Up-cycling e-Waste into Innovative Products through Social Enterprise

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Abstract: Advances in information technology have brought about numerous benefits for many aspects of life. However, the increased pervasiveness of electronic devices has also resulted in significant amounts of e-waste. E-waste now extensively occupies scarce landfill resources and contributes to pollution due to the toxic and highly reactive materials used in construction. This paper describes a unique social enterprise business model that deals with the duel problem of social disadvantage and e-waste. Through building capacity across all sectors in the community, this case study shows how a social enterprise can improve societal outcomes through training and education, whilst also dramatically reducing the amount of e-waste going to landfill. Furthermore, in addition to recycling, this social enterprise model can work with relevant stakeholders to up-cycle e-waste into practical and environmentally conscious commercial products. The social enterprise model (with partner organisations) and spin-off projects have led to multiple individual and commercial successes. This paper provides an overview of how this social enterprise operates and some of the major projects that are underway using up-cycled e-waste.

1 INTRODUCTION

The information age has led to an almost infinite amount of possibilities and applications. The price of technology continues to decrease resulting in computerisation becoming increasingly pervasive. However, this dramatic surge in computing devices and electronics has also led to a negative environmental outcome – electronic waste (or *e-waste*) (Kiddee et al., 2013). E-waste refers to any electrical or electronic component that has been fabricated for use by humans in electronics or a computing capacity, that is now obsolete and has been discarded. While technology companies are keen to promote the next latest gadget on the market, little thought is often given to what happens at the end of the item's usable lifespan. As such, e-waste now accounts for a significant amount of landfill. E-waste is highly toxic, which results in further environmental pollution (e.g., chemical leeching into waterways, explosions from discarded batteries, noxious fumes from burning plastics) (Wong et al., 2007).

Developing countries and areas susceptible to social disadvantage are particularly impacted by e-waste (Babu et al., 2007). In many cases, developing countries are the recipients of vast volumes of e-waste from established countries (in some cases up to 80% of e-waste is exported) (Nnorom and Osibanjo, 2008). Most of the e-waste disposal methods either involve landfill and/or mass burning of the materials (Kang and Schoenung, 2005). However, in recent years initiatives have been enacted specifically targeting productive e-waste recycling via social enterprise and community engagement.

A *social enterprise* is typically a not-for-profit organisation that pursues a positive social agenda ahead of corporate profit (or individual gain) (Borzaga and Defourny, 2004). Many social enterprises exist that target pertinent issues in the community such as affordable groceries for low income earners, free text book donations for students, micro-lending, renewable power generation for disadvantaged communities, and low-cost exercise equipment to promote fitness and well-being (Thompson and Doherty, 2006). Environmentally sustainable products and initiatives are a key focus of many social enterprises.

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This paper describes a unique social enterprise business model that deals with the duel problem of social disadvantage and e-waste. The social enterprise targets disadvantaged members of society and couples them with high-skilled labour to provide valuable training and employment outcomes. At the core of the operation is an e-waste recycling facility that has positive reciprocal arrangements with business to deposit, disassemble and sort e-waste that would otherwise go to landfill. Working in conjunction with the community (academics, governments, entrepreneurs), major components of the e-waste are *up-cycled* (transformed) into new products aimed at road safety, environmental monitoring, 3D printing, education and environmental sustainability. Many of these projects have led to multiple individual and commercial successes, with the revenue being reinvested in the social enterprise to further expand capacity.

This paper is organised as follows: Section 2 outlines related work on e-waste recycling and introduces social enterprise business models. Section 3 presents a case study for a social enterprise that specifically targets social disadvantage and e-waste recycling. Section 4 presents several successful projects that the social enterprise has engaged in with academia and the community that utilise up-cycled e-waste. Section 5 provides some concluding remarks and avenues for future opportunities.

2 e-WASTE AND SOCIAL ENTERPRISE

2.1 e-Waste

Almost 100% of e-waste components are recyclable. There are numerous items that can be recovered from e-waste including plastics, metals, batteries and glass. However, e-waste is one of the fastest growing components of the municipal solid waste stream. Global e-waste recycling rates tend to be as low as 10-15% (EPA, 2018). This means that most e-waste ends up in landfill. E-waste never fully breaks down or gets burned on mass releasing noxious fumes into the atmosphere. The excessive lead in e-waste, if released into the environment, could cause severe damage to human blood, kidneys and the nervous system (Wong et al., 2007).

