

Comparing the merits of materials
used for rainwater goods



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The purpose of this paper is to consider, based on published research, the various merits of the listed materials, and particularly the ecological credentials when applied to rainwater goods. As well as issues related to manufacture of the material, the paper will also consider cost implications, lifecycle, maintenance issues and end-of-life disposal.

Materials under consideration are:

Cast iron PVC Aluminium Copper

Background

Rainwater systems provide a vital function in the preservation of a building, extending its longevity and structural integrity. The affect of missing, fractured or faulty guttering is to allow rainwater to attack the wall structure, potentially washing out mortar joints, allowing rainwater ingress and increasing the potential for frost damage. Many common maintenance issues, e.g. internal damp, dry rot, re-pointing, can be traced back to faulty rainwater goods.

Historically wood, lead, cast iron and to some extent copper, where the materials commonly used. Since 1950 plastics, and in particular PVC, have come to dominate the market. Plastics appear to offer many advantages over metals, in that they are comparatively light weight, easy to install, apparently maintenance free, and lower capital cost.

In recent years copper and cast iron have come back into fashion as doubts emerge over the efficacy of PVC and people look for more sustainable solutions.

This paper attempts to determine the real benefits of each material, looked at from ecological and sustainability aspects.

Embodied Energy

Embodied energy is the energy needed for procuring raw materials, manufacture and transport of the finished products. The total amount of energy needed can be high, considering a complete building if construction, maintenance and repair are included it can account for 20% of the building's energy use during a 50-year life cycle. Reducing embodied energy in the component parts of a building can reduce its overall environmental burden, and provide pointers to reducing capital cost.

In this paper we compare the energy used in the manufacture of a product (not including installation, removal or disposal). Figures are typically provided in MJ per kg. It is recognised that MJ (a million Joules) is a difficult measure for non-scientific people and for ease of comparison 1 litre of petrol has 34MJ of energy. A standard 330ml aluminium drink can has 9MJ and a standard plastic pop bottle 5.4MJ

1MJ is equivalent to 0.28kWh. To put it another way, 1 litre of petrol contains 9.52kWh, or enough energy to run a standard light bulb for about 95 hours.

Why is Embodied Energy Important

Choice of material and design principles have a significant, but previously unrecognised impact on energy required to construct a building. Embodied energy is one measure of the environmental impact of construction and the effectiveness of any recycling, particularly CO₂ emissions.

As an example, the average house in the UK has some 44 tonnes of embodied CO₂ and is likely to emit around 4.5 tonnes of CO₂ each year. A zero carbon house, built of the same materials, will take nearly 10 years to recover the CO₂ emitted in its construction.

The Standard House

For purposes of comparison the use of rainwater goods as would be used in a standard UK house is employed. This house will approximate as closely as possible the average UK house. It will be 150m² floor area over 2 floors and as such will need 10m linear run of guttering and 9.6m run of downpipe, with 2 hoppers, 2 shoes and clips, joints, etc, appropriate to the various materials.

For purposes of comparing costs, a common set of rainwater components are used in all cases. Cost of installation is not included as this will be subject to wide variation across the country, irrespective of the material.

Cast Iron

Manufacture

Iron, as a building material, has a long and proud history. Mass produced rainwater goods were first used in the UK in the late 18th century as a cheaper alternative to lead. As such cast iron manufacture has been subject to regulatory control for many years and while it cannot be said to be a clean industry practice, experience and regulation serve to ensure that it becomes increasingly cleaner.

Embodied Energy

The vast majority of cast iron rainwater goods produced in the UK are manufactured in small foundries producing less than 5000 tonnes of goods per year. There is an import market for these same products from mainly India, and to a smaller extent China, but there is no data available as to the size of these foundries or the methods employed.

Figures from USA Department of Energy, The Institute of Cast Metals Engineers and Tuscan Iron Foundries are largely in accord as to the energy consumed in the manufacturing process. The technology used, and consequently the energy consumed, can vary across the industry, but a benchmark value for the production of 1 tonne of finished goods of 2200kWh electricity is taken. In addition is the energy (and CO₂ content) of the coke used as part of production.



