Introduction:

The following is the final proposal by Negap Wax, Inc. for a dewaxed lube oil basestock and food grade wax production plant. This design assumes that the plant will be integrated with an oil refinery in Baytown, TX, from which we will receive our feedstock of heavy gas oil. This heavy gas oil cut will enter our solvent dewaxing process after being processed by an aromatic extraction unit. Also, the design assumes that the refinery will be processing Minas crude oil, a high wax content crude from Indonesia.

Our solvent dewaxing process will implement a unique blend of methyl ethyl ketone (MEK) and toluene to give added efficiency in both oil dewaxing and solvent recovery. To deoil the wax to food grade quality, we will use the warm-up deoiling process, which is the most efficient deoiling process for low oil-content waxes.[1] Our plant will process approximately 2,000 barrels of heavy gas oil per day. The pour point chosen for our final dewaxed oil is 20°F, producing approximately 50 wt% wax and 50 wt% dewaxed oil, as can be seen in Figure 1. Both the dewaxed oil and the food grade wax will then be sold for profit.

[1] Sequeira, A., “Lubricant Base Oil Processing,” *Lubrication*, 75, Texaco, Inc., White Plains, NY, 1989.

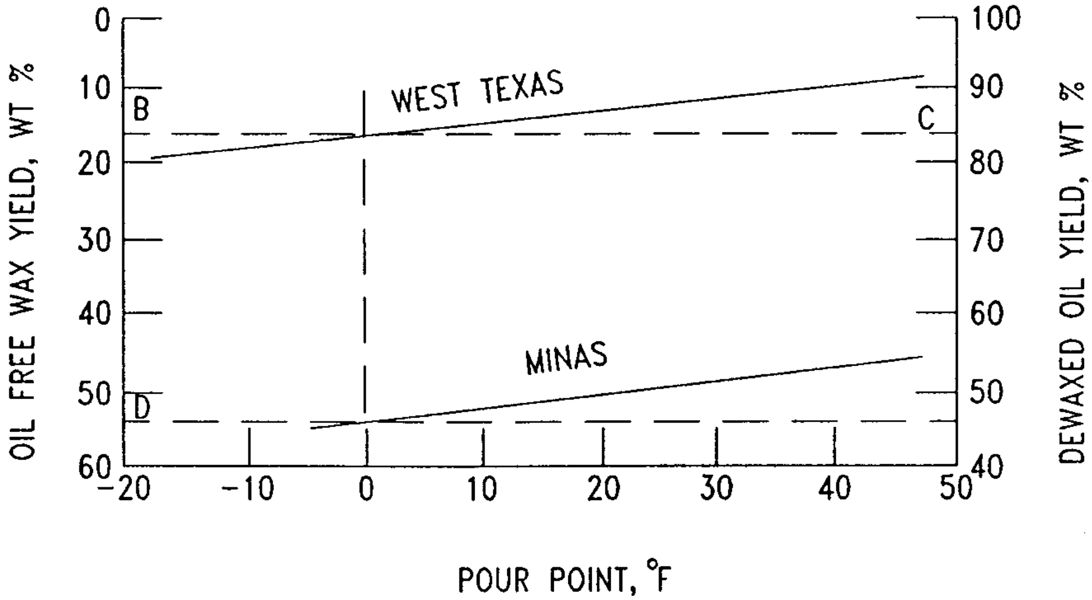

Figure 1: Ultimate dewaxed oil yield for a light neutral raffinate.[2]

Market Review:

Our market analysis has shown that total refined wax production during 1995 by the thirteen manufacturers in the United States was 4.6 million barrels.[3] Since dewaxing oil is the most expensive process in the refinery,[4] we feel that our ability to implement a more efficient process will prove to be a profitable venture and make our company competitive against other manufacturers.

Refined wax, or food grade wax, is a highly valuable commodity, used in the production of many products in today's economy, ranging from chewing gum to crayons. The demand for wax will continue to

[2] Sequeira, A. "Crude Evaluations for Lube Oil Manufacture," Paper presented at Texaco Lubrication Oil Manufacturing Process Symposium, White Plains, NY, May 18-19, 1982.
[3] National Petroleum Refiners Association, 1993 Survey.
[4] Gudelis, David. Improvements in Dewaxing Technology. Esso Research and Engineering Company, Technology Sales. Linden, NJ.

expand with the economy, which will ensure market security for years to come. Some examples of types of products from the dewaxing process are shown in Figure 2 below.

