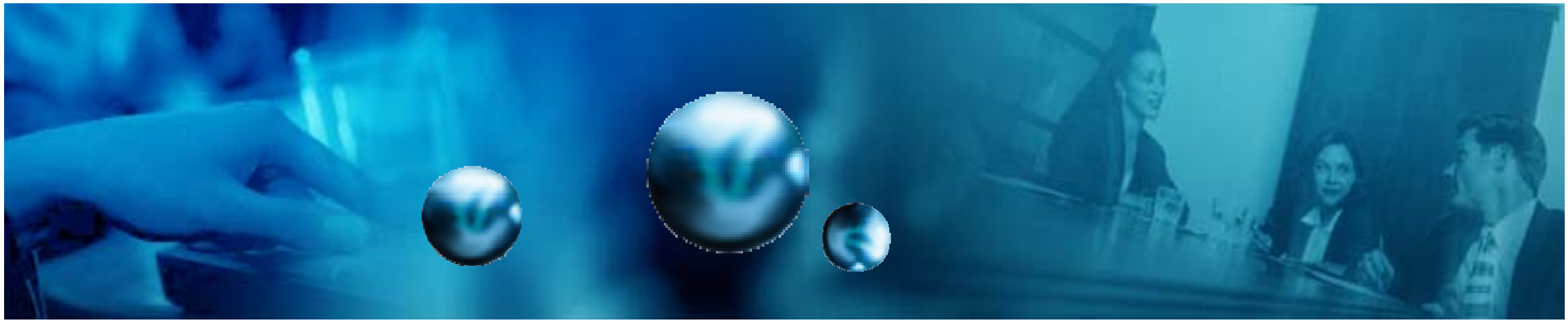
Integumentary Perfections

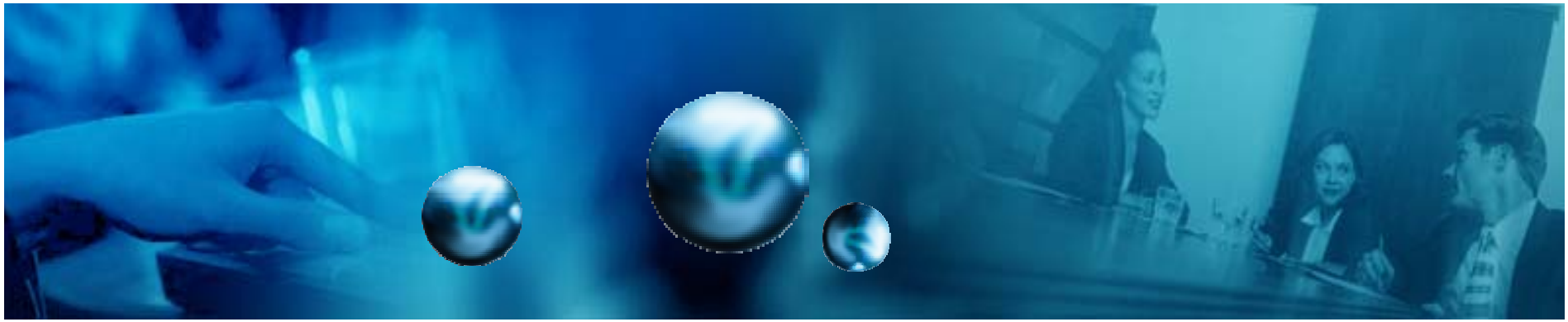


Curtis Baade
Shamara Manora

Agenda

1. The Skin
2. Product Design
3. Economic Analysis
4. Conclusions

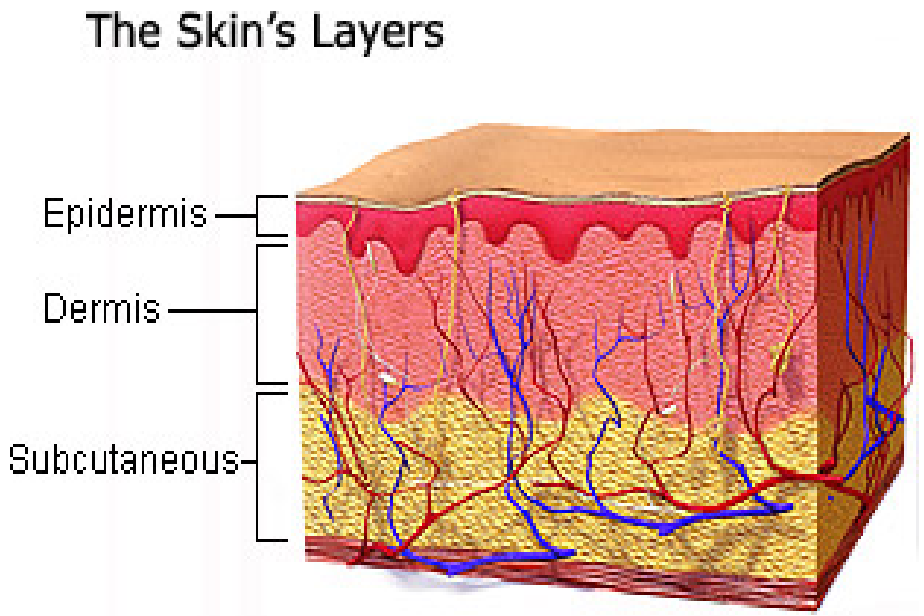
The Skin



Skin Layers

The Skin

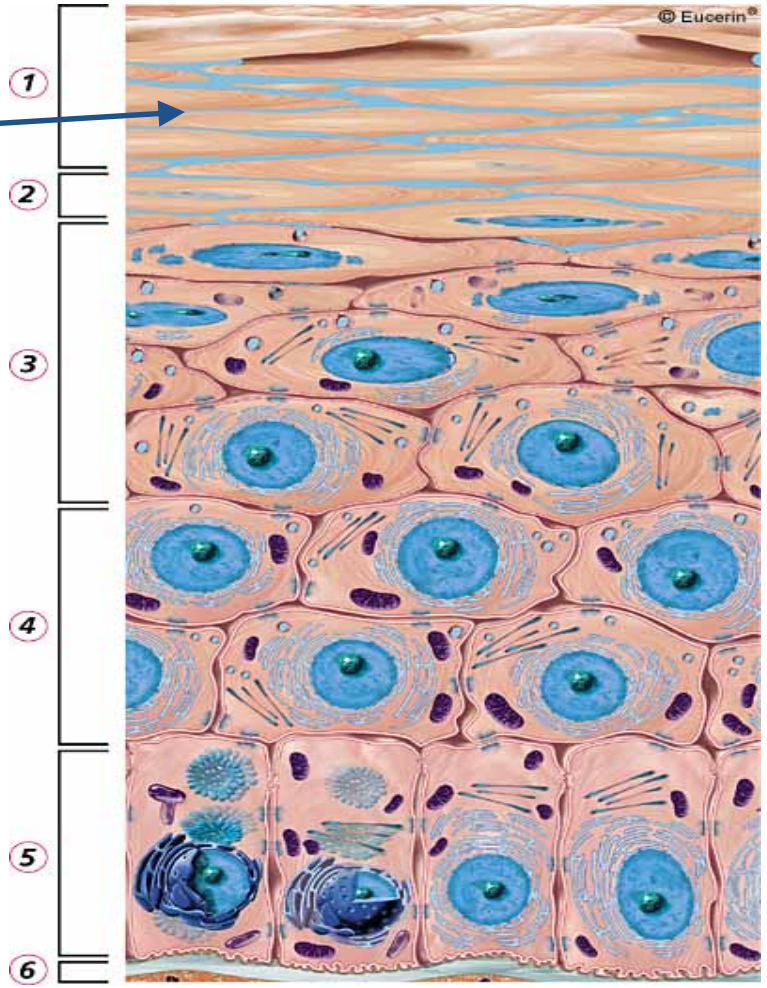
- Semi-permeable barrier between body and environment
- Contains three layers: epidermis, dermis and subcutaneous



Source: http://cancer.healthcentersonline.com/skincancer/basalcellcarcinoma.cfm

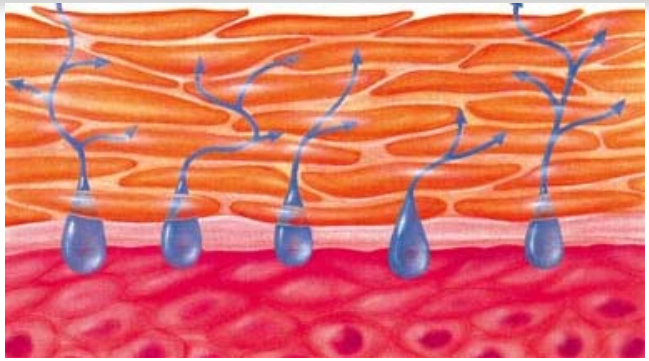
Epidermis

- The outermost layer of the epidermis is the stratum corneum
  - Approximately 20 cell layers thick
  - Location in which desquamation occurs
    - Desquamation is the shedding of the top layer of cells in the stratum corneum
    - Approximately 1 layer per day is released

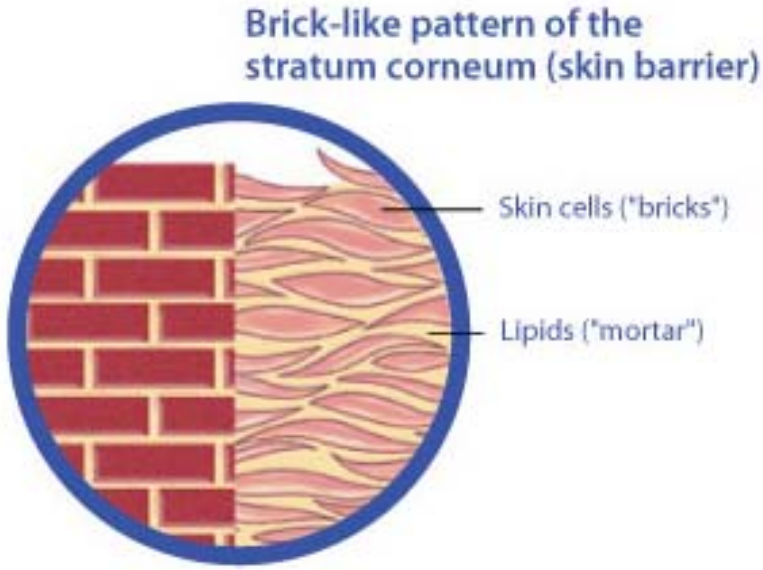


Source: www.eucerim.co.uk

Stratum Corneum



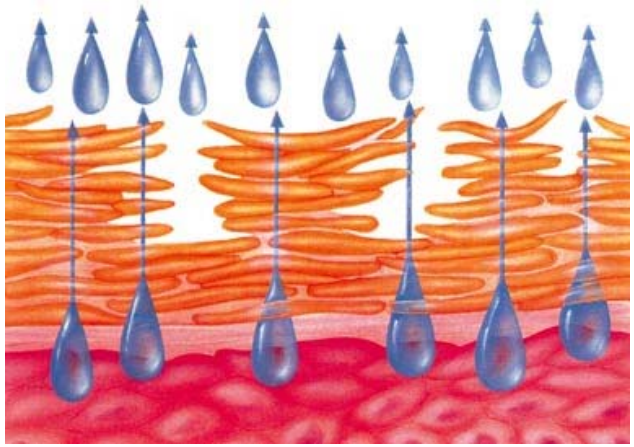
- Contains hydrophilic cells (keratinocytes) surrounded by a hydrophobic lipid bilayer (lipid lamellae)
- Contains natural moisturizing factors (NMF) which are responsible for the absorption and retention of water.



