Developing a Sunflower Seed Sheller for Rural Africa

E105: Professor Ken Pickar

Aimee Eddins
Elisabeth B. Wildanger
Philip Wong

Executive Summary

Our mission is to design an automated shelling machine to improve the efficiency of sunflower oil production in Benin.

Market Opportunity: The market we are targeting is the Benin agricultural market. Highlights of the market are outlined below (note: some information taken from http://www.designthatmatters.org/). Regional trade, rural agriculture, and subsistence farming play a large role in the Benin economy. Because of this dynamic, improving the efficiency of certain agricultural processes in this arid country can have a major impact on rural communities. Oil presses exist for shelled sunflower seeds to create a nutritious and valuable commodity. There exists no alternative to manually removing the sunflower seed shells before using these presses. Improved micro-production will help insulate local communities from the effects of potential volatility of the price of raw goods.

Technology Solution: We will meet this need by creating an impact dehuller (a device that removes the hulls of the seeds). Prototyping has proved the concept of using an impact cracking mechanism. The next step is to develop methods of separating the seeds from the hulls. One possible solution to this is to use the wind created by the impact mechanism to blow the hulls away while allowing the seeds to fall to the bottom.

Target Market: Our primary target market is the Centre Songhai, Mieux Vivre aux Village and possibly other local NGOs. We chose these areas because of their expressed interest in this product and their established relationship with Design That Matters, a MIT based enterprise.

Table of Contents

The Need and the Consumer

There are two basic uses for the sunflower seed dehuller. The first is for nutritious oil—found in sunflower seeds. By using a mechanical dehuller the speed of shelling the seeds will be greatly increased. This will make sunflower oil more accessible to the general public.

Edible oil production is an important commodity. An article written about a company that developed a press for sunflower seeds (to extract the oil) points out that, "Insufficient consumption of dietary fat, an important source of calories, is a common health problem in most developing countries…In much of the region [of Zimbabwe and Kenya], young children subsist mainly on maize meal porridge with sugar and milk. Adding edible oil would be nutritionally desirable" (http://web.idrc.ca/en/ev-30571-201-1-DO_TOPIC.html).

The second basic use is to improve micro economies. The Design that Matters website explains how a dehuller would boost local agricultural enterprises: "Tabletop...shelling machines would provide a major economic boost to rural communities around the world by allowing them to add value to locally-produced agricultural products." If it takes three people to shell "n" pounds of seeds, and with a dehuller one person can shell the same amount of seeds, the two other people are freed up to focus on other aspects of the community economy.

Not only can dehullers boost the production of shelled seeds and consequently, sunflower oil, but they can provide entrepreneurship opportunities for youth in Africa. We are simplifying and cheaply redesigning a product used in first world countries for use in developing countries. The Centre Songhai "promotes agricultural entrepreneurship among the youth in

Africa." A shelling machine could create opportunities for budding youth. For example, an individual can start a business shelling seeds for other people with his dehulling machine.

Sunflower Seed Processing

There are two main kinds of sunflowers grown and used for human consumption: oilseed and confectionery. Oilseed varieties "contain from 38 to 50 percent oil and about 20 percent protein" (DocNewsNo605DocumentNo2377.pdf). Confectionery seeds produce only 25 percent oil (http://Scarab.msu.montana.edu/extension/MTCrop_Profiles/MTsunflower.html). Confectionery seeds are sold commercially for human consumption hulled and in the shell. Oilseeds are primarily used for oil production and are also used in bird feed. Confectionery seeds are larger than oilseed, have black and white stripped hulls and have thick hulls which are only loosely attached to the seed. It is primarily confectionery sunflower seeds that are grown in Benin (and Africa in general). This is largely because the varieties grown were "originally selected to yield bird seed for export" (http://web.idrc.ca/en/ev-30571-201-1-DO_TOPIC.html).

In large scale processing of confectionery sunflower seeds, the seeds are first sifted according to size. The smallest seeds are used for animal feed, medium seeds are typically dehulled and used for production of goods for humans, and large seeds are roasted and sold as snack food. (http://www.saskschools.ca/~gregory/sask/sunf.html)

Current large-volume machines use only a few mechanisms to dehull seeds. The most widely used method is an impact dehuller. An impact dehuller consists of a rotating blade which propels seeds into a hard material outside the diameter of the blades. The force of impact causes the hulls to break.

Seeds are then separated in a variety of ways including shaking conveyor belts, multiple sifting screens, and by vacuum.