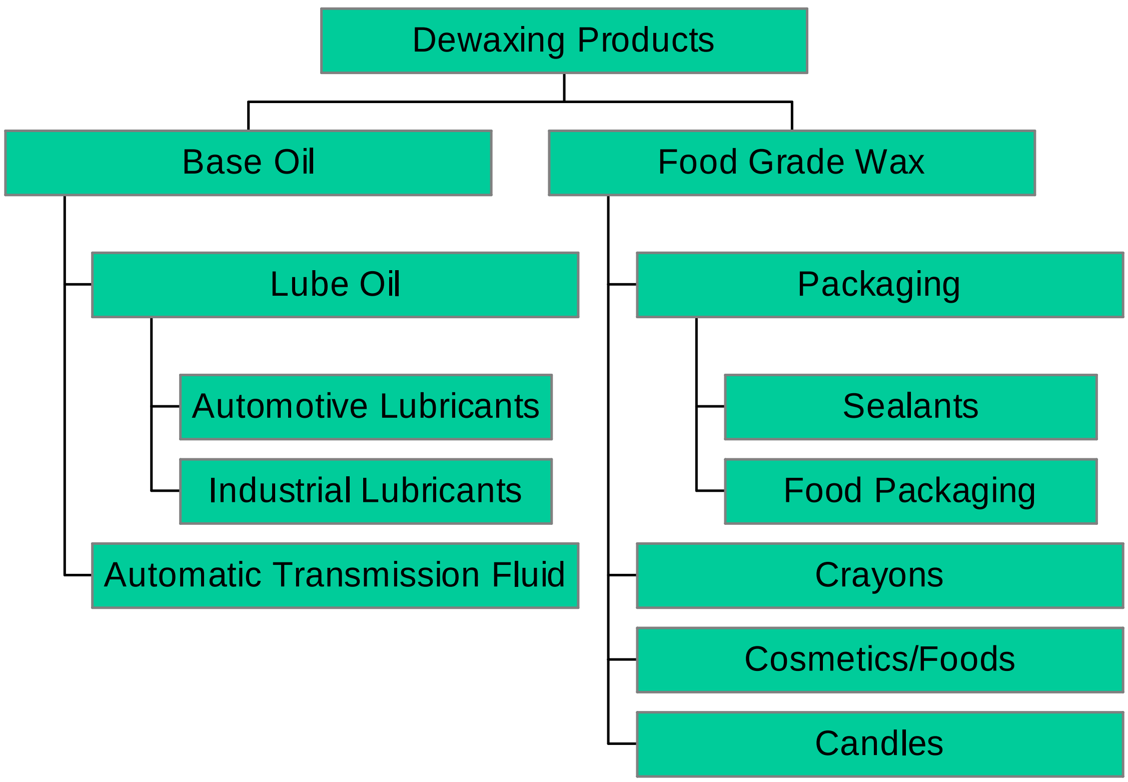

Figure 2: Dewaxing Process Products.[5]

Choice of Process:

Different manufacturers of wax utilize different types of processes. These processes can be divided into two major categories: catalytic dewaxing and solvent dewaxing. In catalytic dewaxing, the main objective is to recover dewaxed base oils. The wax molecules are subsequently broken down in the reaction. Solvent dewaxing utilizes a solvent with a high affinity for oil and low affinity for wax to separate the crude cut into wax and dewaxed oil. One advantage to solvent dewaxing is that both the recovered wax and the dewaxed base oil can be recovered and sold to increase revenue.

The choice of solvent is an important factor in this type of process. The properties of the solvent contribute to the efficiency and capacity of the plant.[6] To choose our solvent, we compared the properties of the two most commonly used solvents, propane and MEK/toluene. Propane is readily available in a refinery, making it a low cost solvent. However, it has a relatively high affinity for wax, making it more difficult to separate the oil from the wax. A lower filtration temperature is necessary with propane solvent than with MEK/toluene solvent to achieve the same wax yield. MEK/toluene has the advantage of a low solubility for wax and a high solubility for oil. Therefore, we chose to use MEK/toluene for our solvent dewaxing process.

To determine the optimum mixture of MEK and toluene in our solvent, we utilized the relations given in Figures 3 and 4. In Figure 3, we determined our MEK/toluene ratio to give us an optimum solvent affinity for oil. For our feedstock, the optimum oil in solvent ratio is about 0.16, which can be achieved at a solvent dilution of 4:1 if the solvent composition is 42 vol% MEK and 58 vol% toluene (40 wt% MEK and 60 wt% toluene).

[5] The International Group, Inc. http://www.igiwax.com. 1999.