In 2018, approximately 49.8 million tons of e-waste was generated worldwide, with an annual 4-8% growth. Each year, globally, around 1 billion mobile/cell phones and 300 million computers are put into production. Every day, over 416,000 mobile devices and 142,000 computers are discarded. Approximately 26.9 million television sets, weighing 910,600 tons, were scrapped in the U.S during 2017 (EPA, 2018).

An EPA report reveals that by recycling one million mobile/cell phones, we can recover more than 20,000 lbs. of copper, 20 lbs. of palladium, 550 lbs. of silver, and 50 lbs. of gold. Mobile/cell phones contain a very high amount of precious metals such as silver and gold. Americans throw away approximately $60 million worth of silver and gold per year (EPA, 2018).

Producing a computer along with its monitor takes at least 1.5 tons of water, 48 pounds of chemicals and 530 pounds of fossil fuels. Compared to disposal in landfills or by incinerators, reusing or recycling computers can create 296 more jobs per year for every 10,000 tons of computer waste processed (Cui and Zhang, 2008). Recycling one million laptop computers can save enough energy to run 3,657 homes for a year.

2.2 Social Enterprise

2.2.1 The Role of a Social Enterprise

A social enterprise is an organisation that addresses a basic unmet need or solves a social problem through a market-driven approach (Borzaga and Defourny, 2004). In recent years, traditional non-profits have become more entrepreneurial and interested in generating earned revenue to supplement charitable contributions. Furthermore, traditional businesses have begun to integrate greater levels of social responsibility and sustainability into their operations. The growth of social enterprise reflects this convergence and helps fill the void between traditional approaches that have focused solely on creating either social impact or financial returns.

A social enterprise's charter is to create value for the community by providing an innovative and unique solution to some entrenched problem. The problem is tackled in a way that brings benefits to people and is achieved in an environmentally friendly manner. Typically, the problem has been unable to be solved by the usual market mechanisms, as such social enterprise focuses on cost effectiveness.

A social enterprise is the inversion of a regular business model. Rather than focusing on individual gain, the goal is to benefit all members of the organisation and the community. As such, many social enterprises focus on improving the livelihoods of the poor or disadvantaged through their operation.

This is also usually achieved by directly including the disadvantaged group in the charter and execution of the social enterprise. Social enterprises may offer a flexible working environment to help engage the disadvantaged groups, such as transient employment arrangements and flexible working hours. The work environment can be targeted to a specific workgroup, geographic community, or to people with disabilities.

2.2.2 Advantages and Benefits

Social enterprise can lead to numerous benefits for the environment, society and individuals involved:

- *Products and Services* – As previously mentioned, a social enterprise will provide a product or service in a manner that traditional market mechanisms have failed. This approach can potentially offer stakeholders a better and more customised solution to the problem. The solution will also be designed in harmony with all other systems (i.e., the environment, society and the people involved).
- *Cost Affordability* – The solutions offered by social enterprise in the form of either products or services are often comparable to the same service provided by a profit-making organisation. This drives down the costs of basic amenities such as healthcare or education. The focus on cost affordability means that typically disadvantaged people now have access to these basic amenities.

2.2.3 Social Entrepreneurship

Social entrepreneurs are afforded some unique benefits through taking a social enterprise approach:

- *Raising Capital* – There are many governmental incentives and schemes that specially target social enterprise. Furthermore, the ethical nature of social enterprise may make it easier to raise capital at below market rates.
- *Support* – Garnering support from like-minded individuals may be easier as those engaged around a cause or common problem will typically be passionate about addressing the problem. The social nature may also mean that people are not as motivated by personal gain and provide resources and/or support typically below the cost of normal market rates.
- *Marketing/Promotion* – Social enterprise tackle difficult problems in a unique manner, therefore it may be easier to attract media attention and community support. The more unique the solution is, typically the more interest there is from the media and community.

