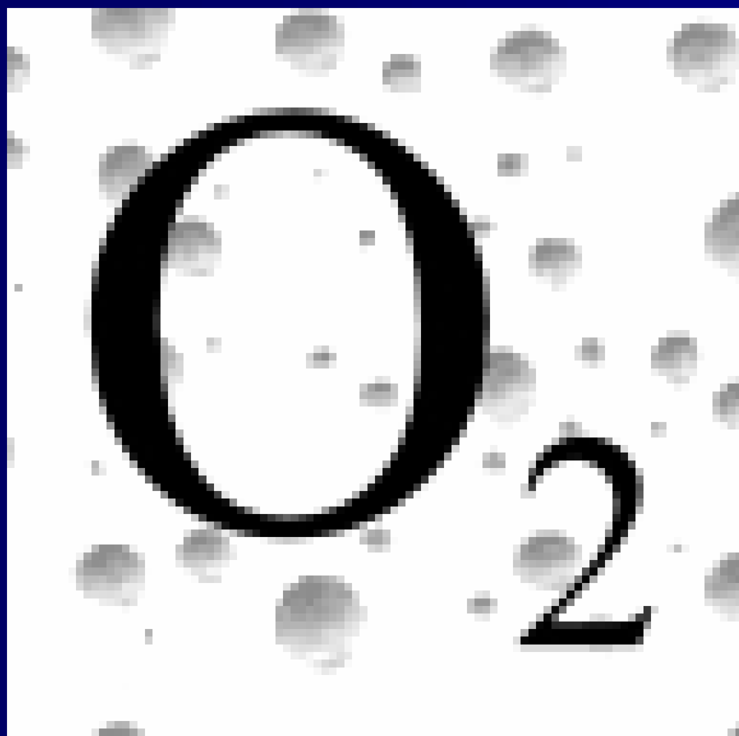
99% Oxygen Production with Zeolites and Pressure Swing Adsorption: Designs and Economic Analysis



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Project Goals

- Develop a portable and hospital air separation process/device with silver zeolites to produce a continuous flow of 99% oxygen
- Recommend the application of the process/device in different markets
- Determine if process/device will be profitable in those markets

Overview

- Market for Purified Oxygen
- Air Separation Methods
- Adsorbent Materials
- Proposed Use of Technology
- Hospital Design
- Portable Design
- Consumer Utility and Preference
- Business Plan
- Risk
- Recommendations

Market for 99% Oxygen

- Oxygen is the third most widely used chemical in the world
- Annual worldwide market of over **$9 billion**.

<u>Main applications:</u>

- Medical oxygen for hospitals and individual use
- Industrial applications for refineries and processing plants

Oxygen in Medicine

- Inhalation therapy
- During surgery to maintain tissue oxygenation under anesthesia
- Resuscitation of patients
- The treatment of such diseases as chronic obstructive pulmonary disease, pneumonia, and pulmonary embolism
- For the newborn experiencing respiratory distress syndrome
- The treatment of respiratory burns or poisoning by carbon monoxide and other chemical substances

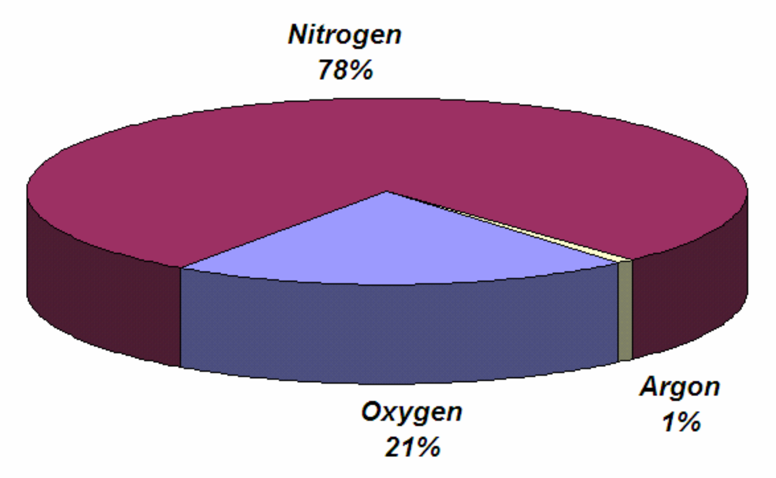
Portable Oxygen Concentrators

- Currently no portable device capable of producing 99% oxygen continuously
- Portable oxygen cylinders with 99% oxygen lasts up to 8 hours
- Percentage of individuals suffering from lung diseases such as chronic obstructive pulmonary disease (COPD) is increasing
- COPD is 4th leading cause of death worldwide

Hospital Unit

- Large hospitals spend an estimated $170,000 per a year on oxygen
- Approximately 350 large hospitals in United States
- On-site unit allows for:
  – unlimited supply of Oxygen
  – Annual savings

Air Separation



- Air is used as feed stock
- Oxygen is separated based on physical characteristics
- Must remove Nitrogen and Argon for 99% Oxygen purity

Air Separation Methods

- Cryogenic Distillation
- Membrane Separation
- Pressure Swing Adsorption (PSA)

Cryogenic Separation

Cryogenic Separation

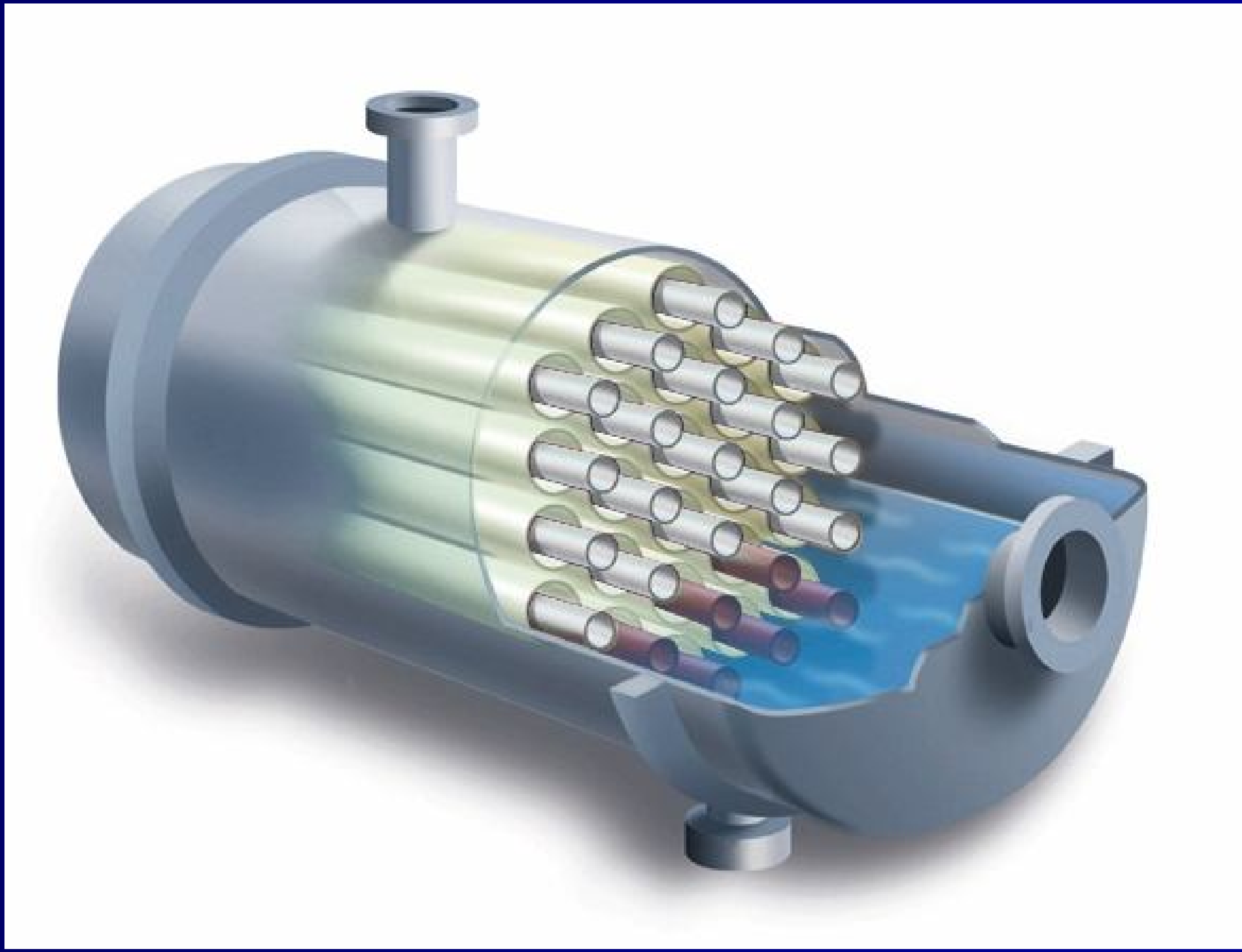
- Leading process for producing 99% oxygen in bulk.
- Involves liquidifying air and distilling the liquid air to separate the Oxygen, Nitrogen, and Argon.
- Can be sold in a liquid form.

  1 L of liquid Oxygen = 860 L of gaseous Oxygen

Cryogenic Separation

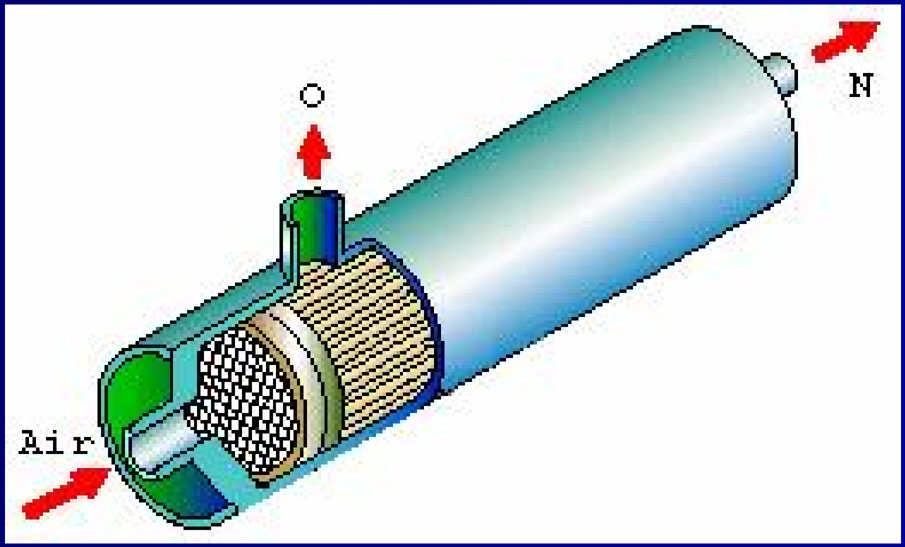
- **Drawbacks**
  - Process uses large bulky equipment
  - Energy requirements are substantial unless demand is more than 60 tons of oxygen per a day
  - Liquid oxygen evaporates back into the atmosphere over time

Membranes



Membranes

- Permeable materials used to selectively separate Oxygen, Nitrogen, and Argon
- Large and medium scale production.
- Pressurized air is passed through the membrane and is separated by permeability characteristics of each component in relation to the membrane.



Membranes

Drawbacks

- Membranes require a large surface area to achieve high product flow rates.
- Large pressures are typically used
  - Safety hazard
  - Large compressors
- Oxygen and Argon molecules are similar in size and have similar permeability properties.
  - This results in a selectivity of ≈2.5 O_2/Ar and a low oxygen recovery.

Pressure Swing Adsorption

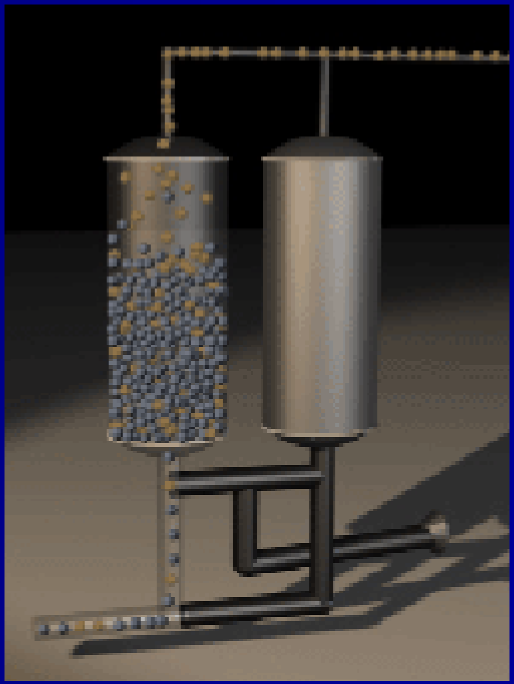
Pressure Swing Adsorption

- Uses sorbents (zeolites, nanotubes) in two adsorption columns to separate molecules.
- Two columns allow for the process to operate semi-continuously.
- 4 Process stages
  – Adsorption/Production
  – Blowdown/Purge

Pressure Swing Adsorption

Stage 1

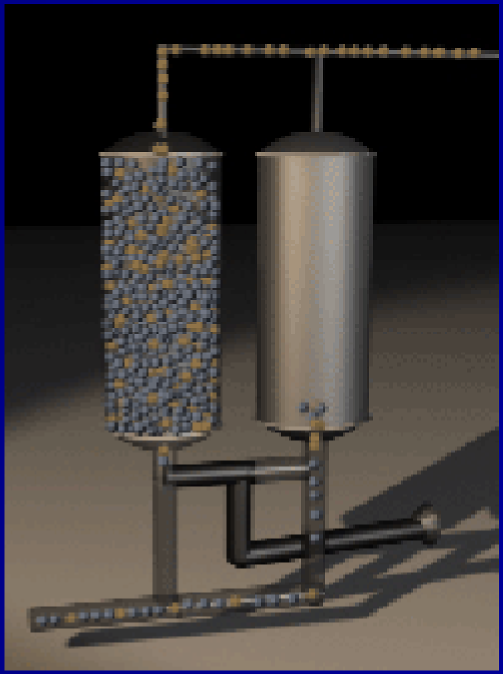
- Compressed air is fed into the first bed.
- Nitrogen and argon molecules are trapped, while oxygen is allowed to flow through.



Pressure Swing Adsorption

Stage 2

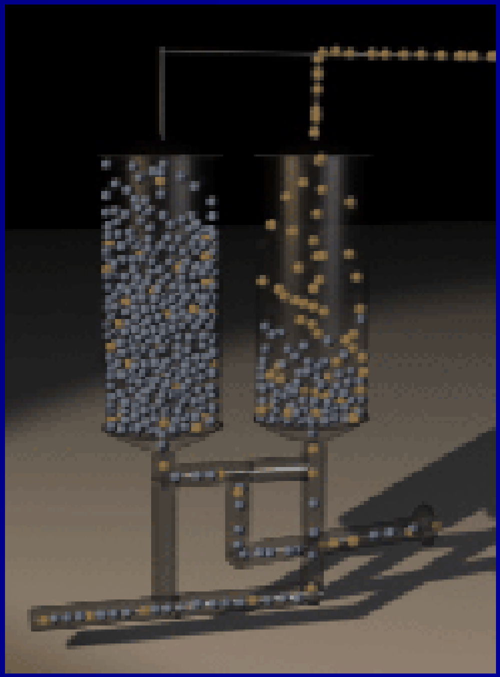
- The adsorbent in the first bed becomes saturated with nitrogen and argon molecules
- The airflow feed is directed into the second bed.



Pressure Swing Adsorption

Stage 3

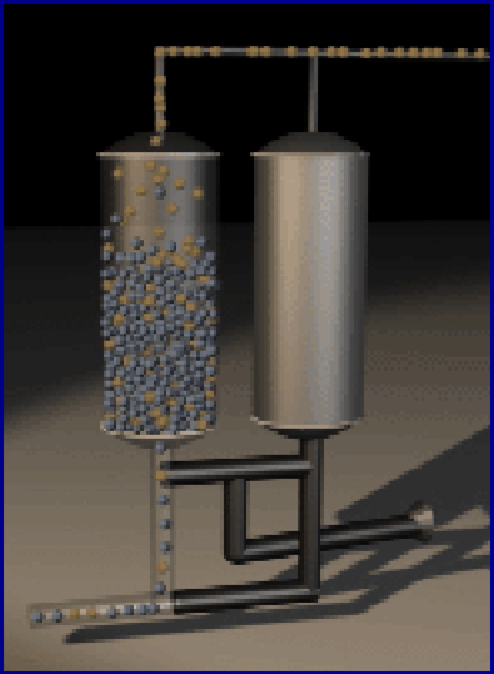
- The adsorbent adsorbs nitrogen and argon in the second bed.
- The first bed is depressurized allowing argon and nitrogen to be purged out of the system and released to the atmosphere.



Pressure Swing Adsorption

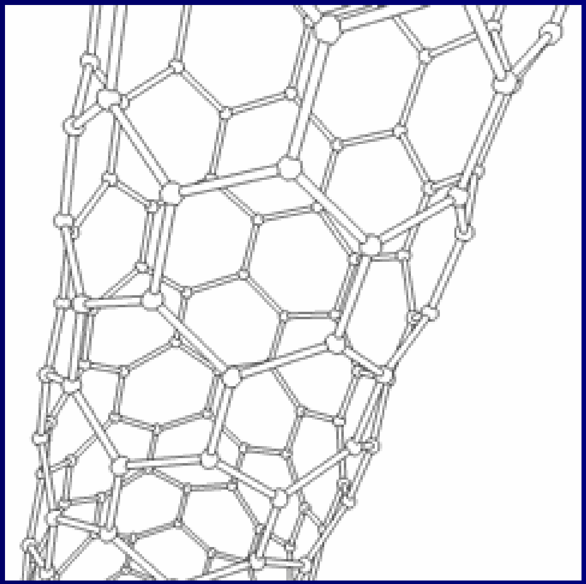
Stage 4

- The process starts over.
- Compressed air is once again fed into the first bed.
- The second bed is depressurized releasing argon and nitrogen molecules to the atmosphere.



Adsorbents for PSA

- Introduction to Zeolites and Carbon Nanotubes
- Structures
- Applications



Silica Gel Pretreatment

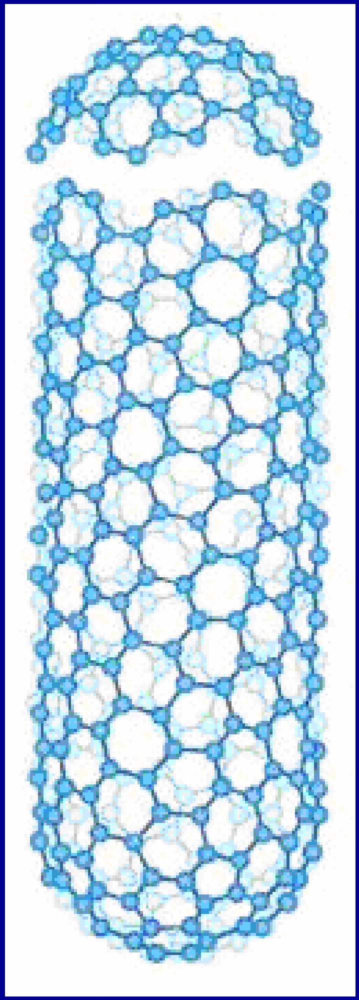
- Pretreatment bed to remove water vapor and impurities such as carbon dioxide
  - Air at 100% humidity is approximately 3% water vapor
- Water can impair the performance of adsorbents in the PSA adsorption columns.
- Silica gel beds are necessary to remove water vapor from the air.
  - A heating coil used to evaporate the water from the silica gel

Kinetic Separation

- Molecular Sieve Carbon (MSC) adsorbents using PSA technology
- Ideal for separation of Argon and Oxygen
  - MSCs in kinetic adsorption can adsorb Oxygen 30 times faster than Argon
    - Creates a problem in design, requiring two PSA systems to collect the adsorbed Oxygen

Carbon Nanotubes

- Sheets of carbon atoms rolled into tubes of varying diameters
- Nanotubes have extraordinary strength
- Potential uses in many industrial processes, including adsorption.



