Assessing the carbon footprint of a PowerSpout

A REPORT FOR

EcoInnovation Ltd

November 2009

Prepared by CATALYST® R&D Ltd

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Disclaimer

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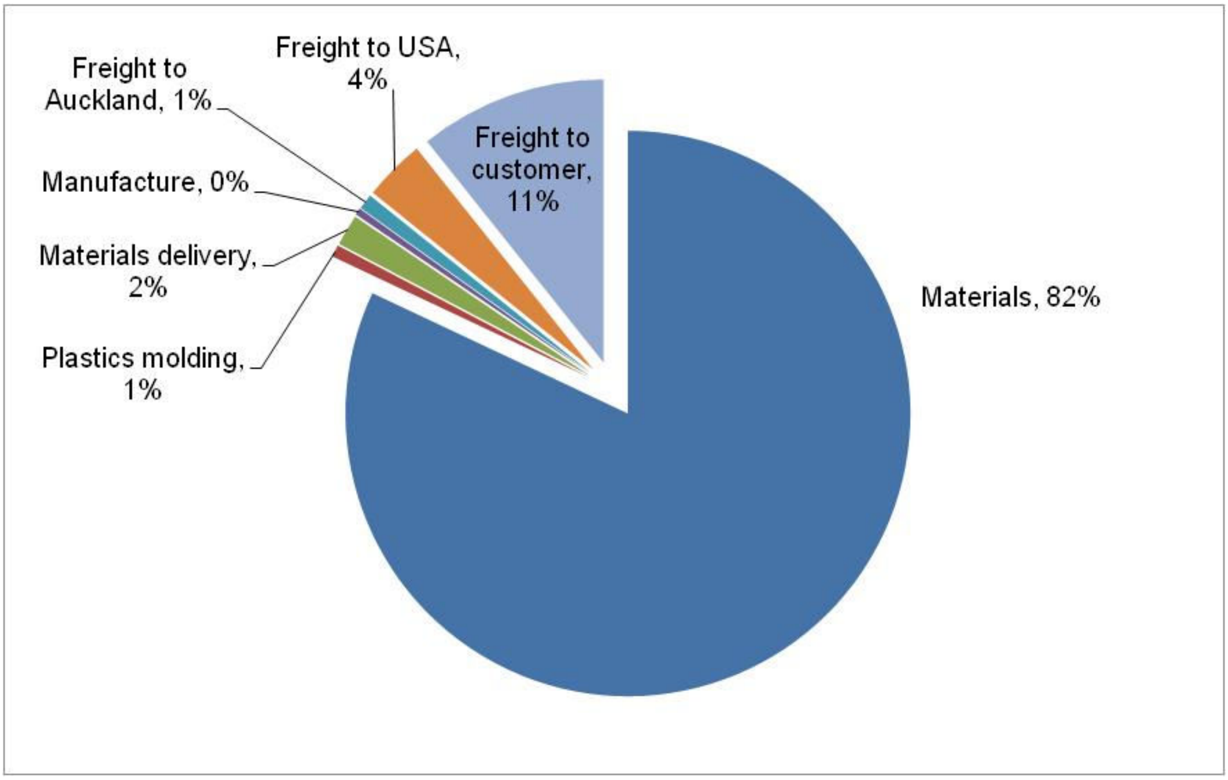
1. Summary

The EcoInnovation "PowerSpout" is a micro-hydro generator ideally suited for power generation in remote areas. It can be used instead of (or in conjunction with) power from the national grid or a generator, or alongside other renewable energy sources.

Each PowerSpout can provide an energy-efficient house with all its power needs, while producing emissions of just 105 $kgCO_2$ over its lifetime of 10 years [1]. As a comparison similar emissions would result from running an efficient generator for a little over 2 days, or taking power from the national grid (USA average) for 12 days.

The emissions from different source activities in the PowerSpout life cycle are shown below.



PowerSpout can produce electricity for 2.4 gCO_2/kWh. Emissions from the national average grid power in the USA are almost 300 times more than this at 720 gCO_2/kWh while many generators emit well over 4,000 gCO_2/kWh.

PowerSpout emits 0.1 tonnes of CO_2 to produce 43,320 kWh. For the same quantity of power the national grid in the USA would emit over 31 tonnes CO_2 and a generator over 181 tonnes CO_2. Hence using a PowerSpout can reduce or avoid significant emissions of greenhouse gases, making this a good technology for climate change mitigation. It is also an effective climate change adaptation tool to increase resilience of remote users to anticipated climate change and associated disruption.

The standard PowerSpout includes 68% recycled components and this proportion is anticipated to rise. Even with this high recycled content, materials production accounts for over three-quarters of the total life cycle emissions. Wherever possible materials are sourced locally and/or transported in bulk to minimize transport emissions.

[1] This analysis is based on a realistic scenario in which the standard Power Spout is assembled in New Zealand and transported by sea to Los Angeles and 1,000 km by road within the USA. It is installed to generate 500W continuously 24 hours/day, 361 days/year (allowing for 1% maintenance time), providing a total of 43,320 kWh over 10 years.

The manufacture of PowerSpout does not contribute to emissions since all energy used by EcoInnovation is produced from renewable energy sources on-site. This includes wind, water and solar electricity, as well as solar heat for space and water heating.

The standard footprint is based on 100 units being transported to Auckland and shipped from there to Los Angeles. Transport from New Zealand to the USA by sea freight contributes just 3% to the total footprint. Transport within the USA is more significant and contributes 11% to total emissions.

While sea-freight is the preferred transport method for PowerSpout units, some are transported by air. Air freight alone would generate emissions of 158 kgCO_2e, contributing to a footprint of 350 kgCO_2e per PowerSpout. Despite much higher transport emissions, a unit transported in this way would emit 8 gCO_2e/kWh. The total life cycle emissions would be equal to running a generator for 7 days or taking power from the US national grid for 41 days.