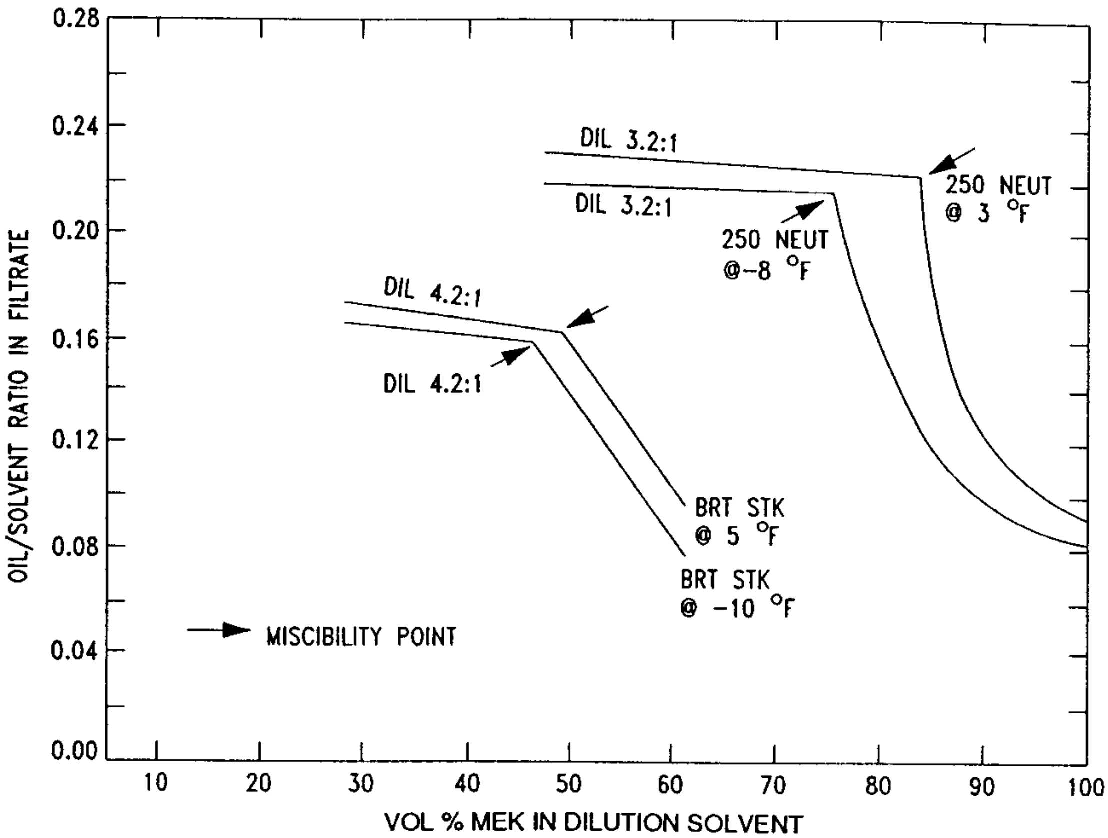

Figure 3: MEK-toluene miscibility diagram.[7]

With this solvent composition and our chosen pour point, T_1, the relation shown in Figure 4 demonstrates how our crystallization temperature was determined. Using the known solvent composition and the solvent dilution ratio, T_2 can be found from this relationship and a temperature

[6] Scholten, G. G., "Solvent Dewaxing," *Encyclopedia of Chemical Processing and Design*, Marcel Dekker, New York, 1983;15:353-370.
[7] Marple, S. and Landry, L.J. "Modern Dewaxing Technology," *Advances in Petroleum Chemistry and Refining*. 1965;24:355.

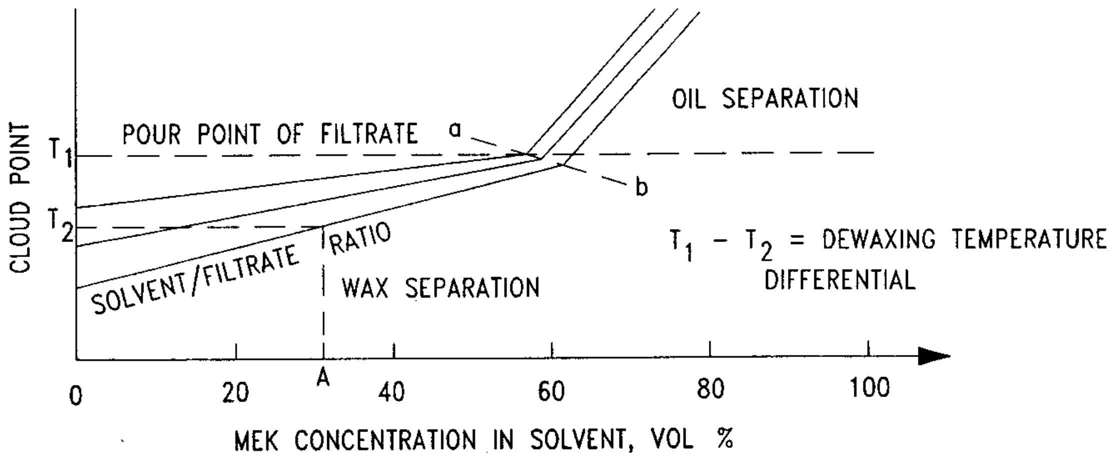

Figure 4: Miscibility diagram of filtrate in toluene/MEK mixtures.[8]

differential can be calculated. For our feedstock the temperature differential is 15°F, which defines our crystallization temperature to be 5°F.

For our fully refined wax to be food grade, it must meet the U.S. FDA requirements listed below in Table 1.

U.S. FDA Requirements for Waxes	
Less than 0.5 % oil content	
Ultraviolet absorbence	
280-289 milimicron	.15 maximum
290-299 milimicron	.12 maximum
300-359 milimicron	.08 maximum
360-400 milimicron	.02 maximum

Table 1. [9]

In order to ensure the purity of our product, samples of wax will be sent to a chemical analyst in the refinery lab. To achieve an oil content of less than 0.5%, the wax will have to be deoiled extensively. The warm-up

[8] See [5] above.

deoiling process has low capital and energy requirements, making it more cost effective for low oil content waxes.[10] This, along with our efficient dewaxing process, should give us the upper hand with our competitors.

Process Description:

The plant process can be broken down into five major areas, as shown in the attached block flow diagram. These five areas are Solvent Crystallization, Dewaxing/Deoiling, Solvent Recovery from Oil, Solvent Recovery from Wax, and Refrigeration Unit.

