VisionCycle

Adaptive, **scalable**, **effective** approach to solving global waste misplacement and waste management issues using computer vision and machine learning

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<u>Summary</u>

Waste misplacement and waste management is a pressing issue that is prevalent across the globe. Consequently, this issue significantly damages earth's environment, and develops negative financial, social, and biological effects. The act of misplacement ultimately begins on the micro level within cities, and expands throughout the country. Therefore, VisionCycle hopes to tackle the issue at the consumer level, and prevent waste misplacement using computer vision and machine learning. More specifically, we are building a hardware and software solution that classifies objects as trash, recyclable, or compost and automatically places it in the correct waste bin.

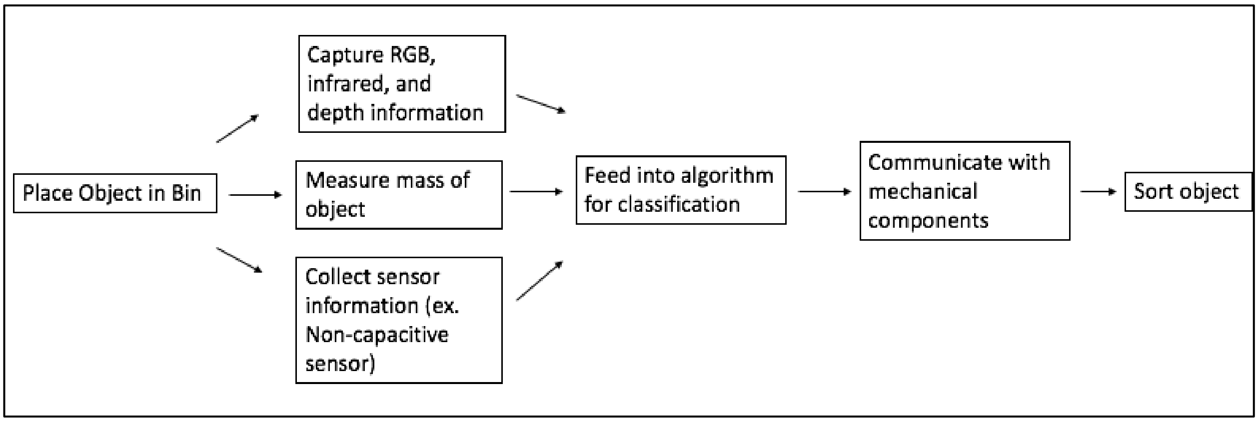


Figure 1: Outline of product pipeline

<u>Problem Statement</u>

As a result of exponential population increase, the Earth's environment faces damage from both natural and human waste. Each year, nations generate 1.3 billion tons of waste, and it is expected to increase to 4 billion by 2100 [31]. The increase in waste threatens the safety, health, and financial conditions across the planet. These ramifications include flooding from garbage-clogged drains, release of methane from contaminated soil and groundwater, lost energy resources, and unnecessarily high waste management costs [31]. America alone misplaces 22 billion plastic bottles every year; with the average American disposing 500 plastic cups and tossing 4.4 pounds of trash [32]. Furthermore, a study sponsored by NASA's Goddard Space Flight Center states that earth's natural resources are at risk of depletion in the coming decades [34].

Similarly, these effects of waste misplacement can clearly be seen on the micro level as well. For example, based on an interview with Director of Cal Zero Waste Program, about 70% - 80% of trash sent to landfills from UC Berkeley are compostable. Furthermore, mixed materials such as bubble wrap envelopes and traditional chip bags, are heavily misplaced objects in the community because it is difficult for consumers to properly pinpoint its correct bin. Lastly, UC Berkeley Zero Waste program mentioned that it is difficult to engage and educate the campus community about waste misplacement, therefore preventing optimal waste placement.