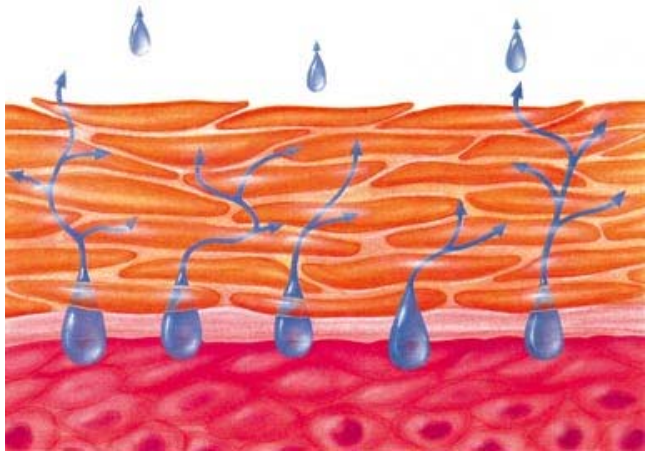
www.cerave.com/barrier.htm

Effects on Skin Barrier

- Reduced or low water content in the Stratum Corneum results in a compromised barrier (chapping)
- This compromised barrier must be restored in order to prevent transepidermal water loss



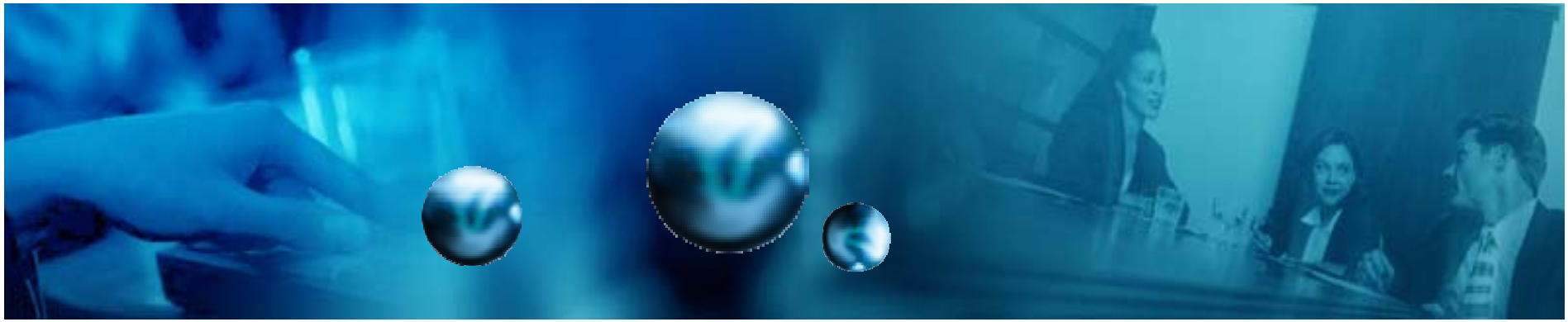
Compromised Barrier



Intact Barrier

Source: http://www.cetaphil.com.au/importance_of_your_skin_more.asp

The Skin



Skin Disorders

Xerosis (Dry Skin)

- Natural moisturizers Stratum Corneum are removed
- Caused by overexposure to water, sun, or cold weather
- Symptoms include dry, itchy skin

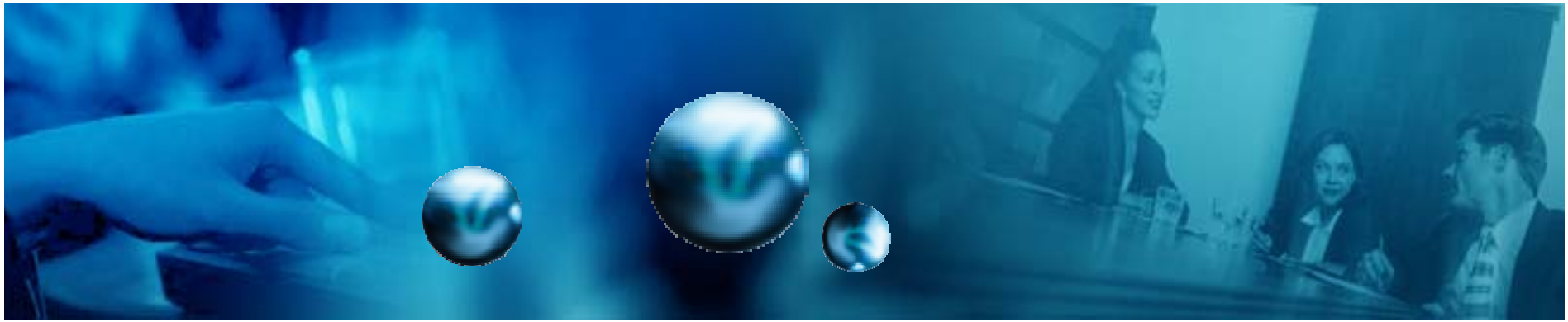
Source: University of California, San Fransico, www.uscf.edu

Ichthyosis Vulgaris

- Incurable, genetic disorder affecting production and/or desquamation of cells
- Caused by
  - low water content in Stratum Corneum
  - enzymatic reactions controlling desquamation are inhibited
- Symptoms include dry, thickened, scaly skin

Source: Geneva Foundation for Medical Education and Research, www.gfmer.ch

The Skin



Treatment Therapy

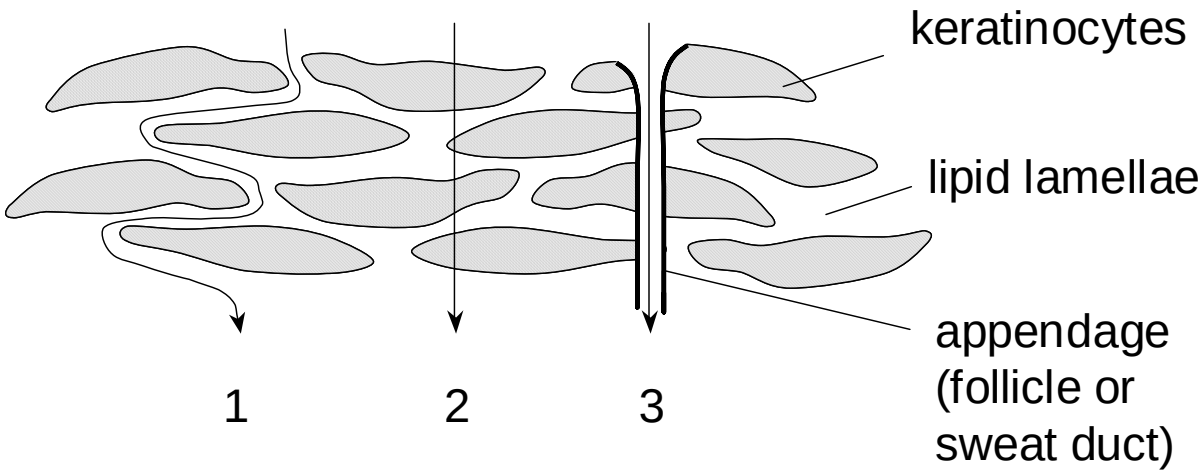
Treatment Strategy

Three key steps to **effectively** treat the disorders

- Promote desquamation
- Deliver moisturizing agents to underlying skin
- Restore the skin's lipid bilayer

Transdermal Diffusion

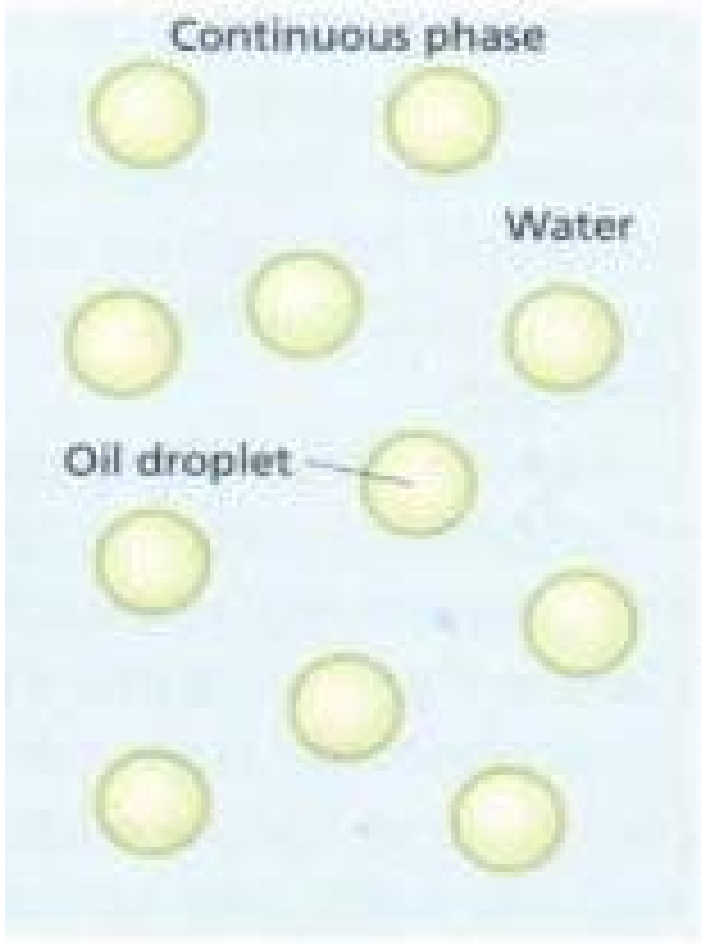
- Percutaneous absorption mostly occurs via transcellular diffusion (Pathway 2)
- Other pathways are
  - Intercellular diffusion (Pathway 1)
  - Diffusion through skin appendages (Pathway 2)



Source: A Geoscience Approach to Modeling Chemical Transport Through the Skin

Moisturizer Formulation

- The simplest vehicle for skin moisturizers are emulsions
- For lotions, oil-in-water emulsions are used
  - Water is the continuous phase
  - Oil is the dispersed phase

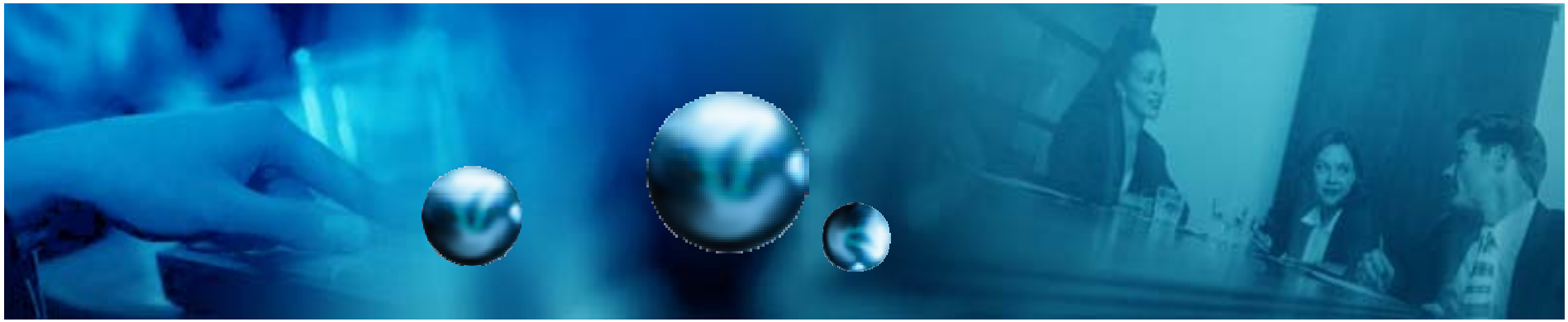


Source: http://www.pg.com/science/skincare/Skin_tws_101.htm

Lotion Composition

- Lotions have active and inactive ingredients
- Ingredients are characterized by a combination of properties (e.g. effectiveness, smoothness, thickness, etc.)