Carbon Nanotubes

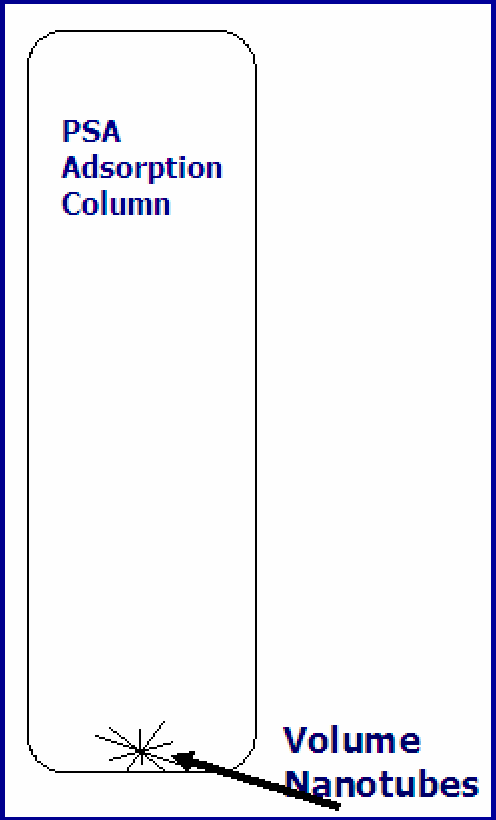
Advantages

- Nanotubes have little interaction with nitrogen at high temperatures due to oxygen's higher packing efficiency, smaller diameter, and entropic energies
- Research has shown that single walled carbon nanotubes (SWCN) of 12.53Å have a selectivity of O_2/N_2 of 100:1 at 10 bar.
- It has been indicated that Argon will have very little interaction with nanotubes

Carbon Nanotubes

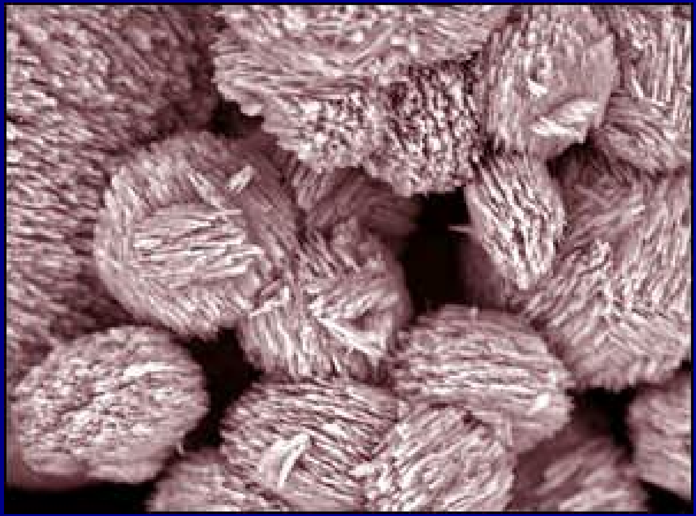
Disadvantages

- Nanotubes are so efficient the volume of nanotubes required for separation of air is much smaller than the volume of feed air.
  - Nanotubes' surface area is not large enough to react with the volume of air required.
  - No current way to disperse nanotubes effectively for PSA air separation
- Price range for nanotubes is $325 to $500 per gram



Zeolites

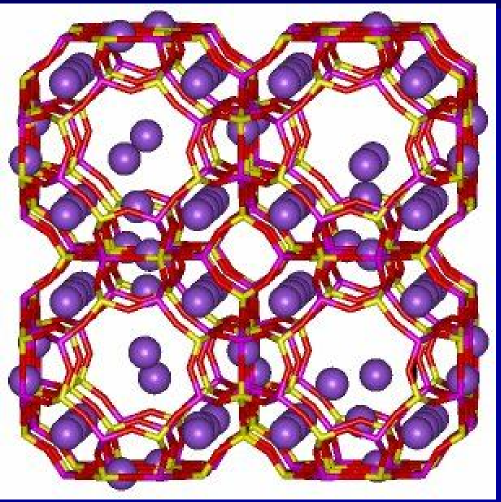
- Microporous crystalline structures
- Lifespan of 10 years
- The zeolite’s structure governs which molecules are adsorbed.
- Various ways of controlling adsorption
  - separate molecules based on differences of size, shape and polarity

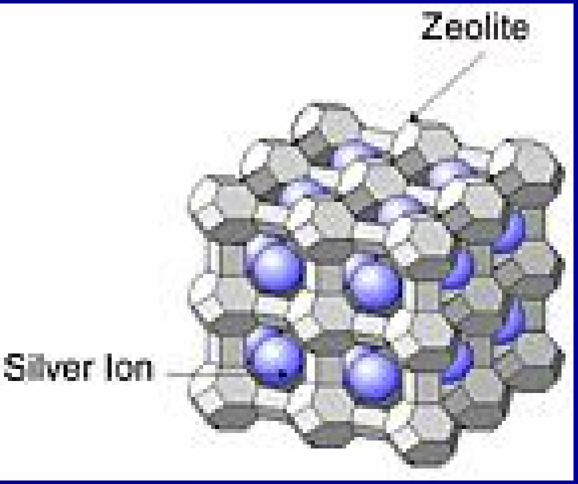


Zeolites

Ion Exchange:

- Metal cations (calcium, sodium, silver) are bound to the zeolite structure
  - Silver cation zeolites have be proven to be best for air separation
- Creates an electrostatic interaction between the cation ion and the molecules being adsorbed



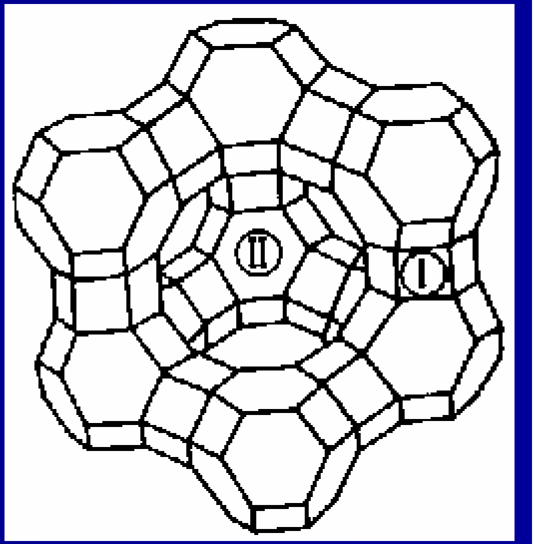


LiAgX Zeolite

- Useful for removing Nitrogen from Oxygen with product throughput .1 kg 02/hr/kg adsorbent.

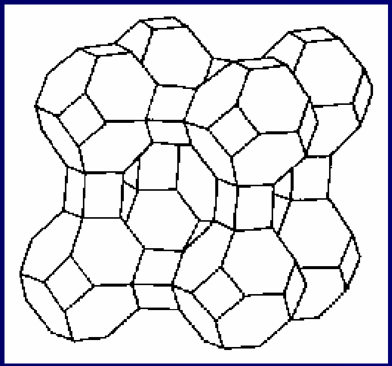
- Can obtain 96.42% oxygen purity with 62.74% Oxygen recovery.

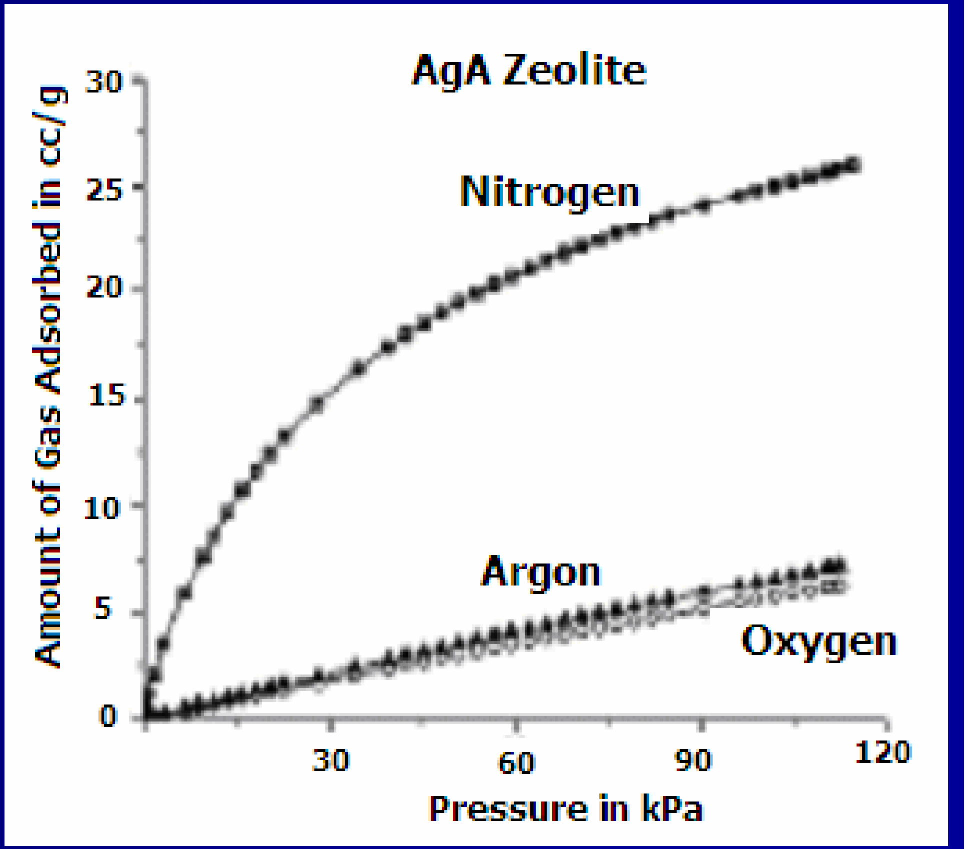
- Drawback is the selectivity of Argon to Oxygen is approximately 1:1.



AgA Zeolite

- Argon to Oxygen selectivity of 1.63 to 1
- 7 cm^3/g of Argon adsorbed at atmospheric pressure
- Nitrogen to Oxygen selectivity of 5 to 1





$F^{0}_{N2}\Delta t = \Delta L_1 A N^{1}_{N2} = v_1 A N^{1}_{N2}$

Equilibrium Adsorption Theory

- Competition between the different molecules on the adsorbent sites exists.
  - Langmuirian Multi-component Theory is used to determine the fractional loading of each component on the adsorbent

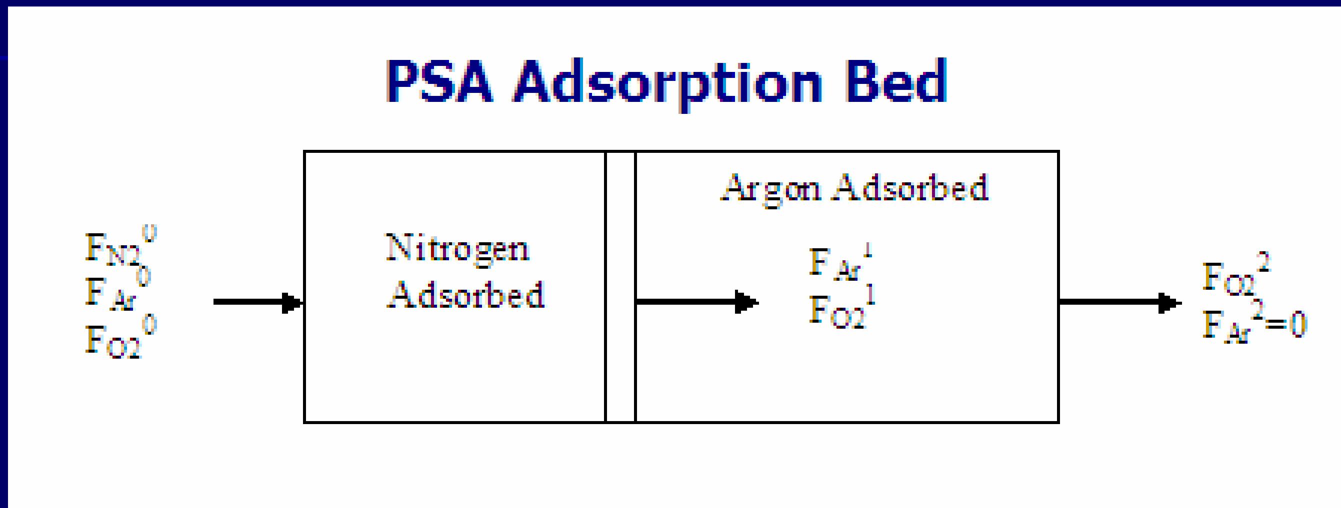
$$\theta_i = \frac{b_i P_i}{1 + \sum_{j=1}^{N} b_j P_j}$$

- Selectivity describes how selective one component is to bind to the adsorbent over another component

$$S_{i,j} = \frac{b_i}{b_j}$$

$F_{N2}^{0}\Delta t = \Delta L_1 A N_{N2}^{1} = v_1 A N_{N2}^{1}$

Equilibrium Adsorption Theory

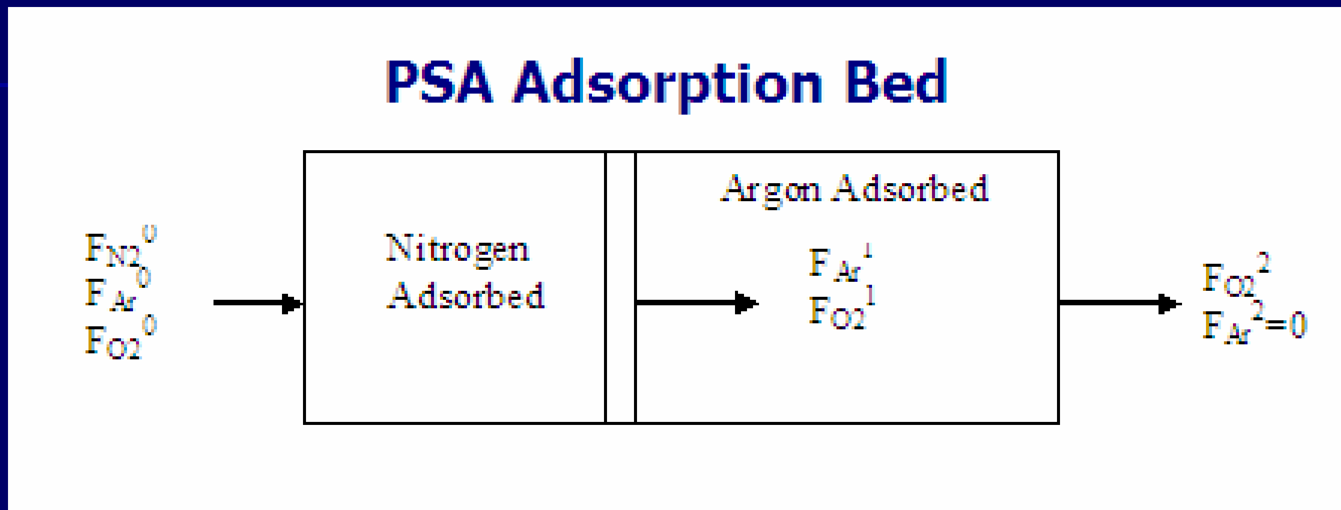


- Material Balances
  - Nitrogen → $F_{N2}^{0}\Delta t = \Delta L_1 A N_{N2}^{1} = v_1 A N_{N2}^{1}$
  - Oxygen → $F_{O2}^{1} = F_{O2}^{0} + (N_{O2}^{2} - N_{O2}^{1}) A v_1$
  - Argon → $F_{Ar}^{1} = F_{Ar}^{0} + (N_{Ar}^{2} - N_{Ar}^{1}) A v_1$

    → $F_{Ar}^{2} = 0 = F_{Ar}^{1} + N_{Ar}^{2} A v_2$

$F^0_{N2}\Delta t = \Delta L_1 A N^1_{N2} = v_1 A N^1_{N2}$

Equilibrium Adsorption Theory



For the adsorption bed to remove both Nitrogen and Argon the velocity ratio of the argon front must be greater than that of the nitrogen front

$$\frac{v_2}{v_1} = \frac{\frac{F^0_{Ar}}{F^0_{N2}} + (N^2_{Ar} - N^1_{Ar})}{N^2_{Ar}} > 1$$

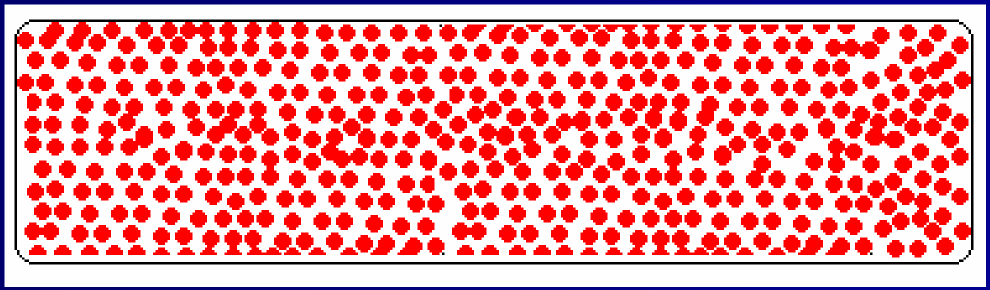
Proposed Use of the Presented Technologies

Proposed Use of Technology

- Pressure Swing Adsorption (PSA) will be used in the design for:
  - Medium scale capacity
  - Safety
  - Cost savings

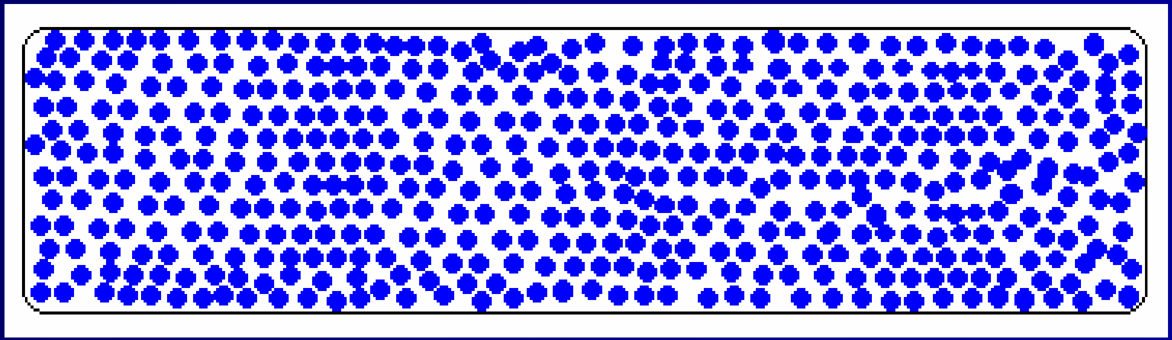
- An analysis of 4 designs using zeolites LiAgX and AgA in the PSA adsorption beds was performed. The column diameter and cycle time was held constant.
  - Design 1
    - LiAgX zeolite
  - Design 2:
    - AgA zeolite
  - Design 3:
    - Mixed ratio of zeolites LiAgX and AgA
  - Design 4:
    - Both LiAgX and AgA zeolites separating them

Design 1: LiAgX zeolite



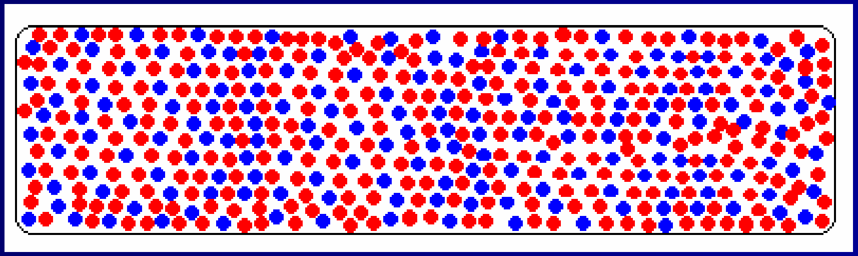
- Nitrogen Removal
  - LiAgX removes nitrogen with a 96.42% purity Oxygen and 62.74% recovery.
  - The is the best zeolite for nitrogen removal
- Argon Removal
  - Argon to Oxygen selectivity of 1:1.
  - Requires a large volume of LiAgX zeolite to accomplish required purity
- Large volume of zeolite is required. Costs and inlet airflow rate increases.

