BECI

Battery Exchange Charging Initiative - BECI

Creating a system for electrically powered taxis to exchange batteries instead of charging – Imperial College London second year group project

Alexander Stott, Justin Spurdens, Jonathan Mason, Rui Guo, Huan Wang, Xioaming Chen, Yang Zhang, Gregory Ghin Min Yap
Supervisor: Javier Barria
2/20/2012

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1. Introduction

As the issue of climate change becomes a bigger part of modern life so the need to replace large groups of polluting, fossil fuel powered cars with cleaner electric vehicles rises in importance (1: p6). However the electric vehicle is still not a widely successful alternative especially in long journeys, where it is not possible to spend a long time refuelling as charging points are not available everywhere and people are not prepared to wait long periods to charge their car. To combat this we feel creating a system to replace the batteries with recharged versions would enable a "re-fuelling" time similar to a petrol or diesel car therefore making it a more competitive option (2: p1). In particular we propose to create a system to allow London taxis to be replaced by electrical vehicles as they are required to travel long distances but are in a localised location so widespread infrastructure is not required.

For this to be feasible we need to design a battery, battery replacing system and a recharging station. The battery must be capable of meeting the needs of the taxis but still be cheap enough to make the system cost effective. The replacement system should be capable of switching the battery in the same amount of time it would take to re-fuel a fossil fuelled vehicle. The recharging system should be capable of supplying enough batteries for use for a large number of taxis. As well as technical issues there are a lot of strategic issues to deal with. For example making the system cost effective is difficult as electric vehicle batteries are still very expensive and keeping the cost as low as a fossil fuel system is important.

Despite the issues, if the problems can be solved this could be a very successful business as it has a broad range of potential uses. If the system proves successful for taxis it can be used for all cars and used across the country and internationally. In this report we will address these problems and conclude as to whether we feel it is a viable business.

2. Overview of Chosen Solution

The solution we propose will have a lithium-ion battery that is removed and replaced by a robotic system and then placed in a charging dock which houses several batteries.

Lithium-ion technology has progressed rapidly and hence is the obvious choice as industry leaders have based their current electric vehicles on it (3-5). The battery has always been one of the main problems with making electric vehicles and there is much research into lithium-ion and other technologies. For example there has been recent research (6) in battery technology that can pump in charged fluid which effectively recharges them. Our system has the capacity to adapt to these new technologies as we have overall control so big changes could be made easily. Also we would already have a strong infrastructure so would be able to adapt and be the immediate industry leader.

A robotic replacement system is optimum as electric vehicle batteries are heavy and large so cannot be easily replaced manually. This is technically difficult to implement. Firstly it must accurately align itself to remove the battery in a safe way. It must then exchange this with a fully charged one and place it in likewise. Safety is the primary concern as there are many possibilities of faults in the battery alignments and location of the correct battery slots. A control system for managing the replacement arm is a key technical area and as shown it would have to be well designed.

Other important design points of our system are battery storage and recharging racks that can be used everywhere, making efficient use of space and allow easy interface with a control system. This is because we will need to create service stations of different sizes with a uniform system so we can mass produce it and decrease costs. Managing the charging of these is also very important as we want to make efficient use of our resources but cannot afford to run out of charged batteries.

Using green electricity is an incredibly important strategic focus of our project as we aim to make the system as clean for the environment as possible. Our main area of interest is using electricity that is being generated and not being used especially at night as this would be cheaper. To do this negotiation for the night time energy of a power station such as a nuclear power plant that is not able to lower its output power may be possible. We also aim to be able to provide after gate closure services for the national grid such as being available to switch on or off a large load, which would provide extra income as well as proving efficient use of energy (7). Some services could be similar to the vehicle to grid network (8) where electricity not currently being used in charged batteries can be put back in to the grid.