Therefore, in order to sustain a healthy environment for the longevity of future generations, it is crucial to address these environmental issues. Statistics show that if materials from the U.S. waste stream was properly recycled, it would generate over $7 billion [33] and if Americans recycled just one-tenth of newspapers, we would collectively save about 250 million trees a year [33]. On a local level, when programs distribute their waste to the respective facilities, trash, recycle, and compost, they have the potential to reduce costs and increase revenue. Furthermore, as shown in the target market diagram (figure 3), our solution has the potential to alleviate waste misplacement, while capturing a profitable addressable market.

Existing Solutions

1. Multi-Labeled Waste Bins

So far, multi-labeled bins have done a great job in providing individuals with the ability to dispose waste in the correct bins. Previous to multi-labeled bins, trash bins were the only accessible option. Although the emergence was these bins were well needed, they pose a few significant limitations. First, it plays the assumption that individuals already have prior knowledge of which bins their items go to. In hopes to resolve this issue, some bins are labeled with image examples and short explanations; however, these labels are at times confusing and do **not effectively** provide a holistic view of which objects should be placed in the respective bin.

2. Waste Management / Recycle Initiatives

In effort to collectively improve the environment and waste management, cities have initiated and developed their own programs to address problems unique to them. Examples of initiatives range from placing charges on households that overproduce trash to banning plastic bags in restaurants and grocery stores. In some cases, these have improved the environmental conditions. However, in other cases, cities are **unable to scale** and deploy these programs because they do not have the financial resources or proper advising.

3. Increase Public Recycle Bins

This is similar to the multi-labeled waste bins, however it is only for recyclable material. The spread of recycle bins have grown, and they are becoming much more accessible. While these recycle bins have decreased the amount of littering and recyclables being thrown in the trash, it requires the bins to be properly spread throughout the whole city to **adapt**. Depending on the size and complexity of the city, this may be difficult.

4. Technology Solutions

These solutions are in the same category as VisionCycle, where they use technology, and possibly, artificial intelligence to solve waste misplacement. Currently, these solutions have made significant progress, which ultimately validates VisionCycle's approach. However, depending on the product, some do not have the capability of classifying objects or they are less affordable than our current solution. We will address all these characteristics below in our proposed innovation section.