Design 2: AgA zeolite



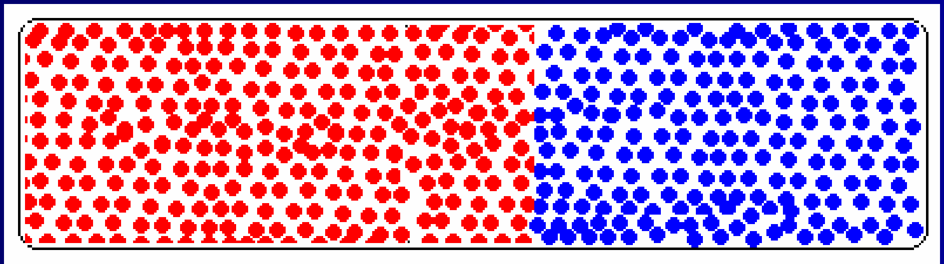
- Nitrogen Removal
  - Nitrogen to Oxygen selectivity of 5 to 1 in AgA zeolite
  - Selectivity is lower than if using LiAgX zeolite
- Argon Removal
  - Argon to Oxygen selectivity of 1.63 to 1
  - Best design for Argon removal
- Large volume of zeolite is required
  - Costs and inlet airflow rate increases.

Design 3: Mixed zeolites



- Nitrogen Removal
  - LiAgX has a higher loading and selectivity of nitrogen than AgA.
  - Not beneficial to mix them in order to rid of the nitrogen.
- Argon Removal
  - AgA has a higher loading and selectivity toward argon, selectivity being 1.63 than LiAgX which has a 1:1 ratio
  - Mixing in LiAgX in the argon removal section would only hurt performance as well.

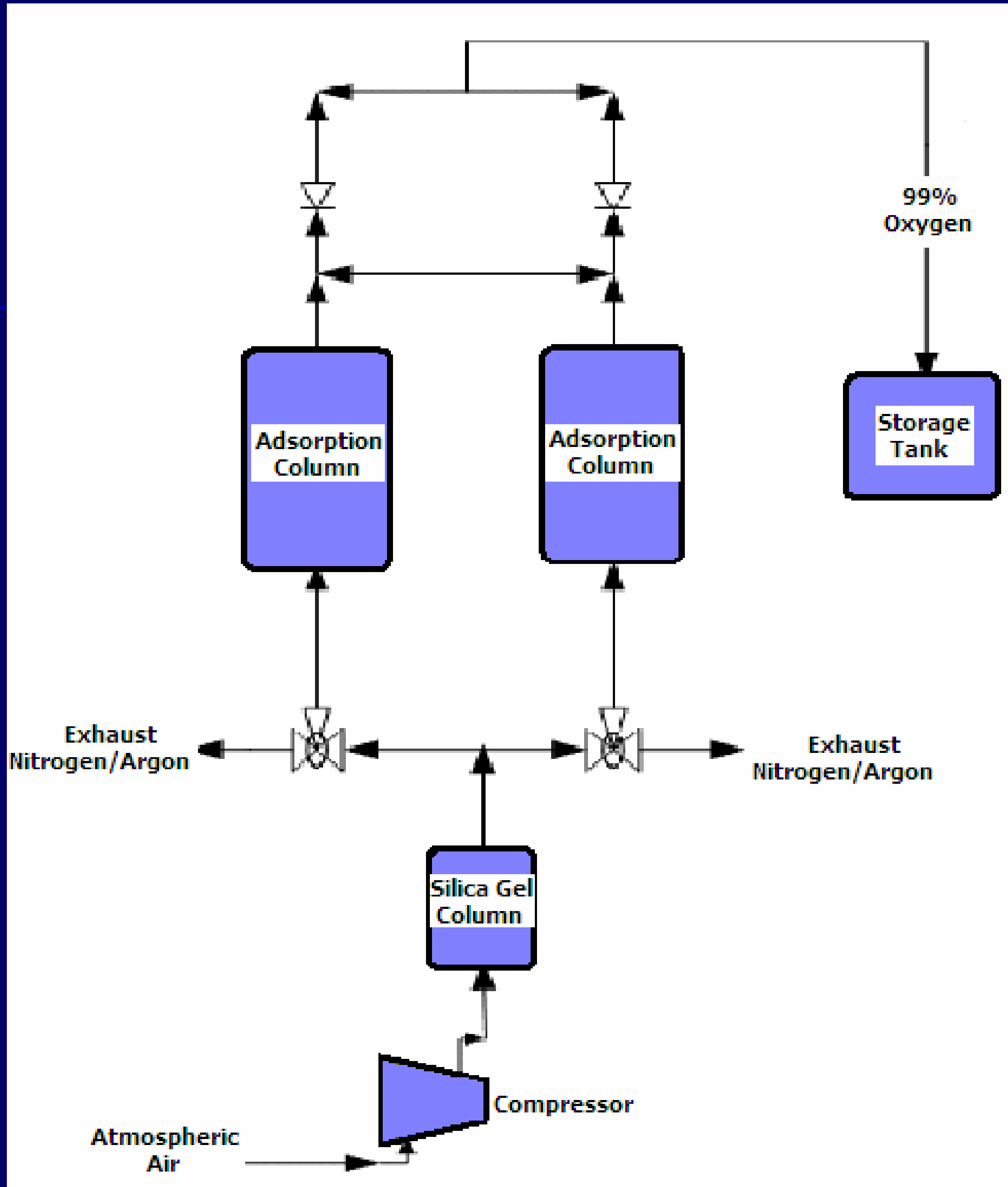
Design 4: LiAgX and AgA zeolites separated



- Nitrogen
  - LiAgX zeolite with a 96.42% Oxygen purity and 62.74% recovery
- Argon
  - AgA zeolite with an Argon to Oxygen selectivity of 1.63 to 1
- The volume is dramatically lower
  - Save money on the zeolite cost and overall unit
- The inlet air flow rate would be less due to the higher recovery of oxygen
- Has been determined **most** beneficial design

Zeolite Design Analysis

Column, Zeolite, and Flow Specifications for PSA Designs			
LiAgX Only		**AgA Only**	
Recovery of Inlet Oxygen	27	Recovery of Inlet Oxygen	20
Inlet Flow Rate (L/s)	1,007	Inlet Flow Rate (L/s)	1,325
Mass of LiAgX Zeolites (kg)	4,342	Mass of LiAgX Zeolites (kg)	5,714
Volume Column (cm^3)	4,058,324	Volume Column (cm^3)	5,339,900
Area Column (cm^2)	5,027	Area Column (cm^2)	5,027
Length Column (cm)	807	Length Column (cm)	1,062
50/50 Mixture		***LiAgX/AgA***	
Recovery of Inlet Oxygen	25	Recovery of Inlet Oxygen	**35**
Inlet Flow Rate (L/s)	1,060	Inlet Flow Rate (L/s)	**362**
Mass of LiAgX Zeolites (kg)	2,286	Mass of LiAgX Zeolites (kg)	**1,614**
Mass of AgA Zeolites (kg)	2,286	Mass of AgA Zeolites (kg)	**601**
Volume Column (cm^3)	4,271,920	Volume Column (cm^3)	**2,069,402**
Area Column (cm^2)	5,027	Area Column (cm^2)	**5,027**
Length Column (cm)	850	Length Column (cm)	**412**


99%
Oxygen
Adsorption
Column
Adsorption
Column
Storage
Tank
Exhaust
Nitrogen/Argon
Exhaust
Nitrogen/Argon
Silica Gel
Column
Compressor
Atmospheric
Air

Hospital Air Separation Design with Pressure Swing Adsorption

Proposed Design - Hospital

Large hospital information

- Approximately 350 large hospitals in the United States (500-1000 beds).
- At any time have 150 users using 5L/min.

Proposed Design - Hospital

- **Goals**
  - Use PSA technology to produce 99% oxygen with all specifications.
  - Provide for maximum capacity of 300 users at 5 L/min of oxygen to adjust for fluctuation in demands.
  - Determine if product is profitable and a plausible option for large hospitals.

Proposed Design - Hospital

First calculate inlet air flow rate of air:

Calculation of Inlet Flow Rate	
Recovery of Oxygen (LiAgX) (%)	62.7
Recovery of Oxygen (AgA) (%)	55.0
Total Recovery of Oxygen (%)	34.5
Assume 30 second Cycle Time	
Oulet Oxygen needed for 300 users at 5L/min	1500
Oxygen Adsorbed per 2 columns (L)	2850
Inlet Oxygen (L/min)	4350
Inlet Air Mixture (L/min)	21750

Proposed Design - Hospital

Adsorbent Results	
Inlet Air Mixture (L)	21750.0
Inlet Air Feed to each column (L)	10875.0
Flow rate air to each column (L/s)	362.5
LiAgX Section of Column	
Product Throughput kg O2/h/kg adsorbent	0.1
Total 96.42% Pure Oxygen from LiAgX	2729.2
Mass of LiAgX Zeolites (kg)	3303.0
AgA Section of Column	
Total Entering O2/Ar mixture (L)	1447.8
Product Throughput kg O2/h/kg adsorbent	0.2
Mass of AgA Zeolites (kg)	1229.5

Proposed Design - Hospital

Column Specifications	
Total Mass of Zeolites per Column (kg)	4532
Total Volume of Zeolites per Column (L)	4236
Column Data	
Volume of Column (L)	4236
Diameter of Column (cm)	80
Height of Column (cm)	421
Total Loading of N2/O2/Ar per Column (kg)	22

Proposed Design - Hospital

Final Components of Design	
Compressor (Palatek)	
Max Flow of Compressor (CFM)	900
Inlet Flow to be Compressed (CFM)	776
Power Consumption (hP)	200
Silica Gel Drying Column	
Volume (cm^3)	20291
Height (cm)	65
Diameter (cm)	20
Mass of Silica Gel (kg)	12

Proposed Design - Hospital

Components Continued	
High Pressure Storage Tank	
Volume to be stored in 60 minutes (L)	92100
Volume of stored air at 10 atm	9210
Compressor for High Pressure Storage (Palatek)	
Inlet Flow to be Compressed (CFM)	55
Max Flow of Compressor (CFM)	100
Power Consumption (hP)	50

Proposed Design - Hospital

Important Results	
Purity of Air (LiAgX)	96.42
Volume of O2/Ar out of LiAgX Section	1448
Purity of Air (AgA)	**>99**
Vol. 99% Oxygen out of 1 Column/30 sec	750
Volume 99% O2 out in 1 min	1501
Users Supplied at 5L/min	**300**

Goals met:

Producing 99% Oxygen

Supply 300 users of oxygen at 5L/min!

Portable Oxygen Concentrator Design

Portable Oxygen Concentrators

<u>Market Designs:</u>

- – Only alternative to carrying bottles of oxygen.
- – Uses PSA to purify air stream.
- – Small enough to carry. Less than 30 lbs.
- – Uses battery power to increase portability.
- – 85%-95% oxygen purity.

Portable Oxygen Concentrators

Necessary Requirements

1. Weighs less than 30 lbs.
2. 99% oxygen purity at 5 liters per minute.
3. Battery life of at least 8 hours.
4. Small enough to take on airplane
5. Low noise
6. Less than $5,000/unit and covered by medicare.

Oxygen Concentrator				
		Weight		
Parts	#	kg	Price	Cost
Column and Tanks				
Adsorption Columns (Al) 1.5 liter	2	1.86	$100.00	$200.00
Drying Column (Al) 1 liter	1	0.0115	$100.00	$100.00
Low Pressure Storage tank (Al) 2 liter	1	1.86	$100.00	$50.00
Packing				
LiAgX Zeolites (Adsorbent)		5	$.4/g	$2,000.00
Silver Zeolite A (Adsorbent)		1.4	$.4/g	$560.00
Silica Gel (Drying)		0.08	$.05/g	$4.00
Other items				
Inlet Feed Compressor	1	2.73	$100.00	$100.00
Nitrogen Exhaust Muffler	1	0.23	$3.00	$3.00
3 Way Ball Valve	2	0.09	$100.00	$200.00
2 Way Solenoid Valve	2	0.09	$100.00	$200.00
Battery	3	0.93	$100.00	$300.00
Control Computer	1	0.09	$300.00	$300.00
Frame (Aluminum)	1	0.91	$100.00	$100.00
Casing (Plastic)	1	0.09	$75.00	$75.00
Final Total Weight (kg)		**9.35**	**Total Cost =**	**$4,192.00**
Final Total Weight (lb)		**20.57**		

Portable Oxygen Concentrators

Goals met with portable oxygen concentrator from initial estimates:

Purity: 99% Oxygen

Cost: $4200 under $5000

Weight: 20.5 lb under 30lb

Small: Estimated Volume .6ft x 1ft x 1ft

Portable Oxygen Concentrators

Portable Oxygen Concentrators

Conclusions/Recommendations:

A competitive/lightweight portable oxygen concentrator with 99% oxygen can be produced.

Perform extensive design estimates and economic analysis.

Consumer Utility and Preference

Consumer Utility and Preference

- Method used to determine relationship between:
  - consumer preference
  - satisfaction

in order to predict product price and product demand.

Consumer Utility and Preference

Theory

The solution to consumer utility maximization is given by:

$$\phi(d_1) = p_1 d_1 - \left(\frac{\alpha}{\beta}\right)^{\rho} p_2 \left[\frac{Y - p_1 d_1}{p_2}\right]^{1-\rho} d_1^{\rho} = 0$$

ɑ = Inferiority Function (Knowledge of product, function of time)

Β = Superiority Function (Consumer preference, comparison to competition “preference”)

Y= Consumer budget= p1*d1+p2*d2

Consumer Utility and Preference

- Further Quantification of β (ratio of consumer preference)

$$\beta = \frac{H_2}{H_1}$$

Preference values must be between 0 and 1. A value of 1 indicates maximum preference toward a product.

If the competitor preference H2= .69 and H1=1 (max) then the overall β = .69/1 = .69

Consumer Utility and Preference

$$\beta = \frac{H_2}{H_1}$$

- **Consumer Preference**

$$H_i = \sum w_i y_i$$

wi= weight based on consumer preference characteristics, smaller than 1

yi= consumer utilities based on evaluation, can be changed to meet specific preference values. Range between 0 and 1. 1 is 100% satisfaction in the product

Consumer Utility and Preference

- **Determining weights**

  1. Identify Important Characteristics for general oxygen supply for a hospital
  2. Determine consumer importance placed on characteristics through surveys
  3. Characteristic relation to product properties
  4. Determine weights to each characteristic from importance surveys

Consumer Utility and Preference

- Important consumer characteristics for hospital design and weights assigned to them.

Characteristics	Weights (wi)
Noise	0.175
Ease of Use	0.147
Appearance	0.112
Frequency of Maintenance	0.184
Reliability	0.205
Durability	0.177

Consumer Utility and Preference

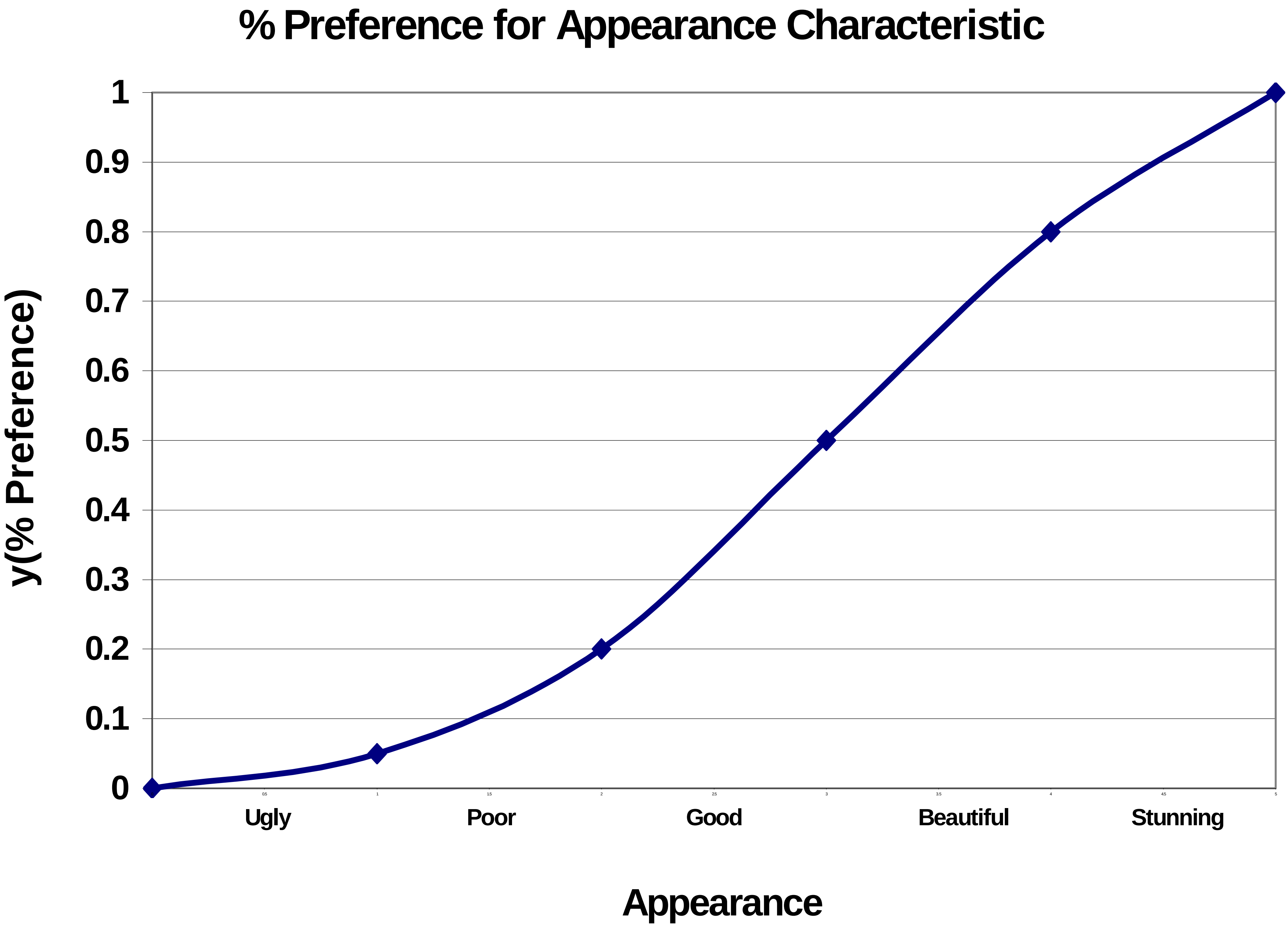
Determining yi (%preferences) of consumer values