2.2.4 Social Enterprise Business Models

Many organisations are now making corporate social responsibility a focus of their business charter. However, most companies are not driven by making a real difference, but rather just a way to improve their public image and profit.

A business model is a structure, design or framework that a business follows to bring value to its customers and clients. A business model's success is measured in one of three main ways:

1. Ability to generate profit for its owners;
2. Ability to generate positive change in the world; and
3. Ability to achieve a *balance* of profit and positive change.

The first metric applies to traditional for-profit companies. The second metric is relevant for traditional charities. The third metric (i.e., a balance between profit and positive change) applies to social enterprises. As such, a social business model is a structure, design or framework that a social business follows in order to bring about a positive change while maintaining healthy financial returns.

3 e-WASTE RECYCLING VIA SOCIAL ENTERPRISE

Substation33 is a social enterprise originally established as an e-waste recycling social enterprise business to reduce the amount of electronic componentry being dumped as landfill. Substation33 has its primary operation in Logan City in Australia.

3.1 Youth Disadvantage in South East Queensland

Logan City is located between Brisbane and the Gold Coast in Queensland Australia. The unemployment rate in Logan trends above the national average. This earns Logan a reputation in South East Queensland as a low socioeconomic area.

There are numerous reasons for this unemployment outcome including: 1) A large migrant population with a locally unrecognised skillset; 2) Prevalence of substance abuse; 3) Either first in family or no one in family has gone on to tertiary education; 4) Low-skilled job opportunities;

and 5) Skill flight (i.e., qualified people move away). Note that it is not always easy to tell which of these are causes or symptoms of the unemployment rate. As a result of these reasons, Logan experiences many social and economic challenges.

3.2 Substation33's Charter

Substation33's primary charter is to connect with people marginalised from mainstream employment for a variety of reasons (such as long-term unemployment, physical or other disability, early school leavers or students at risk of disengaging from school). These people are then mentored by community leaders and are engaged in innovative projects that promote sustainable environmental practices (Taylor et al., 2016).

In addition to working with marginalised community members, Substation33 engages with high-achieving school students, university students and graduates. Most interesting, Substation33 has attracted highly skilled personnel who are referred to as "altruistic volunteers". Altruistic volunteers are people who may have exited the workplace early in their careers due to selling or moving on from their businesses. Such people may become socially isolated and disengaged from the community, whereas Substation33 provides the opportunity for them to re-engage and use their skills for social benefit. Substation33 also works closely with tenured academic staff members from local universities, high school teachers, small business owners and government agencies.

Over time, Substation33 has been moving towards becoming an innovation space – naturally morphing from not only being a recycling centre, but to a melting pot of ideas where e-waste is up-cycled and transformed into commercial/manufactured products. Essentially, Substation33 has become a leading force in taking conceptual ideas arising in the community, innovating around these projects, and delivering commercial outcomes.

3.3 Primary e-Waste Operation

3.3.1 e-Waste Collection

Substation33's core operation is in recycling e-waste. Substation33 has arrangements with numerous companies to collect the e-waste for free, thereby saving the company the expense of having to dispose of it. The community has also been encouraged to establish e-waste deposit sites (e.g., at schools or social clubs), which Substation33 collects from.

Substation33 has entered arrangements with peak recycling organisations such as BidVest. Whenever a consumer purchases an electronic item (such as a laptop computer) a small fee is charged with the item's future obsolesce in mind. This fee is based on the volume of future landfill the device will occupy. Substation33 is then able to reclaim a portion of this fee from the regulatory authority through evidencing that that item has been recycled, thereby saving the landfill resource.

3.3.2 The Recycling Process

Figure 1: The e-waste disassembly line.

Initially, e-waste is deposited at Substation33's premises. The e-waste undergoes a preliminary audit to determine whether any items are still functional and/or can be used in their present form. These items are stowed, and the remaining items proceed to a sorting phase. Once sorted, the items enter a disassembly line (Figure 1). The items are broken up into their constituent components and all salvageable parts are sorted and stowed. Less than 3% of the disassembled parts become landfill.

3.3.3 Recycling/Repurposing Batteries

Figure 2: Battery testing and classification.

