Assessment of pipe materials used in buildings

Carbon footprint and health and toxicity effects

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Abstract

Evaluation of piping materials used in buildings - Carbon footprint and health and environmental effects of harmful substances

At the moment, copper pipes are not allowed in domestic water networks in eco-labelled houses according to the Swan label. The criteria are the same in all Nordic countries. Dissenting views have been expressed, in particular on the need to allow copper pipes for use in residential and comparable buildings. In Sweden, some parties are opposed to the use of copper pipes, as it has been alleged e.g. to degrade the quality of sewage sludge. In Finland, the copper industry has not accepted this view.

The Ministry of Economic Affairs and Employment of Finland has expressed the wish to conduct an objective study so that the environmental impacts of different pipe materials could be compared on a life-cycle basis. In this study, the Finnish Environment Institute (SYKE) collected information on the manufacture of pipe materials, the effects of use on health and the environment, and recyclability. The survey was limited to residential use and water mains inside similar buildings.

Based on the studies, no clear differences were found in the environmental impacts of different pipe materials. Especially with regard to the carbon footprint, the order of priority between different materials can vary e.g. due to the energy sources used and the geographical location of the place of use and manufacture. The recyclability of materials was also taken into account in the study.

No piping material was found to cause adverse health effects. Some experts, on the other hand, have been concerned about the environmental effects of water-soluble copper from copper pipes, but no clear justification was found. Copper is an element that plants and organisms need as a trace element. Based on the study, the amount of copper soluble in the copper pipes was low and no concentrations exceeding the recommendations were detected in the water bodies.

The harmful effect of copper on the aquatic environment and its effect on farmland when using sewage sludge as a fertilizer has been assessed in this study by reviewing previous studies, opinions issued and interviewing experts in the field. Based on these, it can be stated that the effect of soluble copper in water pipes on the aquatic environment cannot be considered significant. Adverse effects of sewage sludge on arable land may only occur in areas where copper levels are already naturally high. There are some such regions in the Nordic countries. This is a very small proportion of the total area of arable land, and it is not justified to prohibit the use of copper pipes for this reason. Instead, the use of sewage sludge as a fertilizer material can simply be prohibited in these fields, and it can be used as a recycled material elsewhere.

Keywords:

water pipes, copper, plastic, carbon footprint, environmental impact, harmfulness, harmful substances, sewage sludge, cultivated fields

Tiivistelmä

Rakennuksissa käytettävien putkimateriaalien arviointi – Hiilijalanjälki sekä haitallisten aineiden terveys- ja ympäristövaikutukset

Joutsenmerkin mukaisissa ympäristömerkityissä taloissa ei rakennusten vesijohdoissa saa käyttää kupariputkia. Kriteerit ovat samat kaikissa Pohjoismaissa. Asiasta on esitetty eriäviä mielipiteitä, erityisesti on toivottu kupariputkien sallimista käytettäväksi asuinrakennuksissa ja niihin verrattavissa olevissa rakennuksissa. Ruotsissa jotkin tahot ovat kupariputkien käyttöä vastaan, koska sen on väitetty mm. heikentävän puhdistamolietteen laatua. Suomessa kupariteollisuus ei tätä näkemystä ole hyväksynyt.

Työ- ja elinkeinoministeriö on esittänyt toiveen puolueettoman selvityksen tekemisestä siten, että eri putkimateriaalien ympäristövaikutuksia vertailtaisiin elinkaariperiaatteella. Tässä selvityksessä Suomen ympäristökeskus (SYKE) keräsi tietoa putkimateriaalien (kupari, muovi ja komposiitti) valmistuksesta, käytön vaikutuksista terveydelle ja ympäristölle sekä kierrätettävyydestä. Selvitys rajattiin asuinkäyttöön ja sitä vastaavien rakennusten sisällä oleviin vesijohtoihin.

Selvitysten perusteella ei löydetty selkeitä eroja eri putkimateriaalien ympäristövaikutuksissa. Etenkin hiilijalanjäljen osalta eri materiaalien välinen paremmuusjärjestys voi vaihdella mm. käytetyistä energialähteistä ja käyttö- ja valmistuspaikan maantieteellisestä sijainnista johtuen. Myös materiaalien kierrätettävyys huomioitiin selvityksessä.

Minkään putkimateriaalin ei todettu aiheuttavan haitallisia terveysvaikutuksia. Jotkut asiantuntijat ovat olleet huolissaan kupariputkista veteen liukenevan kuparin ympäristövaikutuksista, mutta sille ei löydetty selkeitä perusteita. Kupari on alkuaine, jota kasvit ja eliöt tarvitsevat hivenaineeksi. Selvityksen perusteella kupariputkista liukenevan kuparin määrä oli alhainen ja vesistöistä ei ole havaittu suosituksia ylittäviä pitoisuuksia.

Kuparin haitallisuutta vesiympäristössä sekä sen vaikutusta viljelysmaihin puhdistamolietettä lannoitteena käytettäessä on tässä tutkimuksessa arvioitu tutustumalla aikaisemmin tehtyihin tutkimuksiin, annettuihin lausuntoihin sekä haastattelemalla alan asiantuntijoita. Näiden perusteella voidaan todeta, että vesijohtoputkista liukenevan kuparin vaikutusta vesiympäristössä ei voida pitää merkittävänä. Puhdistamolietteen haitallista vaikutusta viljelysmaihin saattaa esiintyä ainoastaan niillä alueilla, joilla kuparipitoisuus on jo luonnostaan korkea. Pohjoismaissa on joitakin tällaisia alueita. Viljelysmaiden kokonaispinta-alasta tämä on hyvin pieni osuus, ja puhdistamolietteen käyttö lannoitemateriaalina on yksinkertaista lopettaa näillä pelloilla. Siten ei ole perusteltua kieltää kupariputkien käyttöä tämän syyn vuoksi.

Asiasanat:

vesijohdot, kupari, muovi, hiilijalanjälki, ympäristövaikutukset, haitallisuus, haitalliset aineet, puhdistamoliete, pellot

Sammandrag

Bedömning av rörmaterial som används i byggnader - koldioxidavtryck samt effekter på hälsan och miljön av skadliga ämnen

I hus som är miljömärkta enligt Svanen får man för närvarande inte använda kopparrör i hushållsvattennätverken. Kriterierna är desamma i alla nordiska länder. Avvikande åsikter har framförts, särskilt önskemål om att kopparrör ska tillåtas i bostadshus och därmed jämförbara byggnader. I Sverige är vissa instanser emot användningen av kopparrör, eftersom dessa bland annat påstås försämra kvaliteten på slam från reningsverk. I Finland har kopparindustrin inte godkänt denna uppfattning.

Arbets- och näringsministeriet har framför ett önskemål om att en opartisk utredning ska göras så att miljökonsekvenserna för olika rörmaterial jämförs enligt livscykelprincipen. I denna utredning samlade Finlands miljöcentral (SYKE) in information om tillverkningen av rörmaterial, verkningarna av användningen på hälsan och miljön samt återvinningsbarheten. Utredningen begränsades till bostadsbruk och vattenledningar inne i motsvarande byggnader.

Utifrån utredningarna hittades inga tydliga skillnader i miljökonsekvenserna för olika rörmaterial . I synnerhet vad gäller koldioxidavtrycket kan rangordningen mellan olika material variera beroende på bland annat de energikällor som används och bruks- och tillverkningsplatsens geografiska läge. Även materialens återvinningsbarhet beaktades i utredningen.

Inget rörmaterial konstaterades orsaka skadliga hälsoeffekter. En del experter har däremot varit oroliga för miljökonsekvenserna av koppar som löser sig i vattnet från kopparrör, men man hittade inga klara grunder för detta. Koppar är ett grundämne som växter och organismer behöver som spårämne. Enligt utredningen var mängden koppar som löses upp från kopparrör låg och i vattendragen har man inte observerat halter som överskrider rekommendationerna.

I denna undersökning har man genom att bekanta sig med tidigare undersökningar, utlåtanden och genom att intervjua experter inom branschen bedömt kopparns skadlighet i vattenmiljön och dess inverkan på odlingsmarkerna vid användning av slam från reningsverk som gödselmedel. Utifrån dessa kan man konstatera att koppar som löses upp från vattenledningsrören inte kan anses ha någon betydande inverkan på vattenmiljön. Skadliga effekter av slam från reningsverk på odlingsmarker kan förekomma endast i områden där kopparhalten redan är hög. Det finns några sådana områden i Norden. Av den totala arealen odlingsmark är detta en mycket liten andel och det är inte motiverat att förbjuda användningen av kopparrör av denna anledning. Däremot är det enkelt att sluta använda slam från reningsverk som gödselmaterial på dessa åkrar och använda det som återvinningsmaterial någon annanstans.