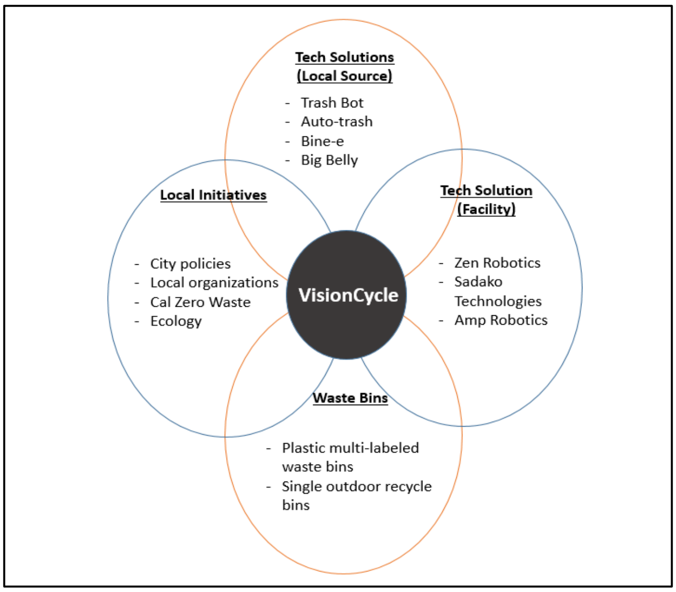


Figure 2: Pedal Diagram of Existing Solutions

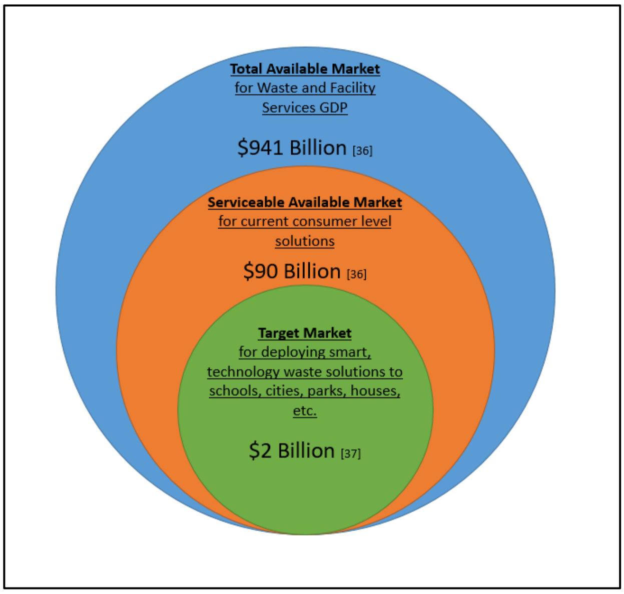


Figure 3: Total Market Diagram

Proposed Innovation:

VisionCycle is our “big idea” that addresses waste misplacement and waste management at the core and improves upon many current solutions. VisionCycle is a computer vision application that classifies objects through computer vision algorithms and automatically places the object into the correct bin, as shown in the figure 1. Currently, we have three proposed solutions for development:

1. Manual Sorting Solution

The first iteration consists of a robust algorithm with naive hardware setup. It will only require the allow us to capture images and classify the object. This will include a high-resolution camera that captures RGB, infrared, and depth, Raspberry Pi Computer Chip, and trash bins with motorized lids. The consumer will simply place the object on a flat surface for the camera to properly capture the image, it will run through our classification algorithm, and then the correct trash bin will slide its lid open. This consumer will then manually place the object to the open waste bin.

2. Automatic Sorting Solution

The second phase is a fully automatic, “smart” trash bin that detects the object and automatically places the object in one of its own three bins. Unlike the first iteration, this only requires the individual to place the items in the “smart” bin and the rest is left for the bin to separate and properly dispose. This phase will include the same devices in the ‘Non-Automatic Sorting Phase’, but with more mechanical features.

3. Universal Module Solution

Lastly, we are considering a solution that universally fits into currently existing trash cans. This would involve a flexible, collapsible module which can be adjusted depending on the size of the trashcan that it is being installed on. In regards to hardware, this approach is similar to the ‘Automatic Sorting Solution’, but without the lower body (three trash cans).

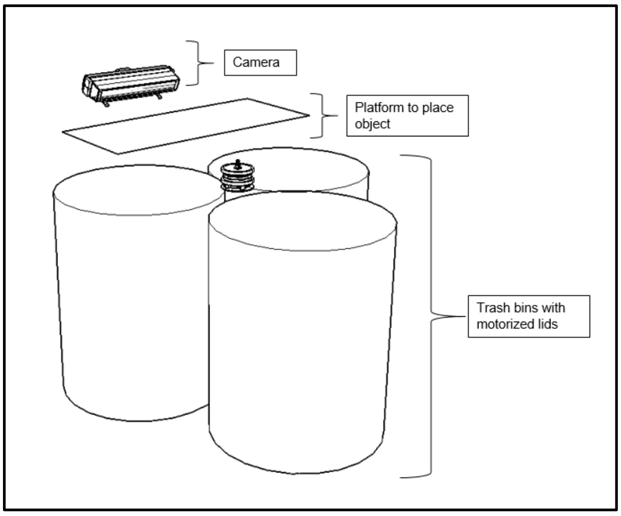


Figure 4: Manual Sorting with Classification

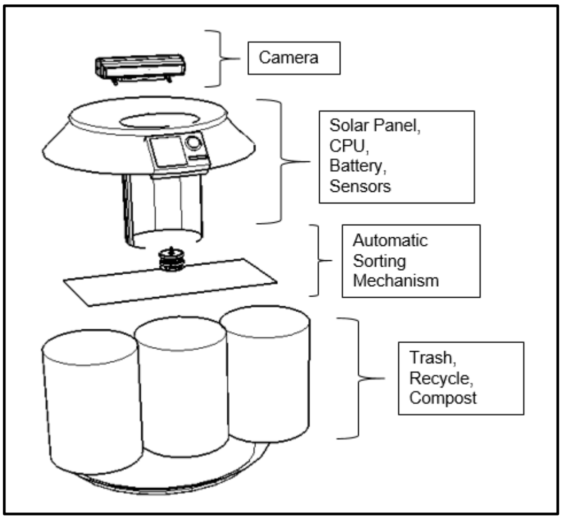


Figure 5: Automatic Sorting with Classification

I. Goals and objectives

1-Year Goals:

1. Reduce the contamination rate of waste in each category (trash, recyclables, and compost) at the source level
2. Provide a low-cost solution for organizations to install to increase number items that end up in the stream of the RRR (Reduce, Reuse, Recycle) model

1- Year Objectives:

1. Develop an algorithm that sorts waste with an accuracy greater than 90%
2. Increase the volume of items that are in the compostable loads by up to 80%
3. Deploy manual sorting phase in at least one location indoors and one location outdoors during Cal Zero Waste pilot program
4. Create the hardware prototype that moves items to correct category determined by our algorithm from manual sorting phase
5. Fundraise $10,000 to support product development over the next year

Post 1-Year Objectives:

1. Scale product to other cities and states
2. Place product in other environments: Airports, sky rises, theme parks, etc.

II. Methods For Achieving Goals and Objectives

In order to properly achieve these goals and objectives, we will need to have the engineering team completely finalized. Currently, we are in the process of recruiting a mechanical engineer and computer vision engineer. The VisionCycle team has been communicating with a few mechanicals engineers from Bay Area Engineering Consultancy and Big Ideas Resources. For computer vision interns, we will find students specializing in computer vision through our close connections with UC Berkeley Artificial Intelligence Research (BAIR) Lab groups. Once we finalize our team, we will design our software and hardware pipelines, and begin building our product.

Furthermore, throughout our building phases, we will constantly be in touch with Cal Zero Waste Program to provide updates, gain additional information regarding the waste management field, and receive product modification feedback. Once we have the prototype complete, we will bring it to Cal Zero Waste to prototype on campus. In addition to having access to Berkeley Community for testing, we will also leverage their resources for marketing and exposure.

We are currently in contact with managers at The House, an incubator based in Berkeley. Since The House accepts early stage startups and supports student founders, VisionCycle plans to apply for the program as soon as possible.

Lastly, VisionCycle has been connecting with many potential partners and investors. In addition to the connections mentioned above, we are being mentored by Kal Deutsch, an investor at Batchery, and in communication with Ravi Kurani, an entrepreneur and investor in sustainable technology.