We also conducted research on commercial cracking methods of other nuts. For peanuts we found that typically they are cracked by passing them through a small groove. A design created for developing countries took this idea one step further by passing the seeds through an ever decreasing aperture, allowing for shelling of multiple sizes of nut with one machine. (http://www.peanutsheller.org/)

A sunflower seed sheller made by the College of Agriculture in India uses a centrifugal shelling mechanism (i.e. an impact dehuller) with a throughput of 1.25 gallons per hour and a power use of 3 horse power. (http://www.fao.org/inpho/isma?p=AdvancedSearchDetail&category=&technique=&lang=en&btn=Search&m=equipment&commodities=100&i=INPhO&topic=&company=&energySource=&n=4)
In Zamibia, women operating mission-owned hand machinery were able to process 150 kg (approximately 330 lb) of seeds per day.
("*Small scale processing of oilfruit and oilseeds.*" Wiemer, Hans-Jürgen, Frans Willem, and Korthals Altes. A Publication of the Deutsches Zentrum für Entwicklungstechnologien - GATE in: Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, 1989. p55.)
An example of large volume throughput impact dehuller from Forsbergs Inc. can process 1500 pounds of seeds per hour with a power usage of 7.5 horse power. (http://www.forsbergs.com/products/15-d-ih.html)

These samples allow for the prediction that the available power source (5 to 15Hp) should be sufficient (if not excessive) for our needs.

Target Market

Our primary target market is local NGOs such as Centre Songhai and Mieux Vivre aux Village in Benin. Our secondary market is local companies and entrepreneurs and customers outside Benin such as in India and other African countries.

This type of market has been proven to be accessible in other African countries such as Zimbabwe and Uganda. Having proven their product ideas for small scale sunflower oil production in other countries, we will need to develop a plan to deter companies from invading our market space as well as to make headway into theirs. Based on the methods used by Zimbabwe company Rural Associated Manufacturers (RAM) Pvt. Ltd (http://web.idrc.ca/en/ev-30571-201-1-DO_TOPIC.html) and the ideas introduced to us in class by Dr. Michael Rosberg, we will begin by forming a need-based partnership with local entrepreneurs.

This product will be used in a rural setting by local farmers. Because of the nature of work it will be replacing, the device may be used by men, women, and children of standard farming ages. The goal is to create a device that a user uses to automatically shell seeds. As a nation, Benin plans to attract more foreign investment in part by developing new food processing systems. This goal fits in nicely with the scope of this project. Another added includes availability of local power sources. Existence of power sources (5 hp, 15 hp engines) allows cost of the device to reach $300, allowing for more design flexibility. A strong working relationship has been established by the Design That Matters (DTM) team which, if possible to use, would be an immense help in designing the product to suit the customer. Facilities and trained staff to test prototypes are in employment at the Centre Songhai.

Existing Competition

As of the publishing of this paper, there are no companies directly competing for our market space. A few other collegiate teams have begun addressing how to best solve the same design problem through interfacing with Design that Matters, but we are confident that we could join forces to continue forward with this enterprise. Other companies and entrepreneurial ventures have established markets in other rural, third world countries such as Uganda and Zimbabwe. These companies are primarily partnerships between companies in the US and small NGOs in each locality. Examples are Africare (http://www.africare.org/at_work/seeds/index.html), Rural Associated Manufacturers Pvt. Ltd, and ZOPP Pvt. Ltd (http://web.idrc.ca/en/ev-30571-201-1-DO_TOPIC.html), small village based companies such as The Amina Edeke Farmers' Association in Uganda (http://www.enterpriseworks.org/_success_ugan.asp), local NGOs such as Appropriate Technology Zimbabwe (http://web.idrc.ca/en/ev-30571-201-1-DO_TOPIC.html), and colleges and affiliated research-based institutions that have resources to create and finance the initial stages of a business. Our competition has already proven the market concept in other countries. However, our technology space has not yet been filled and the differences between countries may be sufficient to keep their experience from affording them too large of an advantage.

One significant difference between other suppliers of machines for small scale sunflower seed production and ours is cost.

IPI in Dar Es Salaam, Tanzania provides hand powered sunflower seed processing equipment that can process 140kg of seed a day with 7 operators but which all together costs $4000 US (this cost includes oil press, dehuller and two other processing machines so we estimate the cost of their dehuller to be $1000 US ("*Small scale processing of oilfruit and oilseeds."* Wiemer, Hans-Jürgen, Frans Willem, and Korthals Altes. A Publication of the

Deutsches Zentrum für Entwicklungstechnologien - GATE in: Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, 1989. p77-8.) Other manual dehullers are approximately the same price. Prices for small scale motor powered dehullers are much harder to find. This may be a result of there being few to no reliable small scale motorized dehullers in operation. The high (estimated) cost of the hand powered dehullers suggests that motorized dehullers (if any should be in operation) would be prohibitively expensive to occupy our market space.