Product Design



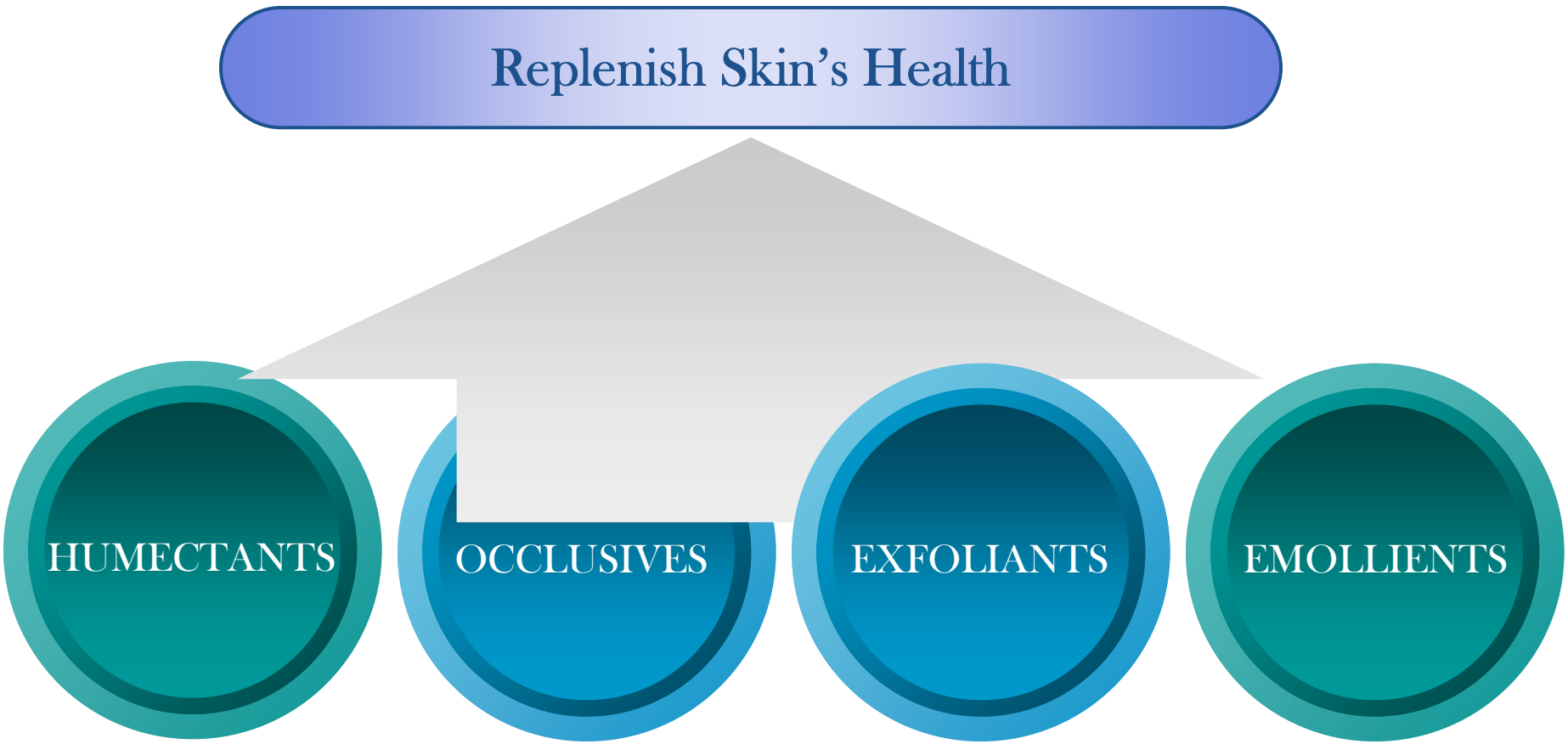
Lotion Composition

Product Regulations

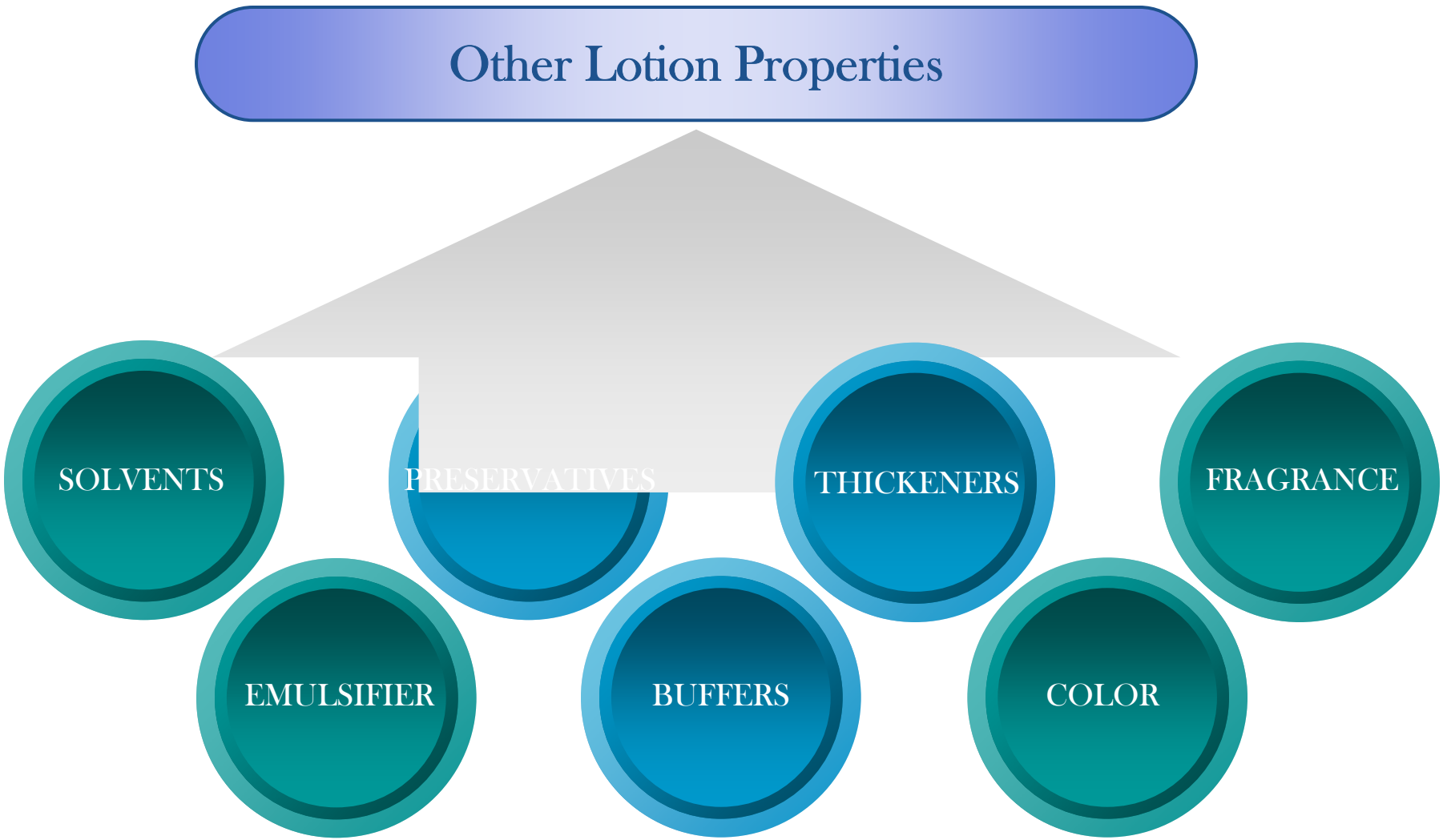
- Since skin moisturizers are considered cosmetic products, they do not have to adhere to FDA regulations
- Cosmetics are subject to restrictions on the concentration of certain ingredients determined by the Cosmetic Ingredient Review

Source: http: www.cfsan.fda.gov/~dms/cos-206.html

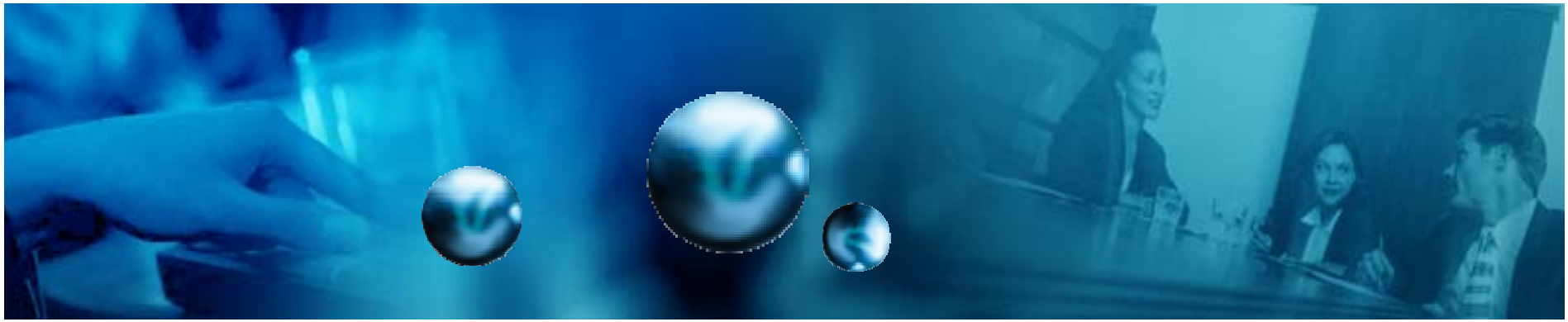
Lotion Composition



Lotion Composition



Product Design



Customer Satisfaction Assessment

Consumer Satisfaction Assessment

- A model was developed to assess the consumer needs
- The model measures how satisfied the consumer is with the properties of the lotion
- Consumer rates lotion characteristics correlated to a physical properties

$$S_i = \sum w_i y_i$$

$$S_i = satisfaction\ (0-100)$$

$$w_i = weight\ of\ \ property\ (0-1)$$

$$y_i = property\ satisfaction\ (0-100)$$

Source: http://www.ou.edu/class/che-design/a-design/Pricing%20of%20Consumer%20Products.pdf

Consumer Surveys

- Consumer surveys were used to determine the satisfaction of the consumer for each property
- The consumers rated the lotion properties based upon extremes (i.e. very thin to very thick)
- Consumer ratings were then correlated to the physical properties of the lotion (surface tension, viscosity, etc.) to find consumer satisfaction

Consumer Satisfaction Assessment

- Ordained surveys were completed to determine the best product and the importance of each property.

Please indicate your preference for each property on the indicated scale **(Scale of 1-X)**. With 1 being your desired product, and the highest number (X) being your worst product.

Thickness: Thickness of the Lotion **(Scale of 1-4)**
Extremely Thick:___ Moderately Thick:___ Moderately Thin:___ Very Thin:___

Durability: The ability for the lotion to wash off or rub off. The Lotion lasts for…**(Scale of 1-7)**
30 minutes:___ 1hr:___ 2hrs:___ 3hrs:___ 4hrs:___ 5 hrs:___ 6hrs:___

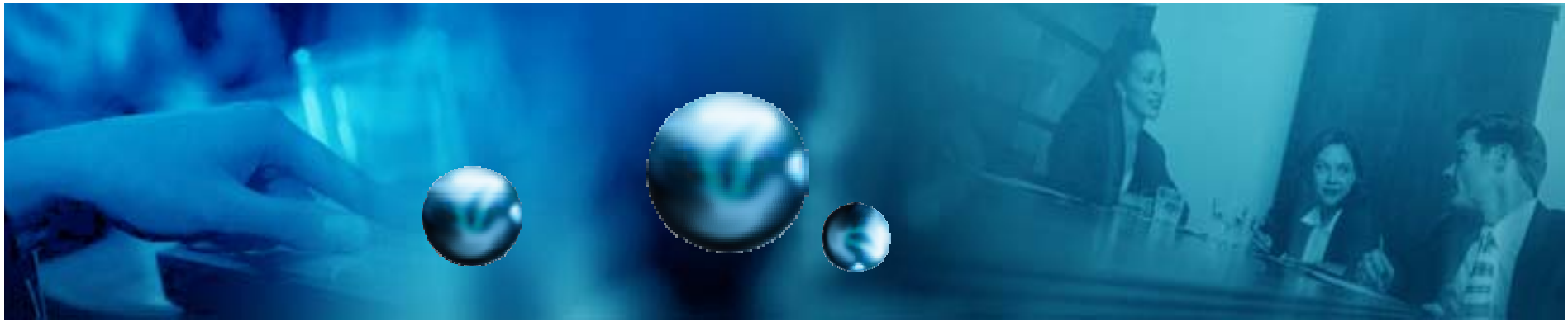
Absorption Rate: How long it takes the moisturizing chemicals to officially absorb into the skin **(Scale of 1-7)**
1min:___ 2min:___ 4min:___ 5min:___ 6min:___ 8min:___ 10min:___

Survey Results

Property	Weight of Property
Effectiveness	24.36%
Thickness	10.16%
Durability	15.19%
Absorption Rate	13.92%
Smoothness	14.61%
Greasiness	11.44%
Spreadability	10.31%