III. How We Are Unique from Current Solutions

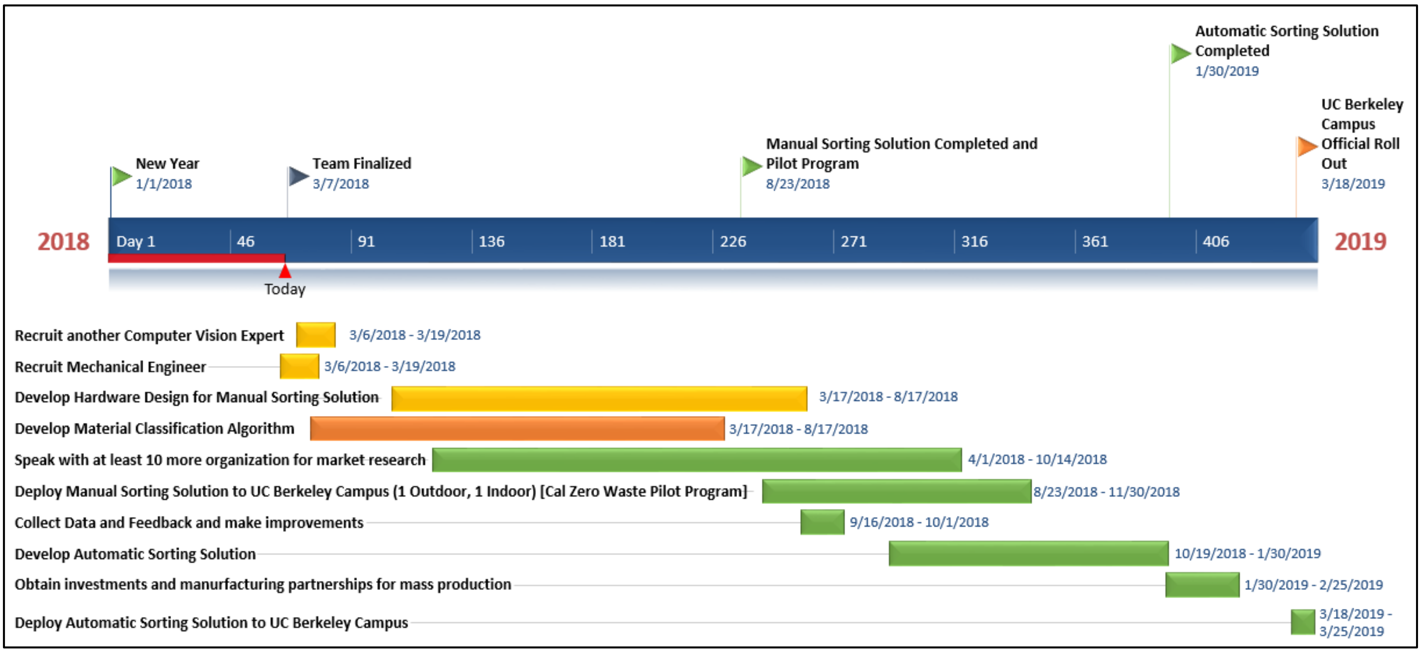
Name	Summary	Pros	Cons	Target Market	What we do better?
Trashbot	Automatic sorting trash bin separating recyclables from trash	- 81% sorting accuracy[1] - Technology is patented[2] - SaaS providing metrics on types of materials tossed[3] - Team has impressive credentials[4]	- Trash can capacity is too small [5] - Selling a entire trash can [5] - Hardware design only allows for sorting of two categories[5] - Small sliding door is the weakest link in the mechanical system [5] - Does not use solar power [5]	College campuses, residential complexes, airports, cities, office buildings [5,6,7]	Automatic sorting bin phase: - Sort three categories (recyclables, trash, compost) Universal-fit automatic sorting module: - fit onto existing trash bins and convert into a three bin system, which will be cheaper than buying a trash can
Big Belly	Large capacity trash can coupled with SaaS that sends notifications on the capacity of the trash can	- Large capacity [9, 11] - closed-top [9] - solar power [9] - built in trash compactor [9] - foot pedal [9, 10, 12] - clear signage [9] - trucks can pick up Big Belly directly [9]	- Unreliable notifications of when the trash can is full [13, 14] - Expensive upfront cost (~$4000) [13, 14] - Indoor version of Big Belly uses electricity [9]	College campuses, residential complexes, airports, cities, office buildings [11,12]	Manual sorting phase: - Material classification, so customers can measure their contamination rate [9] Automatic sorting bin phase: - provide a solution to indoor bins that do not use electricity - sort materials into correct category/bin Universal-fit automatic sorting module: - fit onto existing trash bins and convert into a three bin system, which will be cheaper than buying a

