PVC 4 PIPES

# What Beyond Plastics Gets Wrong About PVC Pipes

Analysis and Response to Beyond Plastics' *The Perils of PVC Plastic Pipes*

**April 2023**

# What Beyond Plastics Gets Wrong About PVC Pipes

Analysis and Response to Beyond Plastics' *The Perils of PVC Plastic Pipes*

*In April 2023, the U.S. organisation Beyond Plastics published a report titled* The Perils of PVC Plastic Pipes. *The report alleges that PVC pipes for drinking water are unsafe, from production to use to disposal. As many communities in the US are currently replacing old pipes, the NGO calls for the use of copper pipes rather than PVC pipes. The following paper documents that this recommendation is based on outdated and demonstrably misleading information about PVC, especially in view of the progress that has been achieved in Europe, where a combination of strict regulation and voluntary action has led to PVC being used safely and increasingly sustainably. If utilities follow the advice from Beyond Plastics, it may have dire consequences for human health and the environment.*

## 1. PVC pipe manufacturing is safe

Beyond Plastics correctly states that PVC is made by polymerisation of vinyl chloride, a highly flammable gas. Vinyl chloride recently caught headlines when a train carrying the substance derailed in Ohio, USA.

Regulation adopted in Europe shows that it is possible to ensure the safety of vinyl chloride transport. In Europe, both vinyl chloride and PVC are generally manufactured at the same plant, which means that there is no need to transport it. However, around 30% of the vinyl chloride still needs to be transported. On average, about 10% of the vinyl chloride produced in Europe is transported by sea ship, 9% by rail, 8% by inland waterways and 4% by road.

The distribution of vinyl chloride is subject to strict regulations within all countries in Europe, and since 2003 the European Council of Vinyl Manufacturers (ECVM) has put in place strong guidelines for its transport. The regulations in force in Europe have ensured that no fatal accident has happened for the past 40 years.

The maximum allowed emissions of vinyl chloride into air and water in the European vinyl chloride and PVC plants are strictly regulated.[1]

Following the discovery of a link between repeated exposure over many years to high levels of vinyl chloride and angiosarcoma of the liver, a very rare form of cancer affecting the blood vessels of the liver, strict exposure limits have been set in the EU to prevent worker exposure.[2] EU experts and regulators have set an occupational exposure limit value under which there is no significant risk to workers' health. Typical levels in vinyl chloride and PVC manufacturing plants are lower than the limit and are monitored continuously.

Workers are regularly tested for even the lowest levels of exposure, and there have been no incidences of angiosarcoma cancer related to exposure.

Additionally, since 1995, ECVM has put in place a voluntary industry Charter for the Production of Vinyl Chloride and PVC in Europe. The successive versions of this Charter have set increasingly tight limits for vinyl chloride emissions from vinyl chloride and PVC plants and for the maximum amount of residual vinyl chloride present in PVC resin.[3]

The Charter also commits the manufacturers to limit workers exposure to vinyl chloride as much as technically possible, which comes on top of the very strict EU work safety regulations and guidelines for workers' health and safety.[4]

The industry-wide compliance with the requirements of the Charters is regularly checked by an independent third-party auditing body.

## 2. PVC pipes preserve drinking water quality

Beyond Plastics alleges that PVC pipes contaminate drinking water through the leaching of "dozens of dangerous chemicals," including endocrine-disrupting substances.

It is well known that PVC pipes do not corrode even after decades of use.[5] Nor are PVC pipes susceptible to tuberculation, a form of internal corrosion and bio-film contamination which can limit flow, increase pumping energy and be a breeding ground for bacteria.[6]

In contrast, a number of studies reveal that copper is vulnerable to corrosion, resulting in various health problems. Copper pipes are more prone to the growth of Legionella bacteria, which can cause Legionnaire's disease, compared to PVC pipes.[7] Additionally, the leaching of copper into drinking water has been linked to structural failure and gastrointestinal issues.[8]

Because it is used below its glass transition temperature (80°C), PVC can be considered as a functional barrier preventing any low molecular weight substances from migrating to drinking water. Migration tests have demonstrated migration levels far below the detection limit of the most modern analytical techniques.[9]

Moreover, the safety of PVC pipe systems for the transportation of drinking water in Europe is tightly regulated. Partly by the EU REACH regulation on chemical substances, partly by the European Drinking Water Directive and its related standards and national legislations, which only allow the use of positively listed substances.[10] PVC pipe manufacturers are subject to third-party certification by accredited laboratories and institutes, who subsequently also carry out regular audits to ensure continued compliance.