Study Population: 48 Males, 50 Females, 2 Not Specified, Total = 100

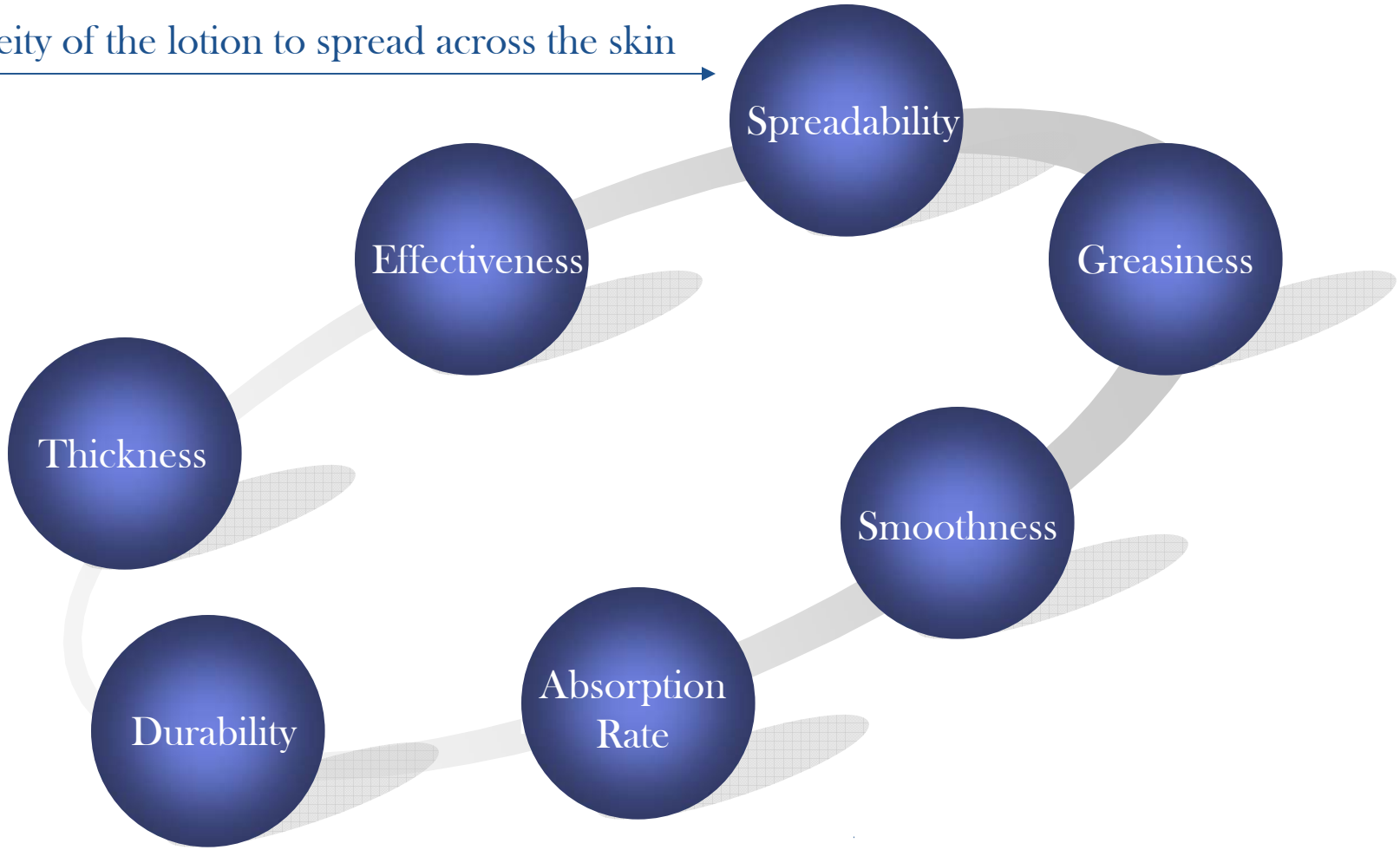
Product Design



Property Correlations

Assessed Lotion Properties

Spontaneity of the lotion to spread across the skin



Effectiveness

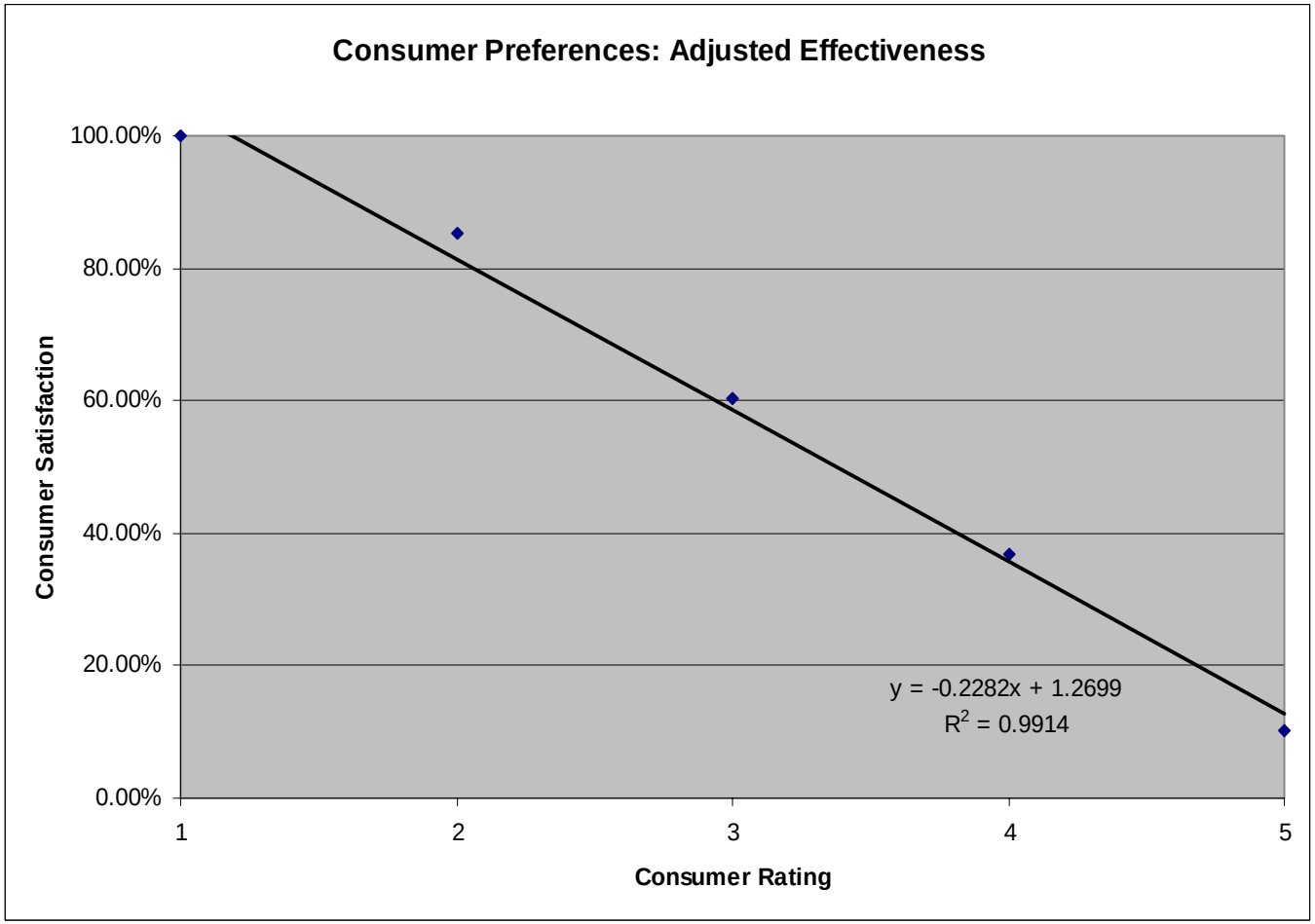
- The effectiveness of a lotion is determined by how well the lotion can treat the skin problems associated with Xerosis and Ichthyosis Vulgaris.
  - Severely dry skin
  - Thickened skin
  - Dismantled lipid bilayer
- Depends on percutaneous absorption modeled by

$$\frac{C_w}{C_w^o} = 1 - \frac{x}{L_{sc}} - \frac{2}{\pi}\sum_{n=1}^{\infty}\left(\frac{1}{n}\sin\left(\frac{n\pi x}{L_{sc}}e^{-\frac{D_{sc}n^2\pi^2 t}{R_{sc}L_{sc}^2}}\right)\right)$$

Effectiveness

Consumer Rating	
1	No Skin Scales Present
2	Few Skin Scales Present
3	Some Skin Scales Present
4	Skin Moderately Scaly
5	Skin Very Scaly

- **Best Product:** Preference (1), Concentration (0.5)



Wetting

$$\gamma_{se} = \gamma_s - \gamma_e \cos\theta$$

$\gamma_{se} = surface\ tension\ of\ \ skin - emulsion$

$\gamma_s = surface\ tension\ of\ \ skin$

$\gamma_e = surface\ tension\ of\ \ emulsion$

$\theta = contact\ angle$

- Wetting is an application of adsorption at a liquid-solid interface.
- Wetting is defined as the displacement of one fluid by another on a given surface.
- Durability and Spreadability depend on wetting properties
- For solid surfaces, like the skin, the contact angle of the liquid must determined using Young's Equation

Source: The Handbook of Cosmetic Science and Technology

Image Provided From: The Water Break Test

Durability

- Durability is how easily the lotion rubs or washes off and depends on adhesional wetting
- The adhesional wetting is the ability of a fluid to adhere to a surface
- The adhesional wetting is quantified by the work of adhesion, W_a
- The work of adhesion is the reversible work required to separate the unit area of liquid from a surface

$$W_a = \gamma_e(\cos\theta + 1)$$

$$\theta = contact\ angle$$

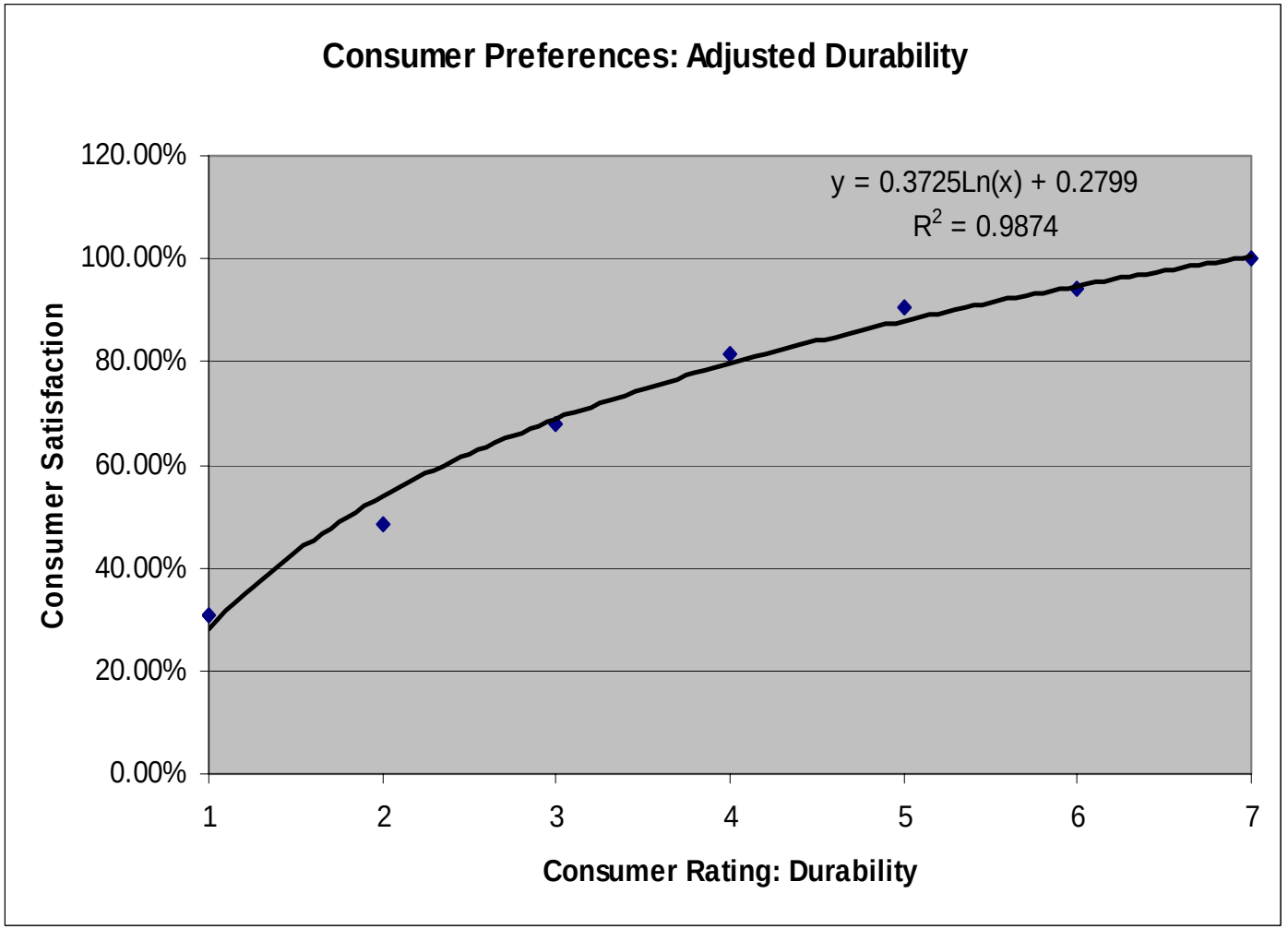
$$\gamma_e = surface\ tension\ of\ \ emulsion$$