Dehuller Design Process

After benchmarking the available dehullers, we brainstormed, coming up with new ideas and design twists off of existing dehullers. In order to evaluate the many design possibilities we knew we would soon have, we created a tool with which to quantitatively rank the design ideas. Our design tool incorporated five major categories: materials, ease of use, ergonomics, and manufacturing. Safety was not considered in the DFX tool because it is an overarching category that cannot be compromised. The design tool was modular which allowed the weighting of each category to be customized. Each category was composed of different criteria and contributed to a given design's final score. This tool allowed us to evaluate the product designs.

The most heavily weighted category in the design tool (DFX tool) was manufacturing. This was the most important category because the entire feasibility of the product depended on it being manufacturable. Materials and safety were categories of equal weight. To make the dehuller viable for a developing country, the cost would have to be reasonable. Since materials play a significant role in the product's cost, this category was quite important. Safety, also, was of key concern. Since the mission of this project is to improve the efficiency of sunflower oil production in Benin, ergonomics and ease of use were categories of lesser significance. If the product turned out to require training because it was not intuitive, the training would be worth the effort because the efficiency of the dehuller would compensate for the time lost for training.

There are some constraints (or, "design challenges") that shaped the weightings within the DFX tool. Some of these constraints were defined by the original agricultural centers that posed this design project to Design that Matters. Other constraints came from the desire to make a socially satisfying and acceptable product.

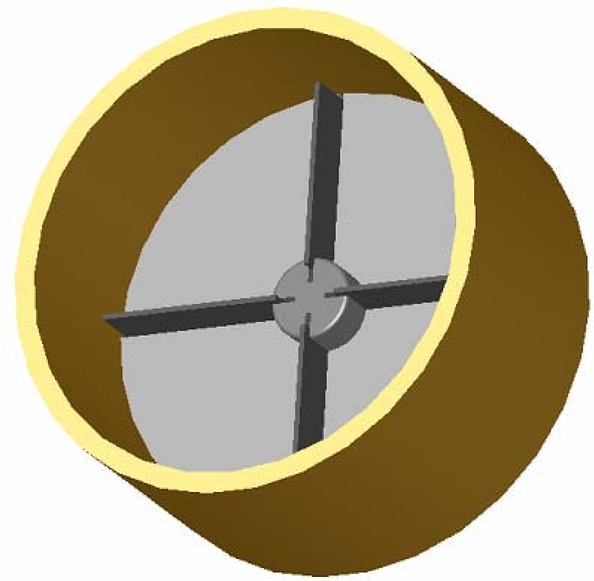
The cost of the device must be equal to or less than $300. This price does not include the power source (the country has 5 hp and 15 hp engines available) but it does include whatever interface between the power source and the device is necessary. In an attempt to minimize dependence on the United States, the materials required for repair must be available locally to the one who has bought the device. This means that the design needed to be made of material that can be found in many places in the world. The mission of our group is to "design an automated shelling machine to improve the efficiency of sunflower oil production in Benin." As such, the design needed to be efficient (especially more efficient than shelling seeds manually). Thus, the cost to maintain the device would need to be reasonable.

To further focus our brainstorming efforts, we created a high-level architecture that highlighted the key functions of each component and their subsequent interfaces. The dehuller was broken down into five necessary components: the power source, the seed feed and entry system, the cracking mechanism, the separation of seeds from hulls, and the output. For each component in the architecture, multiple ideas were discussed.

With the constraints in mind, the variety of design possibilities were ranked and judged using the DFX tool (Appendix). The design that ranked above the rest was an impact shelling device.

Proof of Concept

We designed and machined an impeller wheel that sits inside an 11" cylinder of aluminum. The wheel has steel blades which cause the seeds to accelerate toward the outer wall. After prototyping this part of the device, we were able to summarize the results.



Our dehuller is designed to work solely on the input of one spinning shaft, may it be a motor or an engine. The motor turns the plate at a speed of ~3000 RPM. This driving force moves the acceleration mechanism ("the plate") as well as driving the winnowing process (hull and seed separation). Assuming a mass of 5e-5 kg per seed, each seed experiences an impact force of 0.19-0.69 mN compared to 0.056-0.75 mN in commercial shellers. Further quantitative testing will allow us to detail other device specifications including volume throughput and percent efficiency

Business and Manufacturing Strategy

Our business strategy relies on the basic belief that the most sustainable companies rely on a for-profit model. We have adapted this model and began evaluating proposed business plans by first identifying manufacturing opportunities and choosing a specific manufacturing strategy. Because the Company's product is agricultural equipment, our manufacturing strategy is closely tied to the design of our automated dehuller.