$$H_i = \sum w_i y_i$$

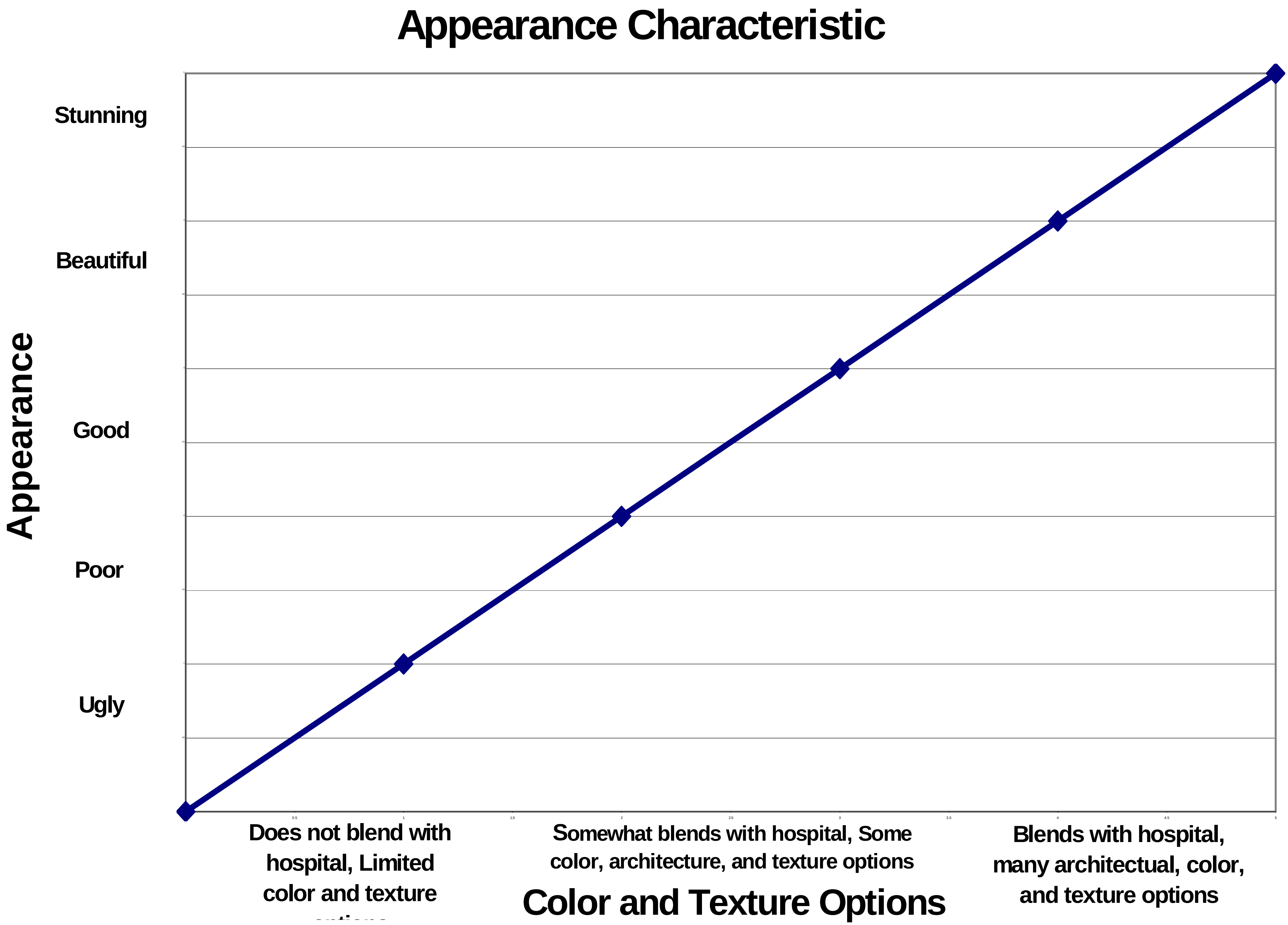
1. Develop expression between %preference and words used to describe each characteristic by consumer description.

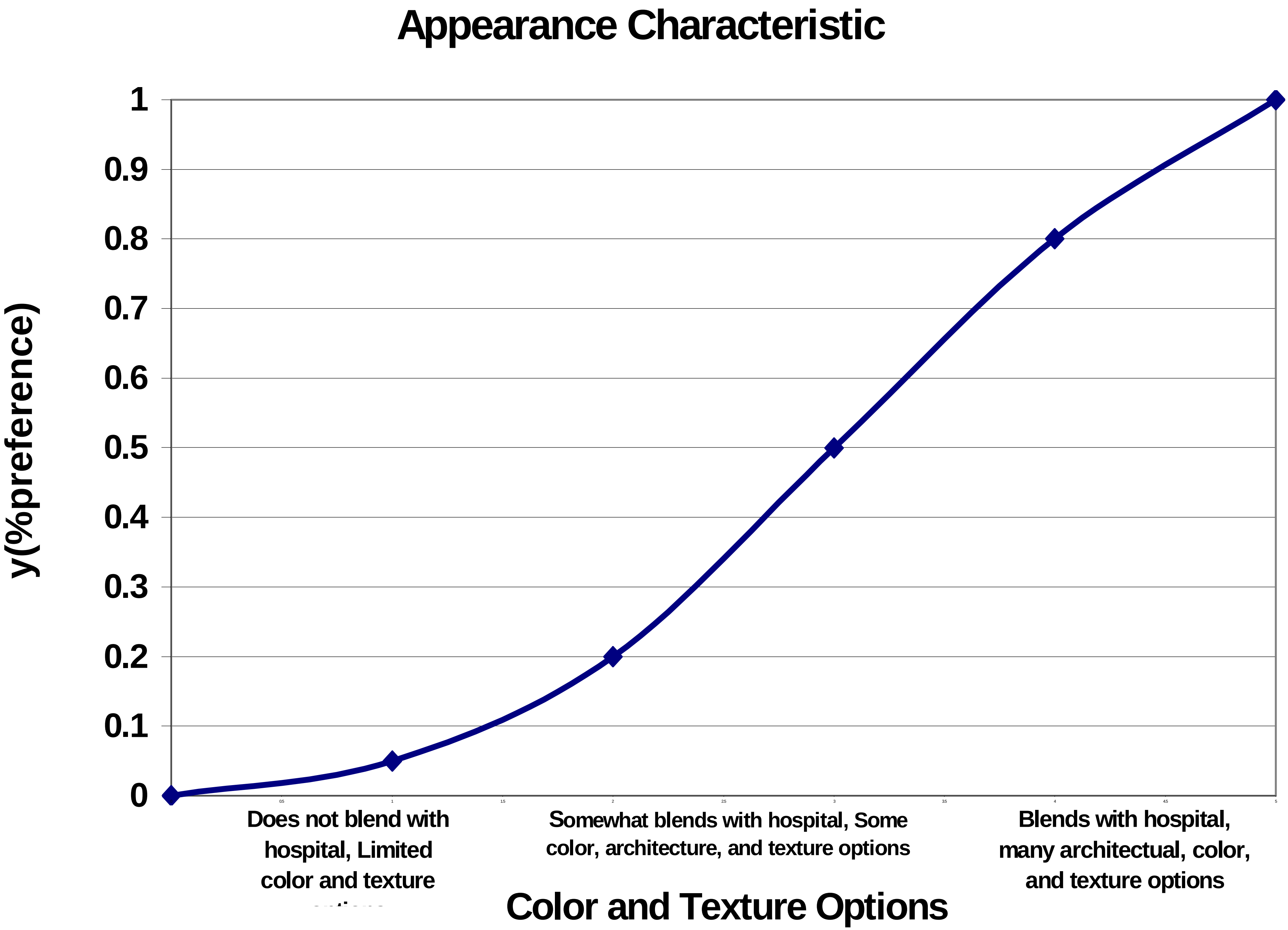
2. Relates the characteristic descriptions to physical attributes.

3. Combine the first two expressions to yield a % preference of characteristic versus physical attributes.



% Preference for Appearance Characteristic
y(% Preference)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Ugly
Poor
Good
Beautiful
Stunning
Appearance


Appearance Characteristic
Stunning
Beautiful
Good
Poor
Ugly
Appearance
Does not blend with hospital, Limited color and texture
Somewhat blends with hospital, Some color, architecture, and texture options
Blends with hospital, many architectual, color, and texture options
Color and Texture Options



Appearance Characteristic
y(%preference)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Does not blend with hospital, Limited color and texture options
Somewhat blends with hospital, Some color, architecture, and texture options
Blends with hospital, many architectual, color, and texture options
Color and Texture Options

Consumer Utility and Preference

Appearance

- **Utility function (yi) generated**

Y(%preference)=-0.0134x3 + 0.1248x2 - 0.0888x + 0.0063 where x=Color/Texture

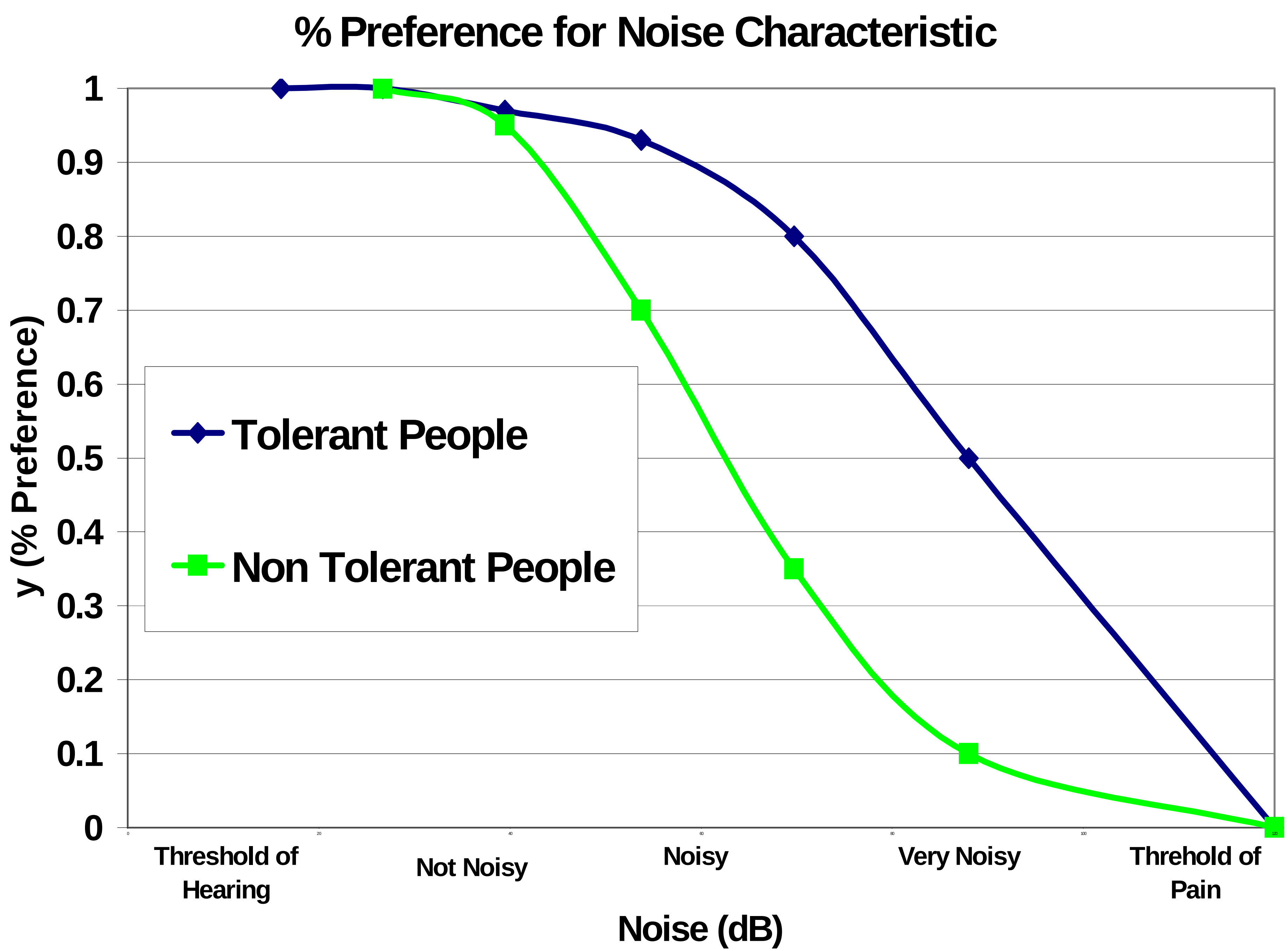
The appearance of the oxygen concentrator depends on the outer casing.

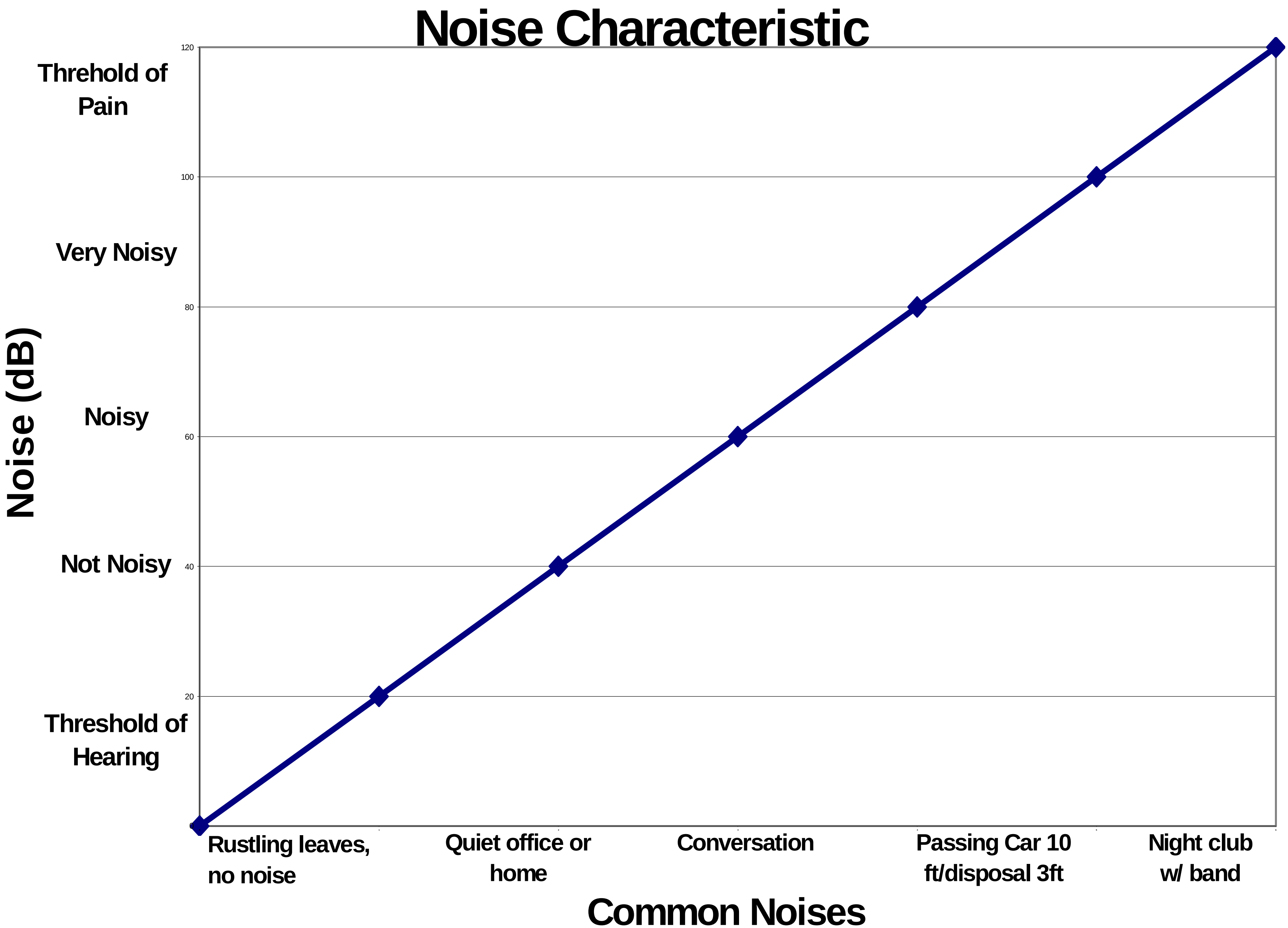
Consumer Utility and Preference

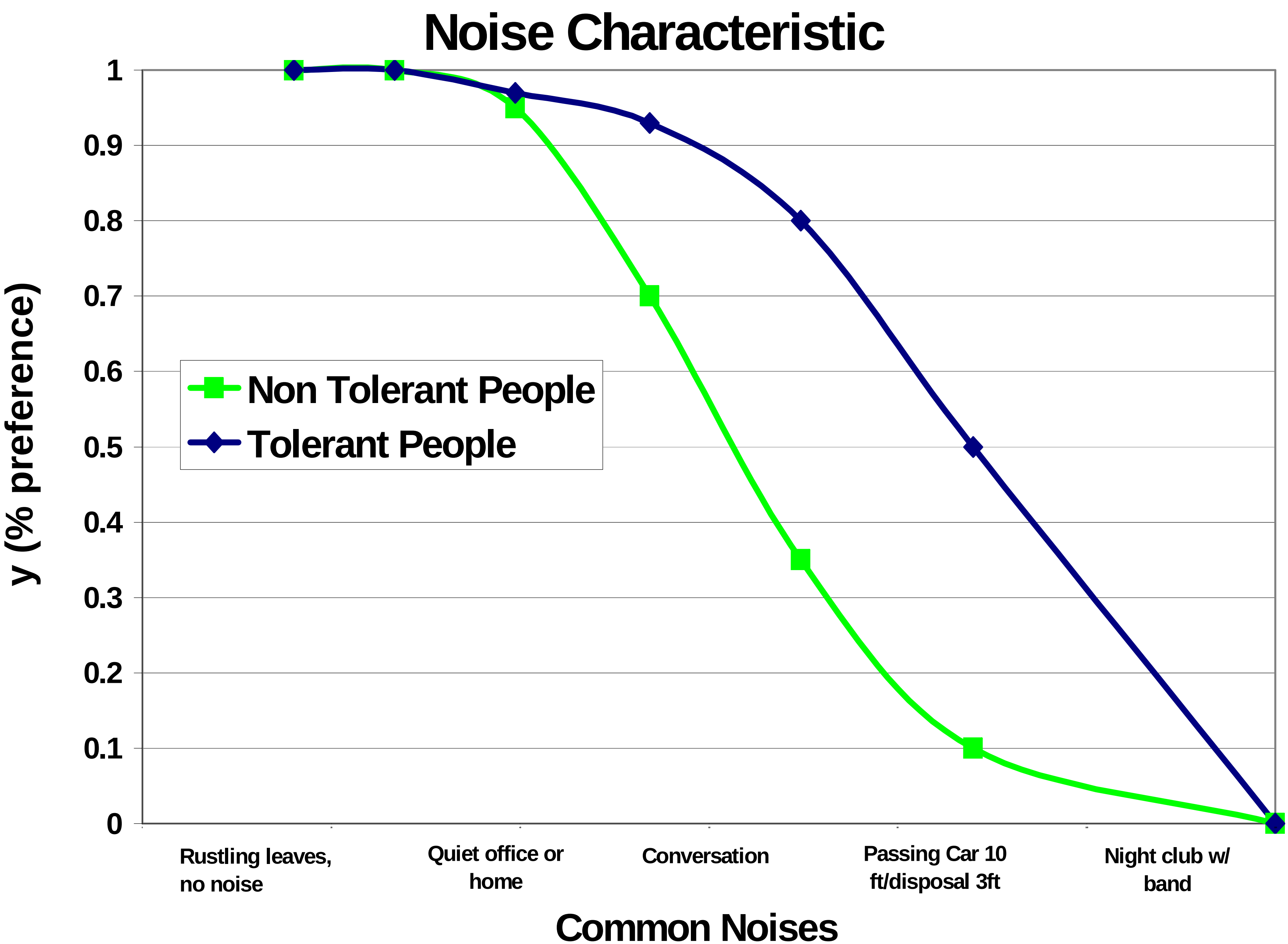
Appearance

- To draw in the most consumers, 3 types of siding materials were looked at: Veneer, Aluminum, and Vinyl.