A worst case scenario should include the maximum package weight and longest (air) transport distance. If a user requires all optional upgrades and extra components including tool kit, the total weight including packaging increases from 22 to almost 31 kg. Transporting this heavier package by air from New Zealand to the UK, and allowing for 1,000 km domestic transport by air rather than road, increases the total footprint to 582 kgCO_2e or 13.4 gCO_2e/kWh. This level of emissions would result from using a generator for 12 days or taking power from the USA grid for 67 days, or from the UK grid for 90 days.

2. Introduction

The EcoInnovation[2] "PowerSpout" is a micro-hydro generator designed around reconditioned components and recycled materials. It offers a wide range of greenhouse gas benefits directly, and many more when evaluated in comparison to alternative options for meeting electrical energy demand. This report quantifies these benefits via an analysis of the manufacture, supply and use of PowerSpout. The results are combined to estimate the total carbon footprint of the electricity produced using this technology.

Life cycle assessment (LCA) is a technique for assessing impacts of products and services over the entire life cycle from raw materials through to waste management. There is guidance available for preparing inventories and interpreting the results including ISO 14064 Standards (ISO, 2006) and the recent Publicly Available Specification (PAS) 2050 (BSI, 2008).

Carbon footprints can focus on the greenhouse gas impacts of organizations, projects, or products and services. The ISO standards cover organizations and projects, as well as validation of claims. The PAS 2050 is widely adopted as the most appropriate standard for products, although ISO 14044 can be used to assess the carbon footprint of a product if the full lifecycle of the product is taken into consideration.

The PAS 2050 is a framework that can be applied to any product. It is intended to help businesses move beyond managing direct GHG emissions to look for reduction opportunities in the supply chains of products and identify key sources of emissions in their supply chain. It can thus assist the prioritization of emission reduction initiatives, as well as providing consumers with transparent and reliable information about the carbon footprints of products. This report uses PAS 2050 for guidance.

This report has been prepared independently for EcoInnovation Ltd by CATALYST® R&D.

3. Scope and system boundaries

The organizational boundaries group emissions together under three different 'scopes' as set out in Table 1. EcoInnovation activities fall into Scope 1 and 2, with activities conducted by other parties included in Scope 3. Many carbon footprints focus on Scope 1 and 2, but this analysis has also included Scope 3 emissions.

Table 1. GHG emissions Scope

		Selected emissions sources
Scope 1	Direct greenhouse gas emissions	Production of electricity, heat or steam, physical or chemical processing, owned transport, fugitive emissions
Scope 2	Indirect emissions which one consumes but which are generated elsewhere	Consumption of electricity, heat and steam
Scope 3	Other indirect emissions which one causes but from emission sources owned by others	Business transport, waste disposal, use of products, purchased products, product distribution and commuting, leased assets, franchises and outsourcing

[2] EcoInnovation Ltd is the owner of PowerSpout LLC and trademark

3.1. Functional unit

The functional unit[3] adopted for this study is a kilowatt-hour (kWh) of electricity from a PowerSpout unit.

The specifications of a PowerSpout unit as installed are shown in Table 2. When packed for distribution the rear cap can be inverted, reducing the length to 340 mm.

Table 2. PowerSpout specifications

Product weight[4]	23 kg
Product size (width x height x length)	470 x 400 x 430 mm
Lifetime (normal maintenance)	10 years (then overhaul)
Output Power	100 – 1,000 W
Power production[5]	8,664 – 86,640kWh
Use of dangerous materials	No
Use of recycled[6] materials	Yes
Use of recyclable materials	Yes

This analysis is based on a scenario in which the PowerSpout is:

- assembled in NZ
- transported by sea freight to Los Angeles
- transported 1,000 km within the USA
- installed to generate 500 W continuously 24 hours/day,
- in operation 361 days/year (allowing for 1% maintenance time)
- able to generate 43,320 kWh over 10 years

A 'worst case' scenario is also included in which a single PowerSpout is transported to Auckland via land and air-freighted to Los Angeles. These extra calculations are noted under transport (Section 6) and interpretation is provided in Section 9.1.

3.1.1. PowerSpout components and materials

The PowerSpout components are:

- Bearing/shaft and fixings
- Smart drive unit
- Pelton rotor
- Electrical components
- Casing
- Jets

Details of each of the above are included in Annex I Table 12 (Section 11).

3.2. System boundaries

The boundaries for this analysis (Figure 1) are:

- Materials used in the manufacture of a PowerSpout (Section 5)
- Transport of the Smart Drive and other parts to assembly point (Section 5)
- Energy required to assemble the units (Section 5)
- Transport of the units from New Zealand to the USA (Section 6)
- Transport from retailer to user (Section 6)
- Disposal (Section 7)

[3] The PAS 2050 and ISO 14040 series of LCA standards specify that a functional unit should be defined that describes the unit of analysis for any study.
[4] Power Spout packaging is minimal since the casing has been designed to function as packaging before reassembly
[5] Assuming 24 hours/day, 361 days/year for lifetime and size range provided.
[6] The potential to increase the use of recycled materials and reconditioned components is under investigation.