### 3. PVC pipes are safe to install

While Beyond Plastics calls for the use of copper instead of PVC due to the plastic's alleged unsafe installation, PVC pipes can provide a safer work environment for installers in several ways.

First, PVC pipes are much lighter than copper pipes, which makes them easier to handle and manoeuvre during installation. This can reduce the physical strain on installers and minimise the risk of work-related injuries or accidents. The lightness also greatly reduces CO2 emissions from transport.

Second, PVC pipes require fewer tools and materials for installation compared to copper pipes. For example, PVC pipes can be easily cut using a simple saw, while copper pipes require specialised tools like pipe cutters or torches. This can make the installation process faster, more efficient, and less costly for PVC.

Third, PVC pipes do not require soldering, which eliminates the need for open flames. This can create a safer work environment for installers and reduce the risk of exposure to hazardous materials or fire-related accidents.

Finally, PVC pipes are also resistant to corrosion and do not require the same level of maintenance as copper pipes. This can reduce the frequency of repair work and minimise the disruption to the work environment.

### 4. PVC pipes are easy to recycle and are increasingly being recycled

Beyond Plastics repeats the often-heard myth that PVC is difficult to recycle and requires separation from other plastic types before recycling.

First, PVC does not differ from other plastics when it comes to recycling. High-quality plastic recyclates depend on good sorting.

Second, several studies confirm that PVC is easily recyclable. Due to the material's composition, PVC pipes and other rigid PVC products can be mechanically recycled 8-10 times without losing their technical properties. This applies to both legacy PVC pipes containing lead and calcium-zinc-stabilised PVC pipes.[11]

Regarding potential risks related to the recycling of legacy pipes, the EU Chemical Agency finds that recycling lead-containing PVC carries less risk for health and the environment than incineration or landfilling.[12]

The European PVC pipe industry is an integral part of the VinylPlus® programme and is committed to increasing the recycling of PVC pipes across the EU. Around 50,000 tonnes of PVC pipes are recycled each year through VinylPlus. Since 2000, around 800,000 tonnes have been recycled. In addition, 75,000 tonnes of recycled PVC are safely used in new pipes each year. This makes pipes the third largest application area for recycled PVC.

**5. Dioxin emissions from PVC pipe production are negligible**

Beyond Plastics mentions dioxins as a by-product of PVC production.  While dioxins are a serious matter, the European case shows it is possible to solve this issue. Europe over the past few decades due to stricter regulations, improved technologies, and changes in industrial practices. This also applies to PVC, which today accounts for about 0.01% of the dioxins emitted from human activities in Europe.

The formation of very small quantities of dioxins can only occur during ethylene oxychlorination, which is one of the process steps leading to the production of vinyl chloride. These dioxin molecules are absorbed by the catalyst, which intervenes in a different phase from the reactants. This facilitates the removal of the catalyst and the absorbed dioxins by filtration and controlled treatment. Waste catalyst is handled as hazardous waste and disposed of accordingly.

The latest version of the aforementioned ECVM Charter limits the emissions into the air of dioxin-like components from the vinyl chloride plants to 0.08 ng Toxic Equivalent (TEQ) by m3 of air. Emissions in water are limited to 0.3 µg per ton of ethylene dichloride produced. Ethylene dichloride is the intermediate leading to vinyl chloride. The emission limits of dioxins during manufacturing are aligned with the strict requirements in place in Europe and must be considered extremely low.[13] To put this into context, 0.08 ng TEQ is equivalent to 0.00000008 grams of dioxin per cubic meter of air, and 0.3 μg is equivalent to 0.0000003 grams of dioxin per ton of ethylene dichloride produced in water.

## 6. Waste management of PVC pipes is not a significant source of dioxin emissions

According to Beyond Plastics, PVC pipes can contribute to the release of dioxins when disposed of in incinerators and landfills since PVC is mainly made from chlorine.

Through VinylPlus, the European PVC industry has for more than 20 years invested heavily in recycling infrastructure and technology to divert as much PVC waste as possible from incineration and landfilling. Currently, it is estimated that around 35% of all PVC waste, including pipes, is being recycled.[14] Through VinylPlus, the PVC industry has tracked more than 7.3 million tonnes recycled since 2000, saving more than 14.5 million tonnes of $CO_2$. To further minimise landfilling and incineration, chemical recycling technologies are being developed to complement mechanical recycling.