Considered over a normal weekly production cycle, where coke is the main fuel source, and including overhead energy consumption, the embodied energy, based on the figures available, is 24.12MJ/kg of finished casting. For the standard house the embodied energy will be 3859 MJ, with embodied CO₂ of 275kg CO₂.

Durability and Maintenance

Cast iron is available in two quality types, grey cast iron and white cast iron. The addition of silicon to the molten iron causes carbon to rapidly come out of solution as graphite. This graphite content offers good corrosion resistance and acts as a lubricant, improving wear resistance. As a result, cast iron rainwater goods have a known life of in excess of 100 years. Maintenance is deemed to be annual painting, and while this provides added corrosion protection its principal function is aesthetic.

Recycling

Post-consumer recycling in the iron and steel industries is a well established practice. In 2005 the USA automotive industry recycled 102% of its iron and steel usage, due mainly to the reduction in the amount of steel used in manufacture.

Iron foundries typically use 70% to 80% recycled material. This is made up of primary scrap – off-cuts, rejects, etc. from the casting process – and bought in scrap. A proportion of new material, pig iron, is necessary to the manufacturing process but the proportion of scrap used at any one time is largely dependent on the state of the scrap market.

The use of this high level of recycled material is a function of the recyclability of iron – it can be melted and re-cast an almost infinite number of times with no degradation – and the well established nature of the scrap metal industry.

Cost

The average retail price of the standard “shopping basket” of components is £834.26.