A system similar to our proposed one is already available. Better Place provides a battery switch station idea and is attempting to implement it in countries such as Israel. However their system is aimed at all compatible cars and whereas there is interest from some manufactures the uptake is slow. Ours though is only aimed at taxis so would only require one company and less infrastructure consequently making it easier to set up. Also we aim to use our energy more efficiently to make it greener and more profitable (9).

3. Strategy

Once we have acquired the initial funding, BECI will be implemented in phases. The first phase would be to set up BECI stations in central London where most of the taxi traffic is and start with a small batch of vehicles. We plan to locate the initial batch of BECI stations near larger taxi ranks, as this will minimize the impact on taxi drivers. BECI capable vehicles will have labels to uniquely identify them and to promote the idea. When we have a stable system, we will develop an extensive network of BECI stations in London and increase the number of BECI vehicles. Once we find that our model is sustainable, we plan to expand the service to other parts of the UK and consider implementing the system to other types of vehicles such as buses or private cars.

In order for BECI to work, we need vehicles that are compatible with the system. That requires us to cooperate with battery and car companies. The company responsible for production of the London Taxis have intentions to make an electric version of the London taxi which would be ideal for us (10). When we have developed a reputation of providing a fast and reliable service of supplying batteries at an affordable price, other companies will be convinced to support our cause.

We will work with power companies to charge batteries at predicable times when demand is the lowest. This will reduce the cost of charging the batteries and the pollution produced. In order to make BECI vehicles truly green, we ideally intend to source our power from environmentally friendly sources slowly phasing out polluting sources. To make this a viable business it needs to be taken long term with the view that it can be expanded to other cities and general cars.

4. Technical

4.1 Battery

The battery is one of the most important parts of an electric vehicle (EVs); and it ‘currently accounts for 30-50% of the cost’ (11) of manufacturing. Therefore it is crucial that the specifications are well matched to the task. These properties include capacity, power, weight and size, charging time (normal mode and quick mode), lifespan, and driving range per charge. For the past two years, Nickel metal hydride batteries have been gradually replaced by lithium ion ones in HEVs (hybrid electric vehicles) and EVs (12). This is due to its high energy/power density and smaller weight compared to Nickel based batteries. From the table 1 (1: p13), Lithium ion batteries present better performance than every other type of battery in terms of energy density (determines the range of the car), power density (determines the maximum acceleration the car can achieve) and size and weight. This is shown in the table below.

Battery type	Lead acid	Ni-Cd	Ni-MH	Lithium-ion
Energy density [a] (Wh/Kg)	35	40-60	60	120
Power density (W/kg)	180	150	250-1000	1,800
Cycle life [c]	4,500	2,000	2,000	3,500
Cost ($/kWh) [d]	269	280	500-1,000	Consumer electronics: 300-800 Vehicles: 1,000-2,000
Battery characteristics	High reliability, low cost	Memory effect	Currently, best value and most popular battery for HEVs	Small size, light weight
Application	Car battery, forklift, golf cart, backup power	Replacement for flashlight battery	HEVs, replacement for flashlight battery	Consumer electronics

Table 1. (1) Technical performance by existing battery type (p.13)

Lithium-ion Battery Performance

Taxis favour large energy capacity over large power output. This is because the taxi drivers prefer longer driving range (larger capacity) and shorter recharge time in order to increase profits, rather than high speed. Currently, nearly every major brand of electric car uses different types of lithium ion (Li-Ion) technology. By researching into the statistics of popular EVs and HEVs brands’ lithium ion batteries, we determined best choice of battery based on technical feasibility and estimated performance.

The systems battery is chosen to have a capacity of 25 kWh and power output of 75kW, a high power wall connector at home would fully charge in less than 3.5 hours. An 80% quick charge system would charge in less than 30 minutes. Its driving range would be 100 miles per charge. To calculate the lifespan we use the guide ‘Lithium-ion batteries appear to be about 10 year/150,000 mile capable’ (13); and a taxi in London typically runs 582 miles per week (14). Therefore the calculated lifespan of our lithium-ion batteries would be approximately 5.0 years.