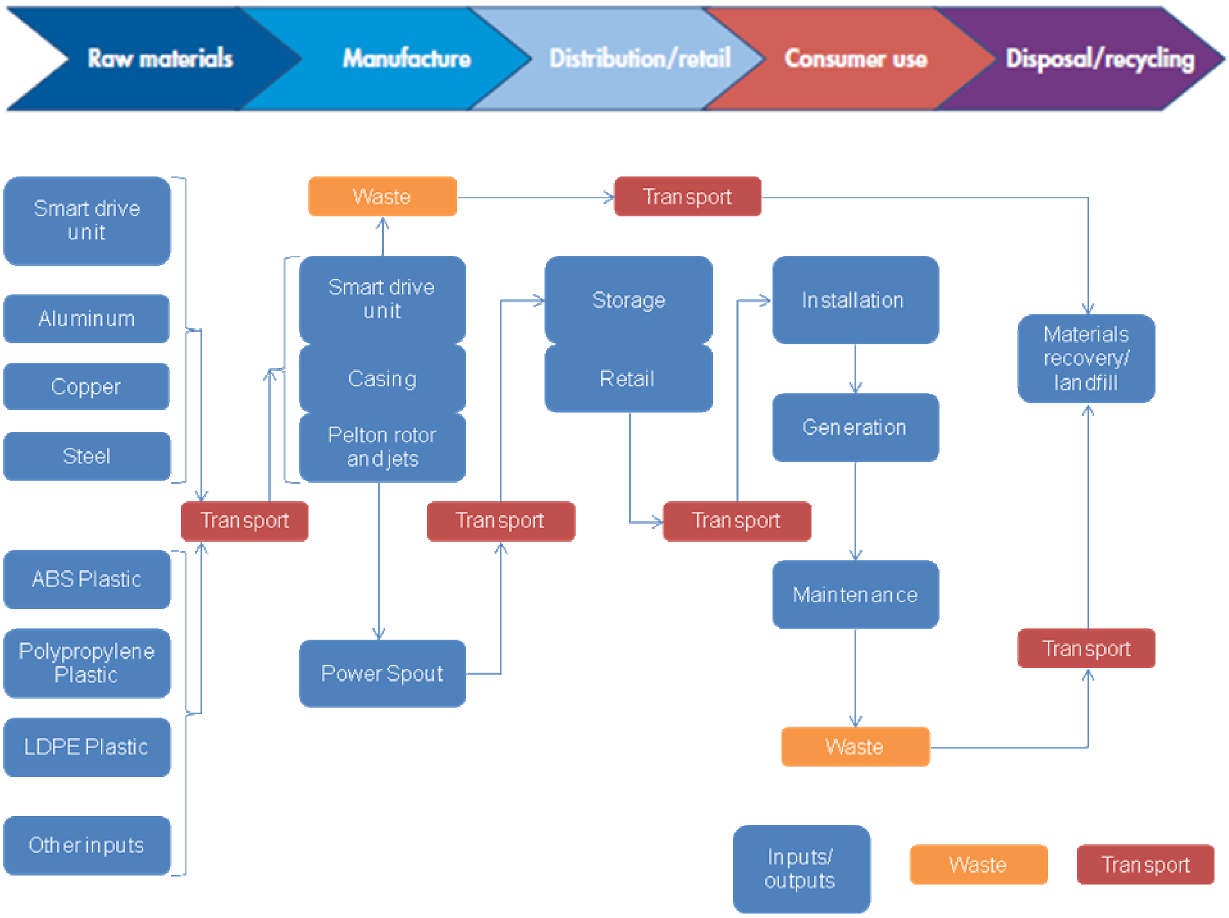
The analysis also considers avoided emissions (Section 8). This can provide information on the emissions that would result from using power from sources other than a PowerSpout (e.g. national grid or generator), but can also help future decisions about best location for manufacture of PowerSpout units.

The following are not anticipated to represent significant emissions from the PowerSpout product and hence have not been quantified. These items are under investigation and may be incorporated in future updates:

- Installation emissions. Transport of the unit to the client site is usually the dominant activity in this phase (1000 km distance incorporated). Additional pipe, cables, etc to complete the installation are not included.
- Maintenance. This element is minimal e.g. 2 new bearings each year, and possibly components of the Pelton wheel and Smart Drive after 5 years (originals would become spare parts).

Company vehicle and business travel are not included because they are outside the conventional product analysis boundaries. These will be included under the EcoInnovation company footprint.

Figure 1. PowerSpout system boundaries



4. Data and methods

Site-specific data have been used wherever possible. Data on materials and energy used in assembly/manufacturing (activity data) has been provided by EcoInnovation and their suppliers[7].

The activity data are used in conjunction with emission factors to determine greenhouse gas estimates. Emission factors related to materials and activities have been derived mainly from the GABI software (GABI, 2008) with some taken from various other sources as noted in the appropriate sections below.

Where materials/products are reconditioned for reuse, the GHG emissions of the product should be allocated appropriately (PAS 2050). For this analysis emissions from new and recycled materials have been calculated and compared. It is assumed the reconditioned components and recycled materials are used twice and hence the life cycle GHG emissions are halved.

[7] Please note that EcoInnovation is continuously seeking to improve the PowerSpout and hence product manufacturing processes and specifications are likely to change over time.

5. PowerSpout Production (NZ)

5.1. Direct greenhouse gas emissions

This category for most businesses and products includes emissions resulting from the use of energy, including fuels for heating and transport.

The PowerSpout product is assembled using only renewable energy generated on site. This includes wind, water and solar electricity, as well as solar thermal for space and water heating. Workshop space heating is also provided by burning wood from a plantation forest on site, and there is no transport and therefore no vehicle fuels consumed during the process of manufacture. Therefore there are no direct emissions associated with the manufacture of PowerSpout.

5.2. Indirect emissions (electricity)

Indirect emissions arise from products or services which one consumes but the emissions are generated elsewhere. This category of emissions tends to be dominated in footprints by the consumption of electricity, which is delivered via the national grid in most situations.

As described above, EcoInnovation is entirely self-sufficient in electricity. Demands are minimized through careful design (buildings and products) and equipment/appliance selection. All onsite heat and power is generated from an integrated renewable energy system incorporating solar (thermal and photovoltaic), wind turbines and PowerSpout units themselves.

The PAS guidelines exclude capital items and hence this section does not include the emissions from the production or installation of renewable energy components (PowerSpouts, solar panels, wind turbines etc). Also excluded are the emissions avoided by not using power from the national grid. The following details are included for completeness.

5.2.1. EcoInnovation workshop power consumption

Electrical energy is used in the work shop to refurbish and reconfigure Smart Drive units, assemble the turbine, machine the shaft and pack the goods. Since this electricity is self-generated it can be seen to avoid the consumption of national electricity and the associated emissions (Section 8.4).