In order to accurately compare potential manufacturing strategies, we created a design tool that identifies the strengths and weaknesses associated with each possible way of manufacturing the dehuller while also allowing us to focus on key manufacturing criteria. The design for manufacturing (DFM) tool is composed of seven major categories: Make/Buy, Inventory Strategy, Worker Training, Worker Motivation, Government Regulation and Import, Infrastructure Issues, and Owners' Sanity. The breakdown of each category is briefly explained below.

- Make/Buy (20%)
    - Low Cost – how much does it cost to make or buy the product with a given manufacturing strategy, lower cost being better
    - Fast turn-around time – how quickly can we manufacture our product
    - Availability of materials – ease of obtaining materials
    - Minimum quantity – can we make a few or is it mass produced right away. Lower score given to strategies that require large minimum quantity
    - Variable cost/capital expenditure – how flexible are these elements to fitting the needs of a small startup business. More flexible and cheaper options given better scores
- Inventory Strategy (10%)
    - Small Inventory – minimizing our inventory is essential
    - Cost of storage – if we have inventory, does it cost a lot to store (lower score if it does)
- Worker Training (7.5%)
    - Adequate – will this strategy provide the worker with the knowledge necessary to make the product
    - Comprehensive – will the worker be able to understand the big picture of the manufacturing process and know how he fits in
    - Safety skills taught – to keep a safe workplace this must be a priority
    - Useful skill set – so that after employment the skills can be used to better the country
    - Focused – will the training be well organized; teaching superfluous facts is a waste of time
- Worker Motivation (7.5%)
    - Competitive wages – important for keeping workers at the company
    - Positive community impact – can the "factory" impact the surrounding community for the better: economically or socially
    - Personal investment/Catch the vision – since our goal is a beneficial goal, workers can rally behind a worthwhile cause
    - Sustainable motivation – e.g. is it feasible to give a competitive salary
- Government Regulation and Imports (20%)

  - Worker benefits – do laws govern what benefits we must give out and can we provide them easily
  - Tax benefit/write offs – can we benefit from starting up a company (profit or non-profit), higher scores for what tax friendly
  - Reliable accounting – ease of keeping financial books straight
  - Reasonable import fees – import fees that greatly affect our manufacturing process receive lower scores
  - Independent from government relations – is it possible to pursue the manufacturing process without working explicitly with a government?
  - Multinational – does the manufacturing strategy allow for expansion to other nations
- Infrastructure Issues (10%)
  - Small overhead cost – the overhead cost should be small to prevent fluctuations in the market from affecting the company
  - Appropriate size – distribution strategies should fit the size of the company
- Owners' Sanity (25%)
  - Health – this category highlights the importance of the owners' (Phil, Aimee, and Beth) ability to sustain the operations of the manufacturing.

We then evaluated six possible manufacturing strategies. The possibilities were: living in the Caltech tunnels and using the student shop to create the devices, recruiting manufacturing engineers at Cal Poly (or partner with another university or college to manufacture the dehuller), completely outsource the manufacturing, live at Beth Wildanger's house and manufacture dehullers while working day jobs, set up a factory in Benin, and finally, lease factory space and follow the traditional business model of obtaining investors. The performance of each idea is evaluated using the DFM tool in Appendix 3. Partnering with an academic institution received the highest score of 504 points out of a possible 700 points. The DFM tool provided insight into the complexities of the manufacturing process and allowed us to anticipate these difficulties in our business strategy.

Initially, using the Design that Matters business model of leveraging relationships with academic institutions will cut down on labor costs. Because of the scope and potential application of the product, we believe that working through collegiate channels will be well received on both sides. While this model will not work for high volume manufacturing, it is enough to improve the product design through multiple production iterations while testing the target market and proving the business model of selling dehullers before scaling up manufacturing. In addition, initially minimizing costs will allow us to provide enough first round financing to reach this first milestone.

After reaching the first milestone, we will pursue a second round of funding which will allow us to reach a critical level of production. In this second round of funding, we will reach out to local angel and venture capital groups. This second round of funding will allow us to travel to Benin to work on site while dramatically increasing our production capability. Expansion of operations outside of Benin into other developing countries will follow. Tapping these markets will allow for increased sustainable demand. At this point, we believe that simple technological changes to our dehuller will allow us to adapt our technology to shelling other types of seeds, further expanding our target market. This business plan is more closely examined in our financial model.

