AUTHOR: **Carol Boyle, Director, International Centre for Sustainability Engineering and Research, University of Auckland**

Marya Mahmood (MEngSt Student, University of Auckland)

Title of Paper: **Comparative Assessment of Embodied Energy and CO_2 of Water Tanks**

Contact *Dr. Carol Boyle*
Organisation *International Centre for Sustainability Engineering and Research*
University of Auckland
Postal Address *Private Bag 92019*
Auckland 1072
Telephone *649 373 7599x88210*
Fax *649 373 7462*
Email *c.boyle@auckland.ac.nz*

Abstract

The main aim of this project was to compare the life cycle energy use and carbon dioxide emissions of different materials of water storage tanks for a New Zealand market. This study analysed the life cycle analysis energy requirements and carbon dioxide emissions associated with plastic, concrete, steel and wood water storage tanks. The energy inputs and emissions for each of the materials were normalised to the 20 years. Results indicate that wood was the best of the four materials, having both the lowest embodied energy and carbon dioxide emissions. Plastic had the highest embodied energy while concrete tanks had the greatest embodied CO_2. Further research is required to complete a full life cycle assessment of the different materials.

Environmental Impacts of Different Materials for Water Tanks

Introduction

There are increasing concerns over provision of water to communities, with an estimated two-thirds of countries facing increasing water shortages by 2050 (GEO4, 2007). While much of New Zealand current has sufficient water, changes in rainfall patterns due to climate change, an increasing consumption of water and a reliance on water for energy provision mean that water conservation will become increasingly important. Certainly in rural areas, many people rely on rainwater tank storage for water provision, both for domestic and agricultural purposes. The storage and re-use of rainwater can reduce demand on the municipal water supply, particularly for non-potable uses such as toilets, laundry and gardening which comprise 65% of total household water demand in Auckland (ARC, 2007). Many people are now opting to invest in water storage tanks to collect rainwater for domestic non-potable use.

Mithraratne and Vale (2007) undertook a life cycle costing and impact assessment of plastic and concrete tanks and mains supply for urban supply in Auckland, NZ. They found that, due to the replacement requirement for plastic over the 100yr lifespan of a house, plastic tanks had a higher embodied energy and CO_2 level than concrete tanks, but that rain tanks would reduce energy use and costs of a water management system for Auckland. The selection of the tank material and the tank lifespan was critical in embodied energy, CO_2 and cost.

There are a number of manufacturers of rainwater tanks in New Zealand, using a variety of materials. The selection of a specific material is often based on the size and dimensions available, cost, lifespan and whether it is above or below ground. Many materials, such as plastic, timber or galvanized steel are inappropriate for in-ground tanks but are highly suitable for above ground tanks. The principle materials used to make rainwater tanks in New Zealand are concrete, high-density polyethylene (HDPE), steel and wood.

Increasingly, the selection of a specific product is being influenced by environmental concerns, not only with respect to performance during the operational life but also considering material production and disposal. Both embodied energy and embodied CO_2 are recognised as important due to the impact on both fossil fuel consumption but also on climate change. Many manufacturers are taking measures to reduce embodied energy and CO_2 to improve environmental performance over the product life cycle. Other impacts on the environment are also being considered although many of these are much more difficult to assess.

The objective of this study was to compare the embodied energy and carbon dioxide of the four materials used for manufacturing rainwater tanks in New Zealand using life cycle analysis. Further research would be required to fully assess the life cycle impacts of the four materials.

Concrete Tanks

Concrete is commonly used as a material for constructing water storage tanks. These tanks can be can be rectangular but cylindrical tanks are generally used for water (Mezaini, 2006). These tanks are usually built of cast-in-place concrete and can be above or on ground. Precasting is the most popular manufacture technique for concrete tanks with reinforced and prestressed concrete being the two most common materials used for construction of water tanks (Portland Cement Association, 2008). Levitt (1997) recommends a minimum 3-5% of steel reinforcement in concrete tanks and points out that higher than 25% reinforcement can lead to problems related to setting of concrete and high probability of corrosion. The actual content of reinforcement in concrete tanks is dependent on the manufacturer and this information is commercially sensitive.

According to Skinner, Reed & Shaw (n.d.) tanks can be centrally produced and transported in one piece to their point of use or larger tanks can be built in sections. Central production has the advantage of better quality control. Concrete tank manufacturers generally provide a 25 year warranty, although concrete water tanks have been known to last 30-35 years (Bhadauria and Gupta, 2006). The concrete water tank design requires attention to strength and serviceability requirements. A properly designed tank must be able to withstand the applied loads without cracks that could cause leakage. A structurally sound concrete water tank that will not leak is constructed by providing the proper amount and distribution of reinforcement, the proper spacing and detailing of construction joints, and the use of quality concrete. The design codes specify high standards of serviceability and rigid requirements for water tightness and crack control to prevent leakage and corrosion of reinforcing steel (Portland Cement Association, 2008; Mezaini 2006).