The total power consumed in the workshop is recorded on a separate meter. The records over the past 3 years indicate that each turbine requires about 2.3 kWh of electricity to make in the EcoInnovation workshop.

5.3. Other indirect emissions

This section describes emissions from sources owned by other parties. This is dominated by the materials used in the PowerSpout, which are summarized in Table 3 (see Annex I for further detail). Each component has been weighed and those that are reused or use recycled materials have been recorded. EcoInnovation prides itself in using reconditioned components, and the drive to increase the recycled materials in other components is ongoing.

5.3.1. Materials production

The emissions in Table 3 relate to the production of the materials rather than the energy used to manufacture a particular component. The emissions for the minor components included under ‘Other’ materials have not been included due to a lack of emission factors.

If the emissions for all recycled components are halved to allow for one previous use, the emissions for materials in a standard PowerSpout unit drop from 86 to 65 $kgCO_2e$. One third of these emissions are related to the aluminum bulk head in the casing. If this could be made from recycled aluminum the emissions would be further reduced to 54 $kgCO_2e$.

Table 3. PowerSpout materials overview

	Total weight kg	Recycled %	Emissions $kgCO_2e$
Steel	5.44	83%	10.51
Aluminium	2.06	24%	27.06
Copper	1.94	66%	14.51
Brass	0.11	0%	0.85
LDPE	4.60	100%	11.26
Polypropylene	1.54	87%	3.04
PVC	1.79	0%	3.72
Polyethylene*	0.60	100%	1.46
PET	0.33	0%	0.84
PP GF20	0.97	100%	1.91
Nylon GF	1.43	0%	10.13
Cardboard*	1.28	0%	0.51
Other	0.08	0%	0.00
Total	**22.17**	**68%**	**85.80**

* Polyethylene and cardboard are both packaging materials.

5.3.2. Plastic molding

Energy used in molding plastic components has been recorded by the supplier. Each PowerSpout unit includes 20 Pelton wheel spoons and a hub. The total energy required for these parts is 4 kWh which is sourced from the NZ national grid and responsible for emissions of 0.72 $kgCO_2e$.

5.3.3. Materials delivery

Transport of the major components to EcoInnovation is carried out as follows:

- Plastic molded parts are sourced locally and travel by truck 15 km
- Smart Drive units travel by truck from Auckland (350 km)
- PowerSpout casings travel by truck from Auckland

Diesel emissions for large trucks are typically 26 $kgCO_2e$/100 km hence the local components add 3.9 $kgCO_2e$ and each truck from Auckland 92 $kgCO_2e$. It is assumed that the emissions from each journey can be spread over 100 units, since bulk loads (or shared transport) are typical. Hence the supply of parts adds 1.88 $kgCO_2e$ to each Powers Spout unit.

Some other small items are either delivered by courier or collected by staff when passing. These have not been incorporated.

6. PowerSpout Transport

Emissions from freight activities from EcoInnovation to Auckland and on to international destinations are indirect emissions (Scope 3).

6.1. EcoInnovation to Auckland

Diesel emissions for large trucks are typically 26 $kgCO_2e$/100 km hence each truck travelling 350 km to Auckland is responsible for 92 $kgCO_2e$. Transport of 100 PowerSpout units in each load therefore adds 0.92 $kgCO_2e$ to each unit.

6.2. Auckland to Los Angeles

It is anticipated the units will be shipped in bulk, e.g. 100 units each time, but the emissions tend to be calculated by weight so the numbers transported in this stage is not a critical factor. The emission factor is usually expressed in tonnes of CO_2e per tonne per kilometer travelled (tCO_2e/t/km). Each PowerSpout unit will be less than 25 kg/unit including packaging.

The distance between Auckland and Los Angeles is approximately 10,500 km. The emission factor for air freight is still under considerable debate but for this analysis is assumed to be 0.60 $kgCO_2$/t/km (DEFRA, 2008). Marine emissions for freight between Auckland and Los Angeles ranges from 0.135 to 0.156 $kgCO_2$e/t/km for large or small container ships respectively (DEFRA, 2008). Table 4 shows the impact of these freight choices on emissions, and hence why sea-freight has been chosen to transport PowerSpout units.

Table 4. Emissions resulting from freight of 25kg from Auckland to Los Angeles

	$kgCO_2$e/t/km	$kgCO_2$e/unit
Sea freight (container)	0.014	3.7
Air freight	0.60	157.5

The PowerSpout casing is rigid and may be sufficient for shipping. However it is assumed here the unit will be transported in a recycled cardboard box. A supply of recycled plastic bubble wrap is available if additional packaging is required. The emissions associated with the cardboard box and bubble wrap have both been included in this analysis.

6.3. Delivery to user

The type of transport (air, truck, car etc) and typical distance from retail to customer are unknown and hence estimating emissions is challenging. However, this analysis assumes 1,000 km transport for a 25 kg package using a light commercial vehicle. Table 5 shows the transport emissions for a single PowerSpout unit transported to the client[8]. For this analysis the calculation is based on the emission factor for a smaller commercial vehicle on the basis of emissions per tonne/kilometre. This results in emissions of 11.2 $kgCO_2$e per PowerSpout unit.

Table 5. Domestic transport emissions in the U.S.A. (per 1,000 km)

	$kgCO_2$e/t/km	$kgCO_2$e/unit
Air flight - domestic/short haul	1.898	47.45
Van/light commercial vehicle (petrol, <1.25t)	0.449	11.23
Van/light commercial vehicle (diesel, <3.5t)	0.272	6.80
Medium petrol car		
Medium diesel car		

For a single unit transported 1,000 km it is evident that the mode of transport is a key factor. Each option may also include supplemental road transport to/from airports or depots and hence the total emissions per unit are approximate.