EV	Battery Type	Capacity (kWh)	Charging time	Fast charging	Battery Life	Driving range/charge	Power
Nissan Leaf (3)	Li-ion	24	<8 hrs (AC240V)	30min (DC50kW)	10 yrs	100 miles	Over 90 kW
Tesla Roadster (5,15)	Li-ion cobalt oxide battery	56	3.5hrs (240V, 70A)	---	7-10 yrs	>200 miles	max 215 kW
Ford Focus BEV [(16)]	Li-ion Tri-Metal	23	3-4 hrs(240V)	---	---	100 miles	100kW

Mitsubishi i-MiEV [4]	Lithium titanate oxide SCiB technology	16	7 hrs (220V)	30 mins	>1000 (83%)cycles	100 miles	47kW
Mini-E [17]	Li-ion	35	3 hrs (240 V, 48A)	---	---	109 miles	150kW
Detroit DE e63 [18,19]	Li-ion Polymer (LiPo)	25	<3.2hrs (32 A)	20 mins (90% DOC)	>2000 charge cycles >3 yrs	112 miles	75kW Max 150kW
Toyota Prius (hybrid) [20]	Nickel Metal Hybrid	1.28	<1.5 hrs	---	180,000 miles	14.3 miles (electric only)	38kW

Table 2. Technical statistics of BEVs and HEVs' batteries of main manufacturer on market

Lithium-ion Battery Type

Lithium-ion technology has been developed over years with innovations in anode/cathode material and form factor. The Detroit DE e63 model uses Li-Ion Polymer for their battery design and has achieved good performance. LiMn2O4 is a type of Li-Ion Polymer anode/cathode suitable for EV as it contains the highest power and high thermal stability, especially for layered compounds. However, it has relatively short life which can be increased by spinels doping, which improves the stability of the anode. In testing, the advanced LiMn2O4 battery has 10-years lifetime. (21)

Supplier	Anode/Cathode	Form Factor	Energy Density
>15 suppliers in commercial production	Coke, Graphite, Hard Carbon, SnO2, LiCoO2, LiNiO2, LiMn2O4, Li(CoNi)O2	Cylindrical, Prismatic, Polymer	>400 Wh/l >150 Wh/kg

Table 3. (22) Technology Data of Li-ion Battery in 2000 (p.1)

Lithium-ion polymer batteries also have other advantages over the traditional technologies (23). They can be packed into different shapes and is lightweight. The polymer pouch cell is one fifth lighter than equal performance cylindrical cell because it contains a flexible polymer-laminated foil case instead of a rigid metal one. This gives us more flexibility in our battery case design and therefore it is easier to create one the car manufacturer is happy with and is usable in the system. Also, lithium-ion polymer batteries have short charging times: Toshiba introduced a new rechargeable battery model in 2007, which provided a rapid charging speed reaching 90% of full capacity in several minutes (24).

4.2 Switch Station

The replacement system has five main parts. First the battery charging rack, which contains ten battery packs and is twenty metres long, two metres deep and one metre high where the batteries are placed to be charged. Second is the vertical robotic arm with two position sensors under the car used to transfer the battery between the car and the switch station. Third is the head of the robotic arm which links with the battery to activate and deactivate the connection with the car so it can be transferred safely. Fourth is the circular magazine where fully charged batteries are placed on one side and empty batteries on the other. Therefore as it rotates the system can manage the flow of batteries. The last is the track under the car, which will move the car to the right changing position.

The battery is cubic as this shape is used by the majority of companies and is therefore easier to manufacture. Locating the battery in the lower-middle part of the car is the best solution as again this is the industry standard. Due to weight distribution this is important as without good drive quality people will not take up the new system. This design also makes the replacement of the battery more convenient.

A clipping system is use to attach the battery to the car. Four clippers are placed on each corner of the battery so the connection is strong. When replacing a signal is sent from the robotic arm head that activates or deactivates the clippers meaning that the battery is securely in place. Also no one can access this without the correct equipment which is a safety feature.