In Solvent Crystallization, Process Area 100, the feed stream is the heavy gas oil cut from the distillation column in the refinery. The refinery stores this stream at a high temperature of 95 °F. This allows us to receive the feedstock without crystallized wax in it, permitting only controlled crystallization within our plant. Before crystallization of the wax can begin, a solvent stream is added to the feed stream to help separate the oil from the wax as it crystallizes. This solvent stream is mainly a recycle stream, with some makeup solvent available. It is heated to 95 °F before being added to avoid "shock treating" the waxy oil feed stream. Shock treatment of the waxy oil stream would cause the wax to form tiny crystals. These small crystals are not ideal for filtration, since they would clog the filter cloth, resulting in a lower wax recovery.

[9] Gillespie, B. et al., "Modern Trends in Lubricating Oil Manufacture," Paper No. AM-78-20 presented at the NPRA Annual Meeting, March 19-21, 1978, San Antonio, TX.

The waxy oil stream, now diluted 4:1 with solvent, continues on to the chiller to be crystallized. The chiller utilizes five scraped surface heat exchangers to gradually cool the waxy oil to 5°F, the crystallization temperature determined earlier. To form crystals ideal for filtration, it is necessary to slowly crystallize the wax, which is why five heat exchangers are needed. A recycle stream from the second filter in the Dewaxing/Deoiling Process Area 200 is added to the waxy oil stream, which are at the same temperature to again avoid shock treating the process stream. The combined stream, containing crystallized wax, continues on to Process Area 200 to be filtered.

In Process Area 200, the crystallized oil/wax/solvent mixture is filtered through three vacuum rotary filters. For the primary filter, the input stream is separated into a dewaxed oil/solvent stream and an oil/wax/solvent stream. After being utilized for heat integration, the dewaxed oil stream continues on to solvent recovery before being sold as a lube basestock. The oil/wax/solvent stream continues through a secondary filter where it is separated into two streams, one containing mostly solvent and another that contains wax with an oil content of 3 wt%. The mostly solvent filtrate is recycled to the main stream in Process Area 100.

The wax stream must then go through a deoiling process to achieve an oil concentration of less than 0.5 wt%. Before entering the

[10] See [3] above.

tertiary filter, the wax stream is heated to remelt the wax. This allows any oil that was trapped within the wax to escape. Warm solvent is added to facilitate separation of the oil from the wax and the heated slurry is passed through another scraped surface heat exchanger to recrystallize the wax. The tertiary filter separates the stream into a hard wax stream and a soft wax stream with mainly solvent. The soft wax stream is recycled to the main stream in Process Area 100. The final hard wax is reslurried with cold solvent to induce flow and then sent to Process Area 400 to remove all of the solvent and be sold as food grade wax.

In Process Area 300, the dewaxed oil stream is separated from the solvent by two flash distillation towers and an inert gas stripper tower. First, this stream is heated in an almost atmospheric pressure flash where 85 wt% of the solvent is recovered from the oil stream. The oil stream is then heated in a high pressure flash, at 73.5 psi, where a subsequent separation of 85 wt% of solvent is achieved. The oil and remaining solvent goes into a stripper where warm inert gas vaporizes the remaining solvent and removes it from the oil. The purified oil is then sold as a lube basestock. The inert gas with the vaporized solvent is chilled and put into a vessel that allows the liquid solvent to settle out from the vapor inert gas.

The solvent is recovered from the hard wax stream in a very similar manner in Process Area 400. However, in this process, only one flash distillation column is needed. The wax-solvent stream is flashed to allow 85 wt% of the solvent to separate from the wax. The wax stream continues on to an inert gas stripper, similar to the stripper in Process Area 300. The wax is then sold as fully refined food grade wax.

Equipment Description:

To better understand our process, it is necessary to describe in more detail the equipment that is unique to solvent dewaxing. The first of which is the scraped surface heat exchanger, shown in Figure 5. This heat exchanger is used for wax crystallization.

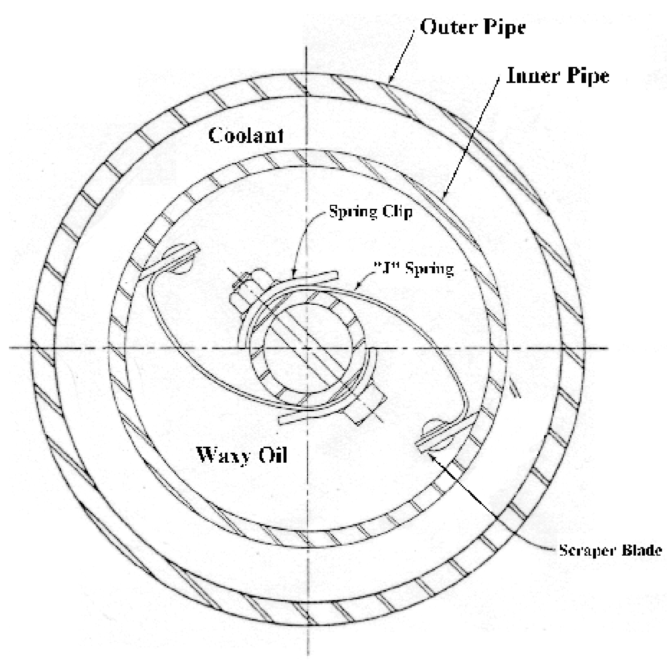

Figure 5: Scraped Surface Heat Exchanger

The warm feedstock runs through the middle of the heat exchanger and the coolant runs on the outside. As the waxy feed is cooled, wax crystals form on the inside of the inner pipe. Because these wax crystals inhibit heat transfer between the waxy feed and the coolant, the sraper blades shown constantly rotate around and remove the wax cake from the inside of the pipe. Although this is necessary to allow more wax crystals to form, it also makes the scraped surface heat exchanger much more maintenance intensive and much more costly.