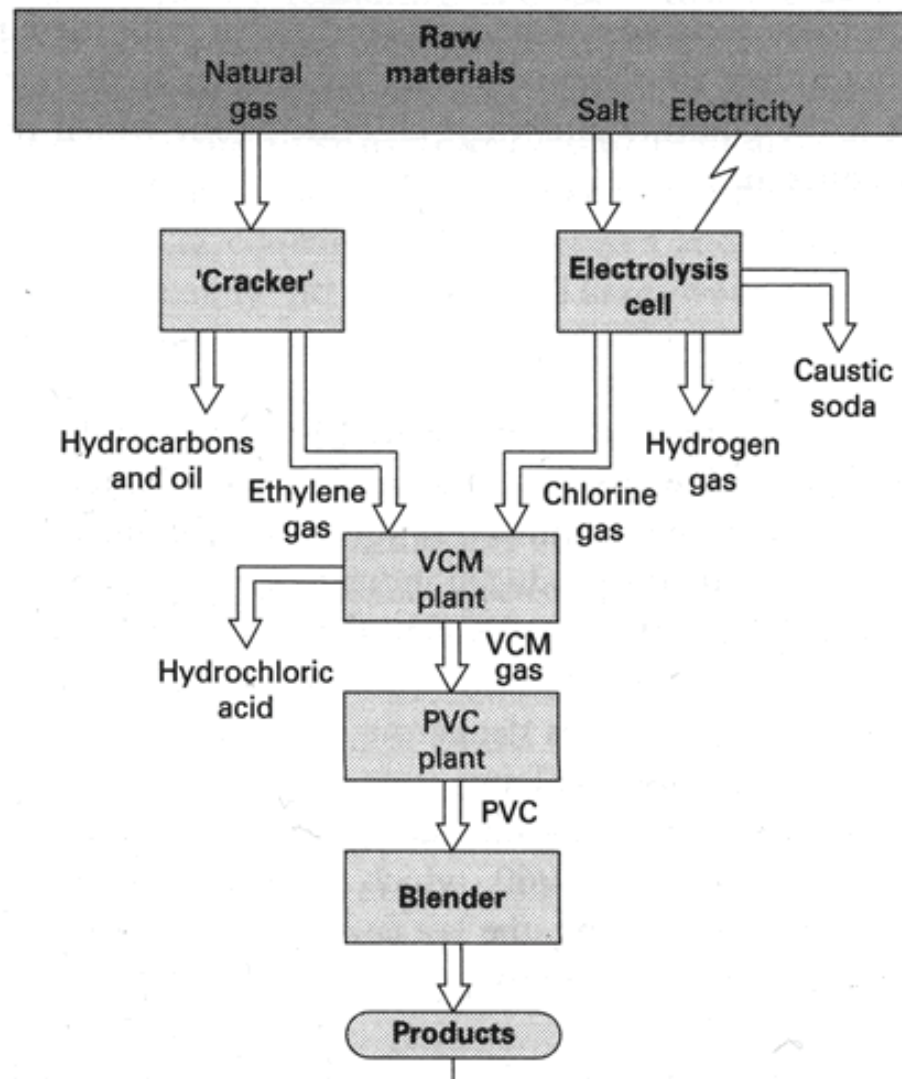
Polyvinyl Chloride - PVC

Manufacture

The environmental impact of PVC, based on published research, can only be considered controversial. The two camps, being environmentalists and the PVC manufacturing industry, unsurprisingly take widely different views. The gulf between their two sets of assertions is so broad as to make meaningful analysis impossible.



The manufacturing process is, in broad terms, described below.



It is incontrovertible that the manufacture of PVC uses large amounts of fossil fuel (worldwide production of PVC is currently around 18 million tonnes per year, about 57% of which is oil, as a raw material), large amounts of chemical additives and that it produces by-products and waste. The arguments exist over the amounts and potential toxicity of these by-products and waste.

The PVC industry has been at pains to publicise the reduction in waste from manufacturing plants, quoting for instance a 91% reduction on mercury emissions since 1977. They also compare emissions and waste to other manufacturing operations, particularly steel manufacture, claiming that PVC "is not worse" than the comparators.

This was to some extent supported by CSIRO (Australia's national science agency) in 1998 and 2001 when they reviewed literature presented by the industry and environmentalist on PVC and concluded: "the balance of available evidence indicates that PVC in its building and construction applications has no more effect on the environment than its alternatives".

It is hard to understand the rationale behind this statement when one of the alternatives considered (for window applications) was wood. But perhaps carries more weight when compared to aluminium or steel.

The production of useful PVC requires additives to enhance particular properties. These are the areas of greatest contention and constitute:-

Plasticizers

These comprise a huge range of chemicals, mostly derived from fossil-fuel. They are used in all PVC products that require flexibility, such as electrical cables, hoses, vinyl sheet flooring, and guttering. While PVC is inherently fire-resistant because of its high chlorine content, the addition of plasticizers reduces this resistance and makes it necessary to add fire-retardants as well.

The most common traditional plasticizer is known as DOP or DEHP (for di-2-ethylhexyl phthalate). About nine million tons of DOP are produced annually worldwide. DOP was identified as a suspected carcinogen in 1987, and its use in medical blood bags was suspended when it was found to be leaching into the stored blood. There are also concerns about DOP released into the environment. The 'U' in u-PVC refers to unplasticized (i.e. rigid) PVC

Stabilizers

Stabilizers are added to PVC to reduce degradation, primarily from heat or ultraviolet light. The main chemical function of stabilizers is to prevent the formation of hydrochloric acid within the PVC (or absorb any that is formed), because the acid promotes degradation of the material.

Traditionally, heavy metals such as cadmium and lead were used as stabilizers. Due to concerns about the toxicity of these elements, the industry has been switching to alternatives for many applications. Nevertheless, a recent article in *Plastics Engineering* reports that 15% of all the cadmium in municipal solid waste incinerator ash comes from PVC products. Lead also continues to be used in large-diameter pipes and in insulation for electrical cables. Common replacements for these metals are calcium-zinc and barium-zinc formulations. Higher costs and technical difficulties are the reasons cited for not using these alternatives in all applications.

In so far as rainwater goods are concerned, it is a plasticized product, where cost is a major marketing consideration. It is therefore likely to contain relatively high levels of both plasticizer and lower cost stabilizers.

Other additives

The list of other additive categories for PVC products is lengthy: processing aids, impact modifiers, pigments, inert fillers such as chalk, lubricants that aid in extrusion, flame retardants, smoke suppressants, biocides and, increasingly, pesticides to prevent rodent attack on pipes used in buildings. These additives are generally used in much smaller quantities than the plasticizers and stabilizers.