Source: Surfactants and Interfacial Phenomena

Durability

Consumer Rating	
1	30 min
2	1 hr
3	2 hrs
4	3 hrs
5	4hrs
6	5hrs
7	6hrs

- **Best Product:** Preference (7), Contact Angle (0°)



Spreadability

- Spreadability is characterized by how easily the lotion spreads over the skin and depends on spreading wetting
- Spreading wetting is how well one fluid displaces another fluid on a given surface (The two fluids are air and lotion) and if the spreading is spontaneous
- Spontaneity depends on the free energy, the interfacial area and the surface tension
- The Spreading coefficient identifies the spontaneity of a fluid to spread

$$S_{se} = \gamma_s - (\gamma_{se} + \gamma_e)$$

$$\gamma_{se} = surface\ tension\ of\ \ skin - emulsion$$

$$\gamma_s = surface\ tension\ of\ \ skin$$

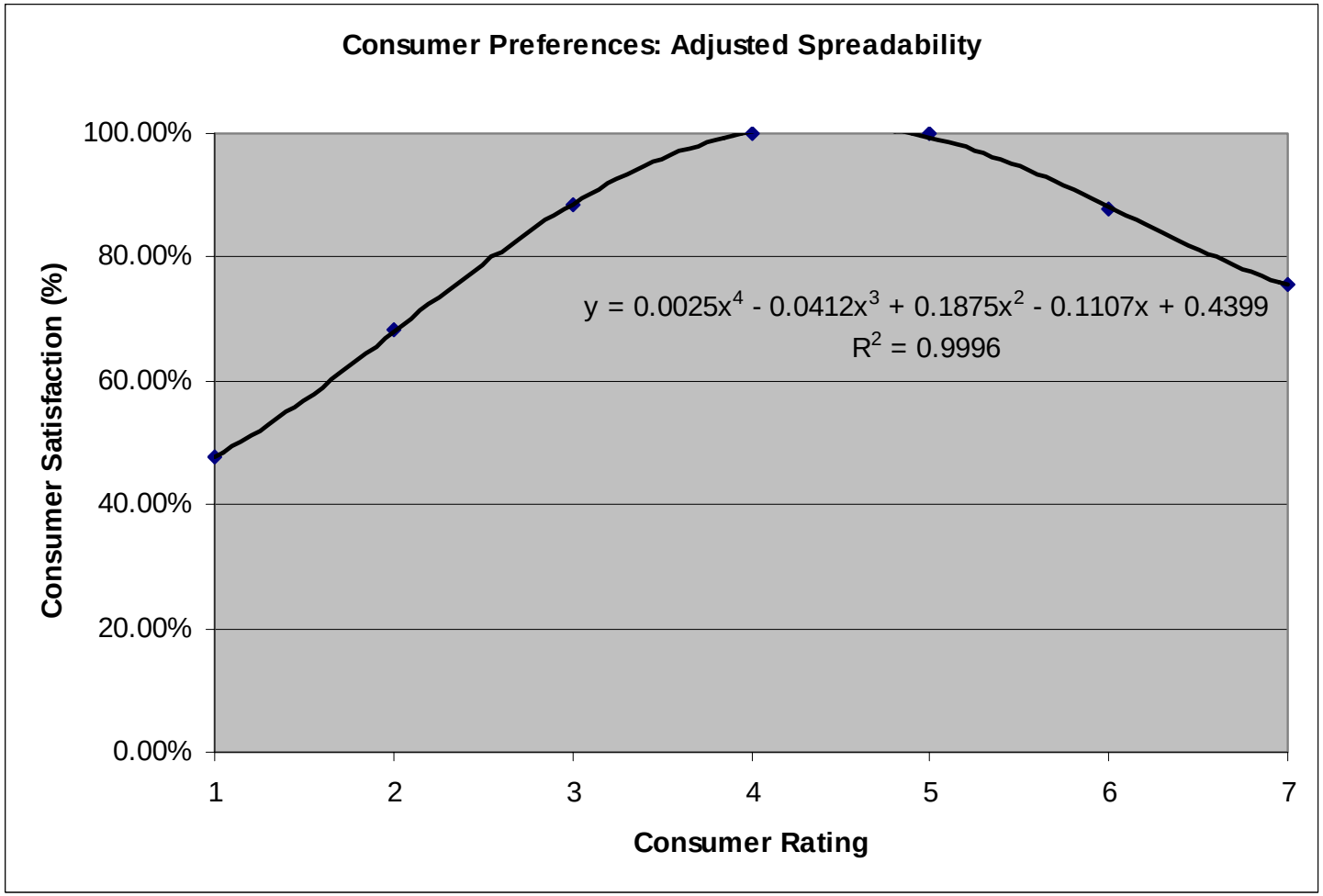
$$\gamma_e = surface\ tension\ of\ \ emulsion$$

Source: Comparison of surface free energy between reconstructed epidermis and in situ human skin

Spreadability

Consumer Rating	
1	0% Spreading
2	7% Spreading
3	25% Spreading
4	50% Spreading
5	75% Spreading
6	93% Spreading
7	100% Spreading

- **Best Product:** Preference (4.5), Contact Angle (72º)



Thickness

- Thickness is the viscosity and shear rate of the lotion

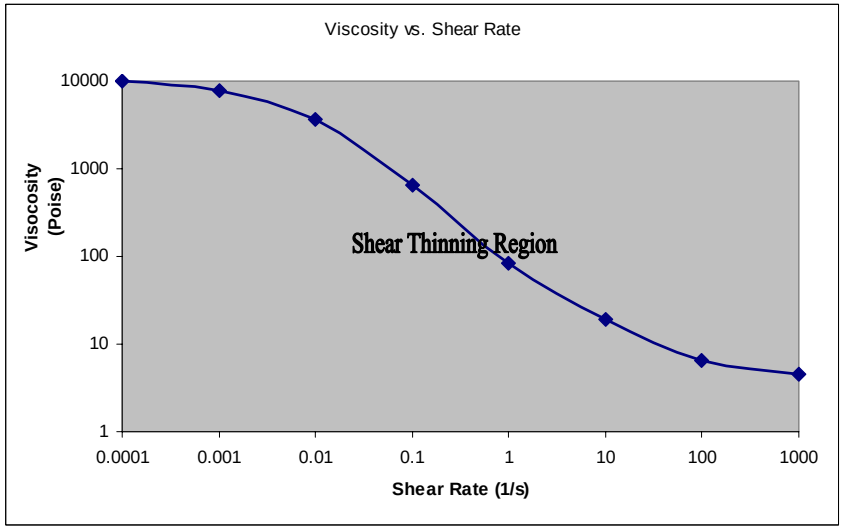
$$\eta = 1 + I(\lambda)\phi$$

$$\phi = volume\ fraction of\ dispersed\ phase$$

$$I(\lambda) = \frac{5.5\left[4\lambda^7 + 10 - \left(\frac{84}{11}\right)\lambda^2 + \left(\frac{4}{\kappa}\right)\left(1-\lambda^7\right)\right]}{10\left(1-\lambda^{10}\right) - 25\lambda^3\left(1-\lambda^4\right) + \left(\frac{10}{\kappa}\right)\left(1-\lambda^3\right)\left(1-\lambda^7\right)}$$

$$\lambda = (the\ volume\ \ fraction)\text{^}1/3$$

$$\kappa = viscosity\ of\ \ dispersed\ \ phase / viscosity\ of\ \ continuous\ \ phase$$



- Shear rate can be related to film thickness

$$D = \frac{dv}{dy}$$

where D is the shear rate

dv is the change in velocity

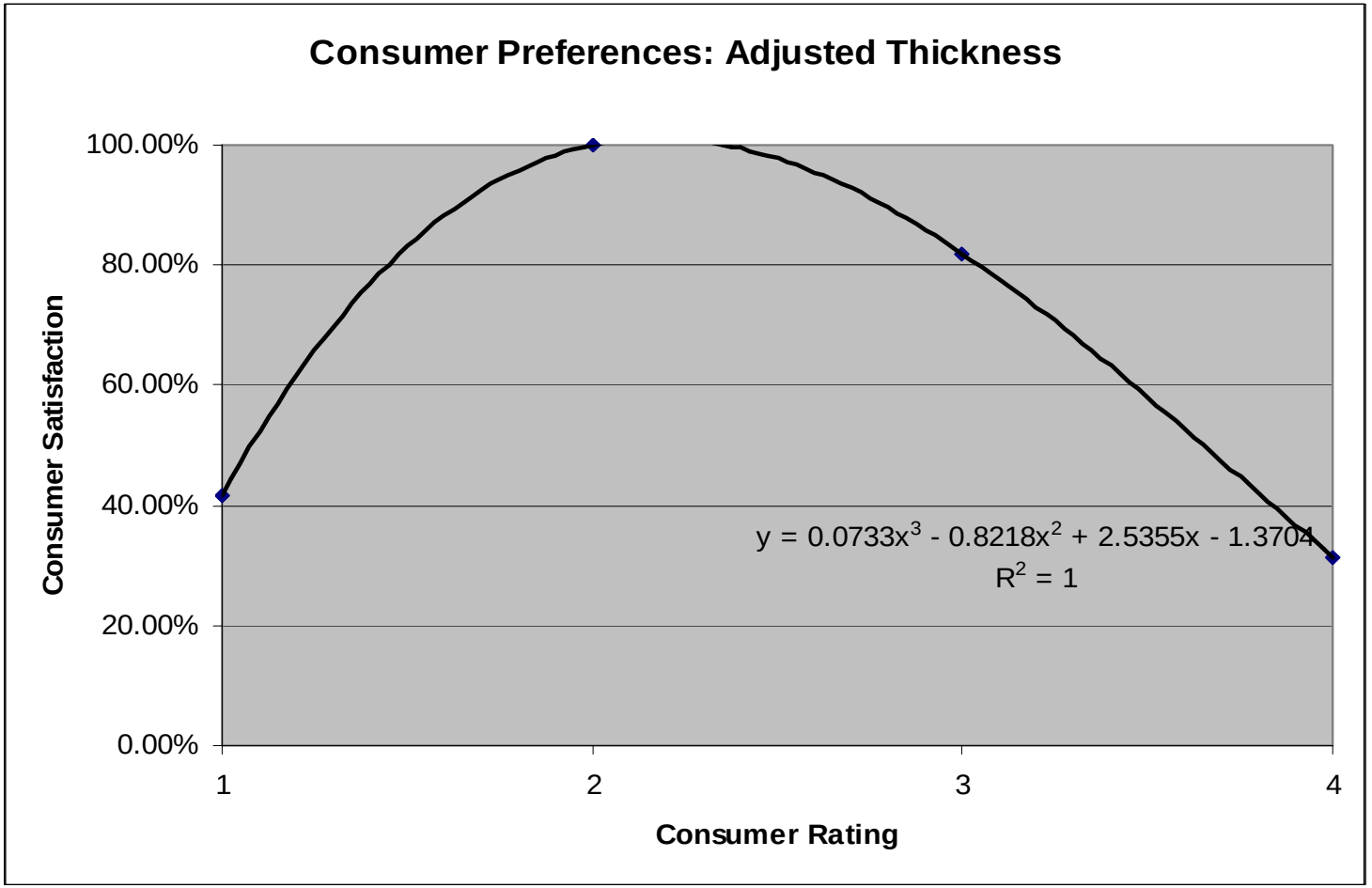
dy is the film thickness

Source: Evaluation of theoretical viscosity models for concentrated emulsions at low capillary numbers