EU regulations set strict dioxin limits on incineration plants. Since the implementation of these regulations, there has been a significant reduction in dioxin emissions from waste incinerators in Europe. According to a report by the European Environment Agency, dioxin emissions from waste incineration in the EU-27 countries decreased by 83% between 2000 and 2018.[15]

Lastly, the generation of dioxins in waste incinerators is a complex process that depends on several key factors. These are temperature, residence time, air flow and incinerator design. The influence of chlorine content in the waste is less important.[16] PVC is not the main source of chlorine in municipal waste. In other words, if all PVC was eliminated from the waste, dioxins could still be formed.[17]

Dioxin emissions from landfill fires are a serious issue, but again the presence of PVC waste is not the determining factor.[18] In fact, because rigid PVC is self-extinguishing, the presence of PVC pipes could well contribute to quelling the fire.[19]

It must be stressed that landfilling is the least sustainable form of waste management and should be discouraged. While landfilling is still used in the EU, there has been a significant shift towards more sustainable waste management practices, such as recycling and energy recovery. This trend is likely to continue as Member States work to meet the targets set out in the EU Landfill Directive and transition towards a more circular economy.

**7. PVC pipes do not cause benzene emissions from wildfires**

Beyond Plastics reiterates incorrect media stories that suggest PVC pipes caused benzene emissions from California wildfires in 2017 and 2018.

The primary source of benzene in forest fires is the combustion of wood. Burning homes and other structures are the secondary sources.[20]

Benzene cannot be produced from PVC combustion in an open-air fire. Some reports suggest trace amounts of benzene can be released in a process known as pyrolysis when it is heated above 350° C in a highly controlled environment in which air is completely absent. However, pyrolysis of buried PVC water mains does not occur during wildfires. And, as PVC pipes are buried, they are heavily insulated from heat.

In fact, there was no evidence of pipes being burnt in the California wildfires.[21] Thus, PVC water pipes could not have released the benzene found in the drinking water in these communities.

The most likely source of benzene in municipal water systems after a wildfire is not from burning or melting water mains but from outside contaminants entering the system via damaged service lines. When a building burns, the service lines that connect to the water mains break, burn, and melt, creating gaps where contaminants can enter the water system. As water in the system is used to fight the fire, suction draws in contaminants. This process is called backflow and can occur regardless of pipe material.[22]

It has also been suggested that benzene can permeate through PVC pipes after accumulating in the soil following wildfires. However, published studies confirm that gasketed PVC pipe is highly resistant to permeation from a wide range of chemicals, including benzene.[23]

**8. PVC pipes do not contain plasticisers**

According to Beyond Plastics, plasticisers such as phthalates have been detected in the leachates of PVC pipes. While PVC pipes are indeed flexible enough to accommodate ground movement when buried underground, they are made from rigid PVC formulations that do not contain any plasticisers.

**9. Permeation through PVC pipes is negligible**

The ability of chemical substances to penetrate through pipe walls or joints is known as permeability. Rigid PVC itself is impervious to substances such as gasoline, benzene, toluene, ethylbenzene and xylene (BTEX), trichloroethylene (TCE), and PFAS in groundwater. PVC piping systems have been extensively reviewed by water distribution companies, and no significant problems have been reported.[24]

**10. Organotin is rarely used for PVC pipes and fittings in Europe**

The report claims that PVC pipes release harmful organotin chemicals. In Europe, organotin is not used for PVC pipes, except for specific applications requiring high chemical resistance and some fittings manufactured in Southern Europe. Instead, manufacturers use calcium-zinc based stabilisers, which are non-hazardous and do not affect the drinking water characteristics in any way.

However, because there are many different types of organotin, environmental advocacy groups have used this to sow confusion about the safety of organotin stabilisers used in PVC pipe manufactured in North America and in rare instances in Europe.

Studies have shown that one organotin, dibutyltin dichloride (DBTDC), may cause adverse health effects. Yet this substance is not present in any of the raw materials used in European or North American PVC pipe, nor is it formed at any point during pipe manufacture, installation, or use.

In the U.S. and Canada, the raw materials used to make PVC pipe often include heat stabilisers that contain tin. These organotin stabilisers have been tested and found to be safe for use in potable water applications. Certification to NSF/ANSI Standard 61 confirms that leaching of organotin stabilisers used in PVC water pipe is not a concern.