Company Financial Strategy and Cash Flow Statement

Please see Appendix 4 for full our financial model. The model reflects our understanding of the Company's cash flow needs. It also sets a realistic performance metric that we, as the Company founders, can work toward to benchmark our financial progress. Our belief is that creating a for-profit enterprise is not taking advantage of the market that we are trying to tap. Instead, we believe that by creating a profitable company, our business model can be both sustainable and reproducible. In order to create the simple financial model, a few assumptions were made. Our assumptions are elaborated in this section. In order to simplify our assumptions, this model does not take into account inflation; dollars in future periods have been discounted to current dollar value.

Our financial focus is on the Company's cash flows for a three particular reasons. First, the current information lends itself best to constructing this statement as opposed to a balance sheet and an income statement. Second, it is the best indicator of Company performance as a start-up. Finally, we believe that the assumptions used to create the cash flow statement stand with the most credibility at this time. The timescale used is one that reports the financial health of the Company every half year. Because we are a start-up company that intends to move quickly, we would like our investors to see that we are planning our finances according to an ambitious and practical timeline, a timeline that cannot be fully captured when reporting in one year increments.

The cash balances section contains the highest level, and most pertinent, information. Investment shows what we believe can be quickly raised through personal and professional contacts. Due to the nature of our enterprise and our proposed partnership with local Benin NGO's, we believe we can successfully launch the company with a first year investment of $20,000. A second round investment of $75,000 will be used to finance expensive portions of the project such as travel and foreign setup expense. This portion of investment will come after proof of concept and prototyping have been completed. Because our product does not rely on heavy development of infrastructure, we believe that this level of investment is both practical and sufficient to successfully launch the Company.

Revenue is constructed simply by multiplying number of devices sold by the selling price of $300 per device. Because the model relies on the formulaically generating an approximation of devices sold by allowing for fraction of devices to be sold, revenue is not in discrete $300 portions. Cash on Hand shows, at two separate times in a half year period, the Company's beginning and ending cash balance. A graph of the revenue growth and cash balance can be viewed in Appendix 5. These figures capture the Company's financial health in a quick snapshot.

The cost section shows, in detail, how the Company intends to spend its money. This section highlights our business strategy of minimizing labor costs by making use of work done in academia. We believe that this competitive advantage will allow us to conserve our financial resources at early manufacturing stages before expanding the production scale. The number of devices produced is reflective of management team's belief in how quickly we can reach a sustainable and profitable production level. Selling price per device is kept stable at $300. Material costs per device are shown to fall by 10% each half as we move towards achieving economies of scale and better efficiency as we improve the integrity of our supply chain. Cost of labor per device and shipping cost per device fall at 10% and 15% respectively each period, again due to economies of scale reached at higher volumes and improving the efficiency of our product cycle. Other costs are taken to be varying percentage levels of production and shipping costs. This section of costs reflects administrative and other costs that are not given in detail in this report. The high cost in this category in the first few years reflects the added expenses necessary to start up the business (for expenses such as travel to Benin and unanticipated costs of doing business) before it levels off at 25% of production and shipping costs.

Our level of inventory captures our marketing and production goals. Modeled after Dell Computers, we will minimize our inventory (seen in devices on hand). As time goes on, we will hold fewer devices in our inventory as a percentage of devices sold as we work toward perfecting this strategy. The level of inventory also shows when we will saturate the Benin market and when the Company will need to expand operations in other countries. Our assumption is that one in five thousand Beninese will have the resources and desire to purchase our device. This means that by 1H 2009, the Benin market will be saturated. This valuable assumption has allowed us to gauge when we will need to begin building market share in other countries. Other metrics shown in the model display burn rate and expected company life span, in months, demonstrate Company financial stability in any period.

The Company management believes that the projected cash flow statement captures both the financial opportunity of this enterprise while establishing important milestones and performance metrics for the Company. We believe that this section reflects the summation of the product design, manufacturing process, distribution, and marketing and sales of the Company.

Lessons Learned

Throughout the course of the term, we saw our thinking evolve as we applied the tools presented in class to our thinking and design processes. A few of the major lessons learned during the term are listed below.

Design for Development

- For-profit companies operating in developing countries are not taking advantage of the population in those countries – sustainability can mean profitability.
- Added complexities come with targeting an overseas market.
- Establishing and leveraging local contacts is essential to doing business in developing countries. Building relationships is essential.