Material	Quoted Price	Total Cost
Vinyl Siding	$1.6/ sq ft [30]	$1,760
Aluminum Siding	$1.7/ sq ft [30]	$1,870
Veneer Stone Siding	$3.5/ sq ft [31]	$3,850


% Preference for Noise Characteristic
y (% Preference)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Tolerant People
Non Tolerant People
Threshold of Hearing
Not Noisy
Noisy
Very Noisy
Threhold of Pain
Noise (dB)


Noise Characteristic
Threhold of Pain
Very Noisy
Noisy
Not Noisy
Threshold of Hearing
Noise (dB)
120
100
80
60
40
20
Rustling leaves, no noise
Quiet office or home
Conversation
Passing Car 10 ft/disposal 3ft
Night club w/ band
Common Noises


Noise Characteristic
y (% preference)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Non Tolerant People
Tolerant People
Rustling leaves, no noise
Quiet office or home
Conversation
Passing Car 10 ft/disposal 3ft
Night club w/ band
Common Noises

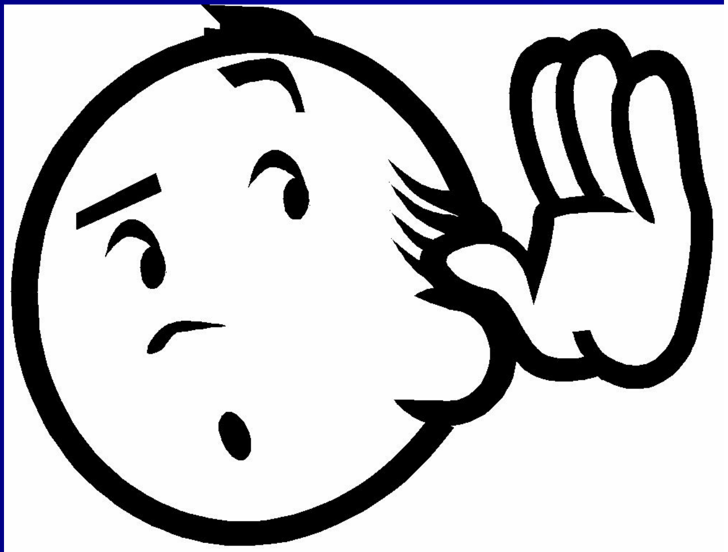
Consumer Utility and Preference

Noise

- **Utility function (yi) generated**

Y(%preference)=-4E-06x3 - 0.0007x2 + 0.0278x + 0.724

where x(common noise)



Consumer Utility and Preference

Noise

- To draw in the most consumers, a layer of noise soundproofing foam will be added to the casing of the concentrator.

Material	Reduction %	Total Cost ($)
Ultra Barrier	95	10141
Quiet Barrier	90	4412
Econo Barrier	80	2119
Sound Proof Foam	65	2406

Consumer Utility and Preference

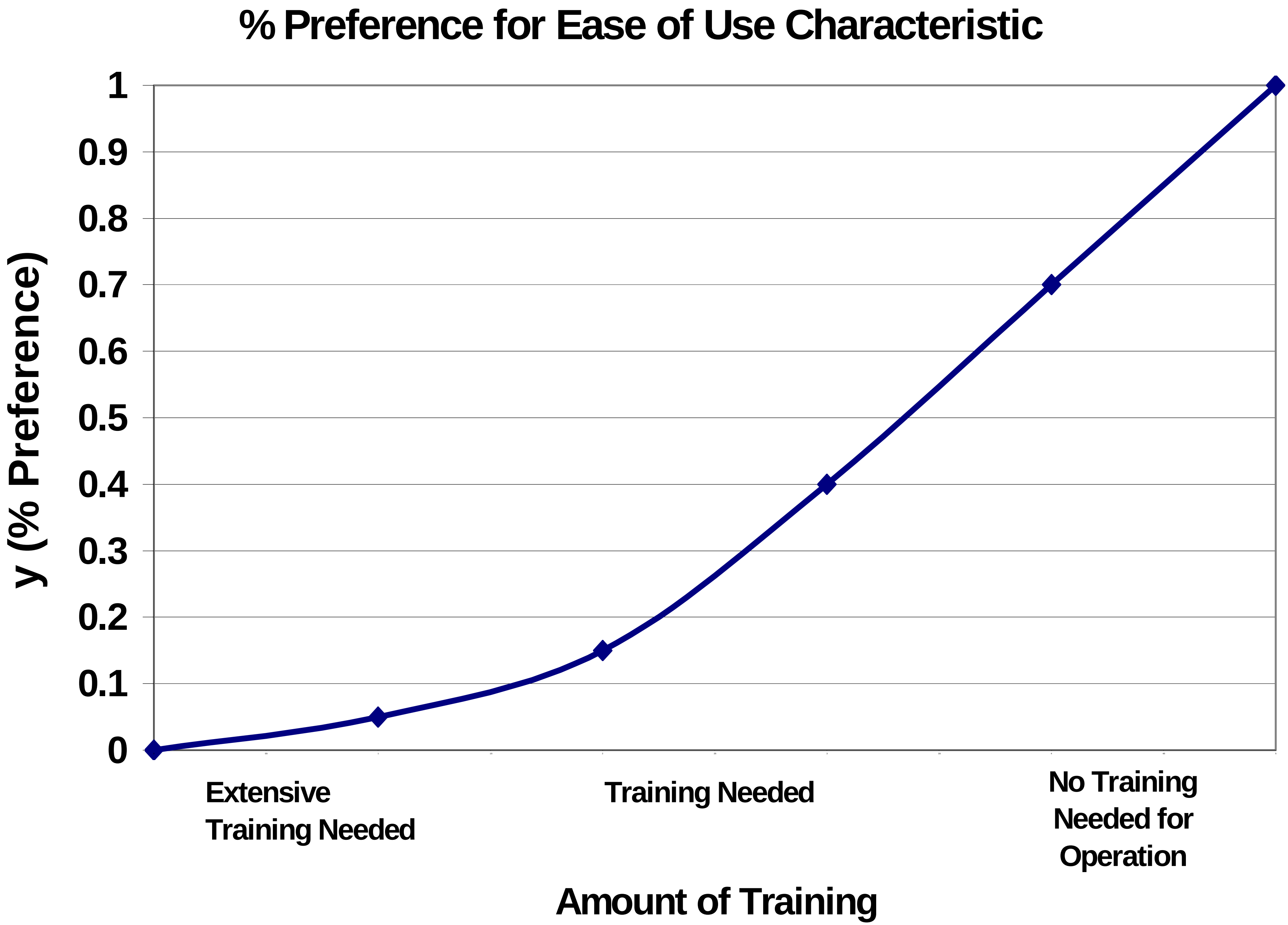
Ease of Use (amount of training)

– Utility Function

Y(%preference)= 0.0366x2 + 0.0227x - 0.0089

where x=(Training Needed)

If no training is needed than the hospital design is easy for anyone to use.


% Preference for Ease of Use Characteristic
y (% Preference)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Extensive Training Needed
Training Needed
No Training Needed for Operation
Amount of Training

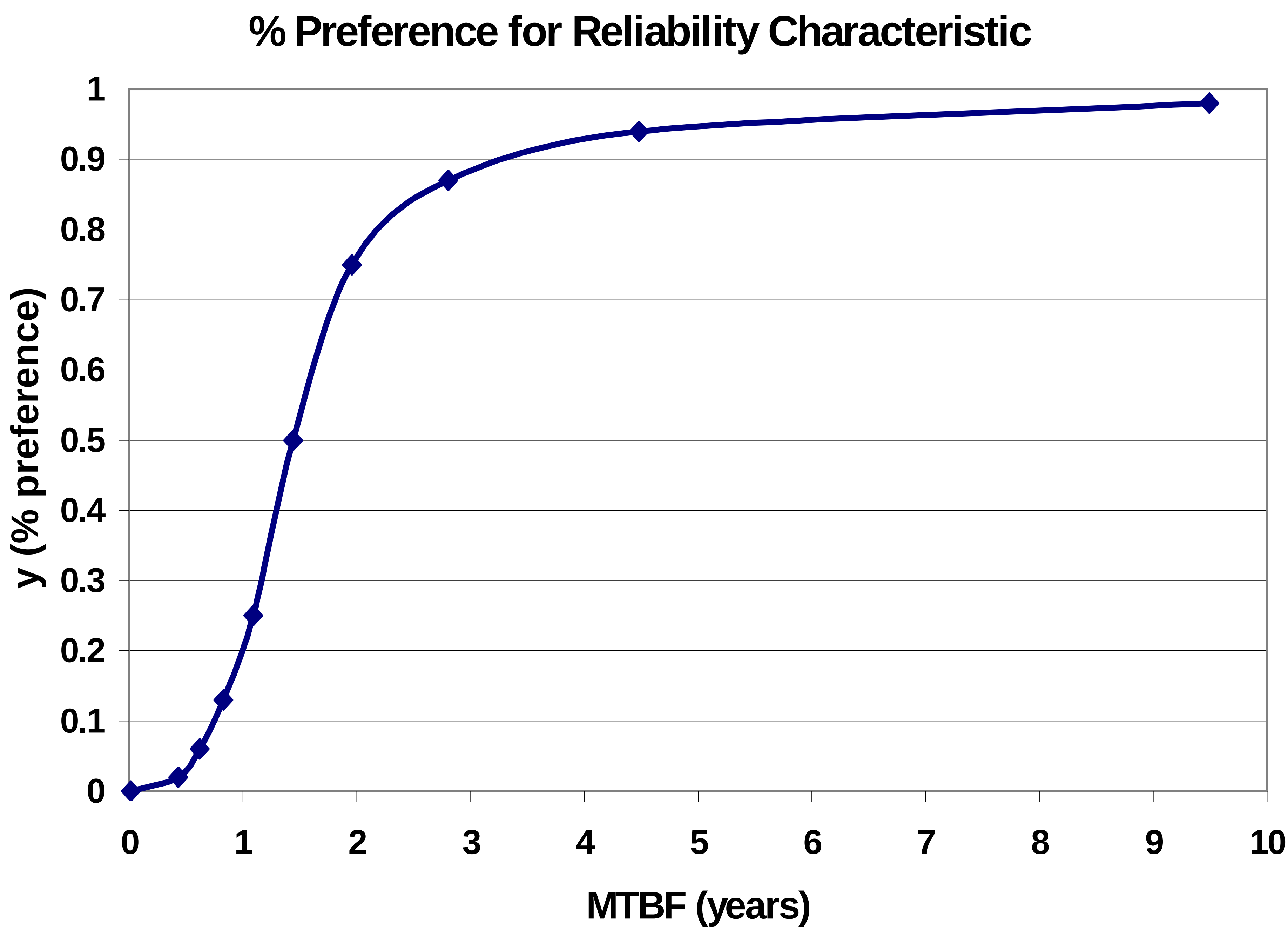
Consumer Utility and Preference

Reliability (MTBF)

- **Utility function (yi) generated**

Y(%preference)=0.0037x3 - 0.0796x2 + 0.5394x - 0.159

where x(MTBF)


% Preference for Reliability Characteristic
y (% preference)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
7
8
9
10
MTBF (years)

Consumer Utility and Preference

Manipulation:

Increase consumer preference by including parts with large MTBF values.

Adding a backup unit to the primary unit will increase reliability. If one unit breaks down, the other unit will turn on.

Consumer Utility and Preference

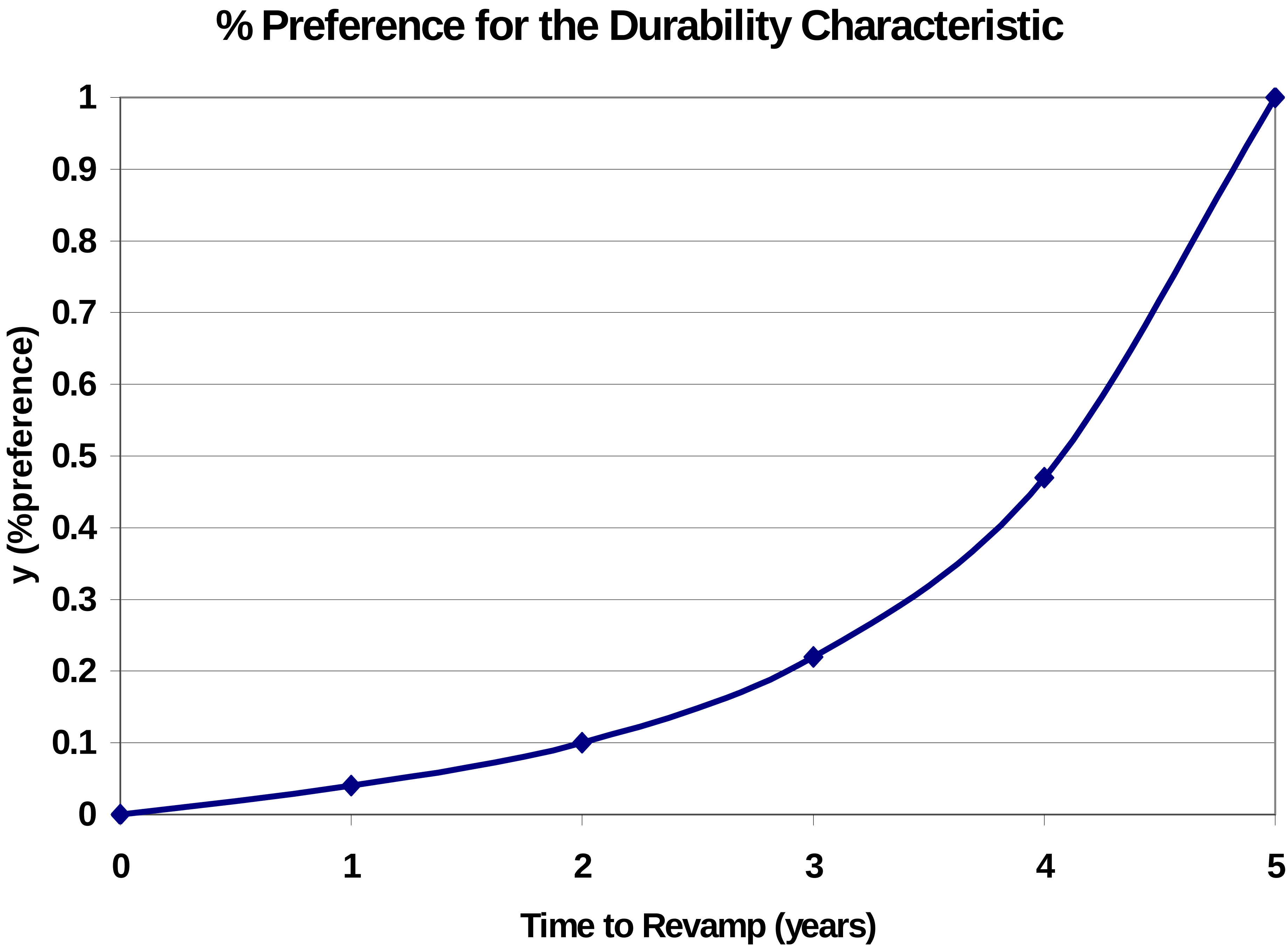
Durability (time to revamp)

- **Utility function (yi) generated**

$Y(\%preference)=0.014x^3 - 0.0475x^2 + 0.0881x - 0.0037$

where x(Time to Revamp)

- Manipulation: Increase consumer preference by including valves and compressors with long term resistance to wear.


% Preference for the Durability Characteristic
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
y (%preference)
0
1
2
3
4
5
Time to Revamp (years)

Consumer Utility and Preference

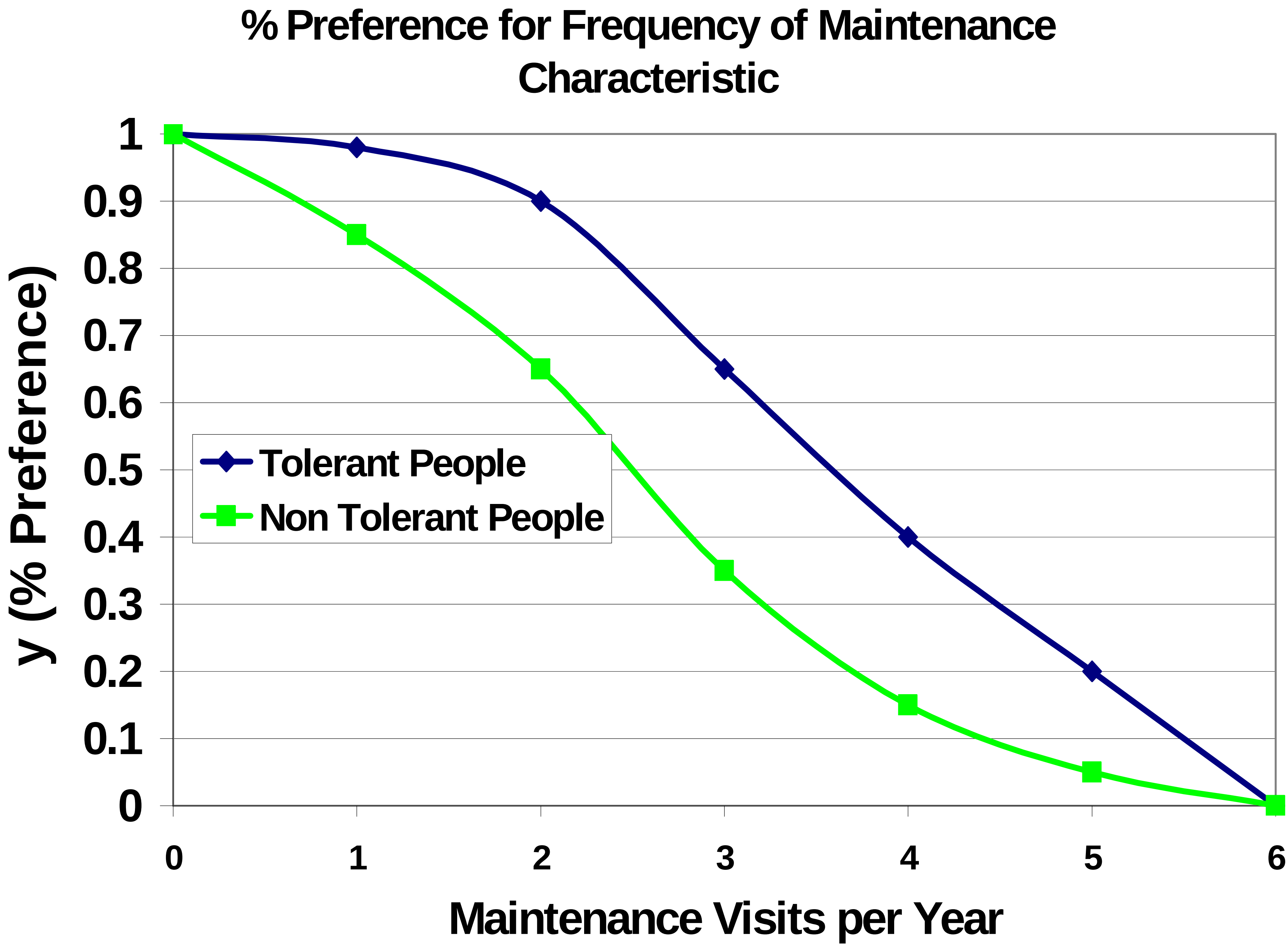
Maintenance(visits per year)

Utility function (yi) generated

Y(%preference)=-0.0083x3 - 0.0607x2 - 0.1012x + 1.0036

where x(Maintenance visits/year)

Manipulation: Greater MTBF leads to less maintenance.