					trash can
Auto-Trash; Green Can	TechCrunch Disrupt Hackathon project trash bin that sorts compost and trash; MHacks Hackathon project trash bin that sorts recyclables and trash	- Low cost solution [15, 18]	- Can only handle sorting for two categories (compost or trash) [15, 18] - Can only take 1 item being tossed into the trash bin at once [15, 18] - Not a company so doesn't offer hardware or software maintenance [15, 16, 17, 18] - Cannot handle identifying item at night or in dark rooms [15, 18] - Small capacity [15,17, 18] - Seems to handle a limited set of items in each category [18]	None	Automatic sorting bin phase: - offer software updates and hardware maintenance crew - handles three categories (compost, recyclables, trash) - prevents the issue of having multiple items tossed in at once - can identify items at night Universal-fit automatic sorting module: - fit onto existing trash bins and convert into a three bin system, which will be cheaper than buying a trash can
Bin-e	Smart bin automatically sorting glass, trash, plastic, paper	- modern design[20, 21, 22, 23] - handles four categories [21] - compacts waste [21] - SaaS notifications on when bin is full [21, 22] - large capacity [21, 23] - mobile app for residential home users [21, 23]	- Finland based company makes it harder to break into US market [21]	College campuses, residential complexes, airports, cities, office buildings, residential homes [21]	Automatic sorting bin phase: - can identify items at night Universal-fit automatic sorting module: - fit onto existing trash bins and convert into a three bin system, which will be cheaper than buying a trash can
Zen Robotics, Sadako Technologies, AMP Robotics	Robotic arms for automatic sorting at waste management facility level	- upwards of 98% accuracy rate [24-30] - can handle large and heavy objects [24-30] - fast recognition of objects (GPU-powered robot) [24-30] - can handle multiple items at once [24-30]	- too expensive for non-industrial level [24-30] - too much machinery is necessary [24-30] - costly energy expenditure [24-30]	Waste management plants [24-30]	We tackle a completely different market, but are competing with them indirectly if we solve the sorting before it arrives at the waste management plant

IV. Challenges to implementation (Ethical, Cultural, or Legal Matters)

VisionCycle shows promising impact on waste misplacement and waste management, however there are some challenges that should be considered. For example, by automating the process of sorting materials, it may reduce the amount of job opportunities in local facility and custodial departments. Furthermore, as VisionCycle attempts to scale products across cities and states, we may come into direct competition with current solutions. This can potentially create logistical and legal problems because it may involve partnership discussions. Lastly, the intelligence and automation may reduce the attempts at education the public regarding waste misplacement. For example, overtime the public may become dependent on the automation and disregard the importance of placing materials in correct bin.

1 Year Implementation Timeline:



Measuring Success:

Metric	Threshold	Impact of Metric
Contamination rate of trash category	Percentage as low as possible	Saving Cal Zero Waste the cost of having to landfill a truck load because of contamination
Contamination rate of compost category	Percentage as low as possible	Potentially increases profit towards and reduces negative environmental effects
Contamination rate of recyclables	Percentage as low as possible	Increasing profit for Cal Zero Waste from the recyclables, but reducing number of trash loads that have to get landfilled due to contamination
Volume of trash after our solution has been installed	Expect to be higher than before our solution	Easier waste management and prevents trash overflow
Volume of compost after our solution has been installed	Expect to be higher than before our solution	Potentially increase revenue and improve environment through increase of composting

Volume of recyclables after our solution has been installed	Expect to be higher than before our solution	Improve recycling revenue

Budget:

I. Supplies Cost This section may include the cost of materials for producing your good or tools needed for your project	**Supplies Cost Details Please include information here you think will be helpful in explaining the total cost, if applicable (e.g. cost per unit, totally number of units required, etc.)**	**Total**
High Resolution RGB, Infrared, and Depth Camera	This device will be the source of vision and imaging for our product. This will be in all-in-one device that provides visual and depth information. Visual and depth information will allow us to analyze 3D features for proper object classification.	$200.00
Load, Weight Sensor	This device will allow us to compute the weight of the object. This information will be helpful in classifying the type of object.	$15.00
Solar Panels	Each Solar Panel costs $0.83/W. We are estimating to need about 80w - 90w to power our trash can and run computations.	$90.00
Lithium Ion Battery Pack	This battery will be used to power the trash bin	$50.00
Programmable Wifi Control Package	This device will be needed to collect data, send software update notifications, and send messages to holder	$1,100.00
LED Lights	This device will help capture visual information at night or in trash can that is not exposed to light	$15.00
Stepper Motor	This will be used for sorting mechanism. Based on material classification, different motors will be running to direct the material into the correct bin. With each at about $15, we are looking to have 4 motors.	$70.00
Plastic Slats	This device will be used to cover and develop shape of trash bin. Typical large size trash bin is 32 gallon. This computes to 25-1/4"Dia. x 30-1/2""H measurement for slats. In order to account for trash, recyclable, and compost, we will need to triple the amount. Each slat for 32 gallon trash bin is $530.	$1,600.00