When replacing the battery the car is parked in a bay on tracks. The driver then can select to change the battery (which will require a 'login' to a profile using a Radio Frequency Identification -RFID- card). The conveyor belt tracks will the lower at the wheels so it will be locked in place and the car will be conveyed along the system changing the battery.

A mechanical arm is designed to lift and fall. Two position sensors are placed on it, once a position error is detected; the arm itself is able to rotate to adjust the orientation. The battery is then removed and placed in the charging mechanism and the full battery is placed into the car.

4.3 Battery Exchange Process

When the driver deems it necessary to replace the battery, they arrive at the station and parks on the conveyor belt tracks. The driver swipes the membership card on a touch-screen where they can select to change their battery (they can also see other information regarding their membership on the system). The tracks then lower under the wheels to lock the car in place. As the car progresses the driver no longer has to take any action and the fully automated system replaces their battery. On the other side, the tracks are raised and the driver is notified that the process is complete.

During the battery exchange, the batteries are loaded in a 'magazine' under the car, which revolves and is reloaded with charged batteries ready to be used. Empty batteries are placed on the vacated slot of the magazine and are moved to a charging bay. This relies on a complex control system but will be a very effective method to maintain the flow of replacing batteries. Figures 1 and 2 show a diagram of the switching and battery clip system.

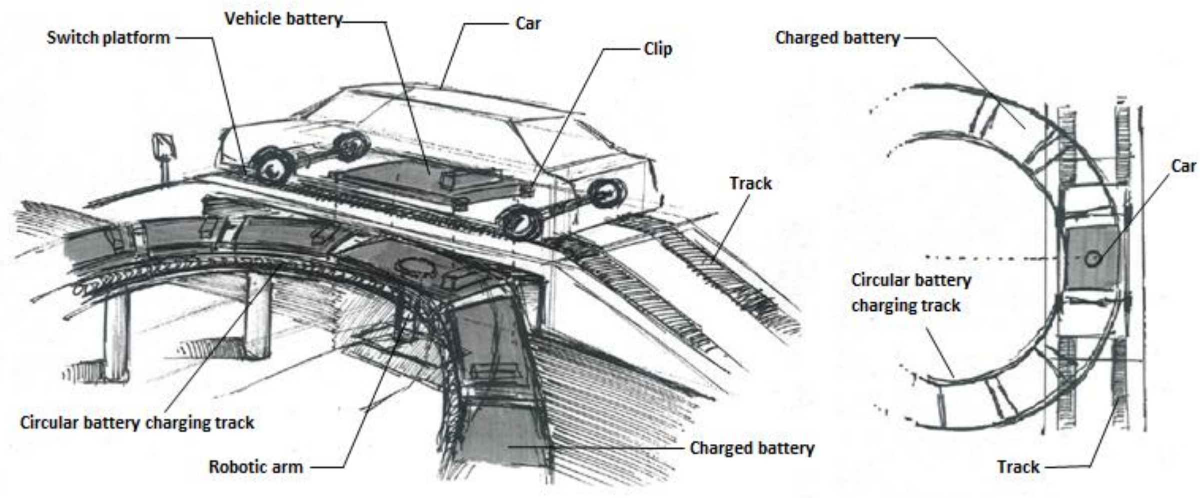

Figure 1: Battery Switch Station diagram showing how battery is changed and circular 'magazine'