The bottom line is that PVC pipe produced in Europe and North America does not contain dibutyltin dichloride and the tin stabilisers that are used are not a health risk.

**11. Copper production harms human health and the environment**

Beyond Plastics' call for copper instead of PVC carries severe environmental and health risks if utilities in the U.S. and elsewhere heed the recommendation.

First, copper production is widely considered to be one of the most significant sources of dioxins.[25]

Second, copper mining causes land degradation, increased deforestation and water and air pollution from sulphuric acid.[26] According to the U.S. Environmental Protection Agency, the mining of copper has the highest waste generation among metals, with leaching of radioactive rock and tailings to groundwater as a major problem.[27]

For workers, copper mining and production can have fatal consequences. Not only do mining accidents result in human fatalities, but copper smelting and refinery are also known to cause cancer for workers.[28] As these burdens are mainly borne by people in the Global South and marginalised vulnerable populations in the U.S. and other high-income countries, copper mining and production may well be an example of environmental injustice.[29]

Further, the environmental toll of non-plastic pipes has been well documented by several independent comparative LCAs.[30] In virtually all instances, PVC has a much lower environmental footprint, including greenhouse gas emissions, than non-plastic materials.

**Conclusion**

Beyond Plastics' report on PVC pipes is based on outdated and misleading information. The use of copper pipes as a safer alternative could have unintended consequences for both human health and the environment. Especially as the example of European regulations and industry-wide voluntary charters shows that PVC production and use are safe and increasingly sustainable. PVC pipes are a safe and reliable option for drinking water systems, with long service life and minimal impact on water quality. And the European PVC industry is committed to sustainable development, including increasing the safe recycling of PVC pipes and other PVC products in the coming years.

## References

[1] European Commission, Joint Research Centre. (2017). Best Available Techniques (BAT) Reference Document for Large Volume Organic Chemicals (LVOC) Production. Retrieved from https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/JRC109279_LVOC_Bref.pdf

[2] European Union. (2004). Directive 2004/37/EC of the European Parliament and of the Council of 29 April 2004 on the protection of workers from the risks related to exposure to carcinogens or mutagens at work. Official Journal of the European Union, L 158/50- L 158/71. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32004L0037&rid=1

[3] ECVM. (2023). ECVM Industry Charter for the Production of Vinyl Chloride Monomer & PVC. Brussels, Belgium: The European Council of Vinyl Manufacturers. https://pvc.org/wp-content/uploads/2023/04/ECVM-charter-pages.pdf

[4] Ibid.

[5] Consult the following paper for references: PVC4Pipes & TEPPFA. (April 2019). 100-year lifetime for PVC-U and PVC-Hi pressure pipe systems buried in the ground for water and natural gas supply. Position Paper. Retrieved from https://pvc4pipes.com/wp-content/uploads/2023/04/position_paper_100_year_lifetime.pdf

[6] Sustainable Solutions Corporation. (April 2017). Life Cycle Assessment of PVC Water and Sewer Pipe and Comparative Sustainability Analysis of Pipe Materials. Retrieved from https://www.uni-bell.org/files/Reports/Life_Cycle_Assessment_of_PVC_Water_and_Sewer_Pipe_and_Comparative_Sustainability_Analysis_of_Pipe_Materials.pdf

[7] National Academies of Sciences, Engineering, and Medicine. (2020). Management of Legionella in Water Systems. National Academies Press. https://doi.org/10.17226/25474

[8] Daniels, S., & Lytle, D. (2014). A Visual Insight into the Degradation of Metals Used in Drinking Water Distribution Systems Using AFM. Paper presented at the AWWA Annual Conference, Boston, MA, June 08 - 12, 2014;

[9] Mercea, P. V., Losher, C., Benz, H., Petrasch, M., Costa, C., Stone, V. W., & Toşa, V. (2021). Migration of substances from unplasticized polyvinylchloride into drinking water. estimation of conservative diffusion coefficients. Polymer Testing, 104, 107385. https://doi.org/10.1016/j.polymertesting.2021.107385

[10] European Union. (2020). Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the quality of water intended for human consumption (recast). Official Journal of the European Union. Retrieved from https://eur-lex.europa.eu/eli/dir/2020/2184/oj

[11] Frank, Andreas & Messiha, Mario et al. (2021). Slow Crack Growth Resistance of reprocessed PVC. Plastic Pipes Conference PPXX, Amsterdam; Yarahmadi, Nazdaneh & Jakubowicz, Ignacy & Gevert, Thomas. (2001). Effects of repeated extrusion on the properties and durability of rigid PVC scrap. Polymer Degradation and Stability. 73. 93-99. 10.1016/S0141-3910(01)00073-8; Fumire, J. & Tan, S.R. (2012). How much recycled PVC in PVC pipes? Plastic Pipes Conference XVI, Barcelona; Leadbitter, J. & Bradley, J. (1997). Closed Loop Recycling Opportunities for PVC. IPTME Symposium, Loughborough University, 3-4 November.