In New Zealand, Mithraratne and Vale (2006, 2007) affirm that concrete rainwater tanks would be the cheapest option, irrespective of the house size, and with less life cycle impact. Additionally, the life cycle CO_2 emissions of concrete tank systems are 3% lower than mains supply of water. According to Neville (2001), the main problem with concrete tanks is the raised pH of the water and its increased content of $CaCO_3$, referred to as carbonate alkalinity, or water hardness. The increase in $CaCO_3$ is induced by carbon dioxide dissolved in the water reacting with calcium hydroxide in the hydrated cement paste. However, the volume-surface ratio of a tank is a consideration, thus, in a large tank, where the volume-surface ratio is large, the potential for leaching afforded to any unit volume of water is small; consequently, the extent of leaching is not of importance unless the water is stored for a very long period.

Recycling

Concrete tanks can be deconstructed and recycled. Recycling concrete provides environmental benefits, conserving landfill space and use as aggregate reduces the need for gravel mining. According to Gaimster and Munn (2007), it is estimated that concrete accounts for some 26% (by weight) of the waste stream in the Auckland region. However, at present only non-premium roading products and base courses are being made from the demolition aggregate in New Zealand. Gaimster and Munn (2007) state that preliminary investigations by BRANZ found that using recycled demolition rubble as coarse aggregate is a viable proposition. The recycling of concrete in New Zealand is likely to become more common with the increasing acceptance of the New Zealand Green Building Council Green Star Office Design rating tool, which awards points for the recycling of waste or demolition concrete. In Australia up to 70-80% of demolished concrete is crushed for reuse as aggregate. The majority of this is used for new road base aggregate (Crowther, 2000). Crowther (2000) points out that, in Australia, recent increases in the rates of concrete crushing have altered the economic patterns of waste disposal with concrete recyclers now removing demolition concrete free of charge. However, the energy expenditure of recycling demolished concrete may be influenced by transportation (Crowther, 2000) and the locations of quarries, landfill sites and crushing plants need to be taken into consideration and balanced against resource extraction and source depletion concerns.

1.1. HDPE Tanks

Plastic water tanks in New Zealand are constructed of rotationally moulded HDPE. Rotational moulding is economical, wastes very little material and excess material can often be re-used in the process. In addition, the tank can be moulded as one part, eliminating high fabrication costs (Tecni-Form Rotational Moulding, 2008).

The process also has inherent design strengths, such as consistent wall thickness and strong outer corners. For additional strength, reinforcing ribs can be designed into the part (Tecni-Form Rotational Moulding, 2008). Various plastic tank manufacturers warrant their product for 20 years. Therefore, this period will be used in calculations in the later sections. HDPE tanks do not require much maintenance but, if required, they can be easily heat fused (Parcher, 1997).

Recycling

Polyethylene water tanks can be recycled by re-melting at the end of their service life, although there is a quality loss (La Mantia, 1993). The major constraint with plastics recycling is the economic viability of the process. The process requires a high capital investment and high inputs are necessary for economic viability and to compete with virgin plastic products pricewise (Waste Watch, 2008). The embodied energy of recycled HDPE is roughly half that of virgin HDPE (University of Cambridge, 2005) but the loss of quality could make recycled plastic unacceptable for water tanks. Water tanks are quite large and would yield a lot of recycled material thus recycling these is both economically and environmentally sound practice.

Steel Tanks

Most steel water tanks are manufactured using hot dip galvanised, corrugated steel. The tank bottom is 1.6 mm galvanized sheets with all joints lapped and bolted at 60 mm centres. Bolts, nuts and washers are hot-dip galvanized steel with metric coarse threads. The tank wall frame, including rings, bands, inside and outside battens, inside and outside fishplates, are fabricated from Grade 300 hot rolled steel sections. These sections are hot-dip galvanized after fabrication; the minimum coating is 450g/m on each side. The panels consist of heavy-duty galvanized 600 g/m steel sheets. A watertight seal is obtained at all joints using rubber-sealing strips between the lapped sheets. The rubber sealing strips are made from ethylene propylene. The tank has a flat / low pitch top consisting of a galvanized steel framework, which is covered with steel decking and includes a 600 mm lockable manhole. The flat or low pitch roof material consists of support posts, base plates and brackets, fabricated from Grade 300 hot rolled steel sections and hot dip galvanized after fabrication. The roof sheet is made from Zinc / Aluminum alloy coated roll formed steel sheet. Steel tanks are prone to rusting, usually at welds and seams. According to Parcher (1997), repairing steel tanks can be difficult, as the welder may have to get inside the tank to weld a repair patch. Manufacturers normally provide a 20-year warranty on steel tanks. Therefore, 20 years will be taken as the useful service for the calculations in later sections.

Recycling

Dudek and Daniels (1993) have developed a process to separate and recover the steel and zinc from galvanized ferrous scrap, which saves energy, decreases zinc requirements, and adds value to steel scrap. Recycling steel tanks could decrease the use of raw materials, provide costs savings to steel-manufacturers and have benefits for the environment but at this point, the process to recycle galvanized steel is not available in New Zealand.