Another major piece of equipment that is unique to dewaxing processes is the vacuum rotary filter, shown in Figure 6.

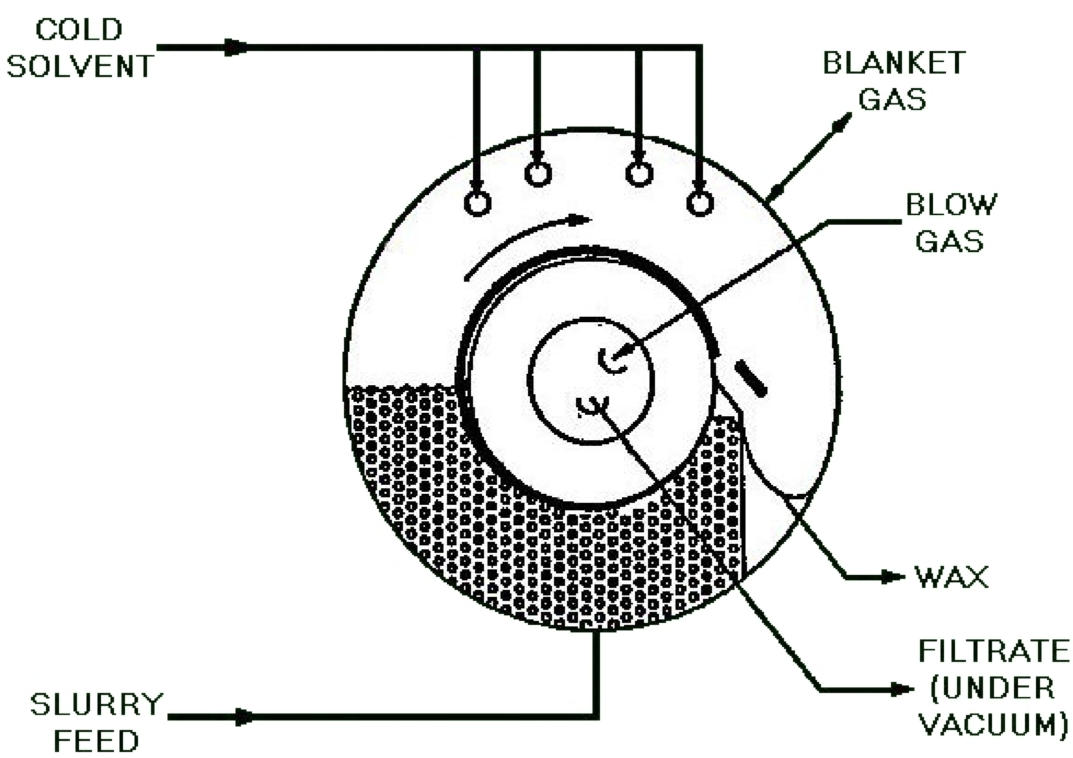

Figure 6: Vacuum Rotary Filter

These filters have large rotary cloth drums, with a vacuum inside the drum to suck the oil through, leaving the wax coated on the outside of the cloth. The wax cake is then washed from above with cold solvent to remove as much oil as possible. As the drum rotates, the wax is scraped off with a stationary knife into a collection basin, where it is reslurried with more solvent. The blow gas shown in the figure helps facilitate the wax removal from the filter cloth. These filters are also maintenance intensive and fairly costly, but are necessary and unique to our process.

Optimization:

In order to reduce both our capital costs and our operating cost, we chose to utilize heat integration and to implement an ammonia refrigeration process. Since our process involves a large amount of refrigerated liquids we focused on heat integration to reduce our ammonia needs. This saved us $31 million annually in refrigeration costs and $1 million annually in heating costs.

Additionally, we chose to recycle our ammonia through a refrigeration unit. Although this unit costs over $12 million to install, the annual savings will amount to $24 million. Thus, through our optimizations we will save over $56 million annually with an initial investment of $12 million.

Economic Summary:

The next step in determining the feasibility of our process is to analyze the economics involved. Using cost estimates from Ulrich[11] and Chemcad, we determined that the total grass-roots capital required to build our plant would be $41 million (See Table 2: Capital Cost Summary). Further, we determined that our annual operating costs would be $32 million (See Table 3: Manufacturing Cost Summary). Using current market values for the price of Minas crude oil, base lube oil, and food grade wax, we expect an after tax return on investment of 46%.

A breakdown of our capital cost can be seen below in Figure 7. Here we can see that our major initial cost is our ammonia refrigeration system. This is understandable, since our entire process is based on refrigeration. Although this is our largest expense, the implementation of this refrigeration system saves us approximately $36 million annually. The second largest expense is the flash distillation columns within our solvent recovery system. The next largest expenses are our scraped surface heat exchangers and our rotary vacuum filters. These are both targets of optimization in the industry and much research is devoted to reducing the number and size of these units.