Nyckelord:

vattenledningar, koppar, plast, kolavtryck, miljöpåverkan, skadlighet, skadliga ämnen, avloppsslam, odlat fält

Contents

1 Background and purpose of the study

Pipe materials used in buildings have raised a debate about their potential environmental impact. Among others Swan ecolabel has taken a position in this debate. Previous studies and surveys have examined the carbon footprint of pipe materials through life cycle analysis and the toxicity to both the drinking water and the environment to which the possible harmful substances enter in wastewater. This study has been carried out on the basis of existing studies and surveys as well as separate expert interviews.

Copper pipes are not currently permitted in the domestic water networks in building with the Swan ecolabel. The criteria are the same in all Nordic countries. Dissenting opinions have been expressed on the topic, and, in particular, wishes have been expressed for the permitted use of copper pipes in residential and comparable buildings. In Sweden, the Swedish Water & Wastewater Association has been opposed to the use of copper pipes due to its alleged deteriorating impact on the quality of sewage sludge. In Finland, the copper industry has not accepted this view.

The Ministry of Economic Affairs and Employment (Purchaser) has requested an objective study to ensure that the environmental impacts of various pipe materials (copper, plastic and composite) are also compared in terms of the carbon footprint on a lifecycle basis. In this study, the Finnish Environment Institute (SYKE) will collect information on the manufacture of pipe materials, the impacts of use on health and the environment, as well as on the recyclability of materials. The study is limited to the use of these materials in water pipes inside residential buildings and other comparable buildings.

2 Material and methods

During the assessment, Finnish Environment Institute collected information on alternative materials from Finland and other Nordic countries. They also contacted Nordic organisations (including the Swedish Water & Wastewater Association and the Swedish Environmental Protection Agency) and Finnish experts, organisations, pipe manufacturers and their representatives. The review also took into account official requirements and existing user experiences.

The life cycle assessment can be used to identify the environmental impacts at each stage of the life cycle. The life cycle of the product comprises the manner in which materials are procured, their processing and transport, as well as the manufacture, distribution, use, possible reuse and maintenance of the product, recycling and ending up as waste. Based on a preliminary examination, it was found that various operators had already carried out comprehensive life cycle assessments on pipes manufactured from different materials (Appendices 1 and 2). Calculations had been performed in a thorough manner and in line with standards, which led this study to comprise of a critical assessment of existing assessments and conclusions on the carbon footprint of pipes made from different materials, drawing on the results obtained.

In addition to the analysis of existing life cycle assessments, the health, toxicity and recyclability impacts associated with different pipe materials were researched. Impurities that dissolve from pipe materials into wastewater were taken into account, but no laboratory analyses were carried out in this study for further investigation of the matter. Studies have also been carried out on the health impacts of pipe materials and a summary of these have been included in this report.

Plastic, composite and copper pipes have been subjected to comprehensive life cycle assessments (LCA) commissioned by both the plastic industry (Appendix 1) and the copper industry (Appendix 2). Assessments carried out by the plastic industry (The European Plastics, Pipes, and Fittings Association, TEPPFA) have compared pipes manufactured from all the aforementioned materials, whereas assessments by the cooper industry (The European Copper Institute, ECI and the Copper Alliance, CA) have only included copper pipes.

The materials for above comparisons have been obtained mainly from Ilari Aho (Uponor Finland Ltd) and Pia Voutilainen (Scandinavian Copper Development Association). Most of the materials are internal to the industry, not public reports. The following chapters and Annexes 1 and 2 summarize the studies received.

3 Carbon footprint of pipe materials

3.1 Introduction

Assessments commissioned by both industries are evaluations were internal assessments by the industrial sector in question and were mainly based on information provided by the member companies of organizations. An exception to this is the copper pipeline assessment carried out by the plastic industry, which is based on second-hand information, i.e. literature and readily available information found on the copper pipeline manufacturers' websites, as well as on databases commonly used in life cycle assessments (Ecoinvent).

The copper and plastic industries were both initially also involved in the EU's Nordic Product Environmental Footprint (PEF) pilot, which the copper industry later abandoned due to differences of opinion concerning methodology. For this reason, the plastic industry's LCA is deficient with regard to copper and is, in the opinion of the copper industry, based partly on outdated information, especially with regard to the data sources used (e.g. Ecoinvent database).

All the assessments have been carried out in accordance with ISO 14040 standards, have been commissioned from external consultants and include third-party critical assessment reports in accordance with ISO standards.

3.2 System framing and functional unit

The assessment by the plastic industry compared water pipe systems made of different materials from cradle to grave. The assessment by the copper industry included the environmental impact resulting from the production of copper cathode and copper semi-products, such as pipes and plates, from cradle to gate. Therefore, both assessments included the manufacture of materials and components needed for pipes, including for mining for copper and other necessary metal raw materials. Plastics and composites included e.g. oil in the HDPE granules, but based on the background material, it remained slightly unclear to what extent oil drilling and its impacts were included in the analysis. In the assessment by the copper industry, the analysis ended with the final storage of finished pipes at the factory, while in the assessment by the plastic industry the life cycle also continued to use, decommissioning after service life and the final use of the raw materials contained in the dismantled products, including the possible recycling of materials. The copper industry's assessment included calculated credits for copper manufacturing by-products, such as gold and silver, sulphuric acid and steam, whereas these were not taken into account in the plastic industry's assessment.

The reference unit or functional unit (FU) used in the copper industry's assessment was one pipe metre, while the plastic industry's assessment used the annual environmental impacts of the built water pipe system in a model home with the expected service life (50 years). All pipe materials were assumed to have the same service life of 50 years, although there is no comprehensive on the actual service life of newer pipe materials such as composite and plastic, and these may be longer or shorter. Copper, on the other hand, has been used for longer and estimates of its service life in hot and cold water pipes vary generally between 40 and 60 years. According to current data, the same estimate has also been used for plastic and composite pipes (Ahola 2014).

As the functional units and frameworks used in the various assessments were different, the assessments could not be directly compared. However, the results could be adjusted to commensurate by making use of initial data, and the following section compares the results obtained in different assessments.

3.3 Results of assessments

The results of the life cycle assessments carried out by the plastic and copper industries for the carbon footprint are presented in Annexes 1 and 2. This paragraph provides a comparison of the evaluations carried out.

In order for it to be possible to compare the assessments to one another, the results must be converted to the same unit. In the initial data of the assessments carried out by the plastic industry, the unit used is the number of metres of pipe needed for the different pipe systems in a model home. The required number of metres for all materials was approximately 48 metres, with 2–3 different pipe sizes. By multiplying the results by the assumed life expectancy of the pipes (50 a) and then dividing the figures by the required number of metres of pipe and taking into account the environmental impacts only from cradle to gate will result on a comparison figure to which the copper industry's assessment can be roughly compared.

Figure 1 shows the carbon footprint of a copper pipe based on both the plastic industry and the copper industry assessments.

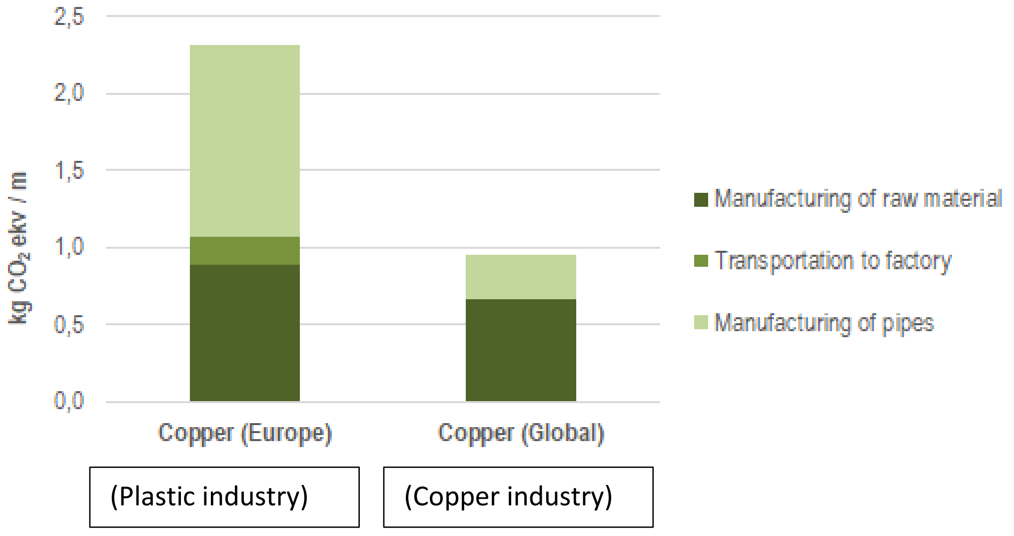

Figure 1. Carbon footprint of a metre of copper pipe according to calculations by the plastic and copper industries. In the bar for the plastic industry, the sensitivity analysis (white line) shows the change in the recycling rate of copper raw material 26 -> 90% and the copper industry bar shows the impact if mining activities are excluded from the impacts of raw material production. The latter of these sensitivity analyses was carried out because it remained somewhat unclear to what extent mining was involved in the assessment of the plastic industry.