7. Other indirect emissions (USA)

7.1. Product retail

PowerSpout units are stored in a warehouse and marketed via the company website. Hence there is no physical retail operation and thus no activities are currently included in this category. This may change in the future if there are local manufacturing and retail activities. Moving some activities and/or sourcing components from within the USA are options being explored to reduce transport emissions from New Zealand.

[8] All emission factors sourced from DEFRA, 2008

7.2. Product decommissioning and disposal

It is not possible to assess the ultimate fate of each PowerSpout unit. However, the reuse and recycle philosophy driving the assembly of the units is also applicable to the end use. The majority of the materials used can be reused or recycled, and EcoInnovation encourages all users to do this as far as possible. It is likely that the main casing, aluminum sheet and bearing block, steel bearings, cooper wire and stainless steel shaft/fixings would all be recycled. Recycling logos have been added as appropriate to plastic components.

In terms of emissions, none of the PowerSpout components are organic and hence will not give rise to GHG emissions. The cardboard box should be recycled, reused or composted. As noted above this is one area that will be monitored and adjustments made as necessary.

8. Baseline

Some assessment processes for carbon footprints incorporate comparison with a baseline scenario or other possible alternative option. In this case the electricity produced by a PowerSpout could have been bought from the national grid or generated by a local generator (petrol/diesel), hence the impacts of each source can be compared. The PowerSpout can be seen as a means to avoid the emissions for an equal quantity of power from other sources.

The power generation at EcoInnovation can also be considered to have avoided the emissions from grid based electricity in NZ. The impact of manufacturing overseas in different places can readily be compared against this analysis.

8.1. NZ electricity emissions

Electricity in NZ is currently generated from a range of sources, with large scale hydro still dominating supply, despite falling from 73% in 1990 to 55% in 2007 (MED, 2008). Annual emissions per unit of power vary depending on a range of climatic factors, including temperature and rainfall, affecting both demand and supply potential. Similarly, some power companies generate using different options and some may take steps to both reduce emissions and to offset remaining emissions to achieve ‘carbon neutrality’.

The emissions reported for electricity generation in NZ since 2000 range from 0.14 to 0.20 $kgCO_2e/kWh$ (MED. 2008) with additional transmission losses of around 0.02 $kgCO_2e/kWh$. This analysis uses a combined emission factor of 0.18 $kgCO_2e/kWh$ (MfE, 2008).

8.2. USA and UK electricity emissions

The emissions from electricity generation in the USA are reported to be 0.72 $kgCO_2e/kWh$ (EPA, 2009).
The emissions from electricity in the UK are reported to be 0.54 $kgCO_2e/kWh$ (DEFRA, 2008).

8.3. Petrol/diesel generators

Independent power supply in remote areas is easily achieved with a simple engine based generator unit. A generator is a convenient, portable and cost effective solution for short term power but when used continuously it can be seen as unfriendly because of noise, fuel usage, maintenance, and lifespan issues.

The range of generators available and the equally diverse array of loads and operating conditions mean that it is difficult to obtain or calculate reliable information on fuel used per unit of electricity. For this analysis, data has been taken from the operation of a 12 kVA diesel generator in an optimized farm trial. The results from this situation (1.59 litres/kWh or 4.18 $kgCO_2e/kWh$) are likely to be at least as good, if not considerably better, than most situations.

8.4. Avoided emissions

8.4.1. PowerSpout generation

A PowerSpout installed to generate 500 W continuously 24 hours/day, 361 days/year (allowing for 1% maintenance time), is able to generate 43,320 kWh over 10 years. Sourcing this quantity of power from the grid in different countries would result in different emissions, as shown in Table 6.

A PowerSpout in the USA could therefore avoid the emission of over 30 tonnes of CO_2e from grid supply over 10 years. A PowerSpout would avoid over 180 tCO_2e if a generator was the alternative option.

Table 6. Avoided emissions from generator and grid electricity

	Emission factor $kgCO_2e/kWh$	Emissions for 43,320 kWh Tonnes CO_2e	Emissions for 2.3 kWh Tonnes CO_2e
NZ	0.18	7.80	0.41
UK	0.54	23.39	1.24
USA (national average)	0.72	31.19	1.66
Diesel 12kVA generator	4.18	181.15	9.62