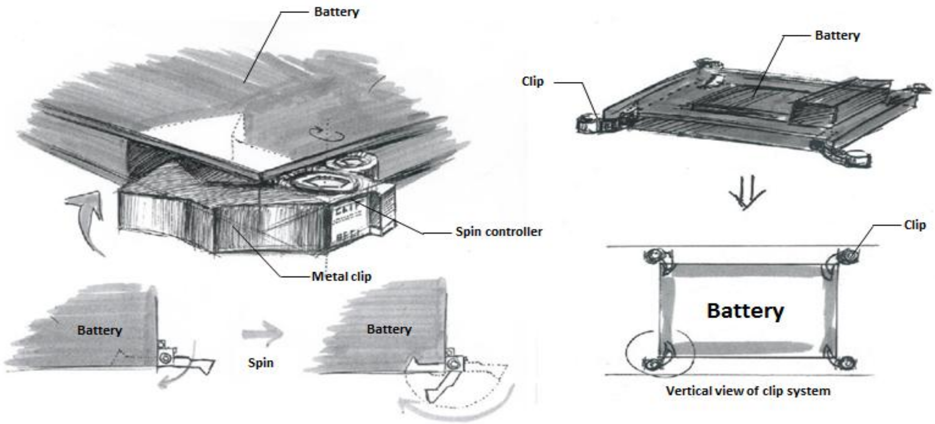

Figure 2: Battery clip to secure the battery in place

4.4 Battery Recharging and Storage System

Storing and charging of the batteries will be done next to the switch area in an underground section. Batteries are transferred from the mechanical arm to a rack area where it will be plugged in to the system. A smart charge algorithm like the one shown in figure 3 will decide which charge method (fast, slow or night time) is required to make the most effective use of resources. Charging systems in each slot constantly observe the charge level to make sure batteries are not over charged and to highlight any faults in the battery. The control system also manages the main charging method. This works by distributing a main "pulse train" of power between the charging batteries. This is then multiplexed in differing amounts depending on each battery's charging requirements. This enables better control over the recharging process.

Storage capacity for empty battery, fully charged batteries
The switch station not only switches the battery quickly, but also stores and charges the battery. Store and charge actions are done in an underground section. The total space can be split into 2 parts. The larger part for storing empty battery and charged batteries. The other contains the slots for charging batteries. The recommended storage temperature for lithium-ion batteries is from -20°C to 25°C. 15°C is the ideal temperature; a control system will be needed to maintain those conditions (25).

Charging area
Once a battery has been removed from a car it is transferred to an empty slot through a series of conveyor belts and then plugged in. The system can then determine the charge level of the battery and decide what charging method to use for it.

Charging modes
The switch station will have a system monitoring the status of each battery and then predict demand for batteries. By analysing the information, the system can determine the appropriate charging mode that should be used. In addition to preventing the system from switching modes all the time, our system will be 'smart' enough to do these operations. Normally, quick charging mode will only be activated during the day due to the busy traffic. If the number of charged batteries is in excess, the empty batteries will not be charged until the night or off-peak. This is the time when electricity is cheapest. An algorithm like the one shown would be employed to implement this (26).

Test for Batteries Performance
A test should be carried out annually to detect if any battery fails to reach the minimum requirements for capacity, power and safety. All batteries are uniquely identified to simplify managing large quantities.

Information storage
A MIFARE DESFire EV1 microchip is embedded in each battery to store essential information, which has a data retention time of 10 years (27). The chip should be to be tolerant to high temperatures of the battery pack. A reader would be placed in each charge area where the system could then log information about each battery. Important information that will be stored in the

microchips includes battery ID, switch stations that have processed the battery recently and performance of batteries in previous safety tests.