Raspberry Pi Computer Chip	This device will act as the brain of the trash bin. It will allow us to compute our algorithms and allow hardware and software to interact.	$50.00
Subtotal Supplies		**$3190.00**
II. Travel & Transportation Costs This section may include any travel costs associated with your project, including lodging costs.	**Travel Cost Details Please include information here you think will be helpful in explaining the total cost, if applicable (e.g. average cost per flight, bus ticket, etc.)**	**Total**
BART Tickets	The team will be travelling from Berkeley to SF to meet with potential partners and investors. Average costs to SF are about $10.	$100.00
Bus Tickets	While the team is in SF, we will be travelling on bus system.	$100.00
Subtotal Travel		**$ 200.00**
III. Personnel Costs This section may include the salaries of anyone you are hiring as part of your project	**Personnel Cost Details Please include information here you think will be helpful in explaining the total cost, if applicable (e.g. FTE and job description)**	**Total**
Mechanical Engineer Makers Space / Office Space	Space on campus to build prototypes, gain access to mechanical materials, as well as space to do work	$500
Software Development Stipend	Developing software	$ 600.00
Hardware Development Stipend	Developing and designing hardware	$ 600.00
Subtotal Other Costs		**$ 1,700.00**
TOTAL PROJECTED EXPENSES Please sum all subtotaled sections above here to give your total projected project expenses.		**$ 5,090.00**

<u>Team Member Biographies:</u>

Franklin Heng is a senior studying computer science at UC Berkeley. He was a computer vision intern at NASA Jet Propulsion Laboratory working on intelligent multi-spectral IR image segmentation. Currently, Franklin is a researcher at UC Berkeley Video and Image Processing Lab, designing sensor suits for a robotic platform and developing computer vision and image processing algorithms. Franklin's leadership and software experience makes him an ideal team member and co-founder.

Edward Qiu is a sophomore studying computer science at UC Berkeley. Some notable startups and organizations include Berkeley Hyperloop, NxtFactor, MoreViews Inc, and inspectX. Experience working with front web technologies and back end web frameworks. He also works closely with Berkeley Haas Entrepreneurship Program and Technology Edward's extensive experience in startups and technology makes him an ideal team member and co-founder.

<u>In Process Recruiting:</u>

Bay Area Engineering Consultancy, currently in talk with founder of Bay Area Engineer Consultancy to obtain a mechanical engineer that will help us with hardware

UC Berkeley Artificial Intelligence Research Lab (BAIR), speaking with computer vision researchers for software development

<u>Advisory Members and Partners:</u>

Kal Deutsch, Partner and Founding Investor-Advisor at Batchery
Adeeba Khairzad, Director of Haas Entrepreneurship program
Kira Stoll, Director of UC Berkeley Zero Waste Program
Michelle La, Manager Assistant at UC Berkeley Zero Waste Program
Ravi Kurani, Entrepreneur and Investor
Peter Mui, Hardware/ Software Expert, Entrepreneur
Andre Carothers, Investor and 25 years of experience in nonprofit management

References:

[1] https://www.aclima.eus/en/clean-robotics-ai-to-sort-recyclables-from-waste/

[2] https://patents.google.com/patent/US20180016096A1/

[3] https://www.geekwire.com/2018/meet-trashbot-cleanrobotics-using-machine-learning-keep-recycling-going-waste/

[4] http://www.cleanrobotics.com/#team

[5] https://interestingengineering.com/the-trashbot-automatically-separates-recyclables-from-actual-garbage

[6] https://www.geekwire.com/2018/meet-trashbot-cleanrobotics-using-machine-learning-keep-recycling-going-waste/

[7] https://techcrunch.com/2016/02/09/the-trashbot-will-eat-and-sort-your-garbage/

[8] http://triblive.com/local/allegheny/12381540-74/trashbot-is-going-to-clean-up-city-hall-in-pittsburgh