[12] European Chemicals Agency. 2018. Opinion on an Annex XV dossier proposing restrictions on lead stabilisers in PVC. https://echa.europa.eu/documents/10162/49810a06-ef58-68b6-ba75-e174a25bfc46

[13] ECVM. (2023). ECVM Industry Charter for the Production of Vinyl Chloride Monomer & PVC. Brussels, Belgium: The European Council of Vinyl Manufacturers. https://pvc.org/wp-content/uploads/2023/04/ECVM-charter-pages.pdf; European Commission, Joint Research Centre. (2017). Best Available Techniques (BAT) Reference Document for Large Volume Organic Chemicals (LVOC) Production. Retrieved from https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/JRC109279_LVOC_Bref.pdf

[14] Conversio. (2021). PVC waste in EU 27+3 countries 2020.

[15] European Environment Agency. (2020). Waste Incineration and the Circular Economy in Europe 2019.

[16] European Commission. (2000). Communication from the Commission on the Precautionary Principle. COM(2000) 1 final. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2000:0469:FIN:EN:PDF

[17] Zhang, M., Buekens, A., Jiang, X., & Li, X. (2015). Dioxins and polyvinylchloride in combustion and fires. *Waste Management & Research*, *33*(7), 630–643. https://doi.org/10.1177/0734242x15590651

[18] Zhang, M., Buekens, A., & Li, X. (2017). Open burning as a source of dioxins. *Critical Reviews in Environmental Science and Technology*, *47*(8), 543–620. https://doi.org/10.1080/10643389.2017.1320154

[19] Wagner, J. D. (2017, July 20). 7 Myths About PVC – Debunked. Building Design + Construction. Retrieved from https://www.bdcnetwork.com/7-myths-about-pvc-debunked

[20] H. Hellén et al., Influence of residential wood combustion on local air quality, Sci Total Environ., 393(2-3):283-90, 2008; Centers for Disease Control and Prevention. (n.d.). Facts about benzene. Emergency Preparedness and Response. Retrieved from https://emergency.cdc.gov/agent/benzene/basics/facts.asp

[21] Isaacson, K. P., Proctor, C. R., Wang, Q. E., Edwards, E. Y., Noh, Y., Shah, A. D., & Whelton, A. J. (2021). Drinking water contamination from the thermal degradation of plastics: Implications for wildfire and Structure fire response. Environmental Science: Water Research & Technology, 7(2), 274–284. https://doi.org/10.1039/d0ew00836b; Yu, J., Sun, L., Ma, C., Qiao, Y., & Yao, H. (2016). Thermal degradation of PVC: A Review. Waste Management, 48, 300–314. https://doi.org/10.1016/j.wasman.2015.11.041;

[22] American Water Works Association. (2015). Water treatment plant design: American Water Works Association. https://www.awwa.org/portals/0/files/publications/documents/m14lookinside.pdf

[23] AWWARF. (2007). Impact of Hydrocarbons on PE/PVC Pipes and Pipe Gaskets [Project #2946]. IWA Publishing

[24] Water Research Foundation. (2007). Impact of Hydrocarbons on PE/PVC Pipes and Pipe Gaskets. Project #2946. https://www.waterrf.org/research/projects/impact-hydrocarbons-pepvc-pipes-and-pipe-gaskets; Vonk, A. (1985). Permeation of Organic Compounds Through Pipe Materials (Pub. #85). KIWA, Neuwegein, Netherlands; Cassaday, G. C., Cole, P., Bishop, P. L., & Pfau, R. E. (1983). Evaluation of the Permeation of Organic Solvents Through Gasketed Jointed Unjointed Poly (Vinyl Chloride), Asbestos Cement and Ductile Iron Water Pipes - Phase 1 Report (Final report prepared by Battelle Columbus Laboratories, Columbus, OH, for the Vinyl Institute); Berens, A. R. (1985). Prediction of organic chemical permeation through PVC pipe. Journal - American Water Works Association, 77(11), 57–64. https://doi.org/10.1002/j.1551-8833.1985.tb05642.x; AWWARF. (2007). Impact of Hydrocarbons on PE/PVC Pipes and Pipe Gaskets [Project #2946]. IWA Publishing; Ruta, G., McManemin, A., & Jayaratne, A.H. (2019). Are PFAS an issue for permeation of plastic water pipes? Water e-Journal.