Based on the assessments, in particular, the carbon footprint of copper pipe manufacturing is considerably higher in the assessment carried out by the plastic industry, with the plastic industry's carbon footprint estimate being more than four times of the footprint given in the copper industry assessment. Impacts related to transport have also been estimated to be significantly higher. As regards the production of copper raw material, it is unclear to what extent mining activities are included in the assessment by the plastic industry, which means the carbon footprint estimated by the copper industry will decrease further (see sensitivity analysis) If the impacts of mining activities are excluded from the assessment. The margin of error given in the plastic industry bar indicates the carbon footprint of the copper pipe, if the copper recycling rate rises from 26 % to 90 %. However, based on background data it remained somewhat unclear how the sensitivity analysis had been carried out, as the impacts of increasing the recycling rate of copper raw material 26 % - > 90 % should be higher. According to the copper industry, the recycling of copper pipes into raw material and their use as scrap copper only uses up about 10 % of the energy needed in the production of primary copper.

The differences between the assessments are partly explained by the origin of the initial data. With regard to data reliability, the data obtained directly from manufacturers provide the most reliable results compared to the average data from different databases. Thus there are more uncertainties related to the plastic industry's copper pipes assessment than to the assessment carried out by the copper industry itself, as some of the Ecoinvent database information on copper pipes used in the plastic industry's assessments was out of date.

Table 1 compares the carbon footprint ranges of pipes made from different materials, taking the aforementioned factors into account.

Table 1. The carbon footprint of pipes made from different materials (kg CO_2 eq/metres of pipe) in plastic industry's and copper industry's assessments.

	Plastic industry (Europe)			**Copper industry (Global)**
Life cycle phase	*Composite*	*PEX*	*Copper*	*Copper*
Manufacture of raw materials of pipes	0.6	0.3	0.2 - 0.7	0.1 - 0.7
Transport of raw materials to the factory [a]	0.0	0.0	0.2	0.0
Manufacture of pipes	0.1	0.2	1.3	0.3
Carbon footprint, CO_2 eq./m	**0.7**	**0.5**	**1.7 - 2.3**	**0.4 - 1.0**
Energy consumption, MJ/m	**14.5**	**15.8**	**26.2**	**6.3 - 12.1**

[a] Impact has been estimated and it deviates from 0, but rounds to 0 with this accuracy

The regional boundaries used in the evaluations also affect the outcome. In the assessment of the copper industry, environmental impacts have been calculated for global copper production, based on real production, energy use and emission inventories in relation to production volumes in different countries, while the assessment by the plastic industry covers the average manufacturing of European pipes. This is particularly evident in the energy sources used, which have a substantial impact on the carbon footprint. The more renewable fuels are used, the smaller the carbon footprint. Natural gas was used as the source of heat in both assessments. For electricity, the assessment by the plastic industry used the average European electricity production at the time of the assessment (coal 38 %, natural gas 28 %, brown coal 25 % and crude oil 9 %), i.e. 100 % fossil fuels. The copper industry's assessment used each country's average electricity in relation to electricity production to determine the electricity used. The energy sources used for electricity were 11 % renewable, 9 % nuclear and 80 % fossil fuels. Therefore, it can be concluded with regard to both assessments that the carbon footprint would be smaller, if the assessments had only examined pipe manufacture in the Nordic countries, because these countries use more renewable energy sources relative to global or European production on average.

3.4 Summary of life cycle assessments

Both the plastic and copper industries have commissioned comprehensive life cycle assessments of the life cycle of water main pipes (plastic, composite, copper) or the environmental impacts associated with its part. The functional units and the system limitations used in the assessments were different, so only a rough comparison of the results can only be carried out by converting the units into comparable ones.

When comparing the assessments, it is clear that the plastic industry's assessment of the climate impacts and energy consumption caused by the copper industry are more than double those in the assessment carried out by the copper industry. As both of the industries will certainly have the best knowledge of the processes involved in manufacturing their own products and the related environmental impacts, it should be assumed that the assessment carried out by the copper industry on the effects of their own products is more accurate than the assessment by the plastic industry, which is based on second-hand knowledge. When examining the results of the life cycle assessments, it should be kept in mind that they are always indicative estimates and may involve significant sources of error.

Based on the results of the assessments, the differences in the climate impacts caused by the manufacturing of different pipe materials are not very large and there is no clear order of superiority between different pipe materials. In plastic industry assessment, the carbon footprint of plastic and composite pipes is smaller than that of copper pipes, while according to copper industry assessment the order is reversed. It can be concluded that the region selected for the assessment and the energy sources used have a significant impact on the final result. Based on the results, the climate change impact of one metre of pipe is the same as driving a 3–5 kilometre journey by car (Ecoinvent database: Transport, passenger car, petrol, fleet average/person-km – RER).

One clear difference in the assessments is the amount of recycled copper used, which is 26 % in the plastic industry's study and 67 % in that of the copper Industry. In Finland, recycled copper can account for as much as 97 %, which has been used in calculating the lower number 0,4 for carbon footprint in table 1. However, the difference in the amount of recycled copper alone does not explain the differences in the results, as the plastic industry's assessment also includes sensitivity analysis for higher shares of recycled copper. However, in these calculations, the effects of copper production remain almost the same as in the baseline scenario, suggesting that the data related to the processing of recycled copper has been incomplete. According to the copper industry, used copper pipes are so good quality for scrap metal that they can be melted immediately without a cleaning phase. Copper recycled for raw material production only uses up about 15 % of the energy needed to produce the same amount of copper from the extracted. The utilisation of used plastic and composite pipes for recycling is limited to recycled plastic products or energy recovery. The raw materials used in pipes cannot be used as such to manufacture new drinking water pipes for hygiene and quality reasons. In general, the metals (copper, zinc, aluminium) required for the manufacture of composite pipes, are also recycled raw materials, but their share in the whole is small.

4 Health and toxicity effects of pipe materials

4.1 Background and legislation on the health impacts of drinking water supply system pipes

On 14 June 2018, the Ministry of the Environment issued decrees on essential technical requirements for PEX pipes and flexible connecting pipes for water installations in buildings. These decrees entered into force on 1 September 2018. The purpose of the decrees is to promote the healthy and safe construction and repair of water services in buildings. Healthiness must be the primary requirement for construction products in contact with domestic water in order to maintain good water quality. The decrees now adopted lay down health-related requirements regarding the properties of the materials to be used, on substances that dissolve from products and on changes to smell and taste.

The issued decrees are based on the Land Use and Building Act and are a continuation of the overall reform of construction regulations. The decrees that apply to essential technical requirements form the foundation for national product approval and provide an opportunity for type approval. Parallel with these decrees, the Ministry of the Environment prepared type approval decrees, which will be issued separately. In the future, similar decrees will also be issued for other product groups.

New plastic water pipes in buildings (PEX plastic pipes) have at times caused abnormal smell and taste in domestic water. One-off notifications on changes to smell and taste have been sent from different parts of Finland. These observations have been made in new buildings or buildings with recently renovated water pipe systems. However, this has been an issue with the products of a single manufacturer, which have already been withdrawn from the market.

4.2 Drinking water quality recommendations with regard to pipeline materials

The Ministry of Social Affairs and Health requests information and measurement results from the municipal health protection authorities concerning cases where it has been observed or suspected that PEX plastic pipes used in buildings have caused a change in the smell or taste of household water.

The quality recommendation for the smell and taste of domestic water is laid down in legislation, according to which the smell and taste of water must be acceptable to users, there must be no unusual changes in these. If there is a foreign smell and taste in water, the municipal health protection authority must determine whether the use of the water may pose a health hazard. Small amounts of chemicals are dissolved into water from all water pipe materials. Many different compounds are known to dissolve from PEX pipes into water. Some of these compounds can be detected in by human senses, but they do not cause health hazards. These include MTBE and TBA.

Copper in distributed drinking water is usually caused by the corrosive effect of water, which dissolves copper from copper pipes in buildings. Concentrations may vary considerably depending in the way water has been in contact with the pipes; for example, copper concentrations are expected to be higher in water that has stood in pipes than in a fully rinsed sample. High concentrations may affect the intended domestic use of water. Toilet fixtures and laundry may stain when the copper content exceeds 1 mg/l. At concentrations above 5 mg/l, copper also gives water a colour and an undesirable bitter taste. Although copper may cause a change in taste, it should be acceptable with a health-based guideline value of 2 mg/l (WHO 2017).

4.3 Studies carried out on the health effects of PEX plastic water pipelines

Some of the substances that dissolve from PEX pipes are well known, while some of their degradation products in particular are still unidentified. Substances most commonly found in domestic water that has come through PEX pipes are:

- MTBE (methyl tert-butyl ether), a compounding ingredient of fuel, smell and taste
- ETBE (ethyl tert-butyl ether), a compounding ingredient of fuel
- TAME (tert-Amyl methyl ether)
- TBA (tert-Butyl alcohol)
- Various antioxidant degradation products

In individual problem areas, small concentrations of solvents such as xylene and styrene may also be present in domestic water.