Wood tanks

New Zealand timber water tanks are typically constructed using radiata pine treated with a copper azole biocide (Timbertank Enterprises Ltd, 2007). The baseboard for a 25000L tank is constructed from 2.54 cm x 20.32 cm treated timber while the staves are 5.08 cm x 15.24 cm or 3.81 cm x 15.24 single tongue and groove, bandsawn, outside face, machined inside face and cut to length prior to treatment. The rafters are 5.08 cm x 15.24 cm or 5.08 cm x20.32 cm timber, treated after machining. The roof shingles are 2.54 cm x 20.32 cm Radiata Pine "Weatherboard" with bandsawn outside face treated. Hot-dipped galvanized steel cables contain this barrel. The cables are 9.5 mm diameter, 1/9 LHOL 160 Grade galvanized steel strand and have minimum breaking load of 3120 kg. The single size, wire stranded core cables are fastened together around the barrel of the tank with specially made cable grips. Wood tanks are lined with a food-grade PVC 0.2mm liner to increase longevity and to prevent leaching of the timber treatment biocide into the water. The structural timber roof, which provides engineering stability, is hermetically sealed and protects the liner and its contents from ultra-violet light and external contamination. Most wood tank manufacturers provide a 20-30 year warranty on their product, therefore, 25 years will be taken as the useful service life for this assessment.

Recycling

There are limited options usually available for recycling timber, although it can generally be reused if it has not degraded due to weathering or other damage. Copper azole treated timber is generally unsuited for composting, or for burning as an energy source. The manufacturer of the treatment claims that the copper can be chemically extracted from the timber at the end of useful life but at present there are no plants in New Zealand, which provide this service.

Methodology

Construction diagrams for each of the four types of tanks were obtained through manufacturers and used to identify the materials used for each tank and the mass of each material per tank. Data from Alcorn (2003) and the Centre for Building Performance Research (2007) were used to identify the embodied energy and embodied CO_2 of the materials in each tank.

The data from Alcorn (2003) and the Centre for Building Performance Research (2007) are specific to the New Zealand context. They use a hybrid energy analysis technique to determine the embodied energy coefficients for building materials. Hybrid energy analysis involves a blend of statistical, input-output and process analyses. Hybrid energy analysis allows for a more rapid and accurate result, in comparison to using a single analysis method. The embodied energy was calculated as the energy produced from the extraction of raw materials, transportation of raw materials to the processing plant and manufacturing processes, and is presented in mega-joules per kg (MJ/kg).

The data was also used to identify the quantities and types of various fuels used throughout the life cycle of a specific material. The known carbon dioxide emission rates for various fuels can then be calculated to determine the life cycle carbon dioxide emission, or embodied CO_2, for the material, and is presented in grams of carbon dioxide per kg (g carbon dioxide /kg). This data was then used to calculate total embodied energy and CO_2 for each type of water tank based on the weight of the materials used.

LCA System Diagrams for Water Tanks

The following are the LCA system diagrams for the four different material types of water tanks used for this project. The dotted line shows the included products and processes for Alcorn's data. Due to time constraints and technical limitations related to data gathering, the calculations for this project were based on publically available typical data only. Although this is a simplified approach to the life cycle analysis procedure, the assumptions in this study were kept constant, enabling a comparative life cycle assessment of the four types of water tanks.

In all cases, the energy for manufacture and recycling has been excluded. A rough calculation of the energy requirements for manufacturing a steel tank, likely to be one of the higher manufacturing energies, shows that it is less than 1% of the embodied energy. It is likely that there is an uncertainty of at least 5% in the data used for these calculations so that manufacturing energy is a minor consideration.

There is some recycled content in most steels but the use of 100% recycled steel reduces the embodied energy in reinforcing steel from 31.3MJ/kg to 8.9MJ/kg. A comparative analysis using recycled reinforcing steel vs virgin steel will be done to determine the sensitivity to recycling. While HDPE can be recycled, due to concerns with quality and the required longevity and quality of the tanks, no recycled content has been included in the HDPE tanks. Recycled aggregate has also not be included in the concrete tanks nor has recycled steel been included in the steel tanks as it is not clear how much recycled content can be used in galvanized steel if quality is to be maintained. Reuse of timber has not been considered for the timber tank as there has been little research on the potential for such use and any problems that could occur.