Laptop batteries are a significant component of e-waste. These components are highly energised and represent a significant danger and pollutant. A laptop battery is made up of multiple smaller cells. When a laptop battery dies, it is usually only one of these cells that is problematic. The rest of the cells are typically in a reasonable condition.

Substation33 operates a special purpose battery unit whereby each laptop battery cell is tested. Batteries are then graded A to D depending on the maximum charge they can hold and their discharge rate (Figure 2). This way, higher and lesser quality cells can be grouped together. These cells can then be repackaged as a battery of any desired capacity with reliable charge in the zone of 3.6 to 4.2 volts. The batteries are then repurposed for use.

3.4 Capacity Building and Successes

Substation33 have diverted over one million kilograms in total of e-waste from landfill. Approximately 100 people per annum who have engaged with Substation33 have gone onto other employment over the last two years. During 2018, 623 people gained work experience through Substation33. Of these, 343 were work-for-the-dole participants, 126 volunteers, 33 school students, 60 special school students, 6 university students and 55 from the youth justice system. Substation33 currently employs 14 permanent staff. Substation33 is typically frequented by up to 50 people per day including volunteer staff and visitors. Substation33 generated $4.25 million for the Australian economy throughout 2018. Substation33 has attracted multiple awards from government, industry and academia recognising their work in the community.

4 UP-CYCLING e-WASTE INTO USEABLE PRODUCTS

Substation33 deals with taking e-waste and up-cycles it (i.e., transforms e-waste into a higher level) to create innovative commercial products that promote environmental sustainability, community development and safety. One of their core activities is looking for ways to improve solar and battery management technology to take products off-grid.

By using recycled battery cells, Substation33 have been able to refurbish or retrofit a vast variety of electrical products. For example, recycled drill battery packs, developing battery-powered electric bikes, repurposed ammunition boxes converted into amplifying speakers, etc.

Substation33's experience is that people with academic, industry and/or commercial experience can engage on a research and commercial level with university students and inventors who have ideas, that support people less fortunate. This has given Substation33 the capacity to tap into a very diverse group of subject matter experts, and low-cost, leading edge technologies, manufacturing equipment and applied science.

Substation33 promotes an innovation "DNA" that can be described as "give and take". Substation33 is happy to help inventors to further develop their ideas in a low-cost manner utilising up-cycled e-waste. However, in return Substation33 asks that they give something back to the community. This could be in the form of providing mentoring to Substation33's marginalised cohorts, applying their specialist skillset to other projects Substation33 is working on, or providing in-kind resources to help support the expansion of Substation33's business model.

In 2017, Substation33 formally activated a hackerspace/makerspace to complement their existing social enterprise e-waste recycling and manufacturing facility. As part of this initiative they formed Innov8 Logan[2] in collaboration with local industry. The following subsections describe some of the projects Substation33 has developed as part of the hackerspace/makerspace through up-cycled e-waste.

4.1 3D Printing Capabilities

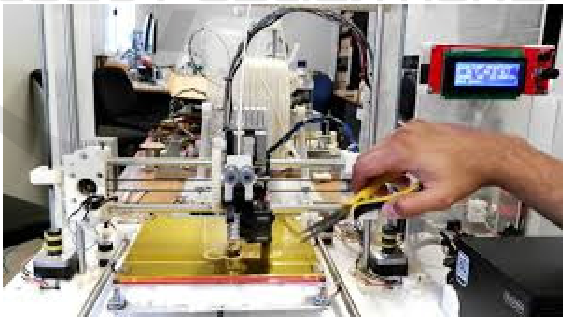

Figure 3: 3D printer assembled from e-waste.

Substation33 can construct 3D printers using up-cycled e-waste for as little as $64 AUD (see Figure 3). Substation33 have built a fleet of over 40 3D printers across Logan City. This provides the ability to mass produce 3D designs for innovation ideas and undertake rapid prototyping for manufacturing purposes. Substation33 works with local schools, educating students on how to construct 3D printers using e-waste and operate them to print innovative

[2] innov8logan.com.au

designs. Substation33 is currently developing one of Australia's largest 3D printers, which is capable of printing objects equivalent in size to a small car.