The concentrations of substances that detach from PEX pipes in water are usually low, i.e. a few micrograms per litre (µg/l) or less. MTBE is the most common of these substances and its content is typically a maximum of some tens of micrograms per litre. A defective PEX pipe can let off up to 1,000 µg/l of TBA. Volatile organic compounds (VOCs) that are vapour may dissolve into water from PEX pipe materials after use of a pipe has begun. The most commonly observed VOCs are methyl tert-butyl ether (MTBE), ethyl tert-butyl ether (ETBE), tert-amyl methyl ether (TAME) and tert-butyl alcohol (TBA). The EU has not set any health-based limit values for these in drinking water. Substances that dissolve from PEX pipe material have been researched in Finland by, for example, VTT Expert Services Oy and the Wander Institute. The researched materials have been a) DTBP peroxide assisted polyethylene, b) silane-assisted cross-linked polyethylene, c) by irradiation cross-linked polyethylene and d) a multi-layer tube with an aluminium layer in the middle and an inner part of the aforementioned PEX material. In addition to TBA, MTBE, ETBE and TAME concentrations in the water were also determined. The impact of the contact period on the volume of TBA was also examined in order to provide guidelines on the control of domestic water quality.

TBA (max 330 µg/l) and some MTBE dissolved into water from material a) pipes. Their concentrations decreased over time. ETBE and TAME were not found in the long-term study water samples in quantities exceeding limits. No concentrations exceeding limits were observed in water samples for materials c) and d). The concentrations of substances dissolved into water from PEX pipes are highest in newly adopted pipes, and long-term testing showed that the concentrations of dissolved VOCs decrease over time. Completed studies found that the health risks related to the substances that dissolve from pipe materials can be reduced by running water before it is used for drinking or cooking. Based on the studies, we know that in addition to the characteristics of a product, the water temperature, flow rate, amount of water run from a tap and its quality and composition affect the concentrations of chemicals that are released from PEX pipes to water.

Changes in smell and taste caused by PEX pipes

PEX pipes can let off a smell into household water even though the concentration of substances measured in water is low. PEX pipes can cause smells in the water for several months after the pipes have been installed. Concentrations that exceed the smell and taste threshold can be smelled and tasted from water:

- MTBE: smell threshold 7–15 µg/l and taste threshold 15 µg/l
- ETBE: smell threshold 1–5 µg/l and taste threshold 2 µg/l
- TAME: smell threshold 8 µg/l and taste threshold 16 µg/l
- TBA: Does not cause any smell or taste to the water with the observed concentrations

Toxicity of substances detaching from PEX pipes

The toxicity of substances (MTBE, ETBE, TAME, TBA) that detach from PEX pipes is reasonably well known. MTBE, ETBE and TAME can be considered relatively harmless, even if exposure continues for a long time. These do not cause acute poisoning symptoms or irritate the skin or eyes at the observed concentrations. They also do not cause skin allergies. Their potential to cause malformations to the fetus or to effect reproduction are minimal. MTBE, ETBE and TAME do not cause mutations or DNA damage.

MTBE is not carcinogenic to humans. MTBE is carcinogenic for test animals, but the tumours caused by MTBE are formed in test animals with a mechanism that does not occur in humans. ETBE's carcinogenicity is not known. Both MTBE and ETBE are decomposed in the body into TBA, which is also carcinogenic for test animals. TBA is at most poorly carcinogenic for humans.

Health risk caused by PEX pipes

Based on exposure and toxicity data, the health risk posed by substances normally released from PEX pipes into household water is low. The concentrations of substances in water are generally low and below the levels known to be harmful. Although, not all the substances found in water have been identified, their concentrations are also low. However, the high concentrations of chemical substances resulting from manufacturing errors in PEX pipes may pose a health risk. Any potential health risk must be assessed on a site-specific case-by-case basis on the basis of the substances present in the water and their concentrations.

Finland, the EU or the WHO have not set statutory limit values for domestic and drinking water for substances released from PEX pipes into water. According to an assessment by the Finnish Institute for Health and Welfare (THL):

- MTBE: No health risks even with long-term use, if the concentration is less than 20 to 40 µg/l (US EPA)
- ETBE: Because the substance is very similar to MTBE, the same concentration of 20 to 40 µg/l may be applied to it
- TAME: No estimate has been given on safe concentration, but the concentrations of a few µg/l as observed in water are not likely to pose a health risk
- TBA: No health risks even with long-term use, if the concentration is less than 500 µg/l (Germany's environmental authority UBA)
- Other substances: If the concentration in water is very low, at most a few micrograms per litre, the health risk can be assumed to be low
- Smell and taste: You can protect yourself from health risk by not drinking water that smells or tastes bad

4.4 Toxicity effects of copper pipes

Debate on substances that dissolve from drinking water pipes and end up in wastewater have mainly arisen due to copper residues. Copper is a natural metal that is present in almost all natural processes. Copper is needed for vital physiological functions, but in excessive amounts, it may cause toxicity. No health effects have been observed with mostly used plastic, composite or copper pipes, and the discussion on the toxicity effects of copper pipes has thus focused on the impacts of copper emissions on land and water habitats. There are very differing views on this issue, especially among Swedish experts.

The sources of the copper loading in the environment include, for example, loads that come with storm waters as well as the copper that travels with waste water through copper pipes to wastewater treatment plants. Some of this copper travels with cleaned wastewater to water bodies and some with sludge to the surrounding soils. There are varying views on the number of these components, as well as on what is considered safe loading with regard to the environment. This is influenced, for example, by the fact that the harmful effect of copper on biota changes with the hardness of water. This topic has been examined extensively, for example, in the book Metals in Society and in the Environment (Landner and Reuther 2004). In the Nordic countries, waters are predominantly soft, but, for example, in Southern Sweden, there are hard waters. -PNEC value (Predicted No Effect Concentration), given in this book, is 8 µg Cu/l as dissolved copper. Copper concentrations in wastewater recorded in literature are generally significantly below this level.

The use of copper pipes is not permitted in residential buildings given the Swan ecolabel. This decision has been made on the basis of copper's suspected environmental impact. During this project, materials were examined, and experts were consulted for their views on the matter with surveys and interviews.

With regard to sewage sludge, the limit value set by the EU varies depending on the situation from 1,000 to 1,750 mg/ kg of dry matter, while Sweden has used 600 mg/kg as its limit value and is reducing it to 475 mg/kg. The average copper content in Nordic sewage sludge is approximately 400 mg/kg. Metal concentrations are high in the Stockholm area's fields, which has been used as a criterion for reducing the use of copper. However, reports compiled by the Swedish Environmental Protection Agency indicate that 25 % of the cultivated fields in Sweden suffer from a lack of copper, and only one quarter of the total amount of copper spread to the fields comes with sewage sludge. Figure 2 below shows a map drawn up by the Swedish University of Agricultural Sciences (SLU) on the copper content and needs of Sweden's fields. According to these estimates, the use of sludge as a fertilizer product should be prohibited on 3.7 % of the all arable land area. Metal concentrations are high, in particular in acid sulphate soils, which are also found in Finland, especially along our west coast. The situation outlined by the Geological Survey of Finland on a map is shown in Figure 3. These areas may be inclined to have high copper concentrations, although this has not been observed to be a problem in Finland.

Län	Areal med Cu-behov, %	Län	Areal med Cu-behov, %
Blekinge	40	Norrbotten	30
Kronoberg	40	Skåne	25
Gotland	40	Örebro	20
Jönköping	40	Östergötland	5
Dalarna	40	Södermanland	5
Halland	30	Stockholm	5
Kalmar	30	Västmanland	5
Västra Götaland	30	Uppsala	5
Värmland	30	Jämtland	5
Västerbotten	30	Västernorrland	5

Det fattas ofta koppar i svenska åkerjordar. Tabellen visar hur stor del av arealen som ligger under gränsvärdet för kopparbrist, dvs lägre än 7 mg Cu/kg jord. (Källa: SLU, Mark- och grödoinventeringen.)

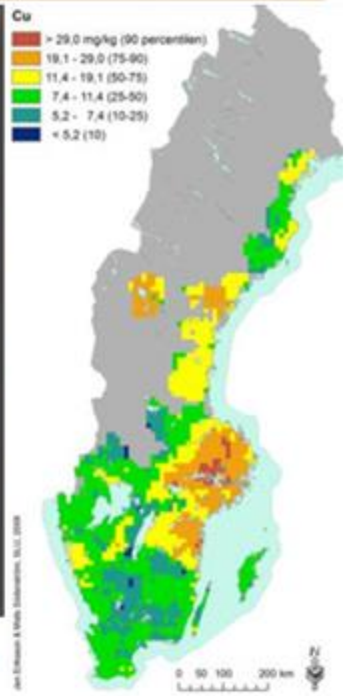

Figure 2. Copper concentrations and need for copper on Swedish cultivated land (SLU 2020, table by YARA). Fertilisation with sludge containing copper is not recommended in Sweden if copper content in soil is more than 40 mg/kg. This kind of soils are 3.7 % of field area in Sweden.