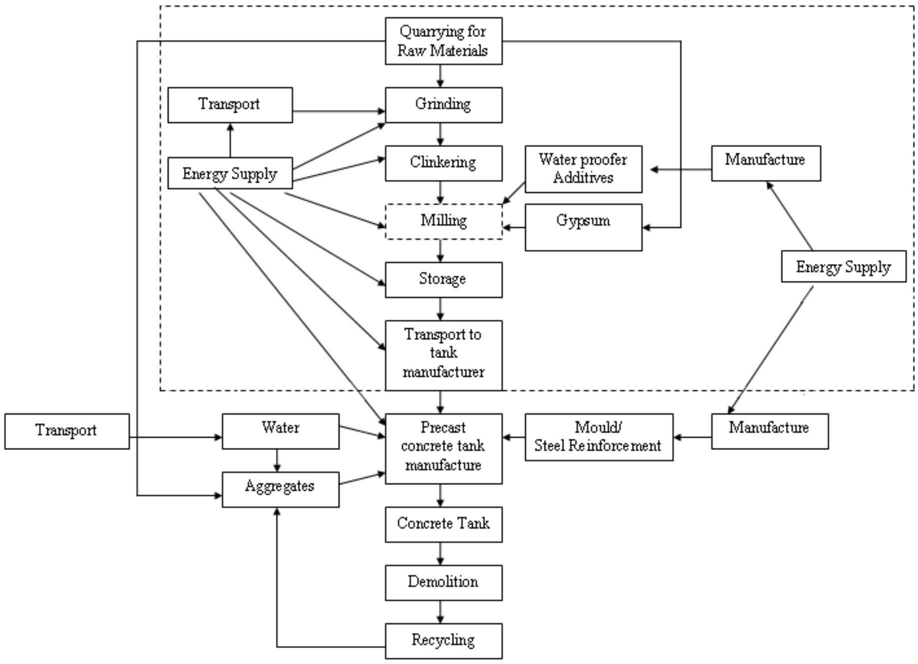

Figure 1: LCA System Diagrams for Concrete Water Tank

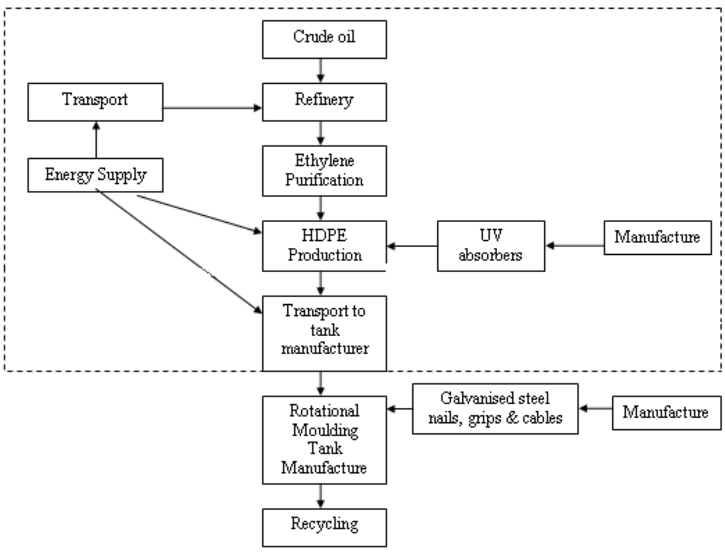

Figure 2: LCA System Diagrams for Plastic Water Tank

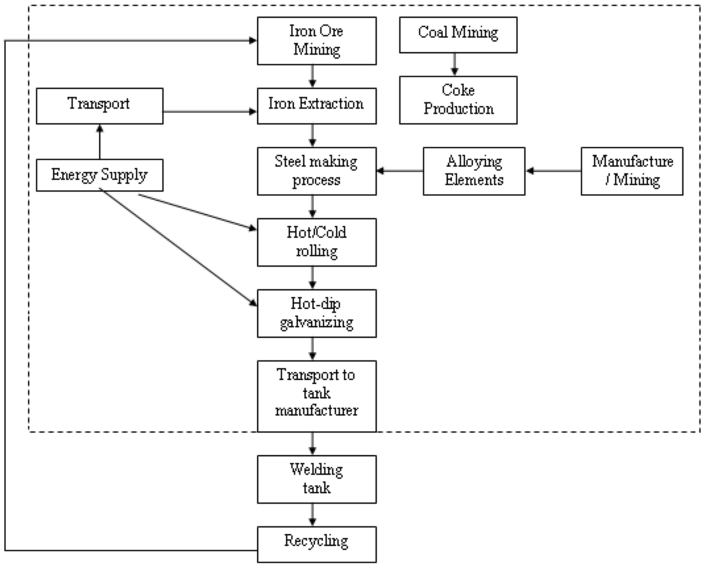

Figure 3: LCA System Diagrams for Steel Water Tank

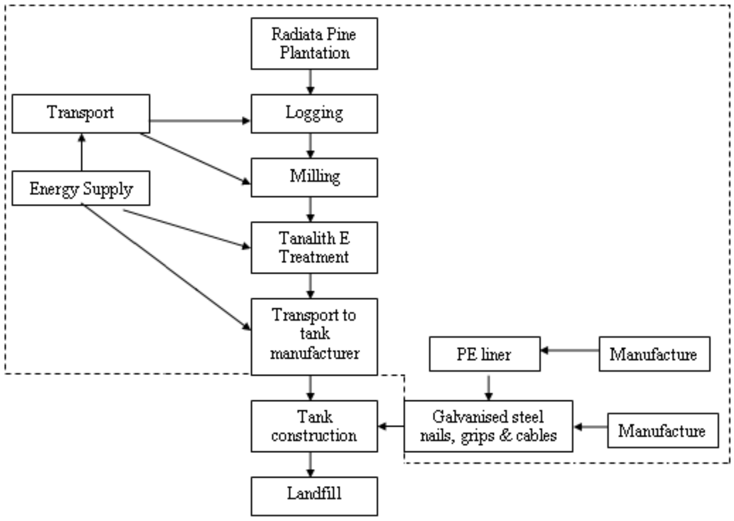

Figure 4: LCA System Diagrams for Wooden Water Tank

Calculation Assumptions

Information was gathered on the manufacturing process of concrete, plastic, steel and wood tanks. The capacity of each tank was 25,000L, which is used for both commercial and residential water tanks. The tanks were all assumed cylindrical in shape, set on ground level with same connections. Therefore, these connections could be discounted in the calculations. The raw materials used to manufacture a concrete tank are steel reinforcement, aggregates, cement and water. The total weight of a typical 25,000L concrete tank is 8250 kg including 4% steel reinforcement. The raw materials used to manufacture a plastic tank were high-density polyethylene (HDPE). The total weight of a typical plastic tank is 375 kg. The raw materials used to manufacture a 25,000L steel tank were hot dipped galvanised steel with a total weight of 342 kg. The raw materials used to manufacture a wood tank were treated Radiata pinewood and galvanized steel cables and grips, with a total weight of 874 kg, including a food grade PVC 20 mil liner.

Travel on land was assumed to take place on rigid trucks to Auckland. Steel, both galvanized and reinforcing, was assumed to be supplied by NZ Steel at Glenbrook and concrete from Golden Bay

Cement in Whangarei. The data for HDPE were assumed to include shipping of plastic resin to New Zealand, and therefore the product could be supplied by a number of suppliers in Auckland so transportation was negligible. Transportation of the timber was assumed to be from the Kaukapakapa sawmill, which is 49 km from Auckland. Transportation was calculated based on the tonnes travelled from the production site.

The embodied energy for each component was calculated using the embodied energy per unit as calculated by Alcorn (2003), and the Centre for Building Performance Research (2007). The total embodied energy of each tank was then the sum of the embodied energy of each component plus the energy for transportation.

$$EE_t=\sum_{c=1}^{n} EE_c M_c + EE_f D M_c$$

Where: EE_t = total Embodied Energy
EE_c = component embodied energy per unit mass
M_c = mass of the component
EE_f = fuel embodied energy per unit travelled
D = distance
M=mass of the component.

Similar calculations are used to determine the embodied CO_2 for each tank, using the data from Alcorn (2003) for embodied CO_2 per unit.