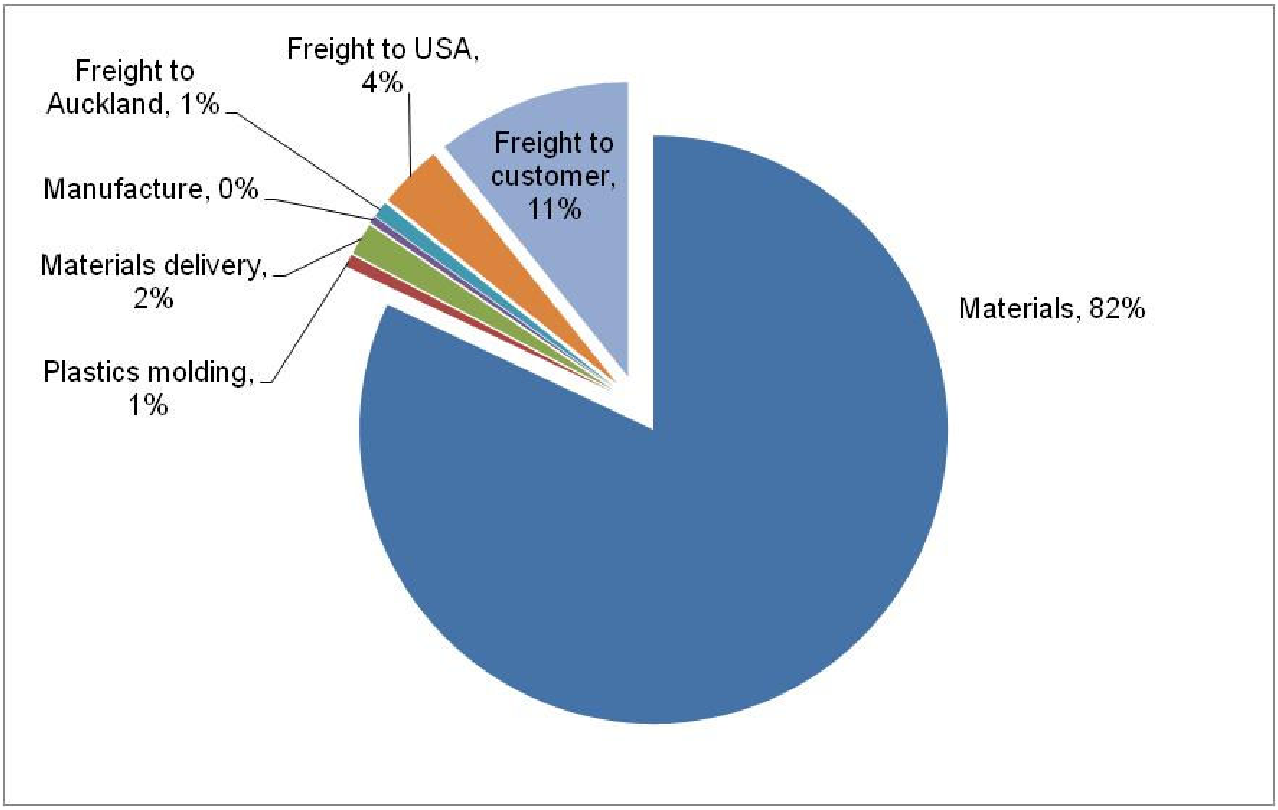
8.4.2. PowerSpout manufacture

Each turbine requires about 2.3 kWh of electricity to make in the EcoInnovation workshop. This power is from renewable energy sources, which have zero emissions, and it also avoids the emissions from grid-based or generator power. Avoiding NZ national grid power avoids minimal emissions (0.4 $kgCO_2e$) but the US grid is more emissions intensive and hence emissions avoided would rise to 1.7 $kgCO_2e$.

9. Inventory Interpretation

The dominant source of emissions from the standard PowerSpout life cycle is the materials used (Figure 2). Applying lower emission factors for recycled materials reduces the proportion from 82% to 77% of total emissions. As noted above the aluminum sheet is a key component but even using recycled material for this, the materials proportion would remain around three-quarters of the total footprint.

Figure 2. Distribution of PowerSpout emissions to source activities (bulk sea freight)



Domestic transport to the customer in the USA is the next largest activity, dwarfing all other activities excluding the materials themselves. As with so many products, transport is a major consideration.

Manufacturing emissions are zero because of the onsite renewable energy, but if the 2.3 kWh consumed in manufacturing a PowerSpout was sourced from the national grid in NZ it would add emissions of 0.4 $kgCO_2e$. If manufacturing was moved to the USA, the equivalent power from the grid would emit 1.7 $kgCO_2e$. Similar calculations can be undertaken to evaluate the impacts of other scenarios, e.g. if the plastic molding was also moved the emissions would increase by 2.2 $kgCO_2e$ due to higher emissions from US electricity. Hence moving the manufacturing base could avoid the emissions from PowerSpout transport to the USA (4.6 $kgCO_2e$ per unit for sea freight), while increasing electrical emissions by 3.9 $kgCO_2e$ per unit. Clearly the emissions are not the only factor to consider in such a decision.

Table 7 shows that total emissions resulting from the manufacture and operation of a standard PowerSpout are 105 $kgCO_2e$. This means approximately 11 $kgCO_2e$ to produce 4,300 kWh each year (12 kWh/day), or 0.0026 $kgCO_2e$/kWh (2.6 gCO_2e/kWh).

Table 7. Emissions for each PowerSpout

	$kgCO_2e$
Materials	85.80
Plastics molding	0.72
Materials delivery	1.88
Manufacture	0.41
Freight to Auckland	0.92
Freight to the USA	3.675
Freight to customer	11.23
Total	**104.64**
Generation over life (kWh)	43,320
Emissions per unit	
kgCO2e/kWh	0.00242
gCO2e/kWh	2.42
kgCO2e/MWh	2.42
tCO2e/GWh	2.42

This quantity of emissions would be emitted within a very short period by other power supply options available. Table 8 shows emission factors for different power supply options and how many kWh can be generated to produce the same amount of emissions as released during the PowerSpout life cycle. For example, the USA grid power could produce 145 kWh, which at the daily rate of 12 kWh/day means slightly over 12 days of power.

Table 8. Emissions comparison

	Emission factor $kgCO_2e/kWh$	To produce 105 $kgCO_2e$	
		kWh	Days[a]
Grid electricity			
NZ	0.18	581	48.4
UK	0.54	194	16.1
USA (national average)	0.72	145	12.1
Generator			
Diesel 12kVA	4.18	25	2.1