Figure 3. Location of acid sulphate soils in the coastal areas of Sweden, Finland and Norway. The metal content of soil may also be high in these areas. (Peter Edén, Geological Survey of Finland)

Overall, the view of the Finnish experts interviewed was that copper would not in any way harm the environment in the concentrations and forms in which it dissolves from copper pipes. On the other hand, some Swedish experts have different views on this, and there has been a debate on the magnitude and the harmful nature of loading on both sides. The concentration of copper in natural waters and fields has remained at low levels, but some research results suggest that they cannot be permitted to rise.

5 Summary and conclusions

During the project, material and research data related to various pipe materials were reviewed and experts from the field were interviewed. There seem to be strong views and opinions in the industry, especially on the toxicity effects of various pipe materials on organisms. This led researchers to believe that experts have interpreted research results differently when formulating recommendations for pipe materials. Such differences in views include the share and effects of copper that flows into fields from copper pipes.

Studies have not found clear differences in the environmental impacts (carbon footprint) different pipe materials. The order of superiority between different materials may vary, especially with regard to their carbon footprint. This is due to factors such as the energy sources used and the geographical location of use and manufacture. From the viewpoint of material recyclability, copper is 100% recyclable as a material and can be used in the manufacture of new drinking water pipes. This is not the case for plastic and composite pipes. After use, some raw materials can be recycled or utilised, for example, in energy production. However, recycled raw materials are no longer suitable for the manufacture of new drinking water pipes for hygiene and quality reasons. Instead, other recycled plastic products can be made of these.

No pipe material was found to cause adverse health effects. On the other hand, some experts have been concerned about the toxicity effects of copper that dissolves into water from copper pipes, but no clear justification was found for this. Copper is a chemical element that plants and organisms need as a micronutrient. The study found that the amount of copper soluble in copper pipes was low and no PNEC concentrations exceeding recommendations were observed in natural water systems. Copper also ends up in water systems from sources other than copper pipes. Copper pipes account for only a few per cent of these emissions (EU 2008).

Pipes manufactured from different materials each have their own place and a purpose for which they have been found to be good. For example, rigid copper or composite pipes are the best option for riser pipes in apartment buildings. This study did not find any clear reason for one of the pipe materials examined in this study being any worse than another with regard to the researched effects (carbon footprint, health, toxicity). As regards the carbon footprint and health effects, there was no significant difference between the pipe materials examined. The share of recycled material used in manufacturing has a significant impact on the carbon footprint, but this share is well known for the Nordic countries. The use of recycled copper as a raw material uses up only about ten per cent of energy needed for the production of primary copper. As the production of raw material for copper pipes accounts for almost three quarters of the total carbon footprint of the pipe manufacturing (with 67 % recycled copper), the share of recycled copper used has a significant impact on the end result.

In this study, the toxicity effect of copper in the aquatic environment and its impact on arable land where sewage sludge is used as a fertilizer has been assessed by examining previous studies and statements, and by interviewing experts in the field. Based on these, it can be concluded that the impact of copper dissolved from water pipes in the aquatic environment cannot be considered significant. The harmful effect of sewage sludge on arable land is suggested to occur in areas where the soil's copper content is already naturally high. The Stockholm area is one such areas in the Nordic countries. This accounts for a very small share of the total arable land, and there are no grounds for banning the use of copper pipes for this reason.

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Interviewed experts

Full Name	Organisation	Expertise /Subject area
Jaakko Mannio	Finnish Environment Institute	Impact of harmful substances on the environment, specific topic fish
Aino Pelto-Huikko	Nordic Water and Materials Institute	Emissions from household water pipeline materials into drinking water
Pia Voutilainen	Scandinavian Copper Development Association	Manufacture of copper pipes, environmental impacts
Teemu Pihl	Cupori Oy	Manufacture of copper pipes, environmental impacts
Kari Kuivalainen	Finnish Plastics Industries Federation	Manufacture of plastic pipes, environmental impacts
Ilari Aho	Uponor Suomi Oy	Manufacture of plastic pipes, environmental impacts
Kristina Svinhufvud	Swedish Environmental Protection Agency	Environmental impacts of copper
Anders Finsson	Svenskt Vatten – The Swedish Water & Wastewater Association, SWWA	Environmental impacts of copper

Appendix 1 Life cycle assessments commissioned by the plastic industry

1 Background

The assessment commissioned by the plastic industry compared water pipe systems made of different materials from cradle to grave. However, it remained somewhat unclear whether the impacts of oil drilling had been included in the assessment.

Data sources included the average data of the largest pipeline manufacturers, as well as literature and available databases, including: Ecoinvent, Ecolizer etc. (Also see the reference details for the Annex). In addition, inquiries were sent to raw material manufacturers, TEPPFA member companies and suppliers. The required pipe and component quantities were calculated for PEX and composite on the basis of the average weights listed in the two largest European suppliers' typical system plans. The design of the copper water pipe system was based on easily accessible information from literature and the information available on the websites of a few manufacturers of copper pipe systems.

The functional unit used was an apartment of a certain size and equipment level (Figure 1), the impacts of which have been divided by the life expectancy of the piping (50 years). More detailed description: "The annual environmental impacts of the selected drinking water pipe system on the pressurized supply and distribution of drinking water (hot/cold) in the specified apartment (100 m², service life expectancy 50 a) from the pipeline inlet to the apartment’s different water points; bathroom, separate toilet, kitchen.”

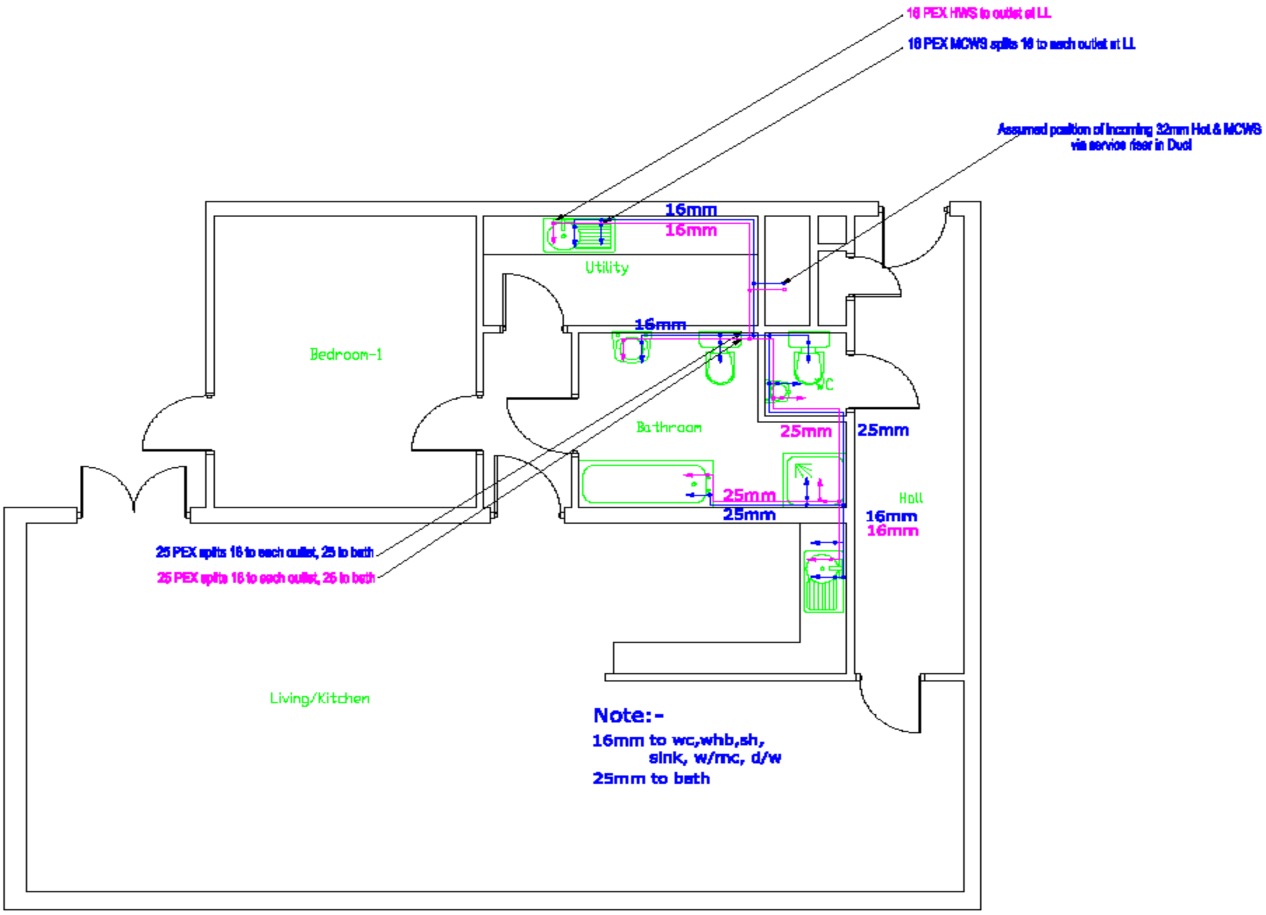


Figure 1. The model dwelling used to calculate the functional unit.