To compare embodied energies, the expected operating life of each tank must be determined and normalised. According to manufacturers, the warranty life of wooden and concrete tanks and concrete tanks is 25 years, while it is 20 years for the steel and plastic tanks. To provide an equivalent comparison, the results were normalised to 20 years. The manufacturers claim that both wooden and concrete tanks can expect much long operating lives and wooden tanks can be refurbished. Concrete tanks may crack if the foundation shifts but are likely to be functional otherwise for up to and exceeding 50 years. Steel tanks tend to rust along joint and seams and, while they can be patched, may fail if rust starts to occur. Plastic deteriorates and becomes brittle, particularly in high UV, although the plastics used in these tanks do have a UV inhibitor. Overall, the warranty life provides a good comparison until manufacturers can provide proof of longer operating lifespans.

Results and Discussion

The results (Table 1, Figures 6 and 7) show that wood tanks have both the lowest embodied energy and CO_2. Plastic tanks showed the highest embodied energy, due not only to the plastic but also the requirement for shipping the resin from Asia to manufacture the tank. If recycled plastic from New Zealand could be used to reduce the virgin component, the embodied energy would reduce significantly. Equally, the use of recycled steel in concrete tanks reduced the embodied energy significantly. The use of recycled steel could also have an appreciable effect on steel tanks.

The wood tank also acts as a store of carbon, which is reflected in its embodied CO_2 (Figure 8). Conversely the release of CO_2 from limestone during cement processing results in a high-embodied CO_2 level for concrete tanks. Similarly, the manufacture of virgin steel releases significantly higher CO_2 than recycling steel.

Table 1 Tank components, transportation and embodied energy and CO_2.

Tank Type			MJ/unit	Embodied Energy MJ	Embodied CO_2 kg/unit	Embodied CO_2 kg
Concrete Tank	*Virgin steel*					
Components	Concrete, kg	7920	1.9	15048	0.214	1694.88
	Virgin steel, kg	330	31.3	10329	1.242	409.86
Transportation	Transport t-km	1325	2.5	3312.375	0.0687	227.5602
Total				28689.38		2332.3
Service life, yrs	25					
Normalised yrs	20			22951.5		1865.84
Concrete Tank	*Recycled steel*					
Components	Concrete, kg	7920	1.9	15048	0.214	1694.88
	Recycled steel, kg	330	8.6	2838	0.0875	28.875
Transportation	Transport t-km	1325	2.5	3312.375	0.0687	227.5602
Total				21198.38		1951.315
Service life, yrs	25					
Normalised yrs	20			16958.7		1561.052
Plastic Tank						
Components	HDPE, kg	375	103	38625	3.447	1292.625
Transportation	Transport t-km	0	0	0	0.0687	0
Total				38625		1292.625
Service life, yrs	20					
Normalised yrs	20			38625		1292.625
Steel Tank						
Components	Galvanised steel, kg	342	34.8	11901.6	1.242	424.764
Transportation	Transport t-km	18.81	2.5	47.025	0.0687	3.230618
Total				11948.63		427.9946
Service life, yrs	20					
Normalised yrs	20			11948.63		427.9946
Wood Tank						
Components	Radiata pine, kg	826	3	2478	-1.657	-1368.68
	Galvanised steel, kg	27.5	34.8	957	1.242	34.155
	PVC 0,2mm, kg	20	70	1400	0.3447	6.894
Transportation	Transport t-km	42.813	2.5	107.0313	0.0687	7.353047
Total				4942.031		-1320.28
Service life, yrs	25					
Normalised yrs	20			3953.625		-1056.22