[25] Wang, M., Liu, G., Jiang, X., Liu, W., Li, L., Li, S., Zheng, M., & Zhan, J. (2015). Brominated dioxin and furan stack gas emissions during different stages of the secondary copper smelting process. Atmospheric Pollution Research, 6(3), 464-468. https://doi.org/10.5094/APR.2015.051

[26] Danwatch. (2016, April 6). Impacts of Copper mining on People and Nature. Retrieved from https://danwatch.dk/en/undersoegelse/impacts-of-copper-mining-on-people-and-nature/

[27] U.S. Environmental Protection Agency. (2019, June 27). TENORM: Copper Mining and Production Wastes. Retrieved from https://www.epa.gov/radiation/tenorm-copper-mining-and-production-wastes

[28] Lubin, J. H., Pottern, L. M., Stone, B. J., Fraumeni Jr, J. F., & Berg, J. W. (2000). Respiratory cancer in a cohort of copper smelter workers: Results from more than 50 years of follow-up. American Journal of Epidemiology, 151(6), 554–565. https://doi.org/10.1093/oxfordjournals.aje.a010243; Enterline, P. E., Day, R., Marsh, G. M., & Henderson, V. L. (1995). Cancers related to exposure to arsenic at a copper smelter. Occupational and Environmental Medicine, 52(1), 28-32. https://doi.org/10.1136%2Foem.52.1.28; The Guardian. (2019, June 27). At least 36 believed to have died at Glencore copper mine in Congo. Retrieved from https://www.theguardian.com/business/2019/jun/27/at-least-36-believed-to-have-died-at-glencore-copper-mine-in-congo; Reuters. (2022, May 21). Work

suspended at Botswana's Khoemacau copper mine after accident kills two. Retrieved from https://www.reuters.com/world/africa/work-suspended-botswanas-khoemacau-copper-mine-after-accident-kills-two-2022-05-21/

[29] Zanetta-Colombo, N.C., Fleming, Z.L., Gayo, E.M., Manzano, C.A., Panagi, M., Valdés, J., & Siegmund, A.B. (2022). Impact of mining on the metal content of dust in indigenous villages of northern Chile. Environment International, 169, 107490. https://doi.org/10.1016/j.envint.2022.107490; DeRose, J. (2019, September 5). San Carlos Apache Say Oak Flat Mine Will Destroy Sacred Land, Cause Environmental Injustice. Phoenix New Times. Retrieved from https://www.phoenixnewtimes.com/news/san-carlos-apache-oak-flat-mine-arizona-environmental-injustice-11348481; Phyo, M. N. (2021, April 15). In the Shadow of Letpadaung: Stories from Myanmar's Largest Copper Mine. Natural Resource Governance Institute. Retrieved from https://resourcegovernance.org/blog/shadow-letpadaung-stories-myanmars-largest-copper-mine

[30] Xiong, J., Zhu, J., He, Y., Ren, S., Huang, W., & Lu, F. (2020). The application of life cycle assessment for the optimization of pipe materials of building water supply and drainage system. Sustainable Cities and Society, 60, 102267. https://doi.org/10.1016/j.scs.2020.102267; Helmcke, S., Hundertmark, T., Musso, C., Ong, W. J., Oxgaard, J., & Wallach, J. (2022). Climate impact of plastics. McKinsey & Company. https://www.mckinsey.com/industries/chemicals/our-insights/climate-impact-of-plastics; Gurskis, V., Tumeliene, E., Ramanauskiene, J., Griguceviciene, A., & Zilinskas, G. (2021). Multi-Criteria Comparative Analysis of Water-Supply & Sewerage Pipes Manufactured from Different Materials. In Proceedings of the 10th International Scientific Conference Rural Development 2021 (pp. 205-210). Lithuanian University of Agriculture; https://ejournals.vdu.lt/index.php/rd/article/view/2784/1891; TEPPFA. (n.d.). Life Cycle Assessment (LCA). Retrieved from https://www.teppfa.eu/sustainability/environmental-footprint/lca/