% Preference for Frequency of Maintenance Characteristic
y (% Preference)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
Maintenance Visits per Year
Tolerant People
Non Tolerant People

Consumer Utility and Preference

All utility functions are used to find % preference to be multiplied by characteristic weights to achieve the preference value.

Y(Appearance)=-0.0134x3 + 0.1248x2 - 0.0888x + 0.0063

Y(Noise)=-4E-06x3 - 0.0007x2 + 0.0278x + 0.724

Y(Ease of Use)= 0.0366x2 + 0.0227x - 0.0089

Y(Reliability)=0.0037x3 - 0.0796x2 + 0.5394x - 0.159

Y(Durability)=0.014x3 - 0.0475x2 + 0.0881x - 0.0037

Y(maintenance)=-0.0083x3 - 0.0607x2 - 0.1012x + 1.0036

$$H_i = \sum w_i y_i$$

Business Model

Competitor (liquid oxygen)	% Preference (yi)	Preference/Characteristic (Hi)
Noise	0.930	0.163
Ease of Use	0.950	0.140
Appearance	0.580	0.065
Frequency of Maintenance	0.360	0.066
Reliability	0.900	0.185
Durability	0.760	0.135
		0.753

Now found competitor H2 value can vary oxygen product to produce several new preference values H1 for different β values.

$$\phi(d_1) = p_1 d_1 - \left(\frac{\alpha}{\beta}\right)^{\rho} p_2 \left[\frac{Y - p_1 d_1}{p_2}\right]^{1-\rho} d_1^{\rho} = 0$$

Example Designs	
	Beta Values
Design1	0.85
Design2	0.92
Design3	0.95
Design4	0.97
Design5	1.05
Design6	1.12

Business Model for Hospital Design

Business Model

Goals

- Determine β value that will maximize NPV at the best price for design.

- Determine the effect of varying α(knowledge) with time with a set β value.

Business Model

Determining P1 and D1: Example of prices and demands from consumer utility maximization with Beta=.85

$$p_1 d_1 - \left(\frac{\alpha}{\beta}\right)^{\rho} p_2 \left[\frac{Y - p_1 d_1}{p_2}\right]^{1-\rho} d_1^{\ \rho} = 0$$

Price	Demand
150000	291
175000	202
200000	140
225000	98
250000	69
275000	50
300000	36
325000	27
350000	20

Business Model

Items now needed to find NPV

- Total Product Costs
  - Raw Materials
  - Variable Production Costs
  - Administrative Costs
  - Advertising Costs
  - Distribution Costs
  - Fixed Charges
- TCI
- Total Equipment Costs

Business Model

Total Product Costs per year

Raw materials (depend on demand)

Raw Materials Cost			
	Basis for Estimate	**Rate or Quantity**	**$**
Silica Gel	$.22/100g quote 20 units sold in first year	920 g	$20
LiAgX Zeolite	$.4/100g quote 20 units sold in first year	4130 kg	$165,200
Silver Zeolite A	$.4/100g quote 20 units sold in first year	1230 kg	$49,200
Quiet Barrier Noise Proof Foam	Quote: $361/sheet	16 sheets to cover casing of unit	$115,520
Vinyl Sidiing	Quote: $1.6/sq ft	1400 sq ft to cover	$44,800
		Total Raw Materials Cost	**$214,420**

Business Model

Total Product Costs

- Variable Production Costs (utilities, supplies, maintenance)

Variable Production Costs			
Utilities	**Basis for Estimate**	**Rate or Quantity**	
Electricity	150 bulbs, 23W, full year operation	$.13/kWh	$3,884
	Office heating/cooling/electronics 900W/hr		$1,157
Water	Assume 100 gal/day	$1.98/1000 gal (Georgia cost)	$723
Operating Supplies (variable costs)			
Pencils	12 BIC Mechanical Pencils $5.50	Use 288 per year	$132
Staples	Swingline $1.50 per box	Use 3 boxes per year	$5
Ink for Printer	$60 per black/color ink combo package	Use 6 per year	$360
Pens	12 Bic Pens $5.50	Use 96 per year	$44
Paper	$33 per case of multipurpose paper	Use 2 per year	$66
Maintenance and repairs on building		Estimate of .05 of FCI	$1,150
	Total variable production costs		**$7,520**

Business Model

Total Product Costs

- Administrative Costs

Administrative Costs			
Employees	**# employees**		
Engineers	1	Assume $60,000 salary/year	$60,000
Accountant	1	Assume $30000 salary/year	$30,000
Skilled Labor	2	Assume $30000 salary/year	$60,000
Traveling Salesman	1	Assume $35000 salary/year	$35,000
Secretary	1	Assume $25000 salary/year	$25,000
Traveling Maintenance	1	Assume $35000 salary/year	$35,000
	Total Administrative Costs		**$245,000**

Business Model

Distribution and marketing expenses			
Distribution and marketing expenses			
	Basis for Estimate	**Rate or Quantity**	
Sales personnel expenses	Assume visits 70% large hospitals = 175, only 3 day/ trip estimate, 35 trips/year		
	Airfare	$400/trip	$14,000
	Hotel	$100/trip per day	$10,500
	Food	$50/trip per day	$5,250
	Rental Car / Gas	$80 per day for rent and gas	$8,400
	Total Sales Expenses per Year		**$38,150**
Advertising	Assume high advertising from calculations	Estimated $100,000	
	Brochures	$1/brochure, send 50 to each hospital/year	$12,500
	DVD	$8/DVD, send 10 to each hospital/year	$20,000
	Mailing expenses	Assume 10lb per box at $20/box	$10,000
	Total Adversing Expenses (high advertisement rate)		**$42,500**
Shipping	20 units shipped in first year from demand es	$.3/kg, unit weight ~ 16000kg	$192,000
Total Distribution and marketing expenses			**$272,650**

Total Product Cost for First-Year
Product: Pressure Swing Adsorption for Large Hospitals

Operating time day/year	250		
Estimated units fabricated/year	20		
	Basis for Estimate	**Rate or Quantity**	$
Silica Gel	$.22/100g quote 20 units sold in first year	1840 g	$81
LiAgX Zeolite	$.4/100g quote 20 units sold in first year	8260 kg	$660,800
Silver Zeolite A	$.4/100g quote 20 units sold in first year	2460 kg	$196,800
Quiet Barrier Noise Proof Foam	Quote: $361/sheet	16 sheets to cover casing of unit	$115,520
Vinyl Sidiing	Quote: $1.6/sq ft	1400 sq ft to cover	$44,800
		Total Raw Materials Cost	$1,018,001
Variable Production Costs			
Utilities			
Electricity	150 bulbs, 23W, full year operation	$.13/kWh	$3,884
	Office heating/cooling/electronics 900W/hr		$1,157
Water	Assume 100 gal/day	$1.98/1000 gal (Georgia cost)	$723
Operating Supplies (variable costs)			
Pencils	12 BIC Mechanical Pencils $5.50	Use 288 per year	$132
Staples	Swingline $1.50 per box	Use 3 boxes per year	$5
Ink for Printer	$60 per black/color ink combo package	Use 6 per year	$360
Pens	12 Bic Pens $5.50	Use 96 per year	$44
Paper	$33 per case of multipurpose paper	Use 2 per year	$66
Maintenance	$5000 per maintenance visit	Estimate 1/10 break down in year 1	$10,000
		Total variable production costs	**$10,607**
Fixed Charges			
Warehouse	**$6.9/sq ft/year quote**	**3200 sq ft, Atlanta, Georgia (20% office)**	$22,080
		Total Fixed Charges	$22,080
Administrative Costs			
Employees	**# employees**		
Engineers	1	Assume $60,000 salary/year	$60,000
Accountant	1	Assume $30000 salary/year	$30,000
Skilled Labor	2	Assume $30000 salary/year	$60,000
Traveling Salesman	1	Assume $35000 salary/year	$35,000
Secretary	1	Assume $25000 salary/year	$25,000
Traveling Maintenance	1	Assume $35000 salary/year	$35,000
		Total Administrative Costs	**$245,000**
Distribution and marketing expenses			
Sales personnel expenses	Assume visits 70% large hospitals = 175, only 3 day/ trip estimate, 35 trips/year		
	Airfare	$400/trip	$14,000
	Hotel	$100/trip per day	$10,500
	Food	$50/trip per day	$5,250
	Rental Car / Gas	$80 per day for rent and gas	$8,400
		Total Sales Expenses per Year	$38,150
Advertising	Assume high advertising from calculations	Estimated $100,000	
	Brochures	$1/brochure, send 50 to each hospital/year	$12,500
	DVD	$8/DVD, send 10 to each hospital/year	$20,000
	Mailing expenses	Assume 10lb per box at $20/box	$10,000
		Total Adversing Expenses (high advertisement rate)	$42,500
Shipping	20 units shipped in first year from demand es	$.3/kg, unit weight ~16000kg	$192,000
		Total Distribution and marketing expenses	$272,650
	Total Product Cost		**$1,568,337**

Business Model

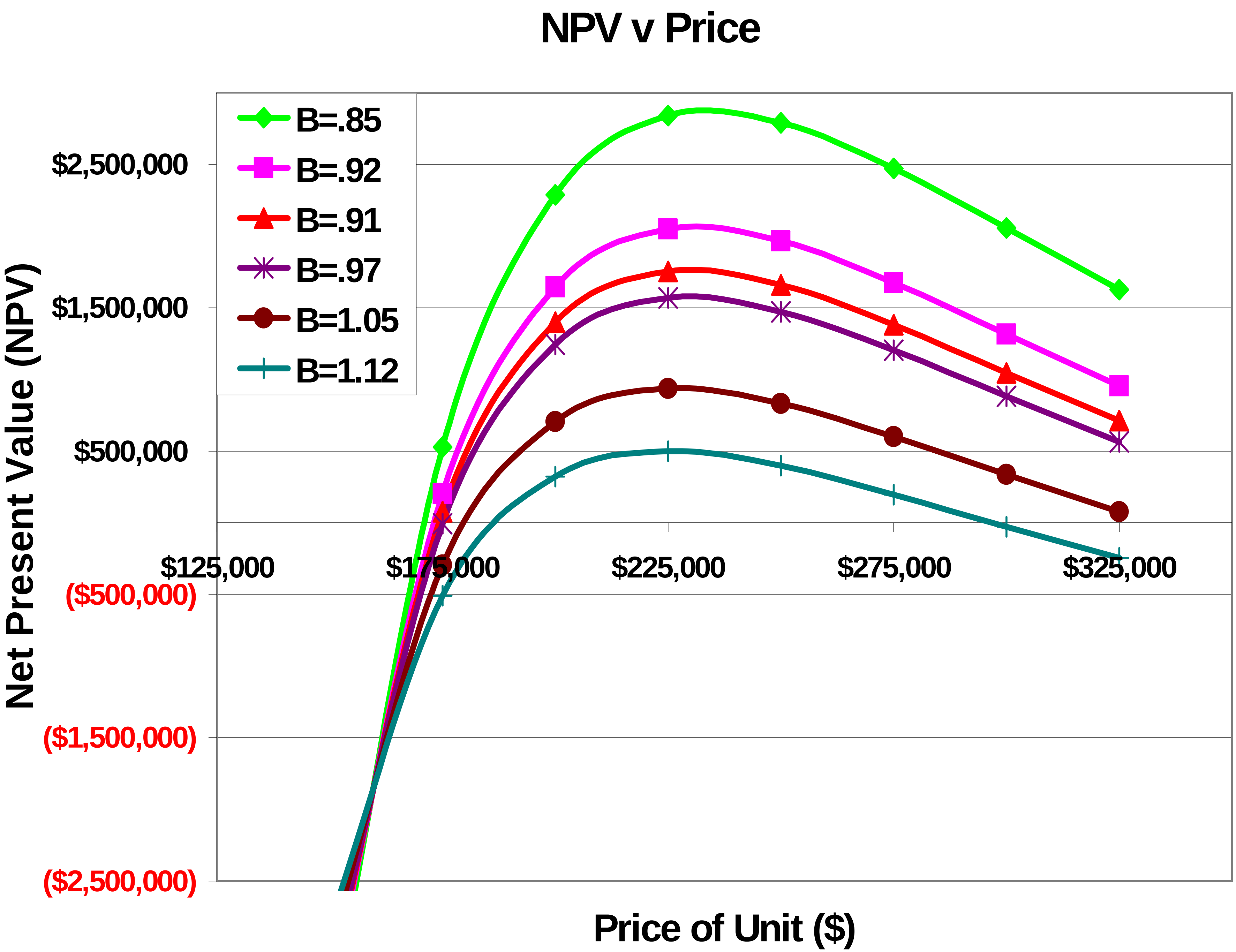
- Now find TCI

Capital Investment for Hospital Design			
		Assumptions	Costs
Office Furniture and Related Equipment		**Quantity**	
Desks	$250/desk (office depot)	4	$1,000
Chairs	$115/chair (office depot)	6	$2,760
Phones	$60/phone (multi line) (office depot)	6	$360
Computers	$800/computer (Dell Precision)	4	$3,200
Office Supplies (stapler, rulers, paper)	$300 for all supplies	N/A	$150
Printer/Copier/Fax Machine	$300 (Intellifax-400e) (office depot)	1	$300
House keeping supplies (Vaccum, Mop)	$200 (Dirt Devil - Bagless Upright)	1	$300
Tools including nuts and bolts	$3000/tool set (home depot)	3	$9,000
Bobcat Forklift	$3000 used price	1	$3,000
Total estimated fixed capital investment			**$20,070**
Working Capital		**15% of TCI**	**$3,542**
Total Capital Investment			**$23,612**

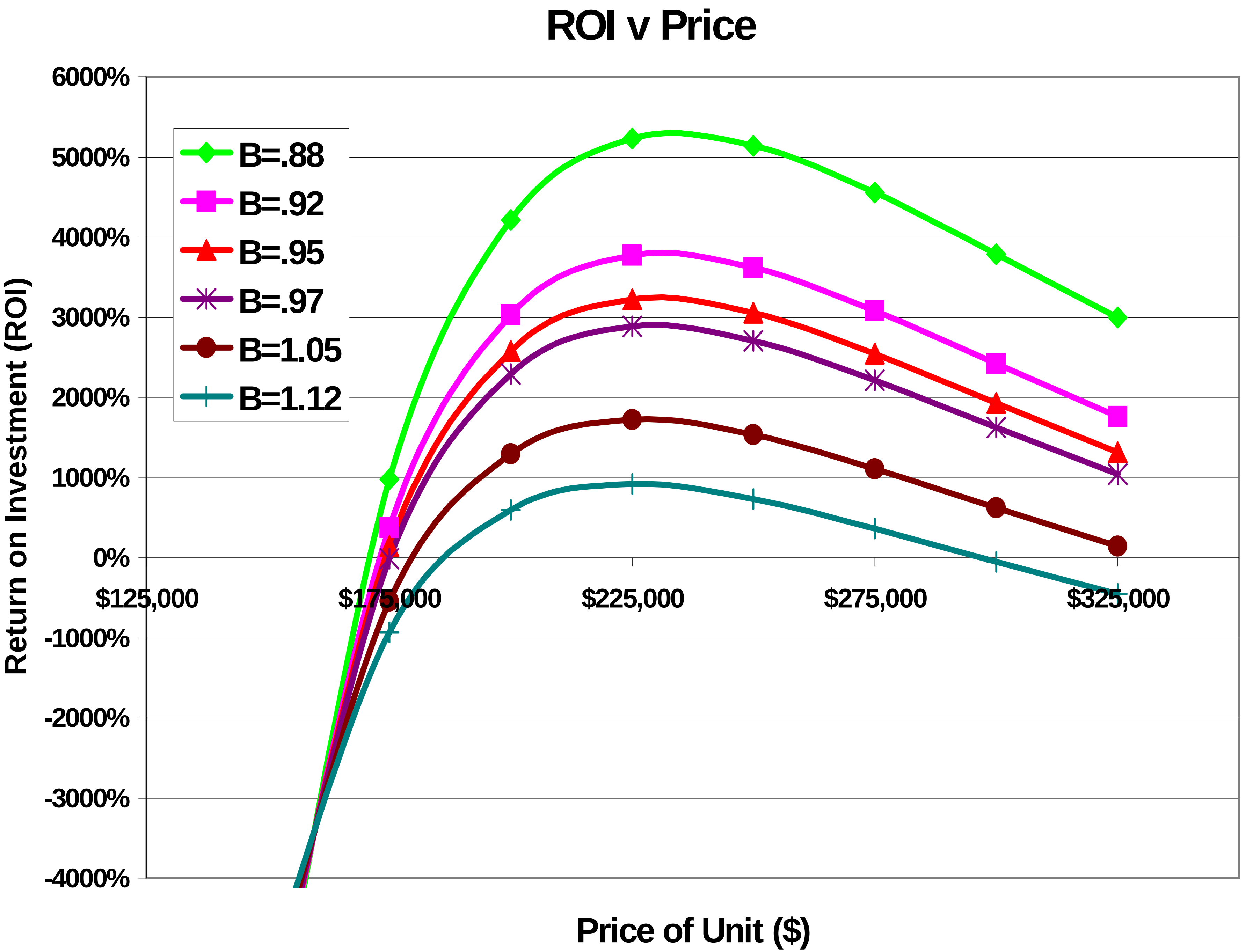
Business Model

- **Lastly, Equipment Costs**

Estimation of Equipment Cost of 1 Unit			
	Basis for Estimate	**Quantity**	**Equipment Costs**
Nitrogen Removal Column	Quote	4	$32,000
Drying Column	Quote	1	$200
Palatek Compressor 200UD	Quote: $9800	2	$19,600
Palatek Compresser H30D7	Quote: $5000/unit	2	$10,000
High Pressure Storage Tank	Fig.12.53 in P&T	1	$12,000
3 Way Control Valve	Quote: $700/unit	8	$5,600
Control Computer	Quote	1	$600
Total Equipment Costs			**$80,000**