Transportation was a minimal factor for all tanks, since all were assumed to be manufactured near Auckland. However, to determine the sensitivity of the analysis to transportation, a comparison was made assuming that the tanks were manufactured in Dunedin, 1443km from Auckland (Figure 8). The weight of the concrete tank resulted in a significant increase in embodied energy and CO_2.

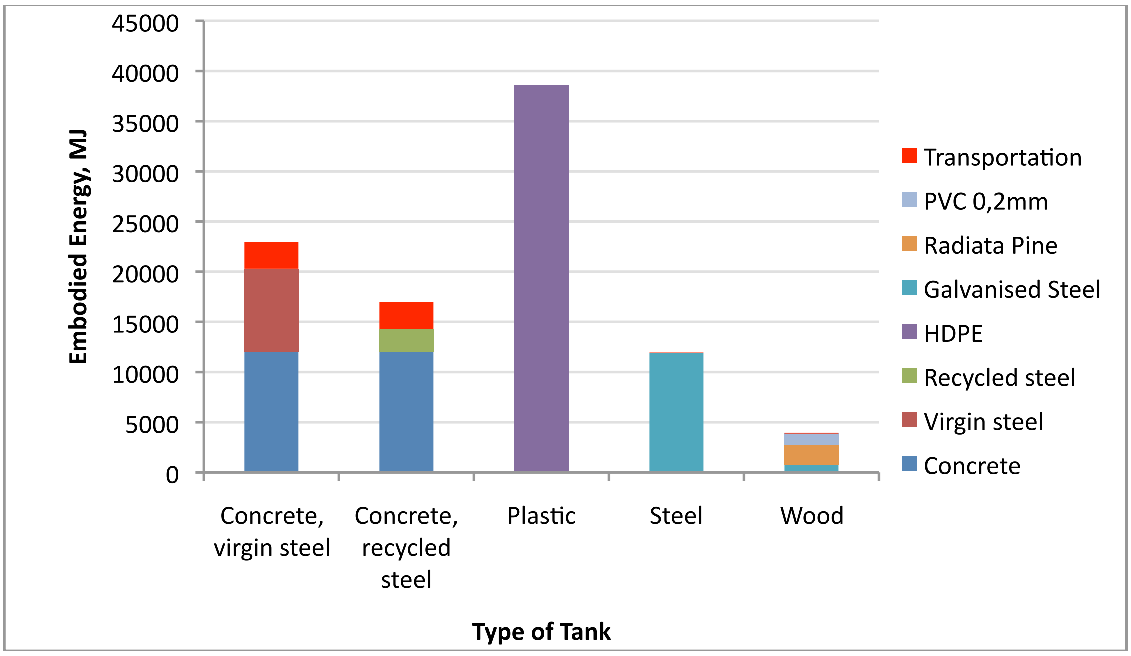

Figure 6 Embodied energy of the four types of tanks, showing the embodied energy of each component, normalized to 20 years.