The focus of the 3D printing initiative is to produce easy to construct, highly marketable and small form factor 3D printers. These are then provided to high schools. This enables students to have access to a reliable, easy-to-use system that makes for a great learning tool and an excellent pedagogical aid for teachers.

The latest v4.0 printer is low-cost and uses recycled and 3D printed parts. This is delivered to schools as a kit. This kit provides an interactive experience where students learn to build, operate, maintain and repair a 3D printer. This affords the students an opportunity to learn about mechanical and electrical design elements and computer aided design. Additionally, students are provided with an introduction to the environmental challenges that fast-changing technology creates.

E-waste contains a significant amount of plastic. To further promote the theme of environmental sustainability, Substation33 creates 3D printer filament from recycled ABS plastic. This plastic can be cleaned, granulated and then processed by an extruder to create 3D printer filament. This can dramatically reduce the price of filament to as little as \$4 / kg (versus \$40 / kg for commercial filament).

4.2 Road Flooded Safety Signs

Figure 4: A road flooded safety sign deployed at a road crossing subject to flooding.

A major product Substation33 produces is a solar-powered flooded road traffic sign (Figure 4). In conjunction with the Logan City Council and Griffith University, Substation33 has developed technologies to detect when a creek or river has flooded a road. The road sign is remotely triggered to display a warning to motorists about the flood hazard. Road crews and decision makers can also remotely view roads that are flooding and map this data as a flood event unfolds via a dashboard.

Substation33 currently operates 80 deployed flooded road signs across Logan City and the Sunshine Coast. In a 2017 flooding event caused by Tropical Cyclone Debbie, not one car entered floodwater where the flooded road signs were active. Substation33 won the national Innovation in Road Safety Award 2017 as a result.

The flooded road safety signs utilise up-cycled e-waste in their construction (i.e., batteries, solar panels and other electrical components). This approach has effectively saved the Logan City Council over \$120,000 per crossing compared to their previous approach to sourcing flooded road signs. This project has provided paid employment for numerous Substation33 personnel.

As a follow-on project, Substation33 is developing a pedestrian crossing road safety sign. The signs are installed on non-controlled pedestrian crossings to alert motorists that someone is trying to cross the road. The pedestrian pushes a button on the sign, which lights the sign up. It is then up to the motorist to slow down or stop to allow the pedestrian to safely cross the road.

4.3 Affordable Aquatic Environmental Monitoring

Figure 5: The Smart Buoy remote aquatic environmental monitoring system.

The Smart Buoys project is about developing affordable aquatic environmental monitoring equipment that remotely collects data in near real-time (Trevathan et al. 2012; Trevathan and Johnstone 2018). The traditional approach to water quality monitoring is to travel to the water body and take a one-off manual sample. This sample is then taken back to a laboratory for analysis. However, this approach is expensive, time consuming, slow and is often of limited usefulness.

In contrast, the Smart Buoys are placed in water bodies and take a series of sensor readings every 15 minutes that are remotely transmitted back to a web-based dashboard (Figure 5). This allows the relevant stakeholders to view how the water quality and condition is changing over time. Such insight also allows the stakeholders to undertake proactive actions during the unfolding of an environment event (e.g., an algal bloom, contamination, flooding).

The latest version of the Smart Buoys collects data on the following environmental parameters:

- Temperature (-400 to +1250 C);
- Light (0.1 to 40,000 Lux in the 300 nm to 1,100 nm wavelengths);
- Turbidity (0 – 4000 NTU);
- pH (0 to 14 pH);
- Dissolved oxygen (0 to 100 mg/L); and
- Conductivity / Salinity (10 µS/cm to 1 S).

This project is being developed in collaboration with Griffith University. The collaboration has led to innovative solutions for power management and electronics miniaturisation. Substation33's extensive 3D printing capabilities have allowed for rapid prototyping of the physical buoy components. Recycled laptop batteries and solar power each buoy.

The system has been deployed across lakes, rivers, dams and creek catchments in South East Queensland and North Queensland. Smart Buoys is the winner of the SeqWater Water for Life Community Grant, Ipswich Environmental Sustainability Award and Transurban Community Grant. Smart Buoys has won the Logan City Council EnviroGrant Scheme for three consecutive years.