NPV v Price
B=.85
B=.92
B=.91
B=.97
B=1.05
B=1.12
$2,500,000
$1,500,000
$500,000
($500,000)
($1,500,000)
($2,500,000)
$125,000
$175,000
$225,000
$275,000
$325,000
Net Present Value (NPV)
Price of Unit ($)


ROI v Price
6000%
5000%
4000%
3000%
2000%
1000%
0%
-1000%
-2000%
-3000%
-4000%
Return on Investment (ROI)
$125,000
$175,000
$225,000
$275,000
$325,000
Price of Unit ($)
B=.88
B=.92
B=.95
B=.97
B=1.05
B=1.12

Business Model

Results:

- NPV over 5 year span= $2,800,000
- Optimal β=.85
- Price of unit $250,000
- ROI for 1st year = 5200%

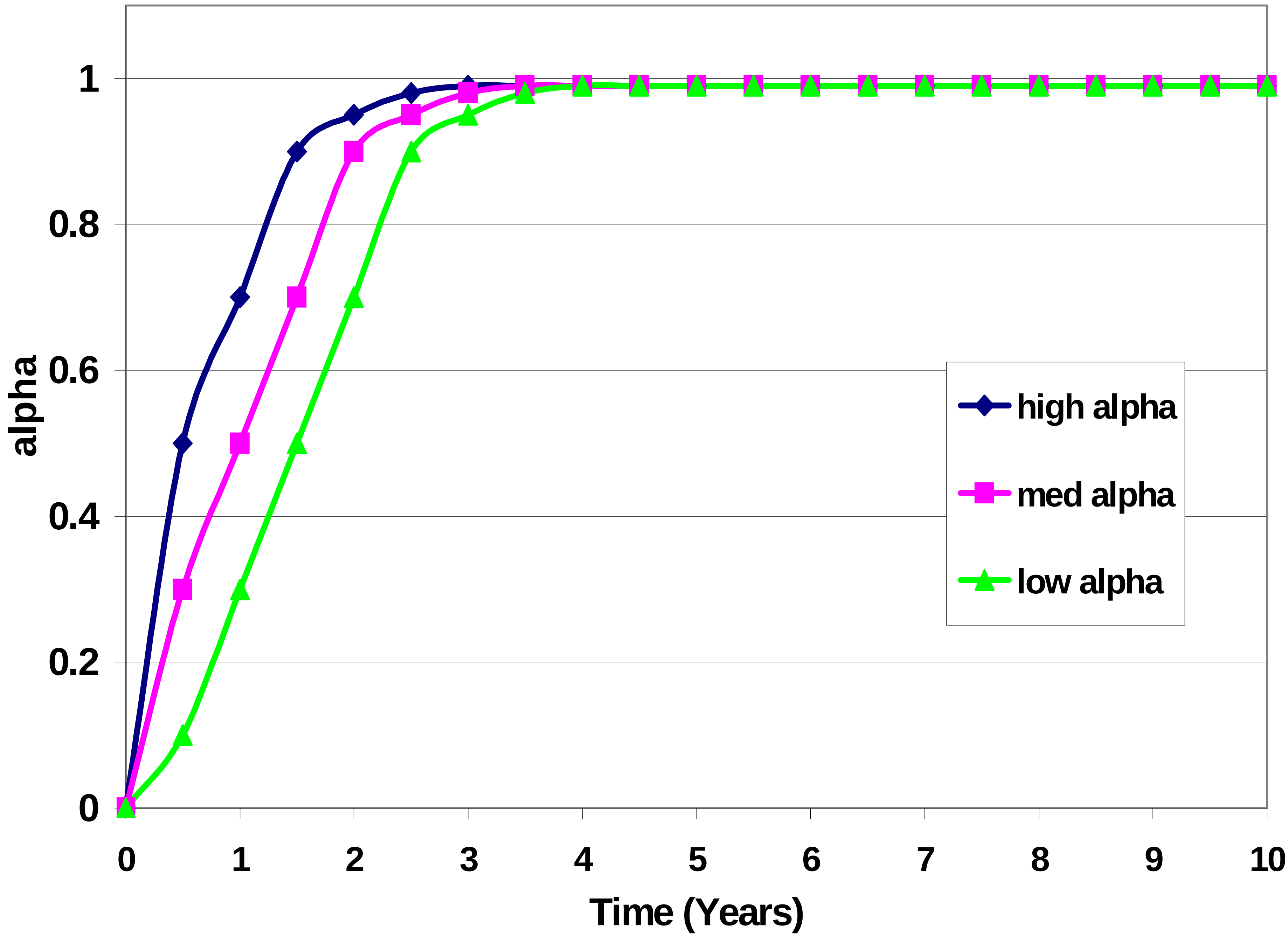
Business Model

Varying a (consumer knowledge) with Time

Business Model

Goals

- Now find knowledge/advertising as a function of time
- Assume full consumer knowledge within 2 years of high advertising.



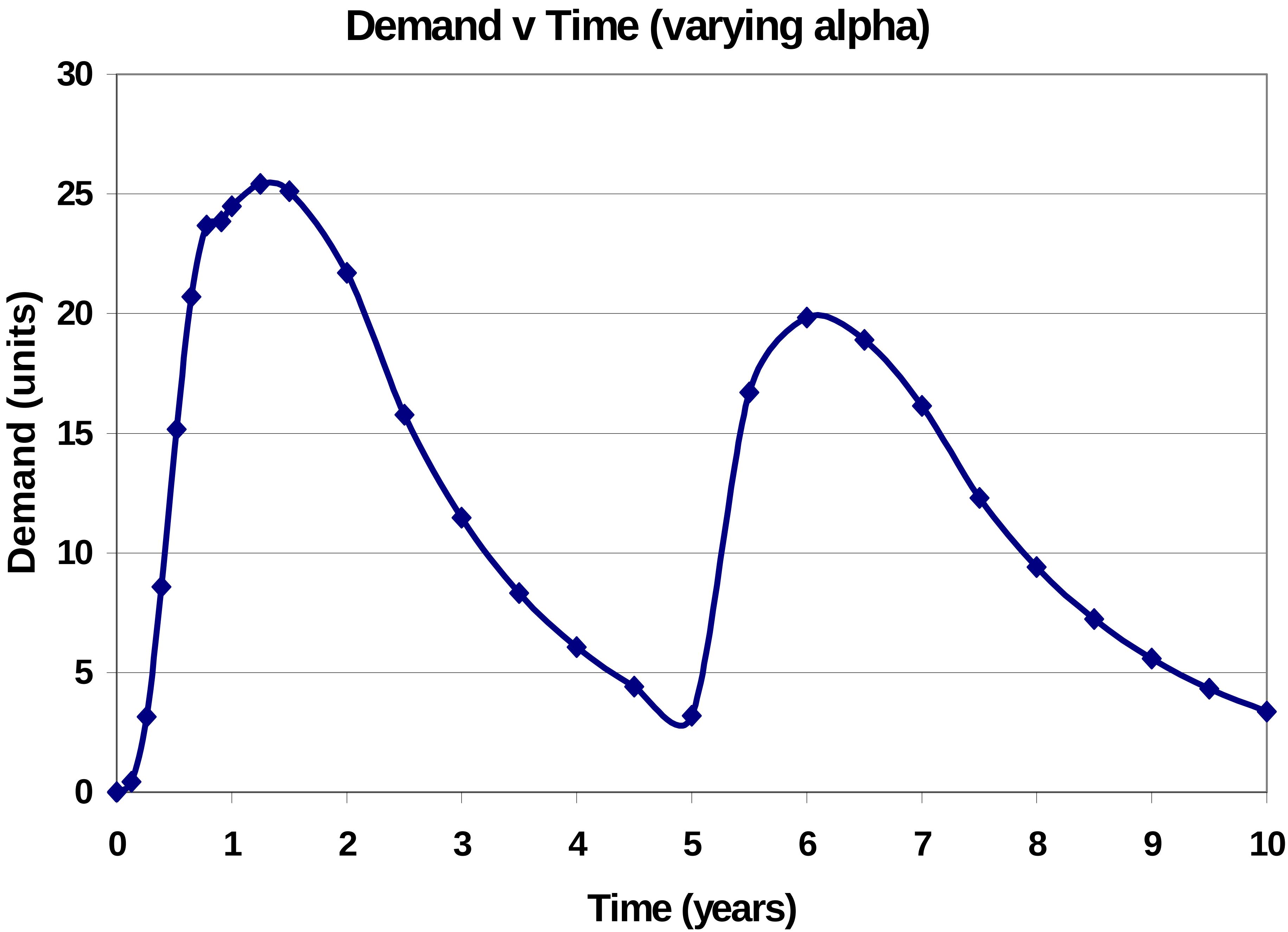
1
0.8
0.6
0.4
0.2
0
alpha
0
1
2
3
4
5
6
7
8
9
10
Time (Years)
high alpha
med alpha
low alpha

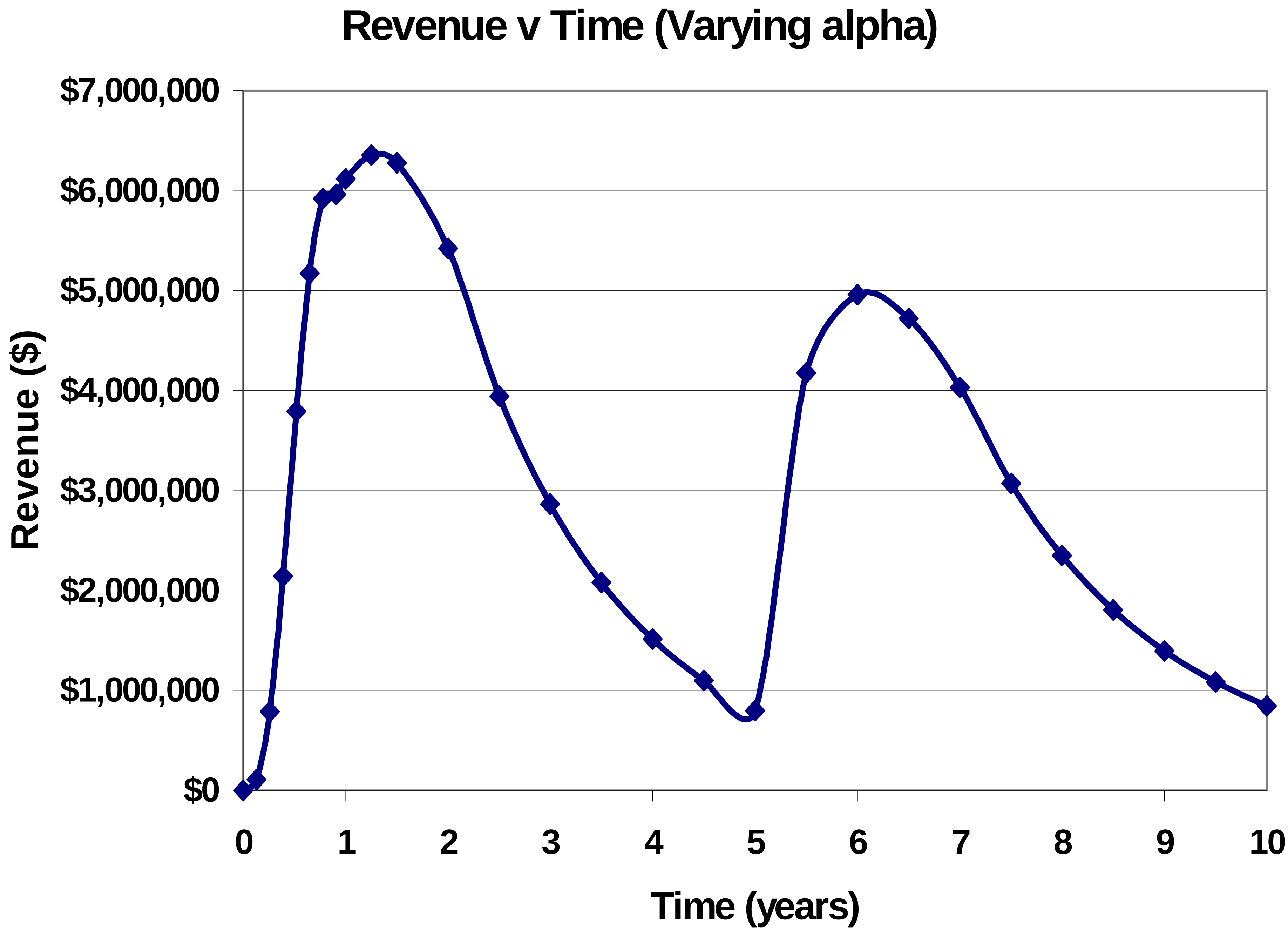
Business Model

Work Completed:

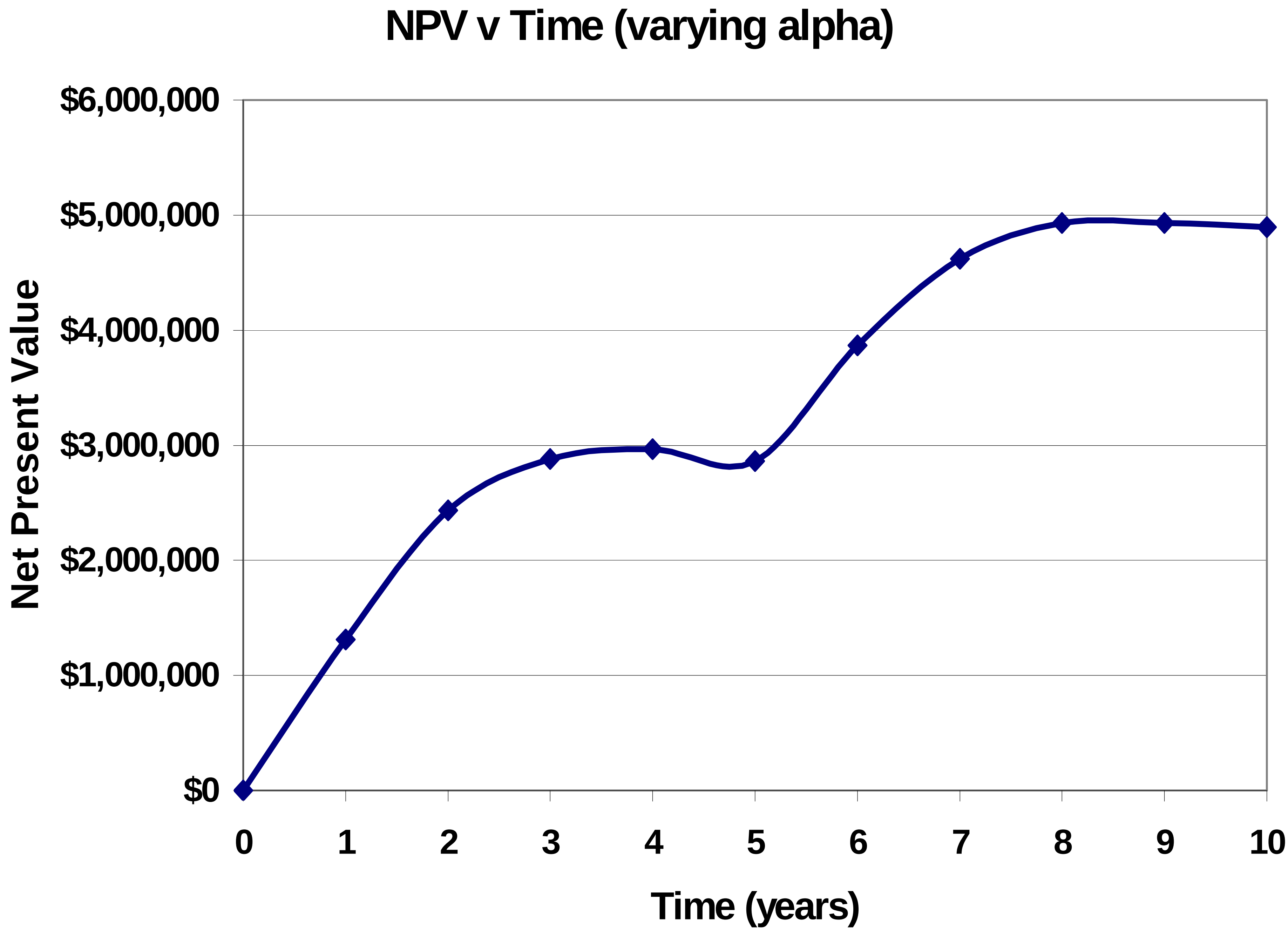
- Vary alpha with time with optimal beta and price.