[9] Conversation with Michelle La and Kira Stoll from Cal Zero Waste

[10] http://www.govtech.com/fs/perspectives/BigBelly-High-Tech-Trash-Cans-in-Philly-Didnt-Work-Out-As-Planned.html

[11] https://www.phillymag.com/citified/2015/08/04/big-belly-trash-cans/

[12] http://www.philly.com/philly/news/pennsylvania/philadelphia/trash-compactors-bigbelly-philadelphia-streets-20171108.html

[13] http://greenwheaton.org/faqbigbellysolarinwheaton/

[14]http://www.syracuse.com/news/index.ssf/2013/07/phillys_4000_big_belly_trash_cans_a_messy_waste_city_controller_says.html

[15]https://techcrunch.com/2016/09/13/auto-trash-sorts-garbage-automatically-at-the-techcrunch-disrupt-hackathon/

[16] http://www.waste360.com/source-separation/auto-trash-smart-trash-can-automatically-sorts-waste-type

[17] https://blog.hackster.io/leave-it-to-auto-trash-to-automatically-sort-your-garbage-6b62dfedf7f
[18]http://www.mlive.com/business/ann-arbor/index.ssf/2013/09/check_out_a_smart_trashcan_and.html

[19] https://phys.org/news/2013-09-smart-recycle-bin-record-breaking-mhacks.html

[20] https://roboticsandautomationnews.com/2017/01/19/smart-trash-can-automatically-separate-and-sort-out-rubbish/10716/

[21] http://bine.world

[22] https://roboticsandautomationnews.com/2017/01/19/smart-trash-can-automatically-separate-and-sort-out-rubbish/10716/

[23] https://www.youtube.com/watch?v=4FKsS96Ytpc

[24] https://www.forbes.com/sites/jenniferhicks/2017/04/04/this-recycling-robot-uses-artificial-intelligence-to-sort-your-recyclables/#2b4ed4f2d353

[25] https://gizmodo.com/this-trash-sorting-robot-could-revolutionize-recycling-511989613

[26] https://blogs.nvidia.com/blog/2016/04/06/robot-recycling-sadako/

[27] https://www.roboticsbusinessreview.com/listing/sadako-technologies/

[28] https://www.youtube.com/watch?v=c0myJzAdOOc

[29] http://www.westword.com/news/amp-robotics-developed-clarke-a-robot-that-sorts-cartons-8981910

[30] https://www.amprobotics.com

[31] Simmons, Ann M. “The World's Trash Crisis, and Why Many Americans Are Oblivious.” *Los Angeles Times*, Los Angeles Times, 22 Apr. 2016, www.latimes.com/world/global-development/la-fg-global-trash-20160422-20160421-snap-htmlstory.html.

[32] “Land of Waste: American Landfills and Waste Production.” *Visit Our Main Website*, www.saveonenergy.com/land-of-waste/.

[33] “Recycling Statistics.” *BYU-Idaho*, www.byui.edu/university-operations/facilities-management/recycling-and-sustainability/recycling-statistics

[34] Ahmed, Nafeez. “Nasa-Funded Study: Industrial Civilisation Headed for 'Irreversible Collapse'? | Nafeez Ahmed.” *The Guardian*, Guardian News and Media, 14 Mar. 2014, www.theguardian.com/environment/earth-insight/2014/mar/14/nasa-civilisation-irreversible-collapse-study-scientists

[35] Hauslohner, Abigail, and Antonio Olivo. “Cities and Counties Come to Grips with the High Cost of Recycling Programs.” *The Washington Post*, WP Company, 23 June 2015, www.washingtonpost.com/local/dc-politics/cities-and-counties-come-to-grips-with-the-high-cost-of-recycling-programs/2015/06/23/b53b98fc-18de-11e5-ab92-c75ae6ab94b5_story.html?utm_term=.61feda04065a.

[36]https://www.bea.gov/iTable/iTable.cfm?ReqID=51&step=1#reqid=51&step=51&isuri=1&5114=a&5102=15

[37] https://www.marketsandmarkets.com/PressReleases/smart-waste-management.asp