	Very Good	Poor
Aliphatic Hydrocarbon Resistance	Excellent	Poor to moderate
Ultimate Tensile Strength	> 4,000 psi	<2,300 psi
Ultimate Tensile Elongation	> 700%	<500%
Plasticizer Requirement	None	Yes
Filler Requirement	None	Yes
Molecular Structure	Contains only carbon-carbon and carbon-hydrogen bonds which require much energy to cleave	Includes carbon-chlorine bond which require less energy to cleave
Crosslinking Due to UV	None	Yes and results in cracking
Seaming Integrity	Uses same material as the parent sheet	Uses solvents which may alter the parent sheet's chemical composition
Low Temperature Brittleness	< -90° C	-40° C
Permeability	$< 1 \times 10^{-12}$ cm/s	1×10^{-10} cm/s

Table 1: Comparison of HDPE and PVC Properties. GSE, 2009

3.3 Conclusion

Due to the harmful health effects of PVC to the factory workers as well to its users, it is advised to avoid PVC for safety reasons. From a construction aspect, HDPE is more convenient and physically practical; this is true without many of the additives which are included in PVC. Currently PVC is in high demand due to its popularity and lower relative costs. However, as outlined above, there are social factors which recommend phasing out PVC. Therefore, UBC projects should innovate and lead an initiative which shifts demand away from PVC material.

4.0 Economic Analysis

4.1 PVC

PVC piping is clearly one of the most widely used plastics we encounter today with PVC sales reaching 14.4 billion pounds in the US and Canada in 2002, and 59 billion pounds worldwide. Posing hazards to human health throughout the course of its life cycle, one must ask why society would continue to use a material that can leach out toxic additives during its useful lifespan. The main reason for this is the cheap cost of PVC due to mass production of the product. When products are produced in massive quantities costs typically drop as the volume of produced material increases (Ackerman, 2003). PVC piping being produced in mass amounts per year has allowed the material to appear cheap, but as alternatives such as HDPE increase production volume, it will allow the alternative material to become cheaper and more competitive when looking at replacing PVC.

Traditional piping material such as iron, copper, clay, and concrete is much stronger under high pressures and extreme temperatures, but due to higher costs and the difficulty of installing and maintaining the large diameter pipes, alternative materials are favored.

End Uses	Consumption (millions of pounds)				Annual growth rates		
	1994	1999	2002	2007 est	94-99	99-02	02-07
Pipes, Tubing, Fittings	4,875	6,685	6,494	7,350	7%	-1%	3%
Construction	2,790	3,990	4,293	5,413	7%	2%	5%
Siding	*1,470*	*2,175*	*2,176*	*2,710*	*8%*	*0%*	*4%*
Windows and Doors	*410*	*700*	*910*	*1,225*	*11%*	*9%*	*6%*
Profiles	*225*	*400*	*525*	*775*	*12%*	*9%*	*8%*
Flooring	*440*	*485*	*457*	*455*	*2%*	*-2%*	*0%*
Roofing	*115*	*100*	*100*	*113*	*-3%*	*0%*	*2%*
Other Construction	*130*	*130*	*125*	*135*	*0%*	*-1%*	*2%*
Consumer Goods	915	1,225	1,225	1,225	6%	0%	0%
Packaging	820	885	839	935	2%	-2%	2%
Electrical / Electronic	540	870	800	905	10%	-3%	2%
Transportation	265	310	280	310	3%	-3%	2%
Home Furnishings	185	240	240	240	5%	0%	0%
Other and Inventory	337	128	259	325			
Total	**10,727**	**14,333**	**14,430**	**16,703**	**6.0%**	**0.2%**	**3.0%**

"Other and inventory" includes medical supplies (200 million pounds in 2002), coatings and adhesives (100 million pounds), and inventory changes for the industry as a whole, which can be positive or negative, and vary widely from year to year.

Source: SRI Consulting (Menlo Park, CA), CEH (Chemical Economics Handbook) Marketing Research Report: Polyvinyl Chloride (PVC) Resins (September, 2003).

Table 2. PVC Consumption Rates. Ackerman, 2003, p.5

4.2 HDPE

HDPE is becoming the most important alternative to PVC due to its evident advantages over PVC piping such as higher strength under pressure and under low temperatures, lower rates of leaks and breakage, and its far less toxic nature. With 1.4 billion pounds sold of HDPE in 2000, sales of HDPE are growing rapidly to compete with PVC (Ackerman, 2003).