Thickness

Consumer Rating	
1	Extremely Thick
2	Moderately Thick
3	Moderately Thin
4	Very Thin

- **Best Product:** Preference (2.3), Film Thickness (0.25cm)



Viscosity v. Shear Rate: http://www.rheologyschool.com

Smoothness

- Smoothness is based on how the skin feels after the lotion is applied.
- The skin becomes rough and chapped when the moisture level of the skin is below 10%.
- Smoothness is based on the amount of fatty oils present in the lotion.
- Smoothness is a function of the greasiness of the lotion. This correlation was found experimentally.

$$S = \mu(-0.0174G + 2.098)$$

where S is the smoothness

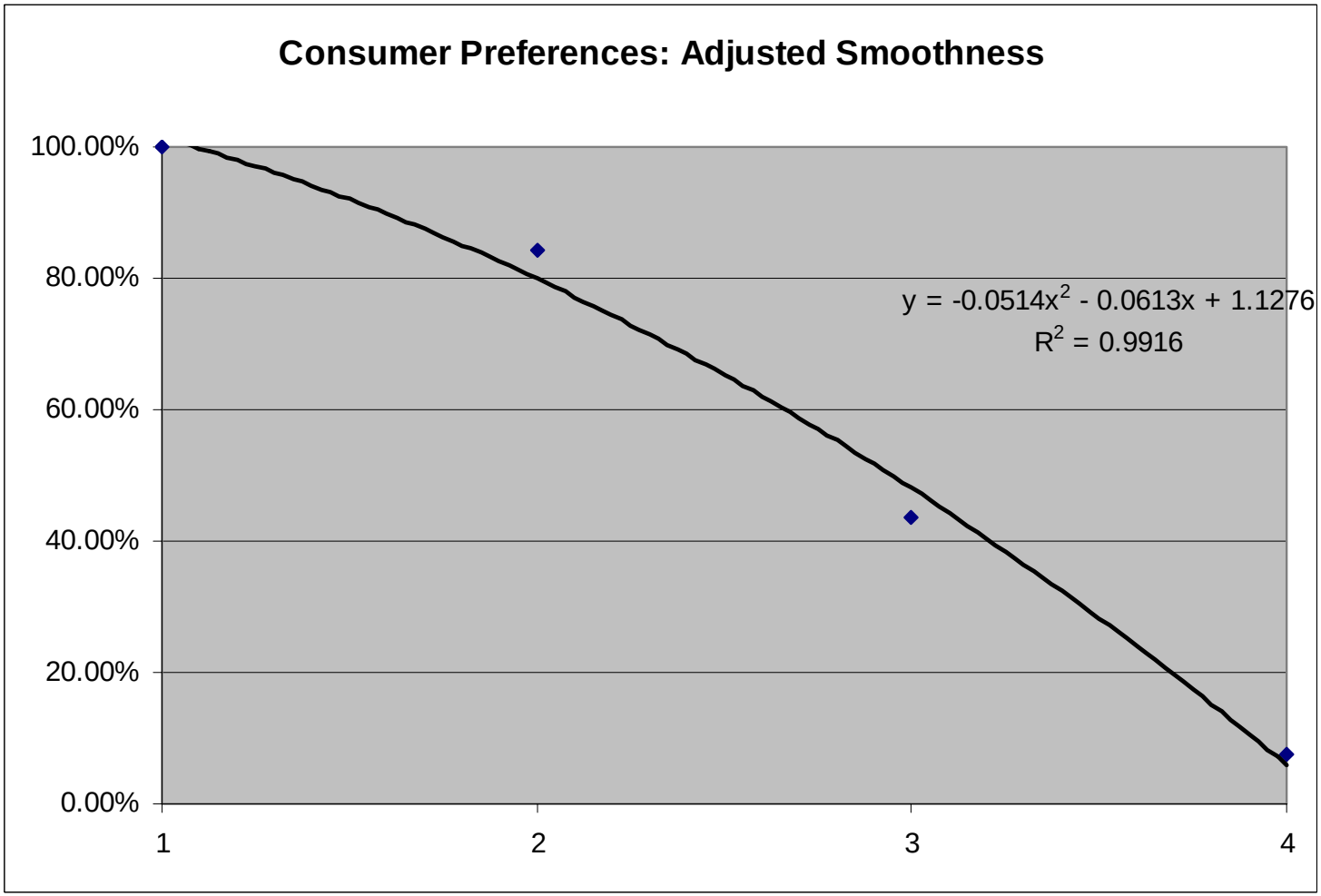
μ *is the skin friction coefficient* $= 0.236$

G is the concentration of fatty oils

Smoothness

Consumer Rating	
1	Very Smooth
2	Moderately Smooth
3	Moderately Rough
4	Very Rough

- **Best Product:** Preference (1), Smoothness (0.37)



Absorption Rate

The Absorption Rate is how long it takes the ingredients to absorb into the skin and is characterized by the steady state intercellular diffusion time

$$t_{ss} = \frac{0.45 L_{SC}^2 R_{sc}}{D_{sc}}$$

t_{ss} = *Diffusion S.S time*

D_{sc} = *effective diffusion coefficient of* $3-$ *phase stratum corneum continuum*

R_{sc} = *retardation factor of the* $3-$ *phase stratum corneum continuum*

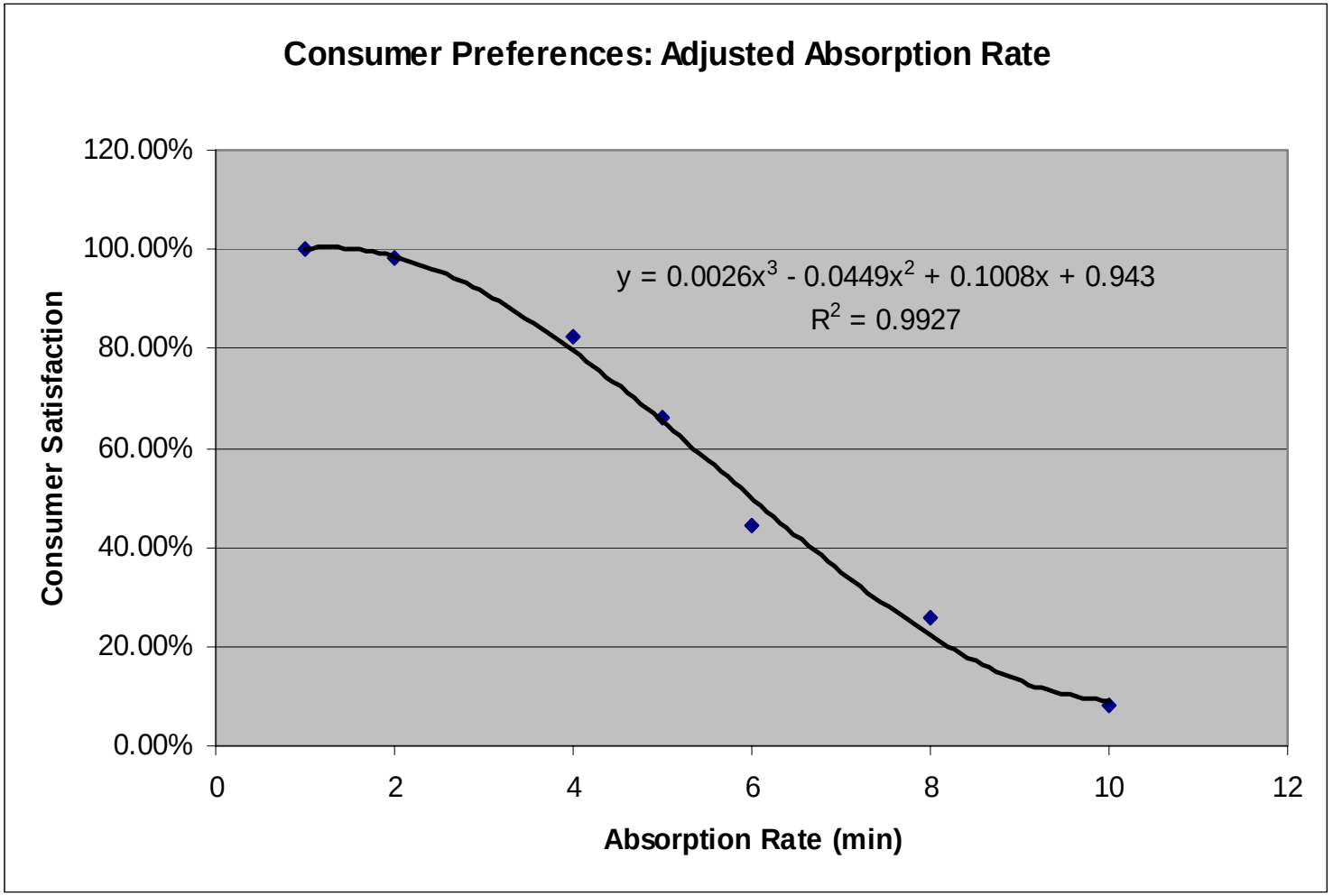
L_{sc} = *distance into stratum corneum from the surface*

Source: A Geoscience Approach to Modeling Chemical Transport through Skin

Absorption Rate

Consumer Rating	
1	1min
2	2min
3	4min
4	5min
5	6min
6	8min
7	10min

- **Best Product:** Absorption Rate (1min-2min)



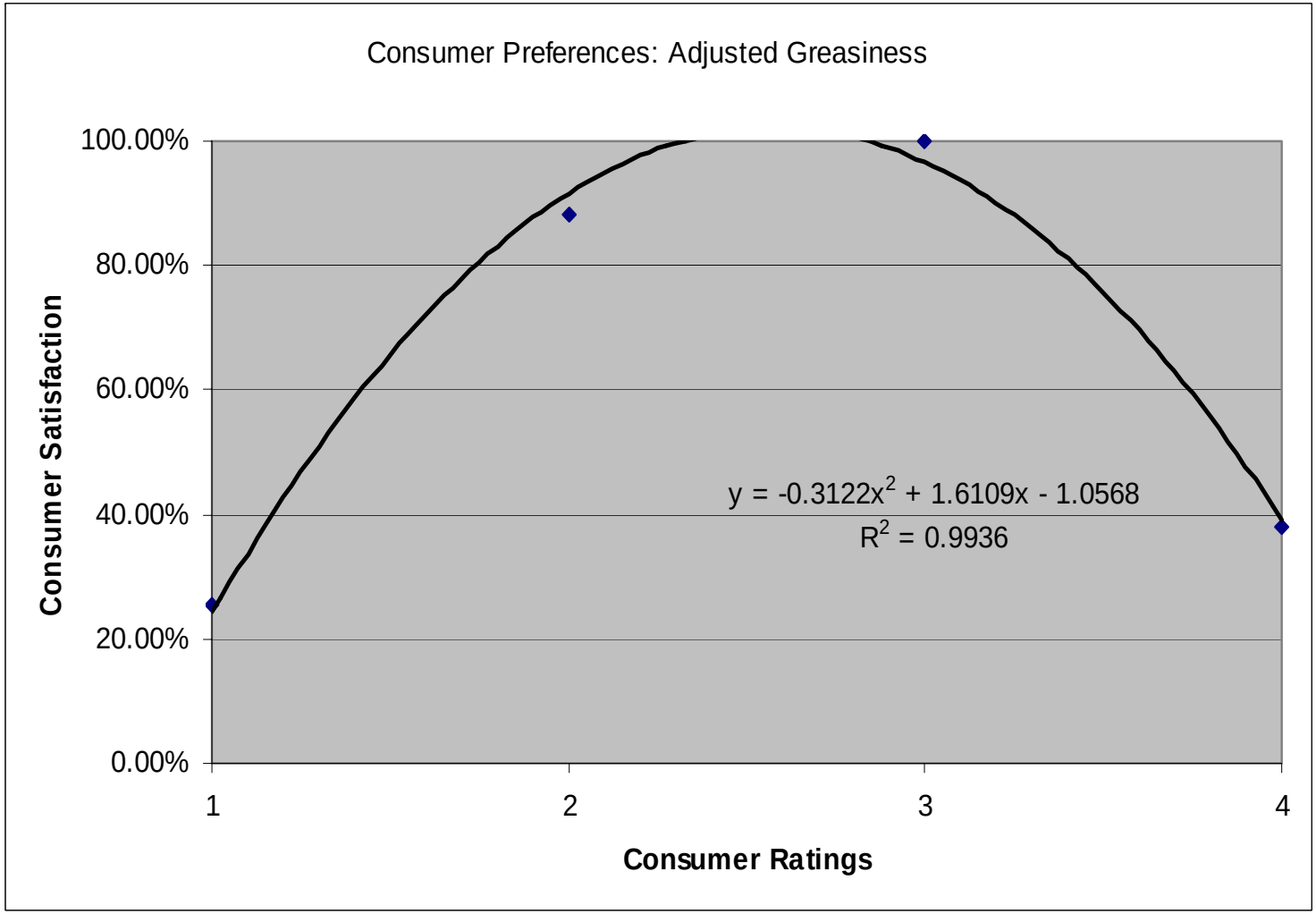
Greasiness

- The greasiness is characterized by the look/feel of the skin after the lotion is applied
- The greasiness can be determined by the amount of fatty oils present in the lotion
- Fatty oils leave the skin looking greasy/oily because of its high concentration of triglycerides or fatty acids
- If a lotion is too greasy the stratum corneum can become swollen and inflamed
- If the lotion does not have enough oils, the skin can remain rough and chapped.