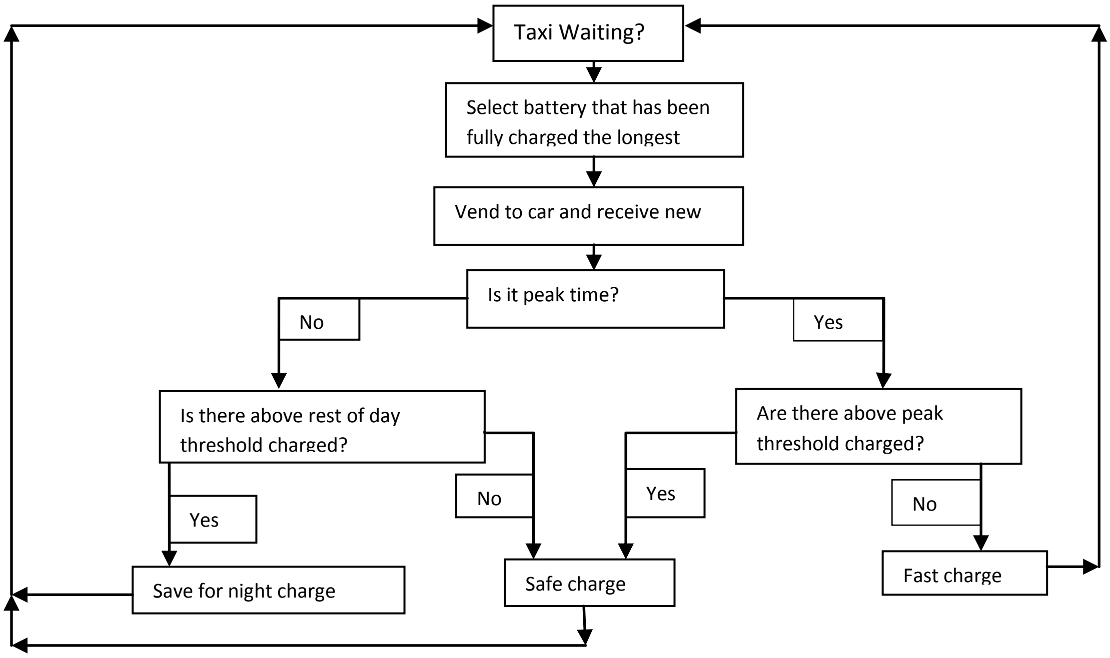

Figure 3: Smart charge Algorithm to show how charge method is selected

5. Finance

When deciding the structure of the system, finance has been a major issue. Originally it system was created for all vehicles but through basic calculations it was found not to be financially viable, especially with such a low rate of electric car adoption. Instead our attention was focussed on implementing a smaller system in a more focussed industry. London taxis are ideal for our type of system financially as; the short term costs are much smaller, far fewer charging stations will need to be implemented, the distances travelled each day are roughly similar and it is easy to predict. As a result a subscription model could be used.

The basis of model is a subscription scheme where taxi companies pay a fixed amount monthly per taxi to use our service stations. On top of this a small charge will be needed to be paid for the electricity used to charge each replaced battery. There are a number of methods in which the electricity can be bought cheaper than normal to increase the profit yielded form this.

Our system has many initial costs and would require a large investment. Firstly the batteries, we estimate these to cost £7500 each according to Howell's guide of '$500 per kWh price estimate for 2012" (28) and it having a capacity of 25kWh. The lifespan of our chosen battery type is roughly five years (shown in the battery section). For the switching station, we calculate it will cost around £320,000 for our system which is the cost of better place's (a good basis to use) (29). Charging a monthly subscription of £125 on top of electricity used we can create a financially viable system that after a large initial investment of £107750000 (spread over five years and offset by an income of £63510000) will make a large profit (£38950000 a year). As the subscription is designed to be low there is little difficulty in increasing it if investors feel it should be. The figures are calculated using our spreadsheet financial model in figure 4.

Creating and building the stations would require an engineering consultancy company. From research, we found that it costs $15M US dollars for 30 petrol stations. Our system would be more as the technology is new but from the previous calculated cost per station added to a reasonable design fee we estimate it to cost £31M ($50M) for 50 stations. This would be spread over a 5 year plan with 3 built in the first, 7 more in the second, 30 built by the third and finally 50 in the fifth.

Another cost to factor into the system is the electricity used for charging. The easiest way to reduce this is to charge batteries during the night, as there is less demand and therefore it is cheaper. This could typically save a third of the price per kWh of electricity (30). For the financial model we have used a basic rate (much higher than we will pay) to estimate the cost. Assuming that each taxi in London will travel 250 miles per day, it will need two new batteries of 25kWh capacity a day. If we assume one charge in the night and in the day and 6.21p and 11.94p per kWh respectively the total fee for electricity per battery is £4.5 GBP per day per battery (31).