[a] assuming generation of 12 kWh/day

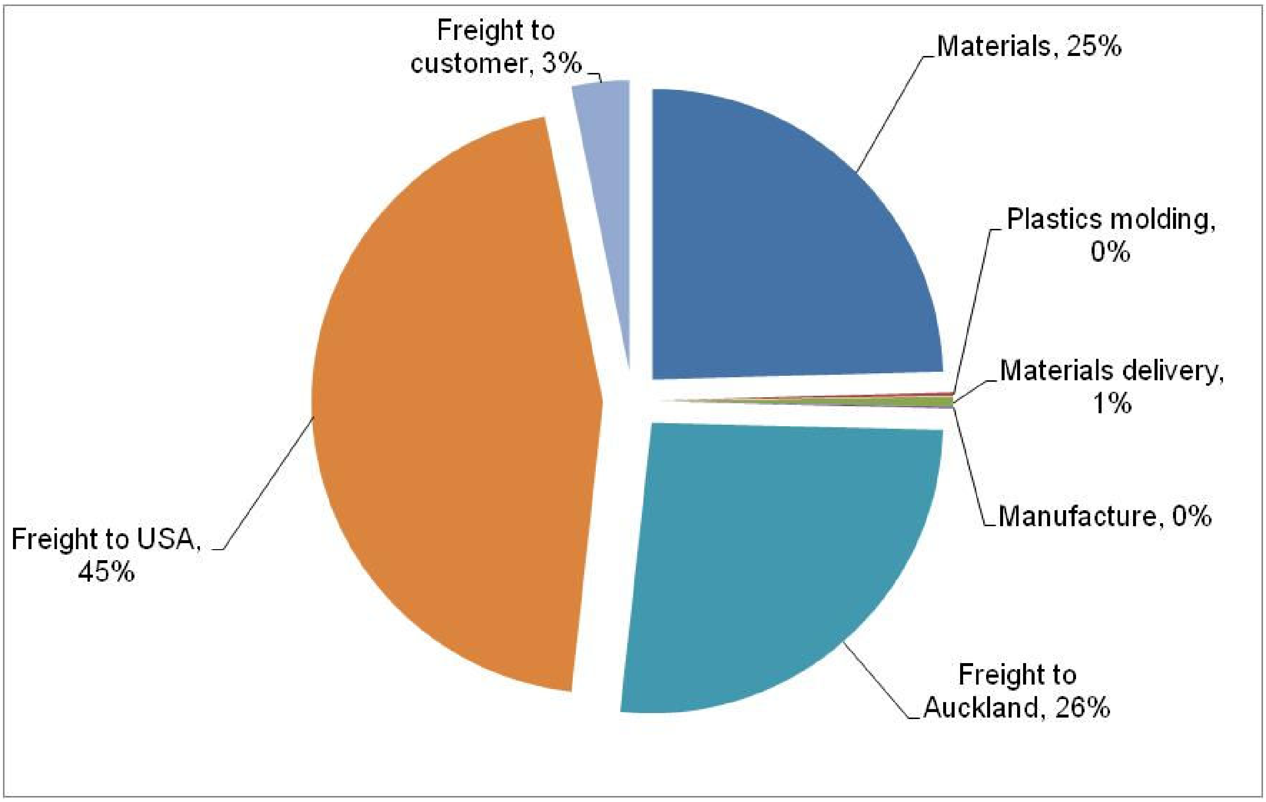
Some analyses compare the emissions before and after a project activity has occurred, e.g. before and after a PowerSpout has been installed, and account for the avoided emissions alongside the actual emissions over a product life cycle. For example, in the USA the PowerSpout could be considered responsible for producing emissions of only 105 $kgCO_2e$ and hence displacing or avoiding the emissions of 31,190 $kgCO_2e$ (Table 6). This example would result in negative net emissions of approximately 31,000 $kgCO_2e$, or having an emission factor of -0.7 $kgCO_2e/kWh$ (i.e. generate 43,320 kWh with negative emissions of 31,000 $kgCO_2e$). This could therefore qualify as a technology for reducing emissions under some climate change mitigation schemes. It can also be considered as a good adaptation technology since it is likely to increase the resilience of rural communities to anticipated climate change and associated disruption to infrastructure (including power supplies).

9.1. Impact of transport

The impact of transport is clearly shown in Figure 3. The standard footprint is based on 100 units being transported to Auckland and shipped from there to Los Angeles. The scenario in Figure 3 assumes a single unit is transported by truck to Auckland and sent by air freight to the USA. These changes more than treble the total footprint to a worst case footprint of 350 $kgCO_2e$ per

PowerSpout and hence affect the relative proportions of each contribution. The freight component for this option becomes totally dominant and materials contribute only 25% of the total footprint.

Figure 3. Distribution of PowerSpout emissions to source activities (single unit air freight)



Despite much higher transport emissions, a unit transported in this way would emit 8 gCO_2e/kWh. The total life cycle emissions would be equal to running a generator for 7 days or taking power from the US national grid for 41 days.

Air freight alone would generate emissions of 158 $kgCO_2e$ which is almost half of the total footprint. Longer distances will inevitably increase the footprint further. For example, if a unit was dispatched by air freight from Auckland to London, UK (18,380 km) the flight emissions would rise further to 276 $kgCO_2e$. This would contribute to a total footprint of 468 $kgCO_2e$ per PowerSpout, or 11 gCO_2e/kWh.

If a user requires all optional upgrades and extra components including tool kit (see Table 11 for complete list), the total weight including packaging increases from 22 to almost 31kg. Transporting this heavier package by air to the UK, and allowing for 1,000 km domestic transport by air rather than road, increases the total footprint to 582 $kgCO_2e$ or 13.4 gCO_2e/kWh. This level of emissions would result from using a generator for 12 days or taking power from the US grid for 67 days, or from the UK grid for 90 days.

9.2. Comparative performance

The emissions per unit of electricity from a standard PowerSpout are 2.4 gCO_2e/kWh which is equivalent to 2.4 $kgCO_2e/MWh$. This is at the low end of the range shown in international LCA studies in Table 9 (Anon, 2008). All the values in Table 9 demonstrate the lower GHG impacts of renewable energy relative to fossil fuel-based energy systems. Within the renewables, hydro and wind are often associated with the lowest impacts (<20 tCO_2e/GWh) while solar photovoltaic panels are somewhat higher (<100 tCO_2e/GWh). In contrast, most fossil-based electricity is responsible for several hundred and possibly over one thousand tCO_2e/GWh (WEC, 2004).