Embodied Energy

Over recent years the production of PVC has been closely studied, to the extent that the perceived embodied energy figure of 80MJ per kg can be accepted with some certainty.

This gives an embodied energy for the standard house of 1148MJ. The embodied CO₂ in PVC is difficult to calculate. DTI figures indicate 1 kg of CO₂ for 0.6kg of delivered product, including raw materials, manufacture and transport CO₂. This gives an overall embodied CO₂ for our standard house of 23.92kg.

Durability and Maintenance

PVC is said to have a life of 100 years. That lifespan is considerably shortened if the plastic is exposed to ultraviolet light (i.e. sunlight) to as little as 15 or even 10 years for lower quality products. There are no practical maintenance options that will extend the life of PVC products.

PVC is subject to distortion and discolouration when exposed for extended periods to sunlight. There are now paints available to overcome the discolouration (which itself has to be maintained on a 2 to 3 year cycle) but there are no effective repair systems for the cracking and distortion caused by repeated heating under sunlight.

Large property managers, housing associations and social landlords, tend to a renewal program for PVC gutters on a 10 to 12 year cycle.

Recycling

Napier University, School of Engineering, state that the production of PVC is an energy-intensive process and produces many poisonous pollutants such as hydrocarbons, dioxins, vinyl chloride, phthalates and heavy metals required for processing. PVC decomposes very slowly and as a waste product it contains environmentally dangerous substances that can seep out into soil and ground water. The recycling of PVC is a complex procedure due to the presence of associated polymers and reinforcements materials.

However PVC is a recyclable product and at the end of its life could be returned to the manufacturing process. Problems exist with the viability of reuse and recycling of PVC due to toxic materials contained in the product, which effectively prevent its economic reuse. Further problems exist with collection and sorting of plastics when so many unlabelled plastics are on the market. Mixed plastics are difficult to use in any but the most crude applications, and the additives in PVC exacerbate this problem. Sorting plastics to type is equally difficult as, for example, PET has very similar physical characteristics.

There are no figures currently available for the amount of post-consumer PVC that is recycled in the UK, and it is understood that there are no post-consumer recycling plants. Across Europe some 200,000 tonnes is recycled, compared to 5 million tonnes being manufactured. That is some 0.04% recycled material which can all be accounted for as the recycling of manufacturing waste.

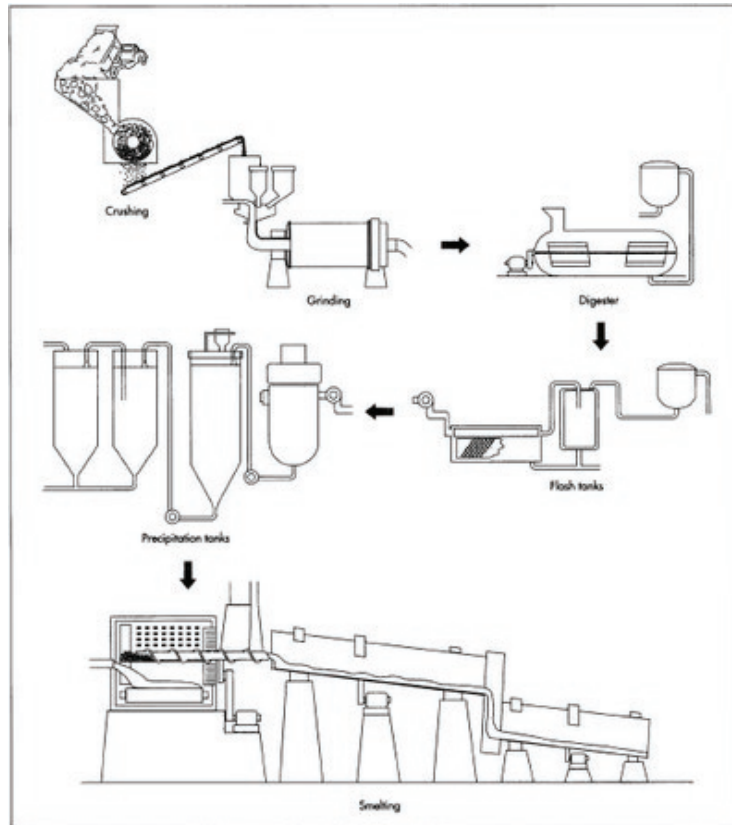
Cost

The average retail price of the standard "shopping basket" of components is £151.80.