HDPE piping has approximately the same material cost as PVC piping, but due to the material being a newer product the labor costs for HDPE are higher. HDPE is the closest competitor to PVC, reaching up to 1.4 billion pounds sold in the US and Canada in 2000, as shown in Table 4. With the current growth in the use of HDPE, it has been projected that this important type of plastic will rise dynamically and amount to almost US$70 billion in 2019 (Ceresena, 2013).

	millions of pounds sold in US and Canada	
	2000	2001
Uses competing with PVC		
Water pipes		
Potable water up to 3"	77	75
Potable water 4" and above	65	58
Irrigation and agriculture	38	37
Sewers and drains	42	46
Conduits	500	193
Industrial and mining	178	174
Landfills	11	14
Crosslinked (PEX) pipe	20	32
Subtotal, competing with PVC	**931**	**629**
Other uses		
Gas distribution	236	210
Oil and gas production	180	180
Other	33	39
Export	36	15
Subtotal, other uses	**485**	**444**
Total	**1416**	**1073**

Source: Plastics Pipe Institute, "2001 Statistics: North American Shipments of Polyethylene & Crosslinked Polyethylene Pipe, Tube & Conduit"

Table 3. HDPE Consumption Rates. Ackerman, 2003, p.14

End use	Alternative materials		Cost per pound of PVC replaced (US $)	
	Low cost	High cost	Low cost	High cost
Municipal water pipe	HDPE	Ductile iron	$0.26	$0.38
Municipal sewer pipe	HDPE	Concrete		
Drainage pipe, culverts	HDPE	Concrete	($0.05)	$0.25
Drain/waste/vent plumbing	ABS	ABS/Copper		
Industrial pipe, conduits	------------ HDPE ------------			
Siding	Aluminum	Clay brick	$0.38	$6.02
Windows	Wood	Aluminum	($0.82)	$0.38
Flooring	Polyolefin	Ceramic tile/carpet	$13.54	$17.07
Wire and cable	----- Polyethylenes, other plastics -----		$3.00	$3.00

1993 Canadian prices converted to US dollars and adjusted for US inflation through 2002.

Separate low- and high-cost alternatives were not estimated for industrial pipe or for wire and cable.

Alternative materials reflect those in use in Canada in 1993, except polyolefin flooring (a polyethylene/polypropylene combination). This product was introduced in Germany in 1996; Environment Canada's low-cost flooring alternative uses the German price.

Table 4. Alternatives to PVC. Ackerman, 2003, p.7

4.3 Conclusion

Looking at Table 5, the lower cost alternative for the replacement of PVC for piping is HDPE, while the higher cost alternative materials range from ductile iron to concrete and copper. Not only does HDPE have great applications under high pressure and under low temperatures, and lower rates of leaks and breakage, but it is also easier to work with and maintain in comparison to the higher cost alternatives. Due to the higher production of PVC and increasing sales, PVC piping is a cheaper material than the current alternatives. Replacing the municipal piping and drainage piping would be an additional cost of $0.26 and $0.05 per pound respectively (US$). Due to the higher production and sales of alternative materials such as HDPE, the estimated costs of the PVC piping phase out would be even lower than suggested in Table 5. This would allow HDPE to become affordable and the top alternative to PVC piping. HDPE is the closest competitor to PVC as it is affordable and more effective than PVC.

5.0 Conclusions and Recommendations

It is clear from this triple bottom line analysis that HDPE is superior to PVC in every key aspect aside from cost. The production and disposal of PVC both release toxic chemicals such as dioxin to the atmosphere. PVC disposal can be done without harmful side-effects through recycling, though with a higher price. Recycled PVC can only be turned into more PVC though, essentially continuing the cycle. HDPE avoids these environmental drawbacks and can be recycled into different materials suitable for other applications, unlike PVC. The recycling cost of HDPE is high, though. The production of PVC releases potentially-cancerous dust into the work environment, harming factory workers. Also, plasticizers and stabilizers added to the material to improve its properties leach into the liquid it is transporting, causing potential illness at its destination. HDPE avoids both of these side effects. Lastly, HDPE brings superior material properties than PVC albeit at a higher price. This price difference should decrease over time as HDPE becomes more popular and thus mass produced to the same degree as HDPE.

The final recommendation is to use HDPE instead of PVC in UBC residential drainage lines. It is stronger and thus less prone to failure, more flexible, and more sustainable, at a cost of just $0.05 to replace per pound of PVC. If UBC Technical Guidelines allow it in the future, it is also recommended to use HDPE in water lines instead of PVC as it does not put residents at risk of consuming the additives used in PVC.

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