2 Compared pipe systems

2.1 PEX

The main components of a PEX water pipe system are PEX pipes as well as PPSU fittings (Polyphenylsulphone) and brass fittings. A PEX pipe is a fixed-wall, single layer pipe that is supplied in a coil. Its raw materials and manufacture methods are shown in Table 1. Further information related to manufacture is also included in Appendix 2.

Table 1. The components, raw materials and manufacturing processes of the PEX water pipe system in a model home. Raw materials needed listed per functional unit in parentheses.

Component	Amount	Raw materials	Manufacture process
PEX pipes	8.15 kg (0.163 kg/FU)	98.4 % PEHD, 1.6 % different chemicals (confidential information; for the purpose of the calculation 50 % alkyl benzene, 50 % phenol.	Extrusion (Electricity 1.9 kWh/kg) (Data averaged from information provided by European plastic pipe manufacturers).
Plastic fittings (PPSU	0.75 kg (0.015 kg/FU)	Polyphenylsulphone	Injection moulding
Brass fittings	1.5 kg (0.030 kg/FU)	Copper and zinc, 60 % recycled raw material (European average)	Melting, casting and turnery

2.2 Composite

The main components of the composite water pipe system are composite pipes, PPSU and brass fittings and metal compression rings. Composite pipe is a pipes with a three-layer structure and an aluminium core. The average of two different composites was used to model environmental impacts; crosslinked polyethylene/aluminium/polyethylene raised temperature (PEX/Al/PE-RT) and polyethylene raised temperature/aluminium/polyethylene raised temperature (PE-RT/Al/PE-RT). Its raw materials and manufacture methods are shown in Table 2. Further information related to manufacture is also included in Appendix 2.

Table 2. The components, raw materials and manufacturing processes of the composite water pipe system in a model home. Raw materials needed listed per functional unit in parentheses.

Component	Amount	Raw materials	Manufacture process
Polymer parts	5.8 kg (0.116 kg/FU)	50 % PEX/Al/PE-RT Outer layer: 98.15 % PEHD, 1.6 % different chemicals (confidential information; for the purpose of the calculation 50 % alkylbenzene, 50 % phenol), 0.25 % titanium dioxide. Inner layer: 99 % PEHD, 1 % stabilisers; phenolic antioxidants, phosphite (50 % alkylbenzene, 50 % phenol used in the calculation) 50% PE-RT/Al/PE-RT Outer layer: 98.75 % PEHD, 1 % stabilisers; phenolic antioxidants, phosphite (50 % alkylbenzene, 50 % phenol used in the calculation), 0.25 % titanium dioxide. Inner layer: 99 % PEHD, 1 % stabilisers; phenolic antioxidants, phosphite (50 % alkylbenzene, 50 % phenol used in the calculation)	Extrusion (electricity 1.056 kWh/kg, natural gas 0.492 kWh/kg) (Data averaged from information provided by European plastic pipe manufacturers).
Aluminium parts	2.2 kg (0.044 kg/FU)	Aluminium, 10 % recycled raw material (European average)	Rolling
Plastic fittings (PPSU)	0.75 kg (0.015 kg/FU)	Polyphenylsulphone	Injection moulding
Brass fittings	1.5 kg (0.030 kg/FU)	Copper and zinc, 60 % recycled raw material	Melting, casting and turnery
Metal compression rings	0.6 kg (0.012 kg/FU)	Stainless steel	Hot rolling on a coil

2.3 Copper

The main components of the copper water pipe system are copper pipes, copper fittings and soldering. As the copper water pipe system may contain copper compression fittings on the one hand and copper brazed fittings on the other, environmental impact modelling assumed that the water pipe system comprised 50 % compression fittings and 50 % soldered joints.

Table 3. The components, raw materials and manufacturing processes of the copper water pipe system in a model home. Raw materials needed listed per functional unit in parentheses.

Component	Amount	Raw materials	Manufacture process
Copper pipes	23.2 kg (0.464 kg/FU)	100 % Copper	Melting, purification of impurities, deoxidation of melted copper with phosphorus (to reduce oxygen content), casting
Copper fittings	3.02 kg (0.060 kg/FU)	100 % Copper	Casting
Soldering	0.009 kg (0.0002 kg/FU)	7 % zinc, 3 % copper	Welding/soldering

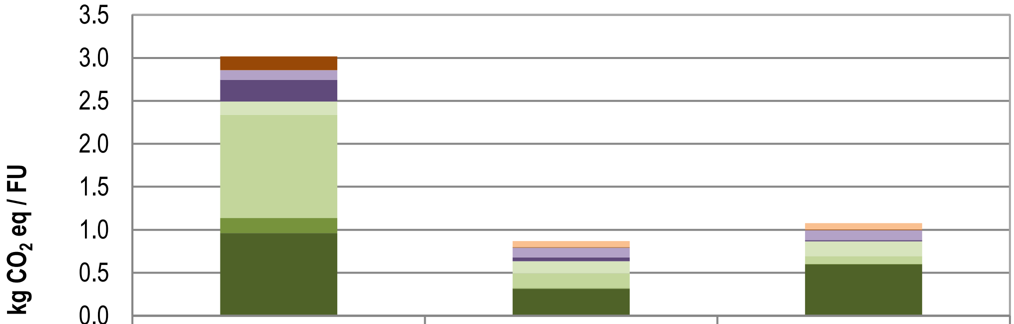
3 Results

The review of environmental impacts has been presented by dividing them into the following life cycle phases; manufacture, building, use and final processing. The various factors included in different phases with regard to different water pipe systems are listed in Table 4.

Table 4. The life cycle phases for various pipe materials included in the life cycle assessments carried out by the plastic industry.

COPPER	PEX	COMPOSITE
Manufacturing phase		
Raw material supply (pipes, fittings, soldering) Transport of raw materials to the manufacturer Manufacture process for copper pipes, fittings and solders Packaging of pipes and components	Raw material production (pipes, PPSU and brass fittings) Transport of raw materials to the manufacturer Manufacture process for PEX pipes and fittings Packaging of pipes and components	Raw material production (pipes, PPSU and brass fittings, compression rings) Transport of raw materials to the manufacturer Manufacture process for composite pipes and fittings Packaging of pipes and components
Construction phase		
Transport to the building site Installation	Transport to the building site Installation	Transport to the building site Installation
Use phase		
Use and maintenance	Use and maintenance	Use and maintenance
Final processing phase		
Dismantling after operational life Transport to final processing Final processing	Dismantling after operational life Transport to final processing Final processing	Dismantling after operational life Transport to final processing Final processing

The climate change impacts of systems comprising various pipeline materials are summarised in Figure 2. Table 3 shows the same climate impacts in more detail with precise figures.



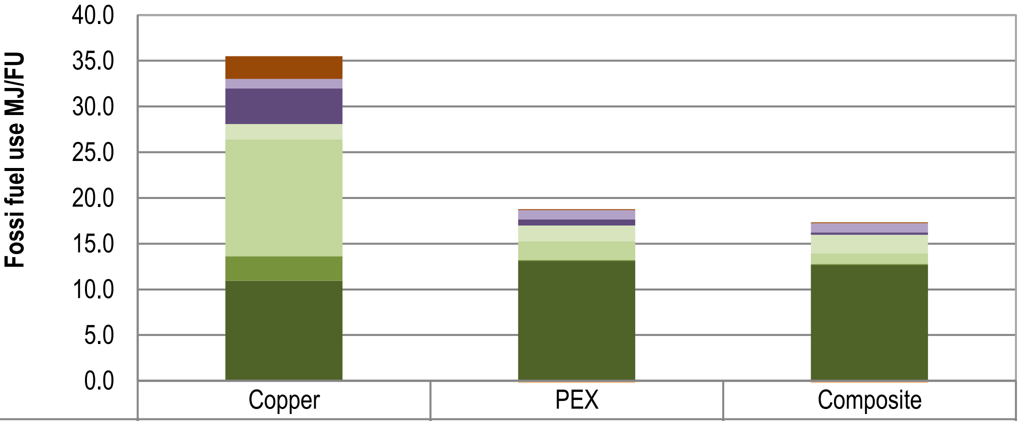
	Copper	PEX	Composite
TOTAL	3.02	0.87	1.08
Final processing	0.00	0.07	0.07
Transport to final processing	0.16	0.01	0.01
Use and maintenance	0.00	0.00	0.00
Installation	0.11	0.11	0.12
Transport to the building site	0.25	0.04	0.01
Manufacture of fittings	0.16	0.14	0.17
Manufacture of pipes	1.20	0.17	0.09
Raw material transport	0.17	0.01	0.01
Raw material manufacture	0.96	0.31	0.60

Figure 2. The climate change impacts of different pipe materials per functional unit (kg CO_2 equivalent), according to assessments by the plastic industry.