Aluminium

Manufacture

Aluminium compounds occur predominantly in bauxite. Bauxite consists of 45-60% aluminium oxide, along with various impurities such as sand, iron, and other metals. Australia currently produces more than one-third of the world's supply of bauxite. It takes about 2 kg of bauxite to produce 0.5 kg of aluminium metal. Caustic soda (sodium hydroxide) is used to dissolve the aluminium compounds in the bauxite, separating them from the impurities.



Depending on the composition of the bauxite ore, relatively small amounts of other chemicals will be used. Starch, lime, and sodium sulphide are some examples. Cryolite, a chemical compound of sodium, aluminium, and fluorine, is used as the electrolyte in the smelting operation. Naturally occurring cryolite was once mined in Greenland, but the compound is now entirely synthetically produced. The other major ingredient is carbon, used as electrodes to transmit the electric current through the electrolyte. During the smelting operation, some of the carbon is consumed as it combines with oxygen to form carbon dioxide. About 0.5 kg of carbon is used for every 1 kg of aluminium produced.

The biggest environmental impact of aluminium is said to be the habitat loss caused by strip and open-cast mining of bauxite. Historically these mines have had a devastating impact on the local ecology but in recent years mining companies are taking a more responsible approach and are working to minimise the effect.

Embodied Energy

Because aluminium smelting involves passing an electric current through a molten electrolyte, it requires large amounts of electrical energy. On average, production of 1 kg of aluminium requires 15 kWh of energy. The true embodied energy varies with the quality of the aluminium and the manufacturing process for the product. Extruded aluminium has a lower embodied energy than cast aluminium.

For the purposes of comparison we take the University of Bath, Inventory of Carbon and Energy figure of 154MJ per kg. This gives a total of 3317MJ for the standard house.

Embodied CO₂ figures from the same source indicate a total of 184kg CO₂ for the standard house.

Durability and Maintenance

There are 3 basic finishes to aluminium products; anodised, powder coated and plastic coated. In all cases the maintenance requirements are minimal, amounting to washing off surface grime. The anodised and powder coated finishes have a life of some 25 years although the plastic coated life will vary with the plastic. The worst case is PVC coated which is said to discolour in around 10 years. In all cases it is the deterioration of the finish that determines the life of the product. Products become aesthetically rather than functionally, unacceptable.

Uncoated aluminium produces an oxidised surface layer that prevents corrosion. Any treatment to failed finishing material tends to remove this oxidation and enable critical corrosion.

Recycling

Aluminium enjoys globally high recycling rates in Europe, where 3 million tonnes (of 9 million tonnes manufactured) come from post consumer recycled material.

Recycling aluminium can require only as little as 15% of the energy needed to produce the primary aluminium from bauxite. Any aluminium product can be recycled and the metal can be re-melted indefinitely. There is no difference between primary and recycled aluminium in terms of quality or properties. Plastic and powder coated aluminium products are more problematic to recycle as the surface finish must first be removed. Notably PVC coated where it is not economically viable and the whole product is typically sent to landfill.

Cost

The average retail price of the standard "shopping basket" of components is £542.80.

Copper

Manufacture

The manufacture and use of copper is older even than that of iron, dating as it does from the bronze age. And as with iron the regulatory controls over its manufacture are well established.

It is a remarkably abundant ore, with only 12% of the world's known resources having so far been mined. It is also fully recyclable, although only 55% of new product is from recycled material. This is due in part to the long life of copper and the relatively small amount of post-consumer product being made available to the scrap market.



Embodied Energy

The majority of copper used in rainwater goods is imported and as such an accurate estimate of the embodied energy is difficult to arrive at. In this case we again take the University of Bath figure of 70MJ/kg which is applied generally to copper used in building elements.