Prototyping & Design

- It takes special equipment to manufacture things larger than 12" (prototyping size constrained by the side of the clamps on the CNC in the mechanical engineering shop)
- An initial prototype can be expensive to make because of a supplier's minimum-purchase price.

- Though surplus motors can be nice for a prototype, a more reliable (and most likely expensive) manufacturer must be pinpointed for consistent supplies.
- Rapid design evolution at early stages plays a major part in the final product design.
- Multiple iterations are needed to successfully design a product ready for the market.

Team Building Skills

- Team dynamic becomes essential when designing a product
- Clear and effective communication between team members from day one is needed to effectively move toward a successful design.

Next Steps

After working to develop a prototype, we are thrilled to see that it actually cracks the seeds. This development came as something as a surprise to us, given that the short timescale of the prototyping phase. Nonetheless, the force generated was sufficient to crack the seeds. The next steps we must take to bring our dehulling device to market include developing and attaching the seed/shell separation unit as well as the flow regulator. After the entire prototype is designed, we will perform comprehensive tests (volume throughput, device lifetime, application to shelling other seeds, etc.). Future tests will allow us to improve our dehuller. Once multiple iterations of the prototyping process are completed, and with the help of other academic institutions, the design could go into the marketing stage as mentioned earlier in the paper.

Conclusion

We successfully completed our desired project goals that were set at the beginning of the course. While many steps did not produce anticipated results, the design, prototyping, and development processes helped us move our ideas, concepts, and dreams toward reality. Every step taken in this project has been an immensely enjoyable and educational experience for each member of the group. Not only have our eyes been opened to the other side of engineering and design, but we are also grateful for the opportunity to explore a business enterprise that we may pursue in future.

Acknowledgements

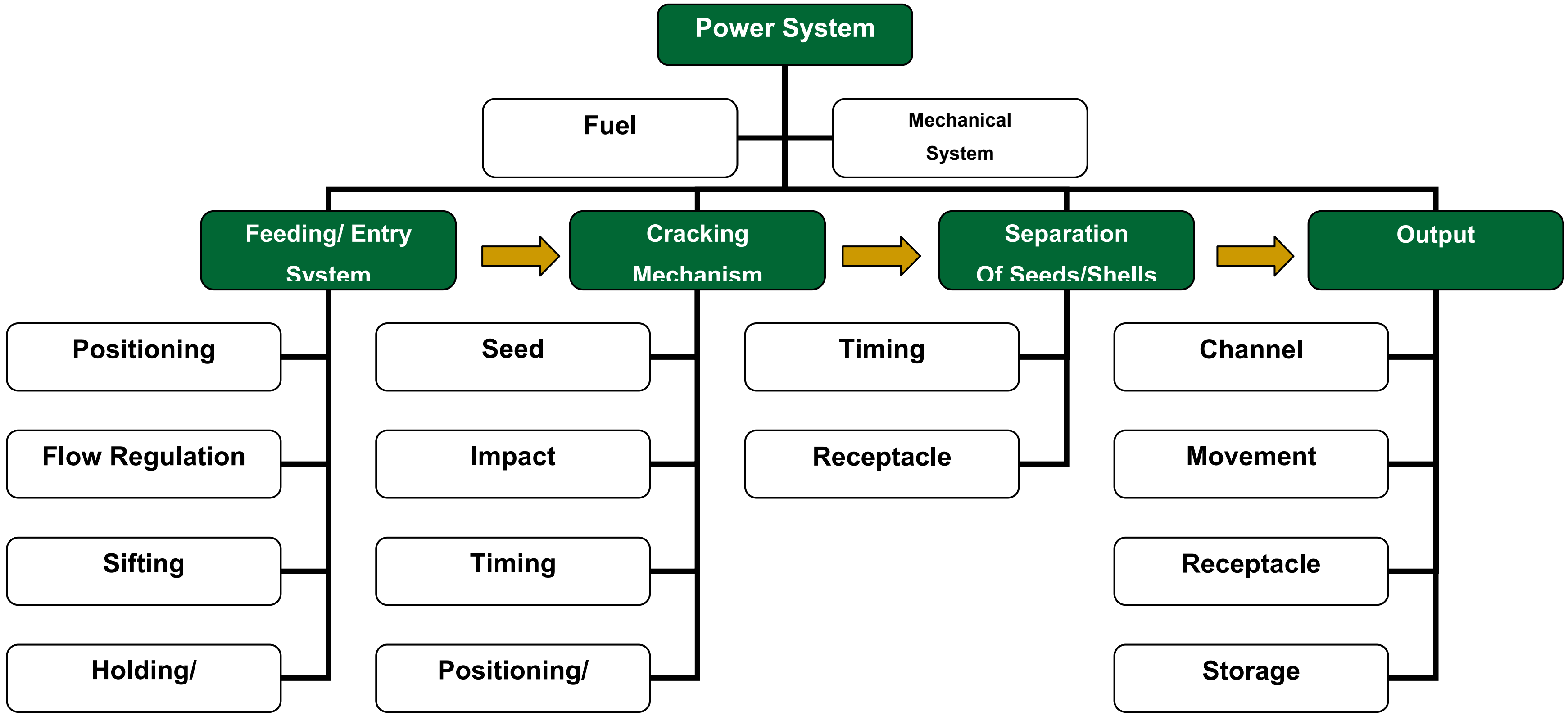
For their generous help and support, our team would like to acknowledge some key players in the development of this sunflower seed dehuller: Professor Ken Pickar, for his feedback and lessons throughout the term; Eugene Mahmoud and Engineers for a Sustainable World at Caltech for proposing and helping to run this class; John Van Deusen for his immense help through the prototyping stages-machining multiple parts, giving advice about materials and adding to our enthusiasm with his own. We also want to acknowledge Jennifer Hawley and Ward Wildanger for their help in machining the base of the device.