Greasiness

Consumer Rating	
1	Very Greasy
2	Moderately Greasy
3	Moderately Dry
4	Very Dry

- **Best Product:** Preference (2.8), Greasiness (13% Fatty Oils)



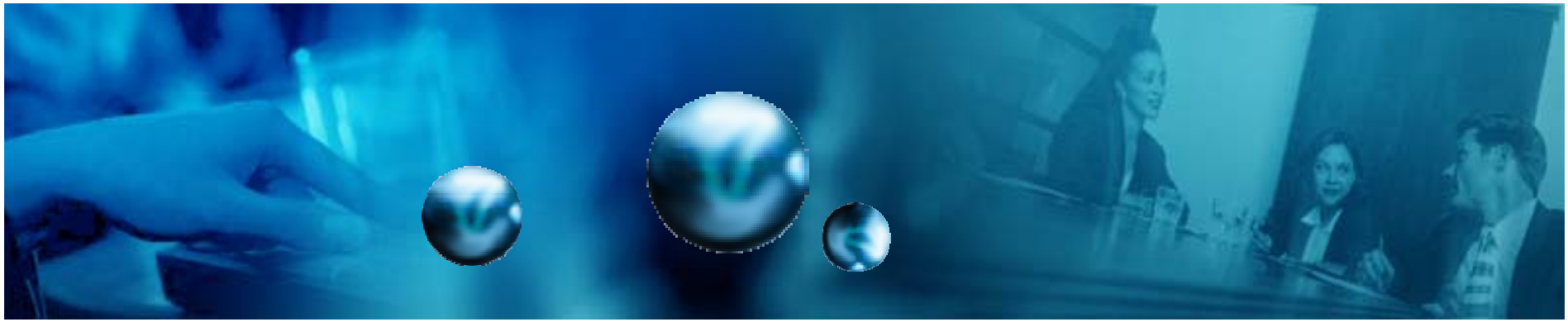
Maximum Satisfaction Product

Lotion Property	Satisfaction Score
Durability	87%
Greasiness	95%
Smoothness	74%
Thickness	95%
Effectiveness	100%
Spreadability	99%
Absorption Rate	82%

Product Satisfaction: 81%
Competitor Satisfaction: 77%

β= NPW=

Product Design

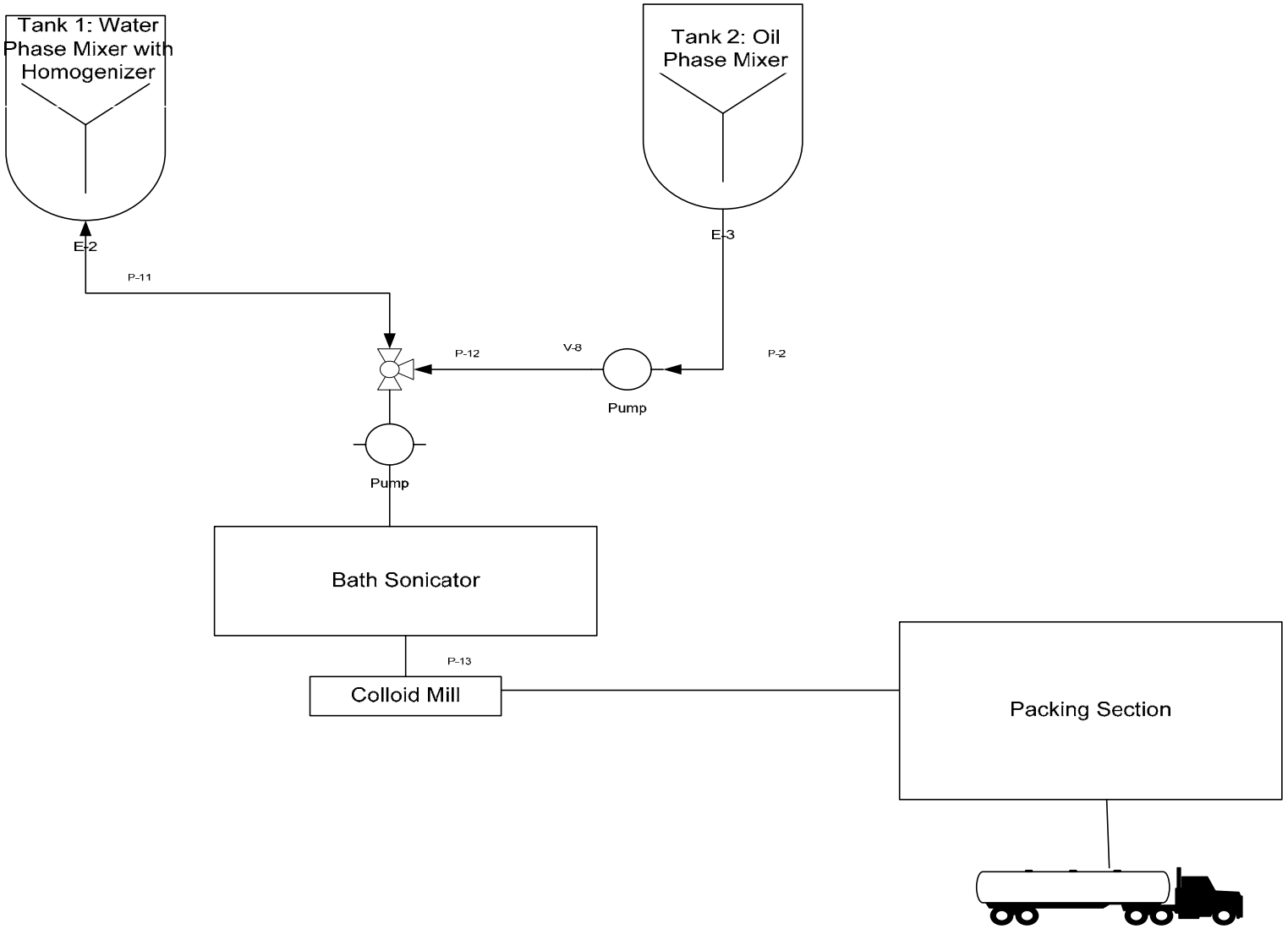


Manufacturing

Manufacturing Procedure

- Two separate phases make up lotion: aqueous and oil phases
- Must completely combine two phases
- Steps in lotion formation:
  1) Heat and mix aqueous and oil phases separately
  2) Combine both phases into one batch
  3) Perform post treatment modifications (i.e. decrease particle size)

Process Flow Diagram



Equipment Costs

Equipment	Cost
Storage Tanks	$10,000
Water Phase Mixing Tank	$8,000
Oil Phase Mixing Tank	$4,000
Bath Sonicator	$60,000
Homogenizer	$11,000
2 Pumps	$11,500
Colloid Mill	$25,000
Total Cost	$129,500

Source: Various Vendors

Plant Location

Buckeye, AZ

- 37 miles from Phoenix, AZ
- Population: 25,406
- Located within the southwest market
- Inexpensive property value
- High Productivity
- Low Labor costs

Source: http://www.rlmartin.com/photos/scenic/arizona/default.htm

Competition Model

$$S = (\alpha d_1)^{\rho} + (\beta d_2)^{\rho}$$

Unsaturated Market

$$D > d_1 + d_2$$

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

$$d_2 = \frac{Y - p_1 d_1}{p_2}$$

Saturated Market

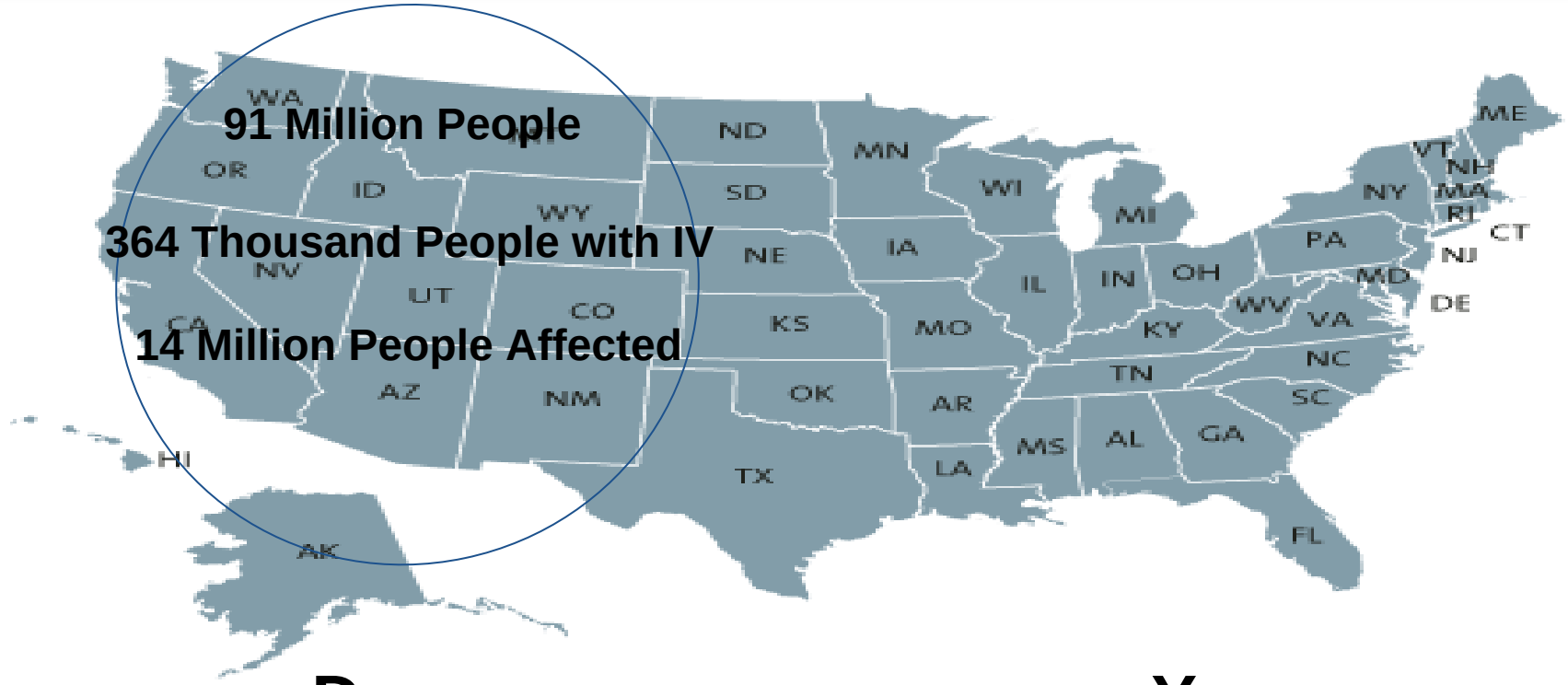
$$D = d_1 + d_2$$

$$d_1 = \frac{D}{1+\gamma}$$

$$\gamma = \left(\frac{\alpha}{\beta}\right)^{\frac{\rho}{\rho-1}}$$

$$profit_1 = (p_1 - a_1)d_1$$

Target Market



D	Y
1.5 Million People will buy Lotion	.5 * 500,000 * 12.13
6 Million Bottles per year	$3,000,000 per month
500 Thousand Bottles per month	