The weight of material used in the standard house will vary with the manufacturer and the grade (thickness) of material used. In this case we have taken what is considered an average of 6.24kg per m². This gives a weight of 49.74 kg and a total embodied energy of 3482MJ.

Using this same average figure gives an embodied CO₂ of 270kg, again using University of Bath data.

Durability and Maintenance

Copper is inherently durable and low maintenance. Careful installation is necessary to allow for lateral expansion when heated by the sun, but if this is achieved then no regular maintenance is needed. It is said to have a life in excess of 100 years, which is demonstrated by installed systems.

Copper forms a natural patina which serves to protect the metal and coating or maintenance to remove this patina is actively discouraged.

Recycling

Copper is eminently recyclable although only 55% of new product is from post-consumer recycling. There is a well established scrap copper recycling industry in the UK and the scrap metal carries a relatively high price. The low recycling figure is attributed to the long life of the products, meaning that they tend to remain in place and there is insufficient entering the scrap market to meet the demand for new product.

Only a tiny proportion, said to be less than 0.1%, of the copper extracted from building demolition goes to landfill.

Cost

The average retail price of the standard "shopping basket" of components is £387.24.

Summary

The table below gives a comparison of the key issues relating to the materials under consideration. The figures are those that apply to the fictional standard house used through out this document.

	Cast Iron	PVC	Aluminium	Copper
Embodied energy (MJ)	3859	1148	3317	3482
Embodied CO ₂ (kg)	275	24	184	270
Fraction Recycled	80%	0	33%	55%
Lifespan	100	12	25	100
Capital Cost (£)	834	152	542	387
Maint. Cost (£ p.a.)	50	0	0	0

The accepted norm for a lifecycle analysis uses a life span for a UK home of 80 years. In this case we are using the base data over a 100 year life cycle to establish its potential to extend the life of the house.

1. Installation cycles	1	8	4	1
2. Embodied energy (MJ)	3859	9184	13268	3482
2. Embodied CO ₂	275	192	736	270
3. Maint & repair costs	100	1216	2168	100
4. Whole life cost	934	1368	2710	487

Notes:

1. Installation cycles is the number of times the product will need to be replaced over a 100 year life span.
2. Embodied energy and CO₂ in the life-cycle analysis is a multiple of the primary data and the installation cycles.
3. Maintenance & repair cost is an estimate of the cost of materials used in maintaining or replacing a system over the 100 year life of the house. It does not include labour costs as these are unpredictable over 100 years.
4. Whole life cost is the capital cost plus cost of maintenance, repair and replacement.

Conclusions

It is clear from the analysis above that the traditional materials of copper and cast iron outstrip the more modern materials, in the long term. In both cases the initial capital cost is higher but both are considerably cheaper over the life of the house. They both also have a significantly lower impact in terms of energy consumption and CO₂ emissions (the low figure for CO₂ from PVC is due to the low weight of the product actually used. PVC has the highest emission figure on a like-for-like basis).

There is a good deal of controversy of the emissions and waste from PVC manufacture, but none for any of the metal products. Ecological arguments for these products tend to be limited to the mining operations.

The notion that cast iron and copper are the more sustainable option is borne out by empirical evidence. High grade buildings of over 100 years old tend to use these materials for rainwater goods and those systems are still in place and functional. They are both 100% recyclable and have well established post-consumer recycling facilities. Aluminium is catching up in this respect but the coatings used on aluminium rainwater goods tends to mitigate against 100% recycling. There is no evidence of any movement towards post-consumer recycling of PVC, and the leaching of toxic waste from landfill PVC is considered a long term problem.

In terms of maintaining the structural integrity of the building cast iron and copper are both less prone to failure. PVC is adversely affected by lateral expansion and contraction, and tends to crack or distort joints. It is this effect that has the major impact on its longevity. Aluminium systems tend to fail with oxidation build up in the joints, causing them to leak.

It is therefore concluded that cast iron and copper rainwater goods perform better over the life of a house and offer the greatest potential to extend that life span.

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