Appendices

Appendix 1 DFX Tool

	Category Weight	Score (1-7) Design 1: Crush	Score (1-7) Design 2: Sonic	Score (1-7) Design 3: Blades	Score (1-7) Design 4: Impact	Score (1-7) Design 5: Water	Score (1-7) Design 6: Laser	Score (1-7) Design 7: Electric	Score (1-7) Design 8: Pressure
Materials (25%)									
Reasonable materials	15%	6	1	5	4	1	1	3	1
Material cost	40%	4	1	4	3	2	1	2	1
Location	25%	6	1	3	4	2	1	2	1
Tools needed	10%	4	1	4	5	4	3	2	1
Recycle/reuse/environmentally friendly	10%	4	3	4	4	3	3	2	2
		4.8	**1.2**	**3.9**	**3.7**	**2.15**	**1.4**	**2.15**	**1.1**
Ease of Use (15%)									
Intuition	15%	5	5	6	6	2	3	1	1
Like it	5%	7	2	5	7	1	5	3	3
Ease of set up	25%	3	2	3	6	3	4	2	1
Maintenance/repair	30%	2	1	3	5	3	2	1	1
Mistake-proof fasteners	5%	6	7	5	6	3	6	3	2
Interface	20%	4	6	5	5	4	5	3	3
		3.55	**3.2**	**4.05**	**5.55**	**2.95**	**3.6**	**1.85**	**1.55**
Ergonomics (20%)									
Cultural fit	25%	6	2	6	6	1	3	2	2
Religious compatability	25%	6	7	6	6	2	3	5	4
Interface ease	30%	5	6	5	5	4	3	3	3
Ethical issues	5%	6	2	6	6	2	3	4	4
Communication/language	15%	6	5	6	6	3	3	5	2
		5.7	**4.9**	**5.7**	**5.7**	**2.5**	**3**	**3.6**	**2.9**
Manufacturing (40%)									
Construction	10%	5	1	3	4	1	4	1	1
Efficiency	15%	4	6	5	5	3	3	3	2
Efficacy	15%	5	5	5	5	3	2	3	2
Upgradability	5%	1	3	2	1	3	2	3	1
Manufacturability	25%	4	1	3	4	2	2	4	1
Robustness	20%	3	2	3	5	3	5	2	1
Size	10%	4	3	4	2	4	6	4	2
		3.9	**2.85**	**3.65**	**4.15**	**2.65**	**3.35**	**2.95**	**1.4**
Final Score (out of 700)		**443**	**290**	**418**	**456**	**254**	**283**	**272**	**165**