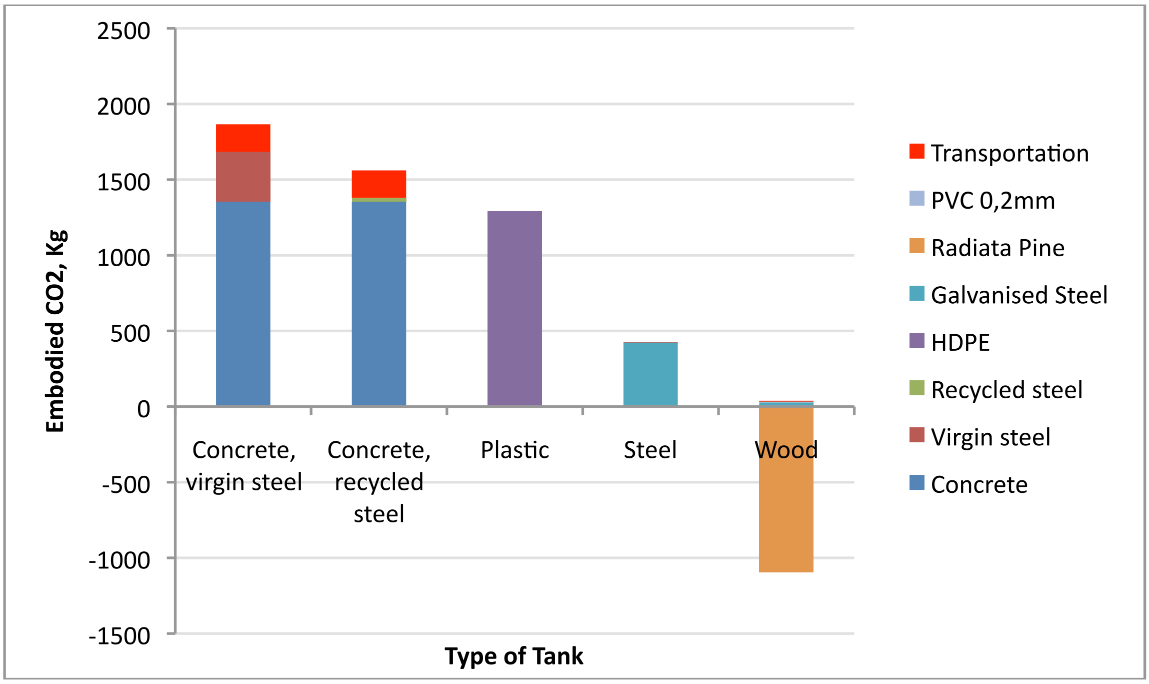

Figure 7. Embodied CO_2 for each type of tank showing the embodied energy of each component, normalised to 20 years.

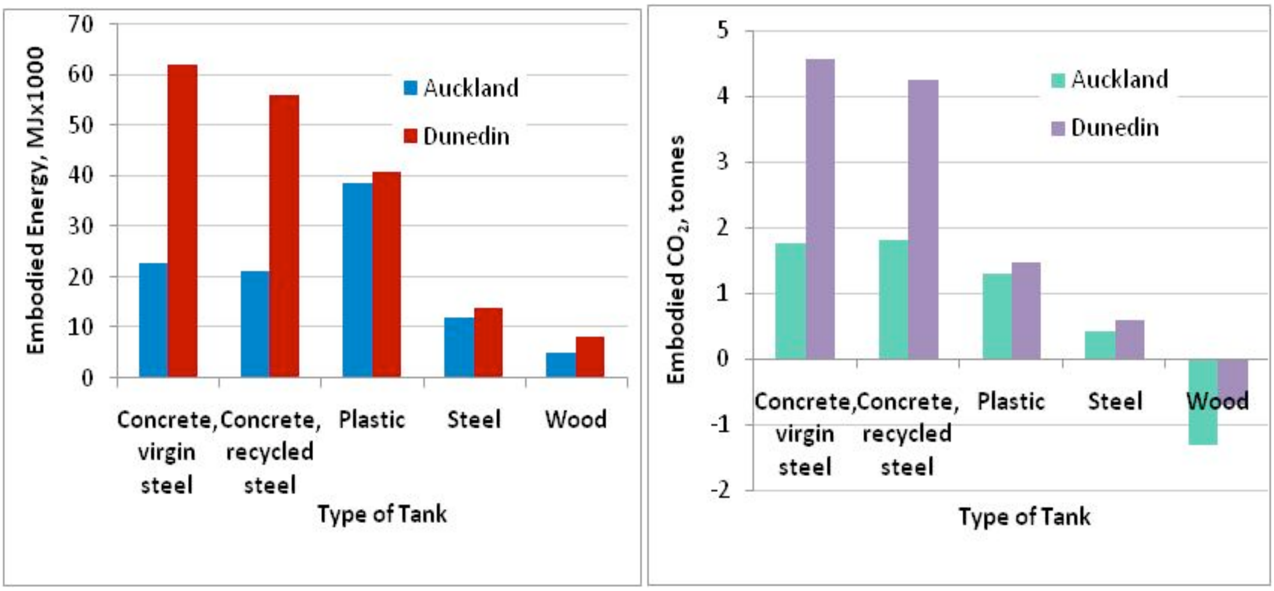

Figure 8. Increase in embodied energy and CO_2 due to manufacture in Dunedin and transportation to Auckland.

Conclusions

The wooden tank has the lowest embodied energy and negative carbon dioxide emissions. Wood was the only material with negative emissions as wood absorbs carbon dioxide. Wood used for water tanks is treated with Tanalith E, which should not contact drinking water and therefore the safety of the tank is dependent on maintenance of the PVC liner. While wooden tanks can be refurbished and the wood can be reused if not deteriorated, there are no facilities currently in New Zealand that removes the copper from treated wood.

The plastic tank had the highest embodied energy due to the HDPE extraction, refining and transportation of the resin to New Zealand. Concrete tanks had the second highest embodied energy and the highest embodied CO_2, primarily due to the release of CO_2 during production. This differs from Mithraratne and Vale (2007) who found that plastic tanks had a higher embodied CO_2 than concrete tanks.

The lifespan of the tanks has a major effect on embodied energy and embodied CO_2. This analysis was dependent on warranty life as there were little verifiable data on the expected operating life of the tanks. Manufacturers for both the wood and the concrete tank claimed that the tanks could be expected to last for up 50 years or more which would reduce the relative embodied energy and CO_2 significantly.