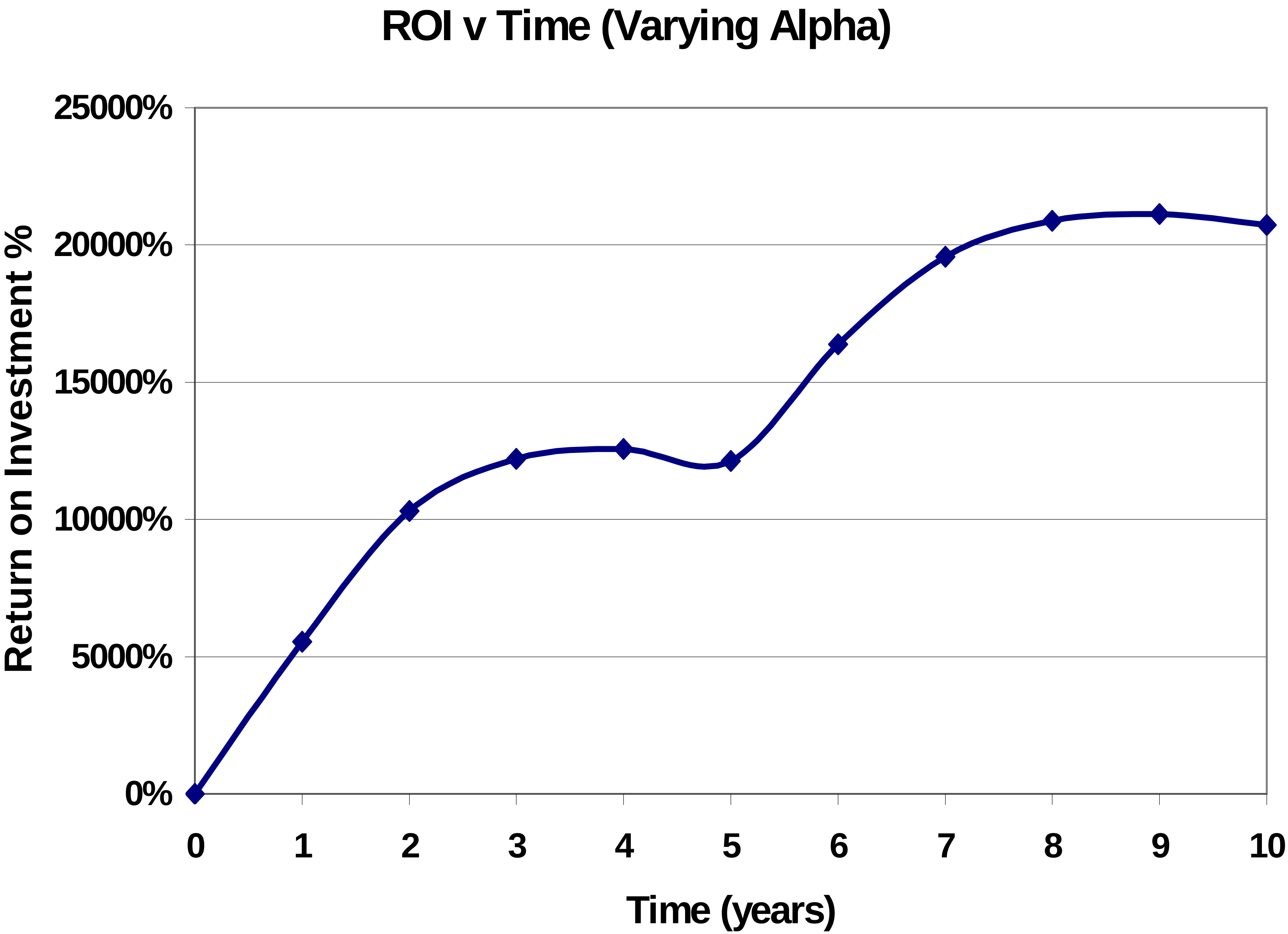
- **Graphs to Plotted:**
  - Revenue versus Time
  - Demand versus Time
  - NPV versus Time
  - ROI versus Time


Demand v Time (varying alpha)
Demand (units)
Time (years)
0
5
10
15
20
25
30
0
1
2
3
4
5
6
7
8
9
10



Revenue v Time (Varying alpha)
$7,000,000
$6,000,000
$5,000,000
$4,000,000
$3,000,000
$2,000,000
$1,000,000
$0
Revenue ($)
0
1
2
3
4
5
6
7
8
9
10
Time (years)


NPV v Time (varying alpha)
$6,000,000
$5,000,000
$4,000,000
$3,000,000
$2,000,000
$1,000,000
$0
Net Present Value
0
1
2
3
4
5
6
7
8
9
10
Time (years)

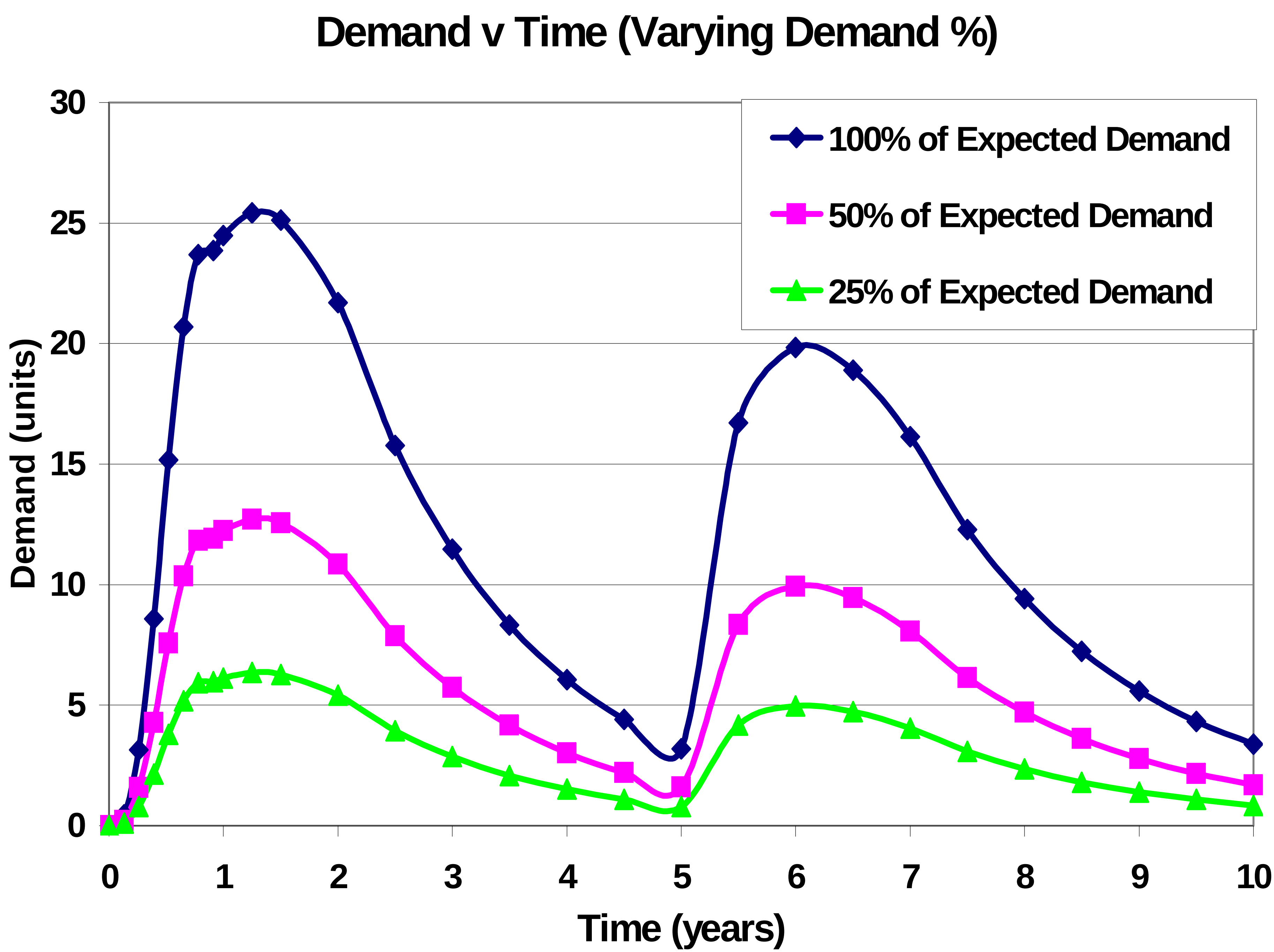


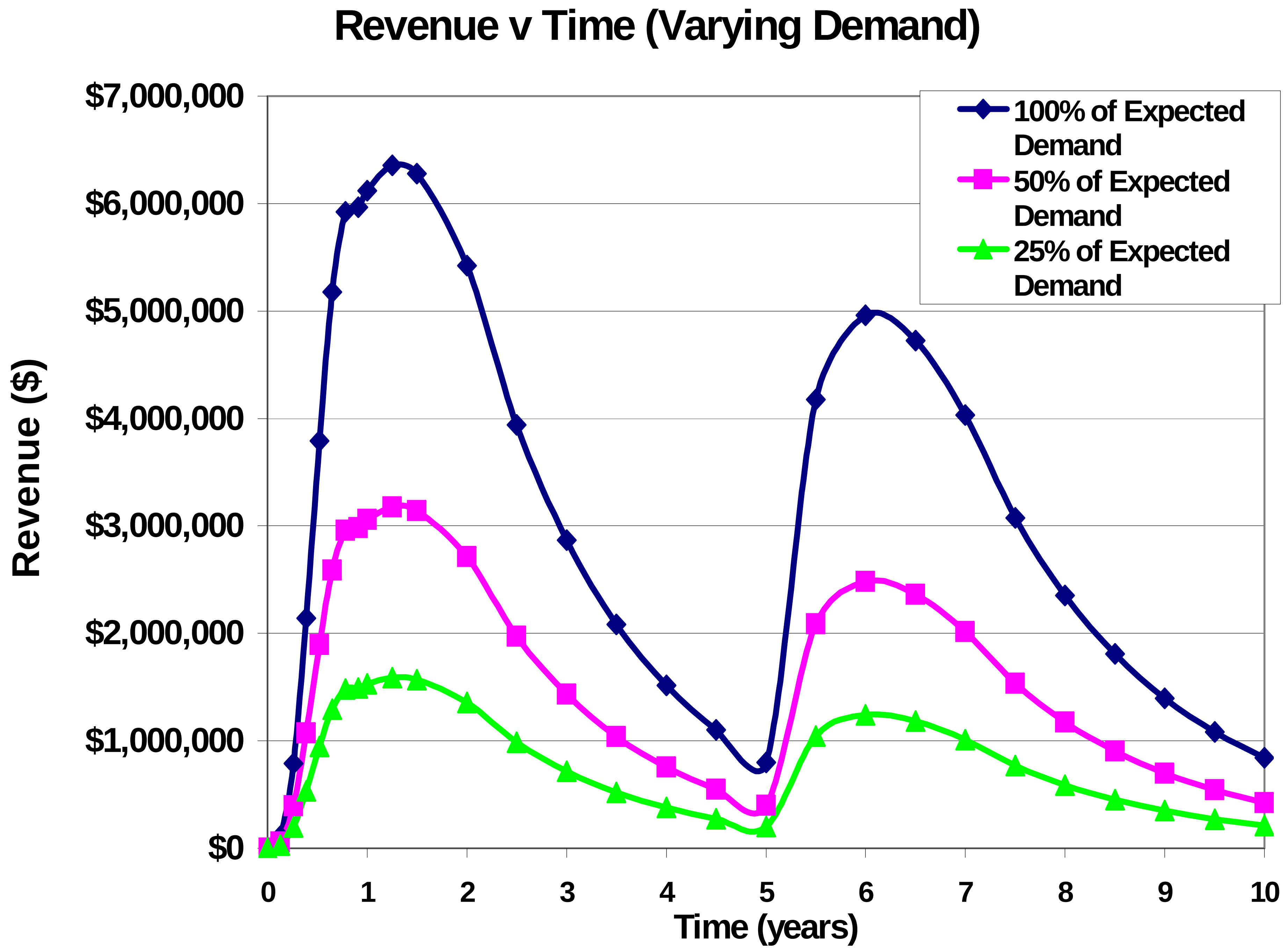
ROI v Time (Varying Alpha)
Return on Investment %
25000%
20000%
15000%
10000%
5000%
0%
0
1
2
3
4
5
6
7
8
9
10
Time (years)

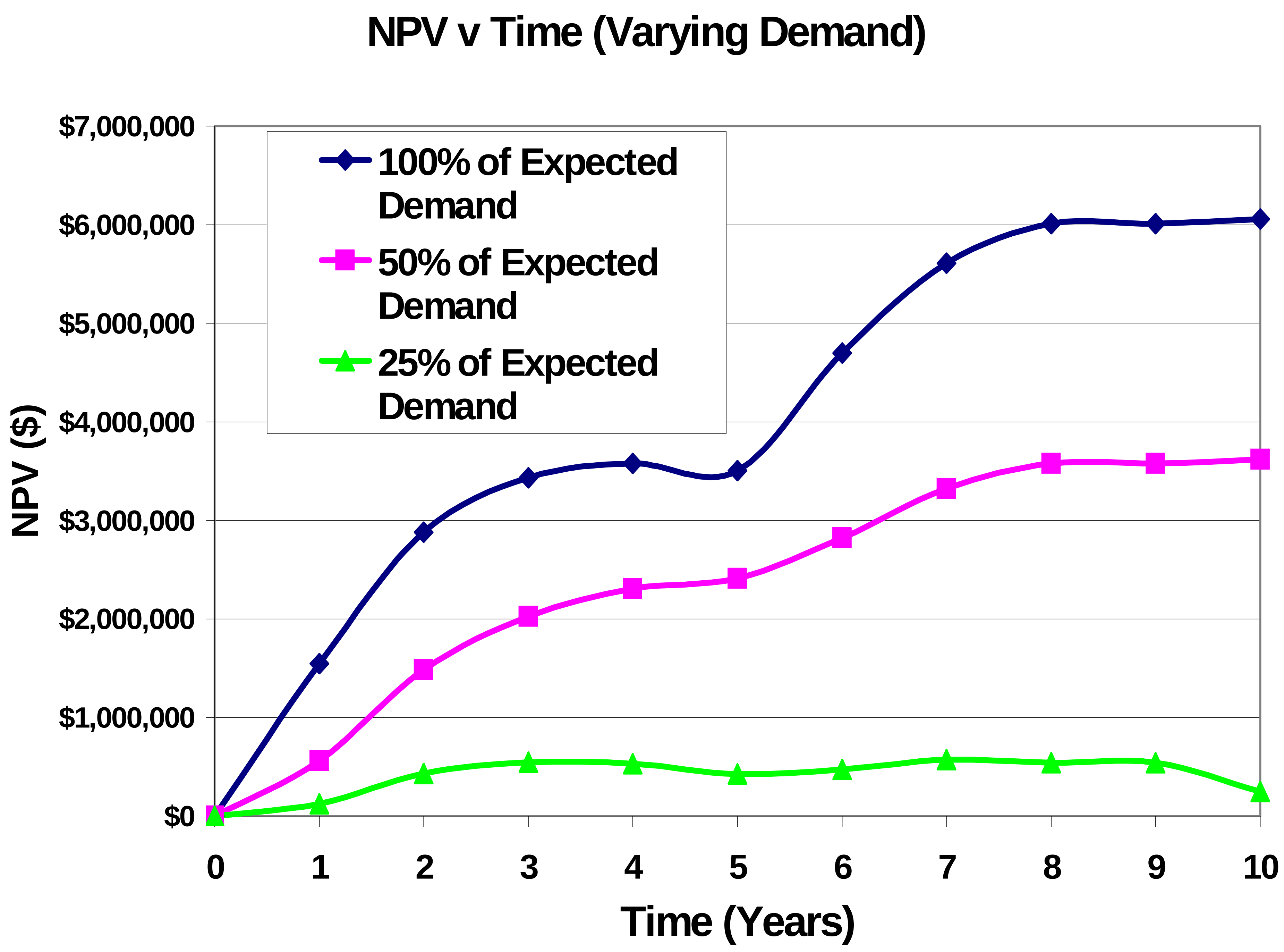
Preliminary Risk Estimates of Oxygen Concentrator

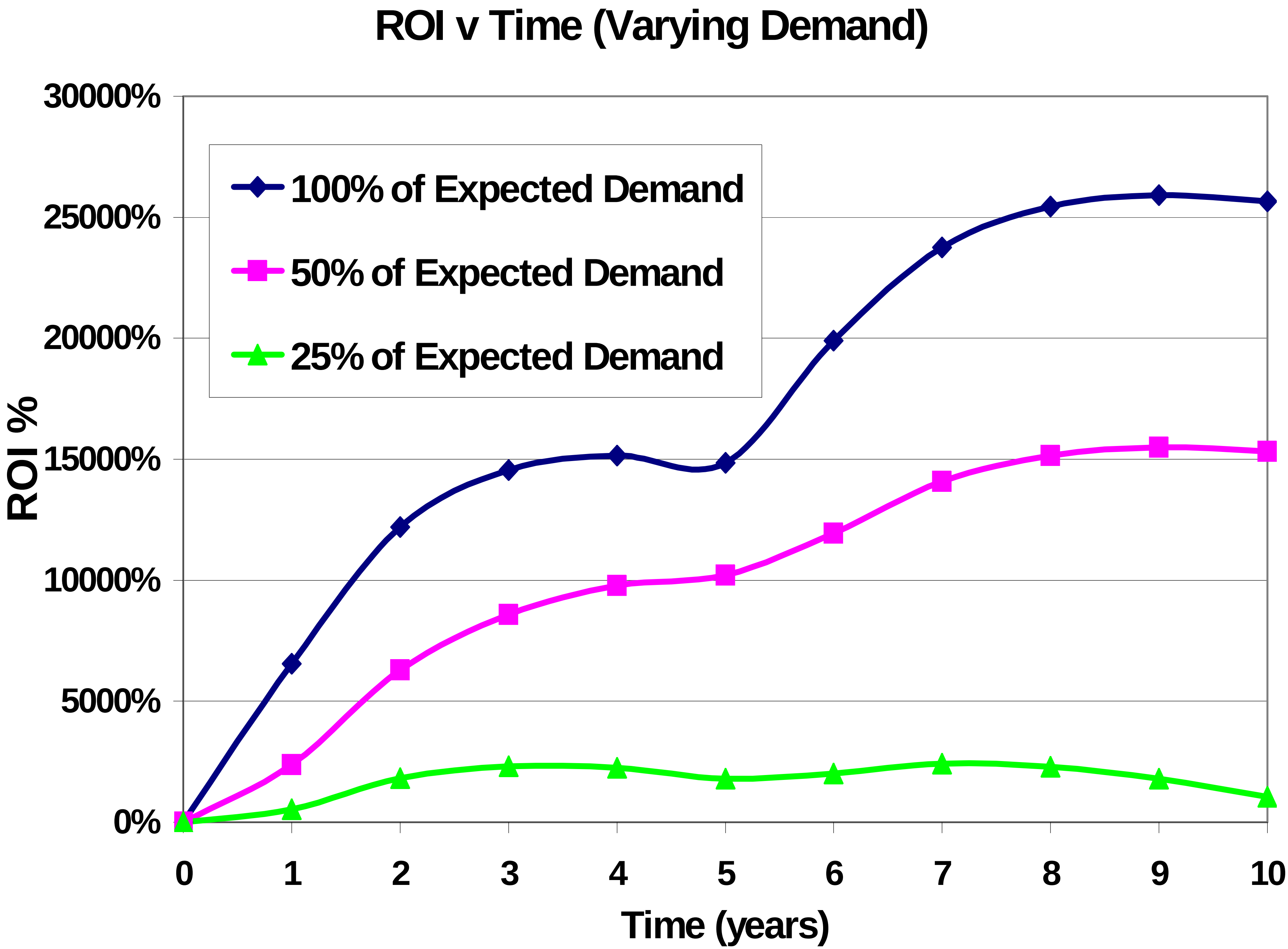
Risk

- Goal of this section is to predict profit if the scenario occurs that less consumers purchase the product.
- Consumer utility maximization could have predicted wrong.
- Copycats may enter market or oxygen prices may drop limiting market.


Demand v Time (Varying Demand %)
Demand (units)
Time (years)
100% of Expected Demand
50% of Expected Demand
25% of Expected Demand
0
5
10
15
20
25
30
0
1
2
3
4
5
6
7
8
9
10


Revenue v Time (Varying Demand)
$7,000,000
$6,000,000
$5,000,000
$4,000,000
$3,000,000
$2,000,000
$1,000,000
$0
Revenue ($)
0
1
2
3
4
5
6
7
8
9
10
Time (years)
100% of Expected Demand
50% of Expected Demand
25% of Expected Demand


NPV v Time (Varying Demand)
100% of Expected Demand
50% of Expected Demand
25% of Expected Demand
$7,000,000
$6,000,000
$5,000,000
$4,000,000
$3,000,000
$2,000,000
$1,000,000
$0
NPV ($)
0
1
2
3
4
5
6
7
8
9
10
Time (Years)


ROI v Time (Varying Demand)
30000%
25000%
20000%
15000%
10000%
5000%
0%
ROI %
100% of Expected Demand
50% of Expected Demand
25% of Expected Demand
0
1
2
3
4
5
6
7
8
9
10
Time (years)

Conclusions

- The hospital project has been shown to be profitable even if demand is less than 75% than expected.

- NPV over 5 year span= $2,800,000
- ROI over 1 year span = 5200%

Future Work

- Research more into practical application of portable oxygen concentrators.
- Further studies on maximization of NPV, ROI, and hospital preferences.
- More in-depth analysis of risk and consumer/competitor reaction estimation.

Business Model

Preliminary Financial Analysis

	Concentrator	Liquid Oxygen
Total Cost per 5 Year	$500,000	$850,000
Total Savings for 5 Years	$350,000	
Average Savings per Year	$70,000	

Final Conclusions

- It is now possible to deliver 99% oxygen to patients in a hospital, and to those who want to enjoy a life without the restriction of bulky liquid oxygen bottles.

Final Conclusions

- This technology would change the lives of millions of patients and those needing oxygen around the world for years to come.

Questions?