According to assessments commissioned by TEPPFA, the climate change impacts of different pipe materials per functional unit were 3.0 kg CO_2 equivalent for copper, 0.9 for PEX and 1.1 for composite. In the figure, the recycling rate of copper is estimated at 26 %. The sensitivity analysis involved the calculation of impacts if the recycling rate of cooper were to rise to 100 %. This would reduce the overall impact of copper to 69 %, i.e. approximately 2.1 kg CO_2 eq/FU. The end result of the assessment is also substantially affected by the fact that around three times more (kg) copper is needed per functional unit compared to plastic pipes.

In terms of energy use, all the water pipe systems used the European average electricity production for electricity (coal 38 %, natural gas 28 %, brown coal 25 % and crude oil 9 % (Ecoinvent database: Electricity, low voltage, European average mix of production)). It is assumed that heat is produced with natural gas in all the water pipe systems (Ecoinvent database: Heat, natural gas, at industrial furnace low-NOx >100 kW).

The use of fossil fuels during the life cycle of different water pipe systems is shown in Figure 3.



	Copper	PEX	Composite
TOTAL	35.50	18.47	17.01
Final processing	0.00	-0.31	-0.32
Transport to final processing	2.48	0.10	0.11
Use and maintenance	0.00	0.00	0.00
Installation	1.04	1.02	1.02
Transport to the building site	3.91	0.66	0.23
Manufacture of fittings	1.66	1.72	2.03
Manufacture of pipes	12.80	2.06	1.17
Raw material transport	2.69	0.11	0.10
Raw material manufacture	10.92	13.10	12.68

Figure 3. The fossil fuel use (MJ) resulting from different pipe materials per functional unit according to assessments by the plastic industry.

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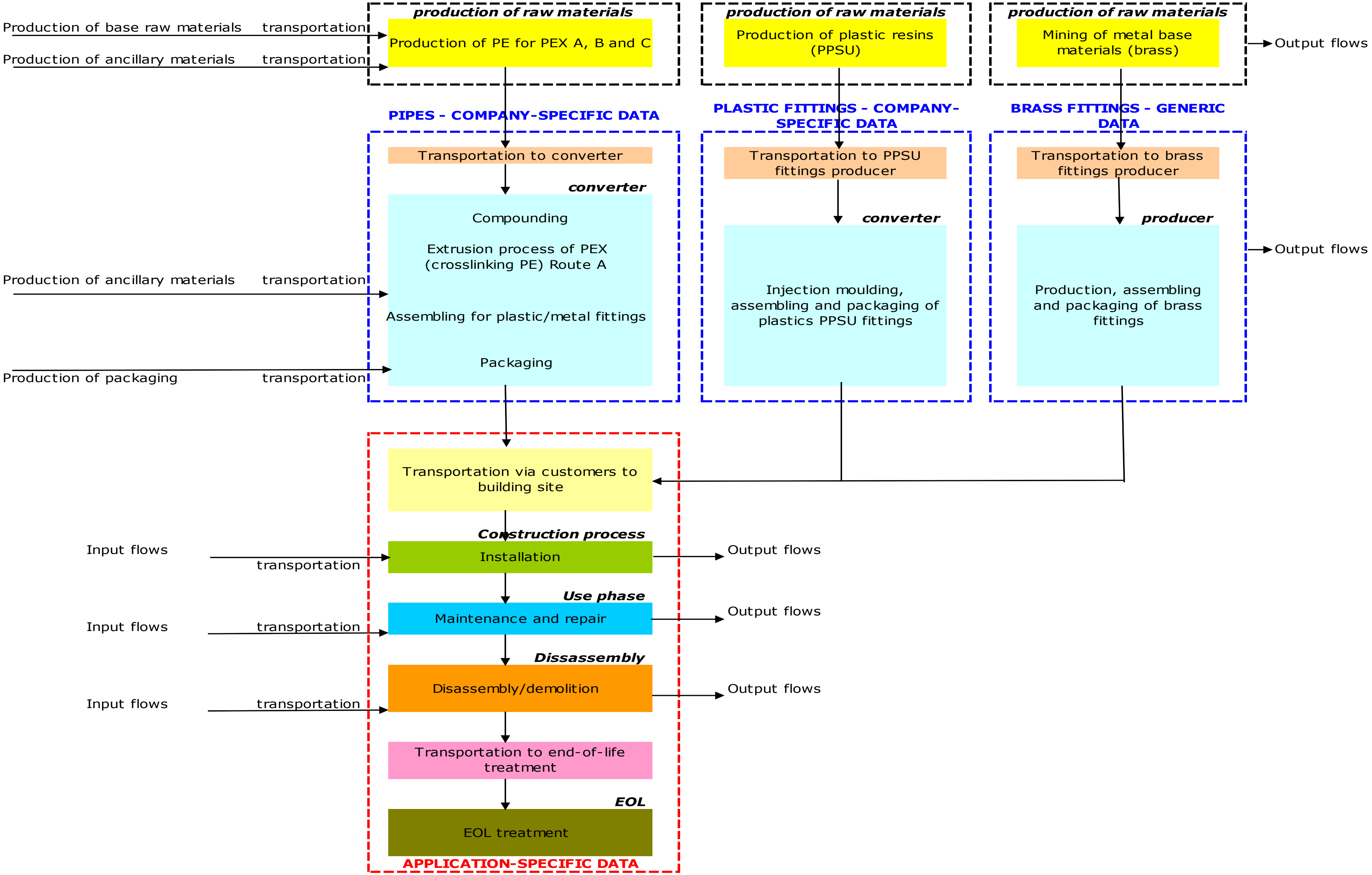
5 Additional information

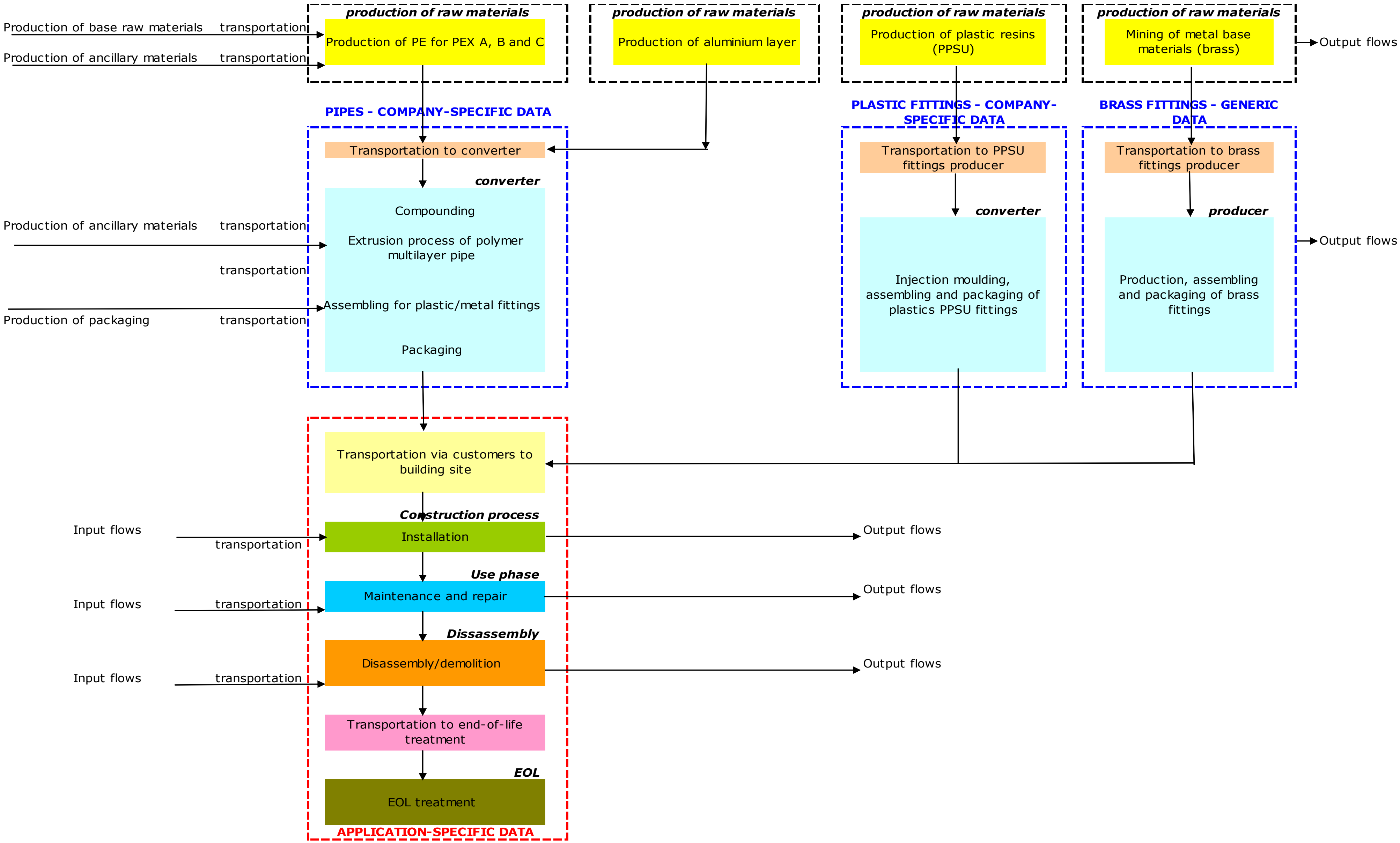
Table 5: More detailed manufacture information on PEX and composite pipes