It may not be feasible to charge all of our cells during this time, a substantial amount of money could be saved and it fits in with the green objective as electricity generated at this time can often be wasted. For example nuclear power stations can't switch on and off quickly so a deal to take night electricity from these would be very cheap.

As we will be drawing a large amount of power, it may be possible to join the National Grid Frequency response scheme. National Grid has an obligation to provide electricity at 50.00Hz ±1%. To maintain this they need large loads that can be switched on or off when necessary for a short period of time. Frequency Control by Demand Management requires our charging stations to provide 3MW of power for a minimum of 30 minutes. By using our charged cells this is feasible and will provide boost of income. (7)

Another up and coming initiative is a Vehicle-to-grid network. In this network power operators store excess power in batteries, or draw power from them when needed. This is ideal for a system like ours when we have many batteries under our control. This could potentially provide an income of roughly $4000 a year per battery (32). The drawback is the excessive charging and discharging may significantly lower the lifetime of each battery.

Our system has definite potential to generate a reliable income as well as provide useful services for the taxi and power industries. The biggest challenges financially will be to convince taxi companies that the monthly subscription cost is of good value and the upkeep of the batteries and the initial cost of the service stations require a significant investment which would be hard to get.

BECI Costing Spread Sheet

	1st Year	2nd Year	3rd Year	4th Year	5th Year	6th year	10 Years
Expenses (£)							
No. Of Batteries	120	550	1100	3300	9900	500	
Cost of Battery	7500	7500	7500	7500	7500	7500	
Total battery cost	900000	3225000	4125000	16500000	49500000	3750000	
R&D	15000000	0	0	0	0		
Operations	500000	500000	500000	500000	500000	500000	
Stations	3	10	30	40	50	50	
Cost of Station	320000	320000	320000	320000	320000	400000	
Total Station Cost	960000	2240000	6400000	3200000	3200000	0	
Total Expense	17360000	5965000	11025000	20200000	53200000	4250000	
Income (£)							
Subcriptions	100	500	1000	3000	9000	9000	
Money Per Sub	1500	1500	1500	1500	1500	1500	
Customer Income	150000	750000	1500000	4500000	13500000	13500000	
Money Back	360000	1650000	3300000	9900000	29700000	29700000	
Total income	510000	2400000	4800000	14400000	43200000	43200000	
Profits (£)							
Year Margin	-16850000	-3565000	-6225000	-5800000	-10000000	38950000	
Running Margin	-16850000	-20415000	-26640000	-32440000	-42440000	-3490000	347060000

Figure 4: financial model spreadsheet

6. Conclusion

BECI is potentially a green-energy powered system which is able to solve the problem in the development and propagation of hybrids and electric vehicles. It breaks through the traditional idea of charging at home/work by mimicking the function of petrol stations by quickly 'refilling' electricity and greatly extends the driving range of electric cars. The system is an integration of technologies, consisting of comprehensive design of switch station, battery technology, battery storage and charging. Although technically difficult it is possible to create a system that satisfies the customer, car manufacturer and the business.

In the report, BECI has proved to be profitable if there is a good response by target clients. The biggest drawback is that it is a high risk investment due to a large initial cost of batteries and switch stations. However, the costs of EV batteries are seeing a reduction of more than 50% by 2020 due to the technology blooming and larger scale production (11). By starting the business with London taxis and a careful business plan of gradually increasing investment, the risk of the project can be reduced. Consequently it can be a profitable solution (but it is very risky and requires huge initial investment that would be difficult to get). Arguably the social benefits of helping to combat climate change could be seen as more important. It provides a new alternative to switching to electric cars with fewer drawbacks in range of travel. Implemented correctly BECI has potential in shaping the future of greener transportation.

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