Table 9. Total lifetime releases of CO_2 from electricity generating technologies

	kg CO_2/MWh					
	Coal	Gas	Solar PV	Nuclear	Wind	Hydro
Source/study						
ExternE	815	362	53	20	7	-
UK SDC	891	356	-	16	-	-
U. of Wisconsin	974	469	39	15	14	-
CRIEPI, Japan	990	653	59	21	37	18
Paul Scherrer Inst.	949	485	79	8	14	3
UK Energy Review	755	385	-	11–22	11–37	-
IAEA	968	440	100	9–21	9–36	4–23
Vattenfall AB	980	450	50	6	6	3
British Energy	900	400	-	5	-	-

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11. Annex I. PowerSpout parts

Table 10. PowerSpout parts and materials

	Quantity	Reused / recycled	Recyclable	Materials
Bearing/shaft and fixings				
Shaft	1	yes	yes	Stainless steel
Shaft retaining nut	1	yes	yes	Steel
Bearing block	1	yes	yes	Aluminium
Rear bearing	1	no	yes	Steel
Front bearing	1	no	yes	Steel
Bearing trim	2	yes	yes	Plastic - polypropylene
Fixings	4	no	yes	Stainless
Slinger housing	1	yes	yes	Plastic - polypropylene
Slingers	2	no	no	Rubber
Slinger to bulk head seal	1	no	no	Rubber
Slinger washer	1	yes	yes	Steel
Fixings	4	no	yes	Stainless steel
Smart Drive unit				
SD rotor	1	yes	yes	Steel
	1	yes	no	Ferrite magnets
	1	yes	no	PP GF30
SD stator	1	yes	no	PP GF30
	1	yes	yes	Steel
	1	yes	yes	Copper wire
SD backing plate	1	yes	yes	Plastic - polypropylene
SD extractor knob	1	yes	no	PP GF30
Optimization washers	6	yes	yes	Plastic - polypropylene
SD washers	2	yes	yes	Steel
Pelton rotor				
Pelton spoons	20	no	no	Nylon GF30
Pelton hub	2	no	no	Nylon GF30
Pelton fixings	20	no	yes	Stainless steel
Pelton nuts	20	no	yes	Stainless steel
Pelton alignment washer	4	no	yes	Stainless steel
Pelton front clamp washer	1	no	yes	Stainless steel
Pelton retaining bolt	1	no	yes	Stainless steel
Pelton rotor front spring washer	1	no	yes	Stainless steel
Electrical				
100 amp 3-phase rectifier	1	no	no	Electrical
M6x10 rectifier fixings	2	no	yes	Stainless Steel
2 m of 32 amp cable	1	no	yes	Copper
32 amp plug and socket	1	no	yes	Various plastic
Cable entry gland	1	no	yes	Various plastic
Silicon thermal paste	1	no	no	Silicon
External lubrication				
Compression male connector	2	no	yes	Brass
Bulkhead union	1	no	yes	Brass
Back nut for bulk head union	1	no	yes	Brass
Nylon black line tube	1	no	no	Nylon
Grease nipple	1	no	yes	Steel

	Quantity	Reused / recycled	Recyclable	Materials
Casing				
Main case	1	yes	yes	Plastic LDPE
Casing end cap	1	yes	yes	Plastic LDPE
Casing end cap sealing strip	1	no	no	Foam Neoprene
Casing end cap fixings	6	no	yes	Stainless Steel
Bulk head	1	no	yes	Aluminium
Bulk head sealing strip	1	no	no	Foam Neoprene
Bulk head fixings	14	no	yes	Stainless Steel
Front glazing	1	no	yes	PET
Front glazing sealing strip	1	no	no	Foam Neoprene
Front glazing fixings	6	no	yes	Stainless Steel
Front glazing toggle latch	6	no	yes	Stainless Steel
Front glazing extra sealing screws	6	no	yes	Stainless Steel
Hex head fix down tech screws	4	no	yes	Galvanised steel
Jets (assume 2)				
Jet holder sleeve	2	no	no	uPVC
Jet holder end cap	2	no	no	Nylon GF30
Jets	10	yes	yes	Plastic - polypropylene
Ball valve	2	no	no	PVC
Hansen 50mm pipe fitting	2	no	no	Nylon GF30
Pressure gauge	1	no	yes	Steel/Brass etc
Packaging				
Internal packing	1	yes	yes	Polyethylene bubble wrap
External box (avoided when shipping)	1	yes	yes	Cardboard

Table 11. PowerSpout optional extras

	Quantity	Reused / recycled	Recyclable	Materials
ME or GE upgrade optional				
ME or GE voltage limiting circuit board	1	no	yes	Electrical
Circuit board fixings	3	no	yes	Stainless Steel
Water element	1	no	yes	Copper
Flat nut for element	1	no	yes	Brass
Wire to connect element to board	1	no	yes	Copper/PVC
Optional extras				
Amp box, range to suit client BE version only	1	no	no	Plastic
Power Spout tool kit	1	no	no	Various plastic/metal
PVC 100m 65NB high pressure manifold	1	no	no	PVC
Jet cap and 5 brass jets for low flow	1	no	yes	GF30 Nylon/Brass

Table 12. PowerSpout materials and related emissions

	Steel	Aluminum	Copper	Brass	LDPE	Polypropylene	PVC	Polyethylene	PET	PP GF20	Nylon GF	Cardboard	other	
Total Weight (kg)	5.44	2.06	1.94	0.11	4.60	1.54	1.79	0.60	0.33	0.97	1.43	1.28	0.08	22.17
Recycled Weight (kg)	4.51	0.49	1.28		4.60	1.34		0.60		0.97		1.28		15.07
Recycled %	83%	24%	66%		100%	87%		100%		100%		100%		68%
Emission factor (kgCO_2e/kg)	1.94	13.14	7.47	7.47	2.45	1.97	2.08	2.43	2.55	1.97	7.07	0.40		50.93
Total emissions	10.51	27.06	14.51	0.85	11.26	3.04	3.72	1.46	0.84	1.91	10.13	0.51		85.80
Total emissions (half emissions for recycled)	6.13	23.84	9.74	0.85	5.63	1.72	3.72	0.73	0.84	0.96	10.13	0.25		64.54