Appendix 2 Product Architecture



Appendix 3 DFM Tool

DFM tool

Scores between 1-7

	Category Weight	Living in the tunnels at Caltech	Recruiting manufacturing engineers from Cal Poly SLO	Outsourcing	Live at Beth's House and have day jobs	Set up factory in Benin	Start up a business and search for investors and lease factory space
Make/Buy (20%)							
Low cost	30%	6	4	4	6	3	3
Fast turn-around time	15%	3	5	3	2	1	5
Availibility of materials	15%	3	3	4	2	2	5
Minimum quantity	20%	7	7	1	6	3	1
Variable cost/capital expenditures	20%	7	5	3	6	2	7
		5.5	**4.8**	**3.05**	**4.8**	**2.35**	**4**
Inventory Strategy (10%)							
Small inventory	40%	7	7	3	7	3	3
Cost of storage	60%	4	5	2	5	7	3
		5.2	**5.8**	**2.4**	**5.8**	**5.4**	**3**
Worker Training (7.5%)							
Adequate	25%	7	7	3	7	7	5
Comprehensive	25%	7	7	3	7	7	5
Safety skills taught	30%	4	6	3	4	6	5
Useful skillset	10%	3	7	2	3	7	2
Focused	10%	6	7	3	6	6	5
		5.6	**6.7**	**2.9**	**5.6**	**6.6**	**4.7**
Worker Motivation (7.5%)							
Competitive wages	35%	1	1	1	1	4	1
Positive community impact	15%	3	4	3	3	5	2
Personal investment/Catch the vision	20%	6	6	2	6	7	2
Sustainable motivation	30%	2	4	2	3	2	2
		2.6	**3.35**	**1.8**	**2.9**	**4.15**	**1.65**
Gov't Regulation and Import (20%)							
Worker benefits	10%	3	3	7	5	3	2
Tax benefits/write offs	15%	6	6	5	6	4	7
Reliable accounting	25%	6	6	5	6	2	6
Reasonable import fees	30%	3	3	2	3	7	3
Independent from gov't relationships	10%	3	3	3	3	4	3
Multinational	10%	1	1	3	1	3	4
		4	**4**	**3.9**	**4.2**	**4.2**	**4.35**
Infrastructure Issues (10%)							
Small overhead cost	60%	7	7	4	7	2	4
Appropriate size	40%	7	7	3	7	2	4
		7	**7**	**3.6**	**7**	**2**	**4**
Owners' Sanity (25%)							
Healthy	100%	1	5	5	3	1	6
		1	**5**	**5**	**3**	**1**	**6**
Final Score (out of 700)		**399**	**504**	**359**	**447**	**311**	**435**

Appendix 4 Cash Flow Statement

	2H 2005	1H 2006	2H 2006	1H 2007	2H 2007	1H 2008	2H 2008	1H 2009	2H 2009	1H 2010
Cash Balances										
Investment	$5,000	$15,000	$75,000	$0	$0	$0	$0	$0	$0	$0
Revenue	$0	$5,400	$14,300	$30,900	$59,800	$105,800	$149,600	$224,200	$299,200	$300,000
Cash on Hand Beginning of period	$5,000	$16,100	$79,500	$55,900	$29,300	$37,900	$64,200	$129,700	$241,700	$407,800
Cash on Hand End of Period	$1,100	$4,500	$55,900	$29,300	$37,900	$64,200	$129,700	$241,700	$407,800	$589,200
Costs										
Number of Devices Produced	4	20	50	100	200	350	500	750	1000	1000
Selling price per device	$300	$300	$300	$300	$300	$300	$300	$300	$300	$300
Material Cost per device	$150	$135	$122	$109	$98	$89	$80	$72	$65	$58
Cost of labor per device	$50	$45	$41	$36	$33	$30	$27	$24	$22	$19
Total Production Cost per device	$200	$180	$162	$146	$131	$118	$106	$96	$86	$77
Shipping Cost per device	$75	$64	$54	$46	$39	$33	$28	$24	$20	$17
Production and Shipping Cost	$1,100	$4,900	$10,800	$19,200	$34,100	$53,000	$67,300	$89,800	$106,500	$94,900
Other (% cost of Prod&Ship Cost)	250%	250%	250%	200%	50%	50%	25%	25%	25%	25%
Other	$2,800	$12,200	$27,000	$38,400	$1,700	$26,500	$16,800	$22,400	$26,600	$23,700
Total Costs	$3,900	$17,100	$37,800	$57,600	$51,100	$79,500	$84,100	$112,200	$133,200	$118,600
Inventory										
% Inventory sold	0%	75%	85%	95%	97%	99%	99%	99%	99%	99%
Devices Sold	0	18	48	103	199	353	499	747	997	1000
Devices Produced to Date	4	24	74	174	374	724	1224	1974	2974	3974
Devices on Hand	4	6	8	5	6	4	5	8	10	10
Other Metrics										
Burn Rate	$640	$2,800	$6,300	$9,600	$8,500	$13,200	$14,000	$18,700	$22,000	$19,800
Company Lifespan (months)	1.8	1.6	8.9	3.1	4.5	4.8	9.3	12.9	18.4	29.8

Appendix 5 Revenue and Cash Balances