This project has provided education and training for Substation33 staff, university students and high school students. Smart Buoys has also resulted in several spin-off projects for remotely monitoring the water height of creeks/rivers, and remote dust sensor data acquisition in a new housing estate.

4.4 PowerWells

Figure 6: A PowerWell being deployed in a village in South East Asia.

PowerWell's charter is to repurpose recycled laptop batteries and other e-waste componentry to provide a renewable power supply for remote communities. A bank of recycled laptop batteries is configured with a solar panel and power management electronics.

The system can be used to charge mobile phones, torches, computers, lights and other devices. The goal is to provide electricity to remote or disadvantaged communities who may not have a reliable power source, or no connection to the electricity grid. The system raises revenue by charging users a minor fee, whilst promoting a sustainable lifestyle.

This project has won several grants, including the JetStar Flying Start Grant. There are over 20 operational PowerWells currently in use throughout isolated regions in Indonesia and East Timor (Figure 6). The project employs 2 technical staff and engages with Substation33's existing labour force in training, development and manufacture of the equipment.

4.5 Electric Bikes

Figure 7: An electric bike.

The electric bike, or *e-bike* uses recycled laptop batteries and 3D printed battery modules (see Figure 7). A standard bike (often taken from scrap) is converted by adding recycled batteries and a purchased mid-drive motor kit. The battery pack provides over 1kW-hour resulting in a range of around 100km with minimal peddling.

The battery packs are designed to have a very long life. By using recycled laptop batteries, the cost of the e-bike can be reduced to just the cost of the motor kit. The e-bike is an educational tool to teach people how to build battery systems and e-bikes.

4.6 AMPLFY Bluetooth Portable Speakers

AMPLFY is a revolutionary online platform, designed to disrupt the traditional business of buying and selling portable speakers (Figure 8). The goal is to educate people to become creators, tinkerers and innovators so that they now become the disrupters. Substation33 provides the kit and instructions for people to learn how to build their own speakers for the purpose they desire. The kits and instructions are designed to allow individuals to be as creative as possible. This project desires to bring back the age of handcrafted and bespoke goods and empower as many people as possible to become the creators.

Figure 8: An AMPLIFY speaker kit.

4.7 Solar Trailer

Substation33 have developed a mobile solar power battery storage trailer (Figure 9). Equipped with multiple solar panels, the solar trailer is capable of supplying power to over 20 televisions simultaneously. This project has important ramifications in areas that may lack traditional electrical infrastructure (e.g., a rural/remote area or developing country). Furthermore, this product will become more relevant as existing residential solar systems move into obsolesce and discarded solar panels transition to e-waste. In 2019, the solar trailer was used to power several stalls at the Logan Eco Action Festival.

Figure 9: The solar trailer.

5 CONCLUSIONS

E-waste is an increasing global problem. While almost 100% of e-waste components are recyclable, e-waste recycling rates continue to be low. Part of this problem is due to the way people view the industry. Social enterprise can play a significant role in changing people's attitudes towards recycling through combining several causes together to provide a community-led solution.

This paper introduced Substation33, which is an e-waste recycling social enterprise. Substation33 engages people who are marginalised from mainstream employment. In exchange for providing services in e-waste recycling, these people are afforded with valuable skills and training in electronics, 3D printing, programming and general computer technology.

A significant component of e-waste is discarded laptop batteries. Substation33 recognises the stored energy potential of these components and proactively salvages, reconditions and then ultimately repurposes the batteries for use in other products.

Through its operations, partnerships and skilled labour force, Substation33 has established a hackerspace/makerspace to complement the e-waste operation. This has resulted in notable commercial products including 3D printing farms, flooded road safety signs, smart environmental water quality monitoring buoys and PowerWell solar battery banks for remote communities. This particular hybrid social enterprise business model is a testament to Substation33's success in tackling multiple social and environmental problems simultaneously.

Future work involves seeing whether this social enterprise business model can be replicated in other areas – especially developing countries where mounting e-waste is a problem. Additionally, we will continue to expand the use of the products being developed through Substation33.

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