Use of recycled materials in manufacturing the tanks would also reduce embodied energy and CO_2. To be most effective, the material should be recycled in New Zealand but any recycled content would have an effect. Manufacturers should assess how they could incorporate recycled materials into tanks without compromise water quality or tank operating life.

Transportation has an effect on both energy and CO_2, but, except for the concrete tank, that effect is minor. However, this assumes that the complete concrete tank is shipped, rather than just a component such as the cement. Shipping only cement would likely have a minimal effect on both energy and CO_2.

The data used for these calculations assumed manufacture in New Zealand. Should a tank be manufactured in Australia or China, data specific to those countries would have to be used to provide an effective comparison with tanks manufactured in New Zealand. Overall, however, these results show that wood water tanks have the lowest embodied energy and CO_2 of the four tanks assessed for New Zealand.

References

Alcorn, A., 2003. *Embodied Energy and Carbon Dioxide Coefficients for NZ Building Materials.* Wellington, New Zealand, Centre for Building Performance Research, Victoria University of Wellington <http://www.victoria.ac.nz/cbpr/documents/pdfs/eeco2_report_2003.pdf> [Accessed August 2008].

ARC, 2007. *Rainwater Tanks Fact Sheet.* <http://www.arc.govt.nz/albany/fms/main/Documents/Environment/Water/.../Stormwater%20factsheet%>[Accessed August 2008].

Bhadauria, S. S. and M.C. Gupta, 2006. In-Service Durability Performance of Water Tanks. *Journal of Performance of Constructed Facilities* 20:136-145.

Centre for Building Performance Research, 2007. Table of Embodied Energy Coefficients. Victoria University, New Zealand. Available at http://www.victoria.ac.nz/cbpr/resources/index.aspx

Crowther, P., 2000. Building Deconstruction in Australia. IN KIBERT, C. & CHINI, A. (Eds.) *Proceedings CIB Task Group 39 - Deconstruction, Annual meeting, 2000* Watford, U.K., CIB.

Dudek, F. J. and E.J. Daniels, 1993. Recycling Galvanized Steel:Operating Experience and Benefits. *Zinc `93.* Hobart (Australia), Energy Citations Database Technical Report <http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=10185263> [Accessed 30 October 2008].

Gaimster, R. and C. Munn, 2007. *The Role of Concrete in Sustainable Development.* <http://www.cca.org.nz/pdf/2007sustainabilitypaper.pdf> [Acccessed 31 October 2008].

La Mantia, F. P., 1993. *Recycling of Plastic Materials*, ChemTec Publishing, Ontario, Canada pp189.

Levitt, M., 1997. Concrete Materials: Problems and Solutions. Taylor&Francis Publishers, UK, pp127.

Mithraratne, N. and R. Vale, 2006. Rain Tanks or Reticulated Water Supply? *5 th Australian Conference on Life Cycle Assessment,* Melbourne. <http://www.landcareresearch.co.nz/publications/researchpubs/Mithraratne_Melbourne_2006.pdf>[Accessed 19 August 2008]. landcareresearch.co.nz.

Mezaini, N., 2006. Effects of Soil-Structure Interaction on the Analysis of Cylindrical Tank, *Practical Periodical on Structural Design & Construction* 11:50-57.

Mithraratne, N. and R. Vale, 2007. Conventional and alternative water supply systems: a life cycle study. *International Journal of Environment and Sustainable Development* 6:136-146.

Neville, A., 2001. Effect of cement paste on drinking water. *Materials and Structures* 34:367-372.

Parcher, M. J., 1997. *Wastewater Collection System Maintenance*, CRC Press, Boca Raton, FL.pp327.

Portland Cement Association, 2008. *Concrete Tanks, Buildings Home.*

< http://www.cement.org/buildings/concrete_tanks.asp> [Accessed 5 November 2008].

Skinner, B., B. Reed and R. Shaw, n.d. *Ferrocement water tanks*. Leicestershire, UK, WEDC Loughborough University <www.lboro.ac.uk/departments/cv/wedc/ wedc@lboro.ac.ukwww.lboro.ac.uk/well/resources/technical-briefs/36-ferrocement-water-tanks.pdf> [Accessed 15 September 2008].

Tecni-form Rotational Moulding, 2008. *The Rotational Moulding Process*. <http://www.tecni-form.com/rotational-moulding.php> [Accessed15 August 2008].

Timbertank Enterprises Ltd., 2007. Building and Service. http://www.timbertanks.co.nz/building--service.aspx [Accessed 29 November 2008].

University of Cambridge, no date. Recycling Plastics. The ImpEE project, Department of Engineering, University of Cambridge, http://www-g.eng.cam.ac.uk/impee/topics/RecyclePlastics/files/Recycling%20Plastic%20v3%20PDF.pdf?sid=eb993c34566ce248022c9b6bac866369 [Accessed 29 November 2008].

Waste Watch, 2008. *Waste Online*. <http://www.wasteonline.org.uk> [Accessed 15 September 2008].