[11] Ulrich, G *A Guide to Chemical Engineering Process Design and Economics* 1984 329:340

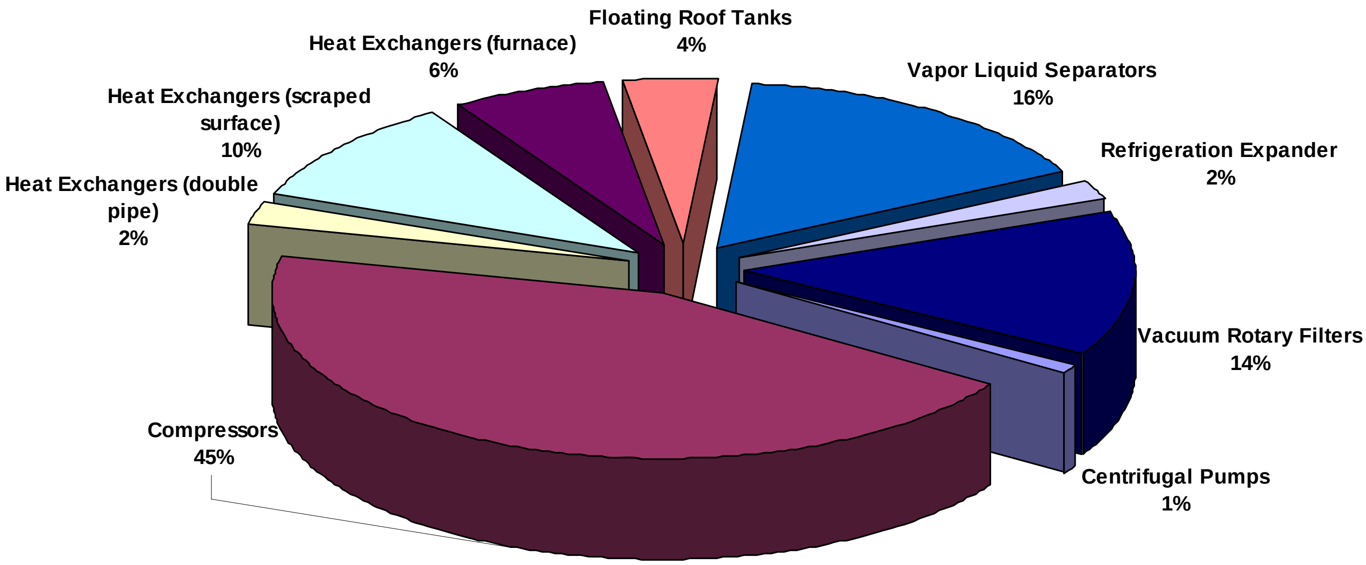

Figure 7: Capital Cost Breakdown

Using the process outlined in Ulrich[11], the manufacturing costs were calculated. The results of the analysis are shown in Table 3 and Figure 8. The majority (63% or $16 million) of the manufacturing cost is for the heavy gas oil cut from the refinery. Additionally, our process requires 1.6 million dollars of utilities per year. The bulk of this cost comes from the electricity needed to run the ammonia refrigeration unit and the fuel needed to run the furnace.