Data for the extrusion of 1 kg of PEX pipes		
Input flows	**Amount**	**Unit**
HDPE resin raw materials mixture	1,064	kg
Cooling water losses	0,0845	kg
Process water, extracted from ground	0,0538	kg
Ink for marking pipes	0,51	g
Packaging of pipes		
EURO-flat pallets	0,002638	kg
cardboard	0,081	kg
PP straps	1,16	g
packaging film	0,005	kg
Energy for extrusion		
electricity	1,9	kWh
Output flows	**Amount**	**Unit**
Emissions		
HC	0,4	g
PM10	0,08	g
BOD 5	0,00084	g
COD	0,00843	g
Suspended solids, unspecified	0,00314	g
Packaging waste		
wooden packaging	0,0067	kg
plastic packaging	0,0016	g
paper/cardboard packaging	0,0034	kg
Other waste flows		
hazardous waste	0,45	g
product scrap, not recycled	0,064	kg
mixed industrial waste	0,0088	kg
Transport of waste to waste treatment	50	km

Data for the extrusion of 1 kg of polymer multilayer pipes		
Input flows	**Amount**	**Unit**
Polymer multilayer recipe of raw materials mixture	1,0289	kg
Aluminium layer	1,0234	kg
Cooling water losses	0,0845	kg
Process water, extracted from ground	0,0538	kg
Additional water use	1,1366	kg
Ink for marking pipes	0,51	g
Packaging of pipes		
EURO-flat pallets	0,00173	kg
cardboard	0,083	kg
PP straps	1,18	g
packaging film	0,005	kg
Energy for extrusion		
electricity	1,056	kWh
gas	0,492	kWh
Output flows	**Amount**	**Unit**
Emissions		
HC	0,04143	g
PM10	0,08	g
BOD5	0,00084	g
COD	0,00843	g
Suspended solids, unspecified	0,00314	g
Packaging waste		
wooden packaging	0,0067	kg
plastic packaging	0,0016	g
paper/cardboard packaging	0,0034	kg
Other waste flows		
hazardous waste	0,45	g
polymer product scrap (recycled externally)	0,0289	kg
aluminium product scrap (not recycled)	0,003228	kg
aluminium product scrap (recycled externally)	0,02018	kg
mixed industrial waste	0,0088	kg
Transport of waste to waste treatment	50	km



Life cycle flow chart of the PEX Hot & Cold water pipe system (Buildings)



Life cycle flow chart of the polymer multilayer hot & cold water pipe system (Buildings)

Appendix 2 Life cycle assessments commissioned by the copper industry

1 Background

The study commissioned by the copper industry assessed the environmental impacts of the manufacture of raw copper and semi-processed copper products, such as pipes and plates, from cradle to gate. The functional unit used for copper products such as pipes (15 mm / 1 mm) is 1 metre of pipe (0.39 kg/m). The assessment includes the mining, concentrating, smelting and alternative hydrometallurgical production route and manufacture of copper pipe ending when the product is in its final form at the factory (cradle to gate). It does not include use, treatment of discarded products or copper scrap. According to information provided by manufacturers, the share of recycled copper (scrap copper) used in the manufacture of copper pipes is on average 67 %, and this figure has been used in calculations. In Finland, the recycled copper share in pipes is 97 %, which has been used in calculating the lower number 0.4 for carbon footprint in table 1.

By-products resulting from the production of copper, such as gold, silver and nickel, and sulphuric acid from the steam produced as a by-product, have been taken into account as credits. Their contribution to the resulting environmental profile has been taken into account in the calculations both in terms of economic value and mass. The data sources used were global copper producers' and manufacturers' inventory data compiled by Thinkstep (currently Sphera) for ICA. (Reference data for the Annex).

2 Results

The environmental impact assessment is divided into the production of raw material (copper cathode), the transport of raw materials to the factory, and the production of copper pipes. The resulting carbon footprint of the copper pipe was 0.954 kg CO_2 eq/metre of copper pipe. The share of transports was insignificant.

Based on the results, the environmental impacts of copper products depend heavily on the impacts of copper cathode production and the share of copper scrap used in the production. Clean copper scrap, such as copper pipes, can be used directly for the production of copper products (as a substitute for copper ore/cathode) without any further processing need. The geographical location of the production site is also of great importance, as the origin of the electricity and heat used in the manufacture has a significant impact on the final result. This analysis used each production country's average electricity and heat in relation to production volumes for both copper cathode and pipeline production. 11 % of energy sources were renewable, 9 % nuclear and 80 % fossil fuels (Table 1). On the other hand, the carbon footprint of copper produced in the Nordic countries can be estimated to be significantly smaller, as a larger share of the electricity used here is produced using renewable energy. Figure 1 shows the phases and methods for the manufacture of copper products

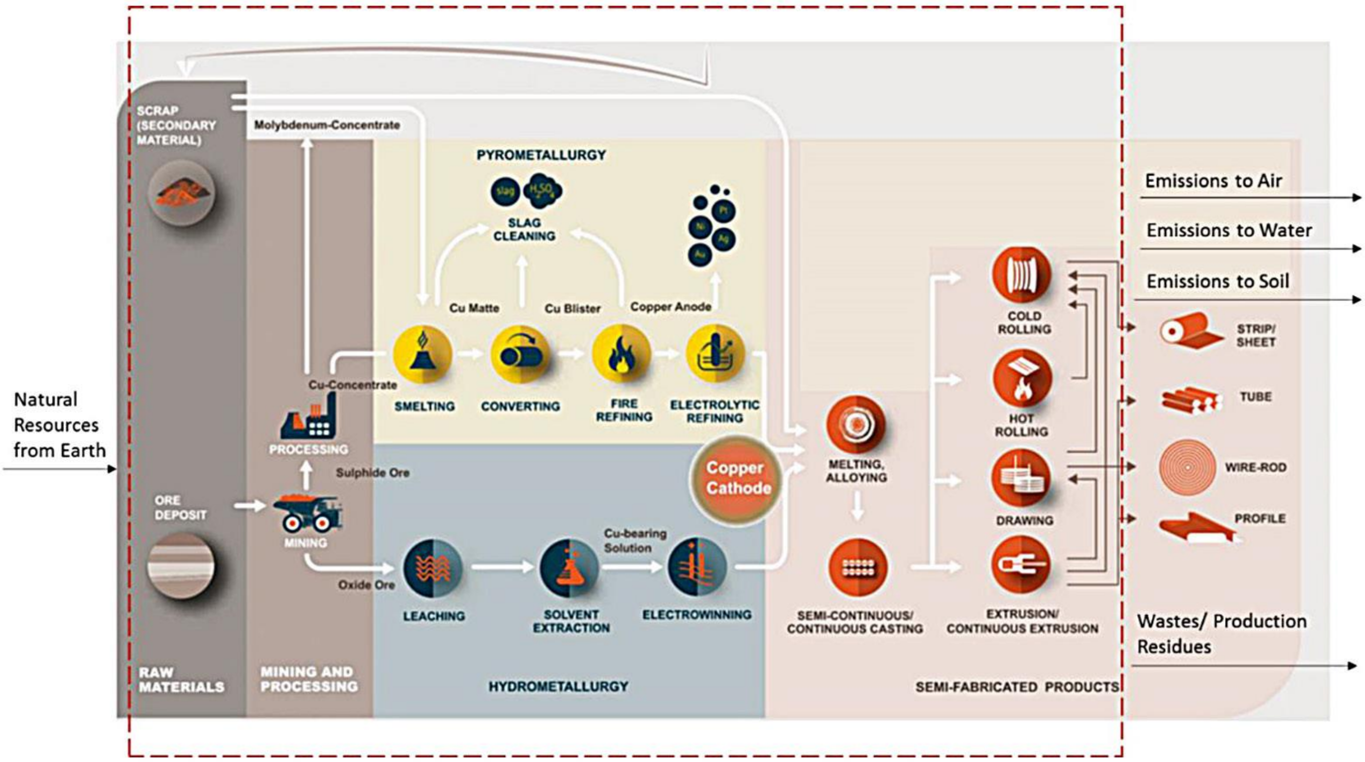


Figure 1. Phases of manufacturing copper products (ECI 2016).

Table 1. The origin of the energy used to manufacture a metre of copper pipe.

Energy source	Quantity (MJ)	Share
Crude oil	0.719	6 %
Coal	3.1	26 %
Brown coal	1.36	11 %
Natural Gas	4.34	36 %
Nuclear power	1.14	9 %
Water	0.579	5 %
Sun	0.525	4 %
Wind	0.287	2 %
Total	**12.05**	**100 %**

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