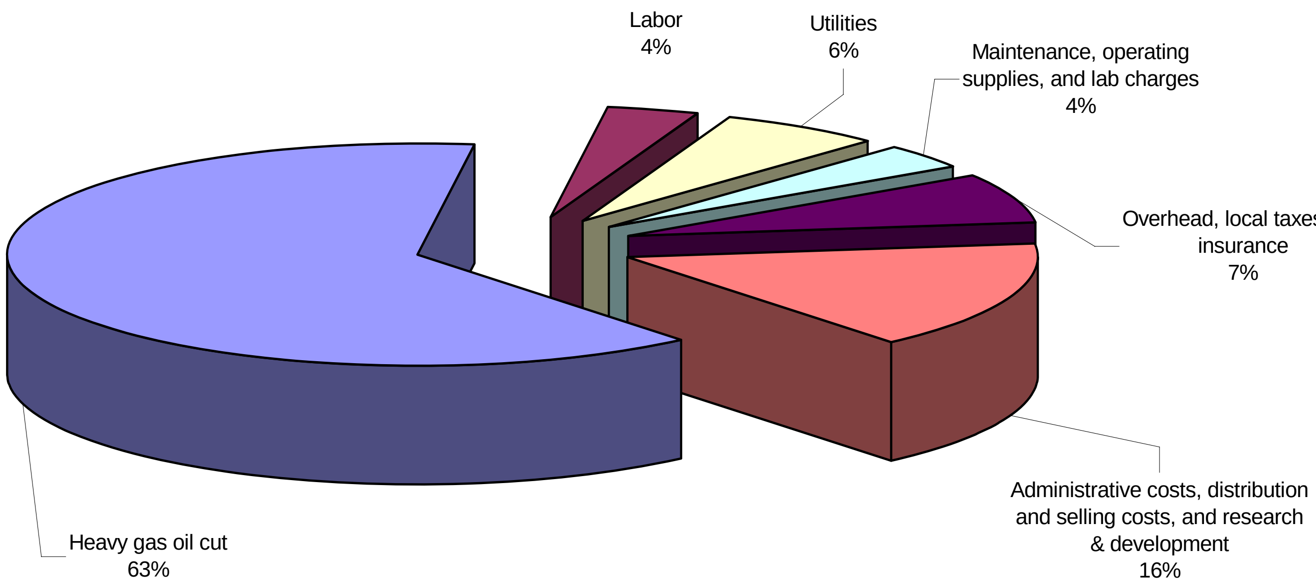

Figure 8: Manufacturing Costs before taxes

Eight operators per shift are required to run the plant. They will be paid $31,000 a year, and assuming four shifts/week, this amounts to $992,000 for thirty-two operators. Table 4 shows where the operators are needed.

The wax will be sold at $0.82/kilogram and the lube oil will be sold at $0.32/kilogram. With a tax rate of 50%, our rate of return is 56%. As shown in Figure 9, our plant will make a profit just after its second year of operation and continue on to make a profit of $13.4 million per year after taxes.

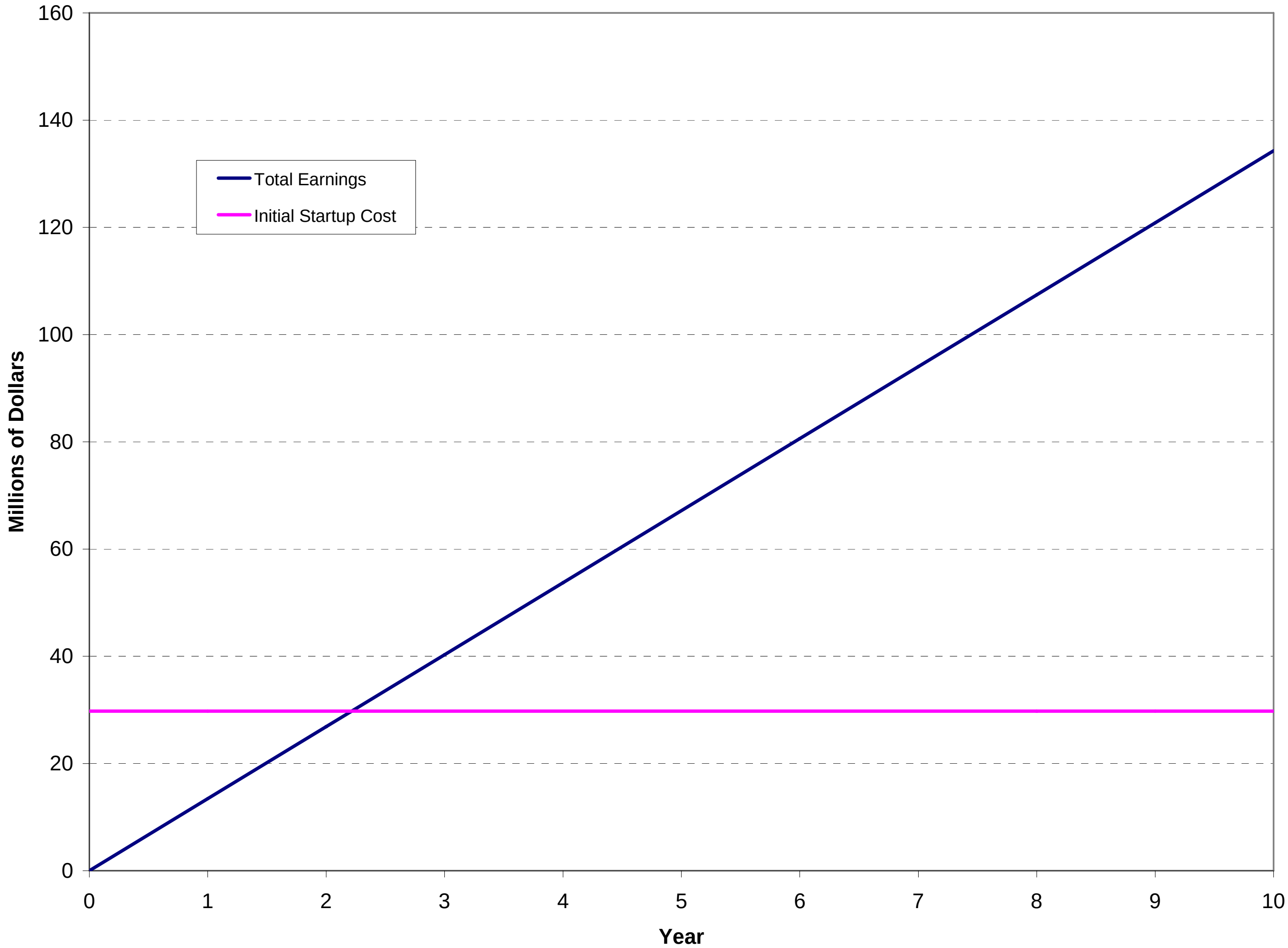

Figure 9: Profit Margin per Year

Equipment	Number of operators per shift	Total Number of Operators
Furnace	0.5	0.5
5 Compressors	0.2	1.0
21 Heat Exchanges	0.1	2.1
7 Process Vessels	0.5	3.5
3 Rotary Filters	0.1	0.3
Total number of operators per shift		7.3 → 8

Table 4: Operators Breakdown

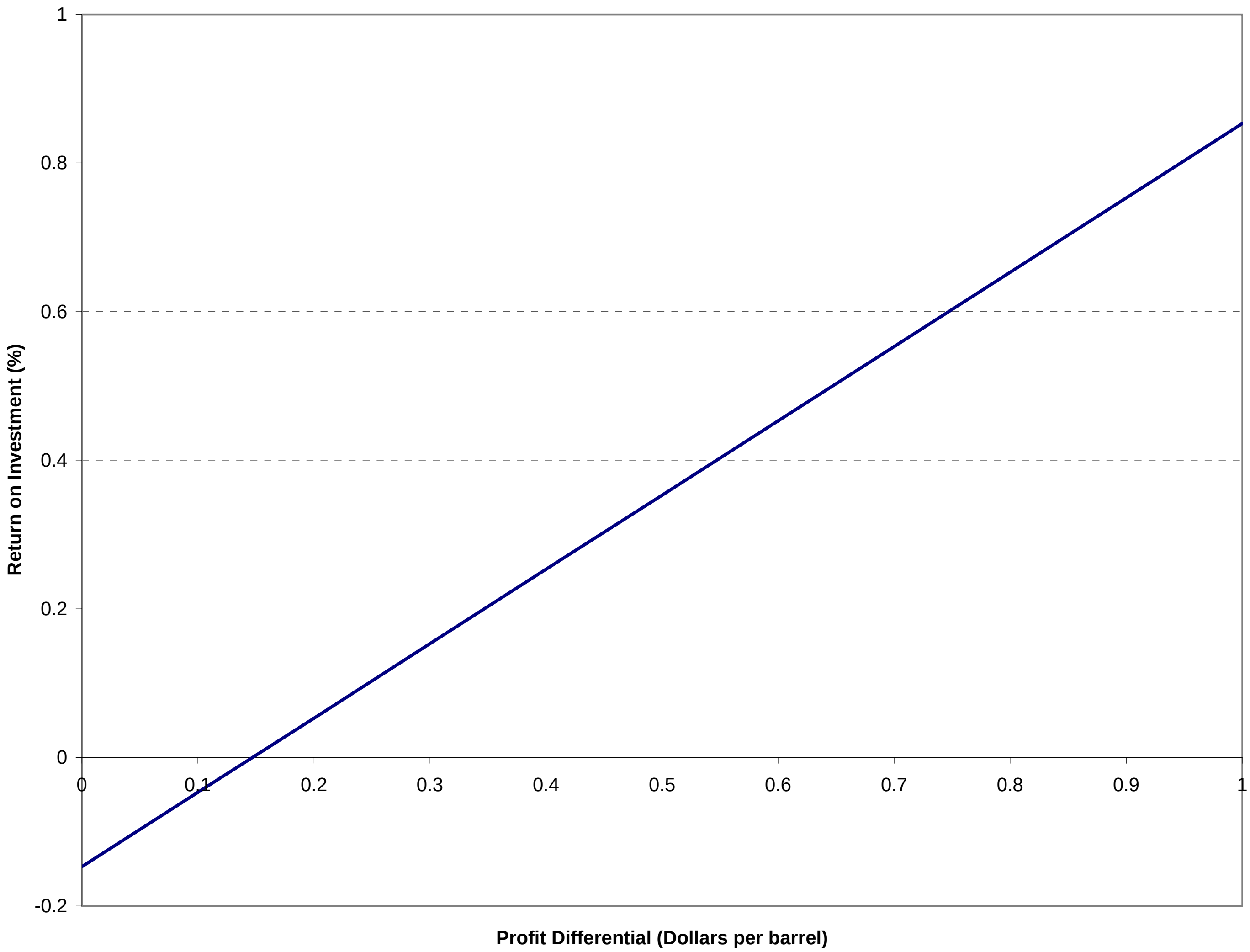

Figure 10: Sensitivity Analysis

The effect of price changes of our feedstock and our products on the return on investment is shown in the sensitivity analysis in Figure 10. The profit differential is the average cost of feedstock minus the average sales price of food grade wax and dewaxed oil. A positive rate of return will be realized if the profit differential is $0.15 per barrel. Our profit differential is almost $0.70, giving us a return on investment of 56%, as mentioned earlier.

With these economic conditions, our plant will be profitable and successful. We ♥ wax!

Design Basis

Feedstock Rate	2000 bbl/day (255 mton/day) heavy gas oil
Feedstock Composition	50 wt% oil, 50 wt% wax
Product Wax Rate	127 mton/day, less than 0.5 wt % oil content
Product Dewaxed Oil Rate	127 mton/day
Utilities Available	Steam, Air, Electricity
Ambient Conditions	32 F to 110 F, 80-98% Relative humidity
Estimated Economic Conditions	\$0.82/kg wax, \$0.32/kg oil
Total Utility Costs	\$1.6 Million/Year
Total Operational Costs	\$25 Million/Year
Total Capital Costs	\$43 Million
Net Annual Profit (pre-taxes)	\$27 Million/Year
After Tax ROI	56%