Beta and TPC

$H_2 = .75$ $H_{1max} = .91$

Beta	TPC
.82	$4.30/bottle
.85	$4.80/bottle
.9	$5.00/bottle
.95	$5.50/bottle
1	$5.50/bottle

Summary of Parameters

$$D = 500{,}000$$

$$Y \approx 3{,}000{,}000$$

$$\alpha = 1$$

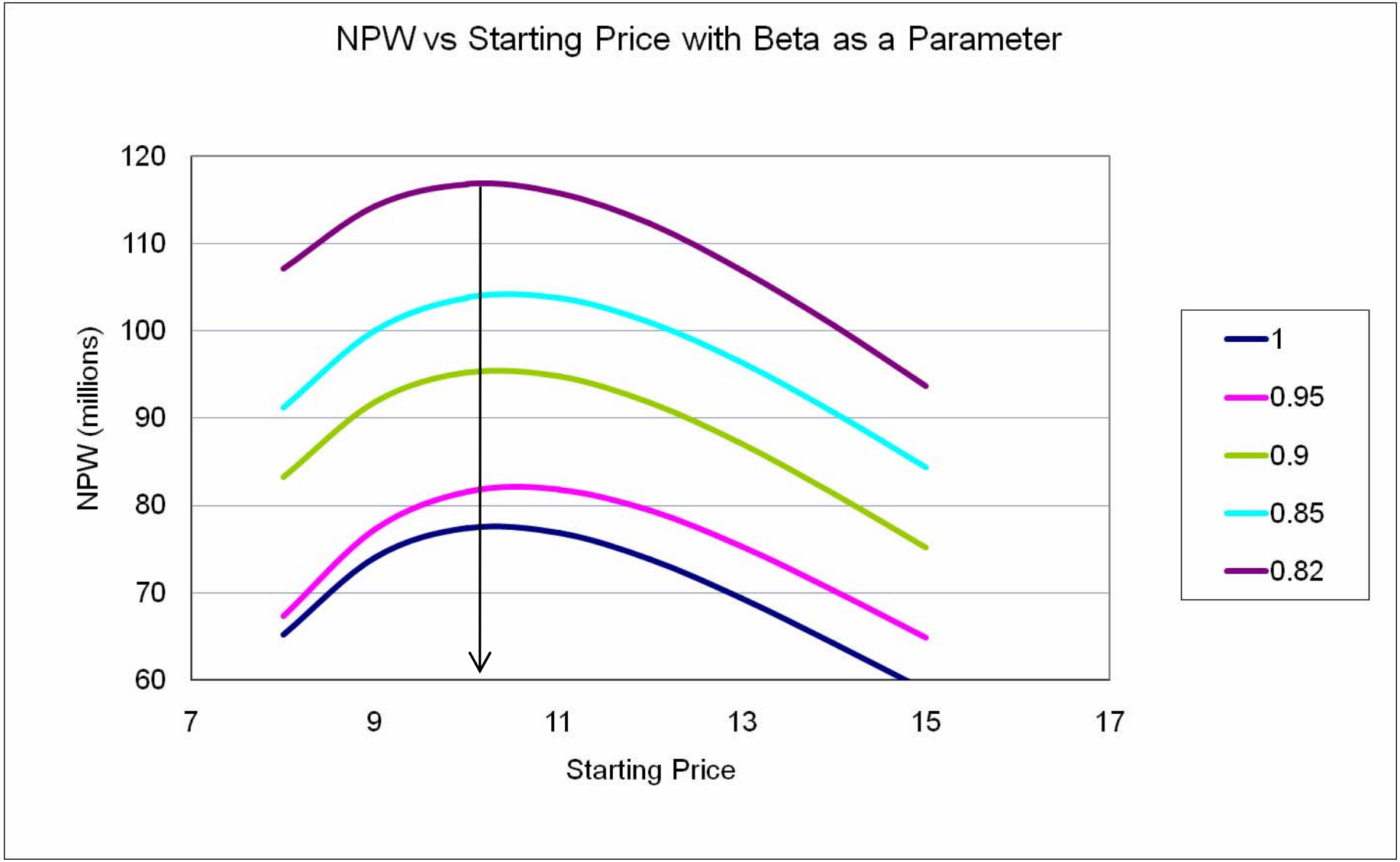
$$\rho = .75$$

$$p_2 = \$12.13$$

$$p_1 = \$8 \rightarrow \$15$$

Beta	TPC (a_1)
.82	$4.30/bottle
.85	$4.80/bottle
.9	$5.00/bottle
.95	$5.50/bottle
1	$5.50/bottle

Constant Prices



Price Response

$$S = (\alpha d_1)^{\rho} + (\beta d_2)^{\rho}$$

Unsaturated Market

$$D > d_1 + d_2$$

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

$$d_2 = \frac{Y - p_1 d_1}{p_2}$$

Saturated Market

$$D = d_1 + d_2$$

$$d_1 = \frac{D}{1+\gamma}$$

$$\gamma = \left(\frac{\alpha}{\beta}\right)^{\frac{\rho}{\rho-1}}$$

Price Changes

$$p_2 = p_{2,o} - \varphi\left(p_{2,o} - a_2\right)\left(\beta \frac{d_{2,o} - d_2}{d_{2,o}}\right)^{\alpha_1/\alpha_2}$$

$$Max\left(profit_1 = (p_1 - a_1)d_1\right)$$

	1	2	3	4	5	6	7	8	9	10	11	12
Our price	p_1	p_1	p_2	p_2	p_3	p_3	p_4	p_4	p_5	p_5	p_6	p_6
Their price	p_1	p_2	p_2	p_3	p_3	p_4	p_4	p_5	p_5	p_6	p_6	p_7

Summary of Parameters

$D = 500{,}000$

$Y \approx 3{,}000{,}000$

$\alpha = 1$

$\rho = .75$

$p_2 = \$12.13$

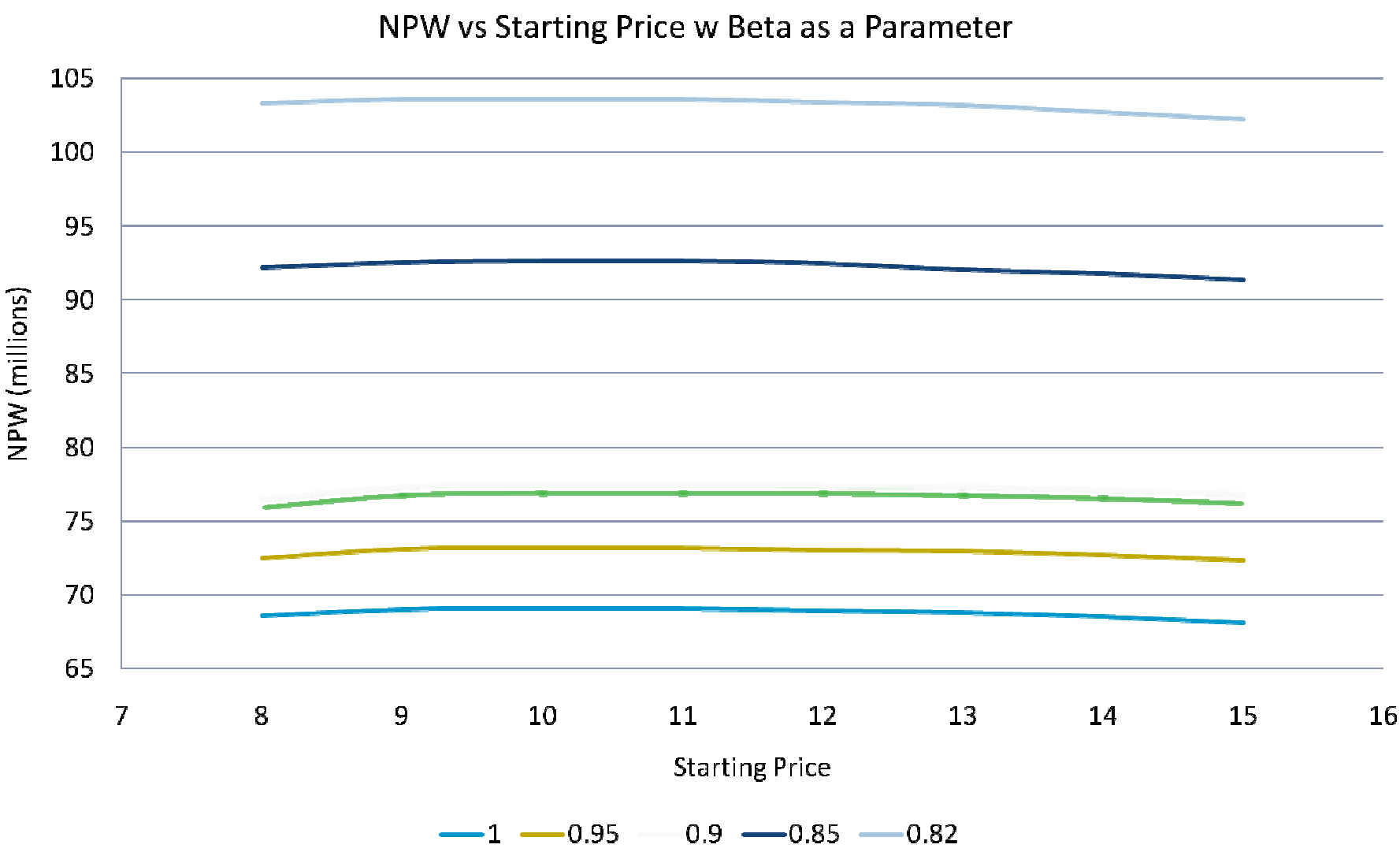
$a_2 = \$7$

$p_{1i} = \$8 \rightarrow \$15$

$p_{1\max p} = \$7 \rightarrow \$20$

Beta	TPC (a_1)
.82	$4.30/bottle
.85	$4.80/bottle
.9	$5.00/bottle
.95	$5.50/bottle
1	$5.50/bottle

NPW


NPW vs Starting Price w Beta as a Parameter
NPW (millions)
105
100
95
90
85
80
75
70
65
7
8
9
10
11
12
13
14
15
16
Starting Price
1
0.95
0.9
0.85
0.82

Price Response

$$S = (\alpha d_1)^{\rho} + (\beta d_2)^{\rho}$$

Unsaturated Market	Saturated Market	Price Changes
$D > d_1 + d_2$	$D = d_1 + d_2$	$D' > d_1' + d_2'$
$d_1 = \left(\frac{\alpha}{\beta}\right)^{\rho} \frac{p_2}{p_1}\left[\frac{Y - p_1 d_1}{p_2}\right]^{1-\rho} (d_1)^{\rho}$	$d_1 = \frac{D}{1+\gamma}$	$d_1' = \left(\frac{\alpha'}{\beta'}\right)^{\rho'} \frac{p_2}{p_1}\left[\frac{Y' - p_1 d_1'}{p_2}\right]^{1-\rho'} (d_1')^{\rho'}$
$d_2 = \frac{Y - p_1 d_1}{p_2}$	$\gamma = \left(\frac{\alpha}{\beta}\right)^{\frac{\rho}{\rho-1}}$	$d_2' = \frac{Y' - p_1 d_1'}{p_2}$

$$Max(profit_1 = (p_1 - a_1)d_1) \qquad Max(profit_2 = (p_2 - a_2)d_2')$$

Summary of Parameters Perfect Information

$$D = 500{,}000$$

$$Y \approx 3{,}000{,}000$$

$$\alpha = 1$$

$$\rho = .75$$

$$p_{2i} = \$12.13$$

$$p_{2\max p} = \$7 \rightarrow \$20$$

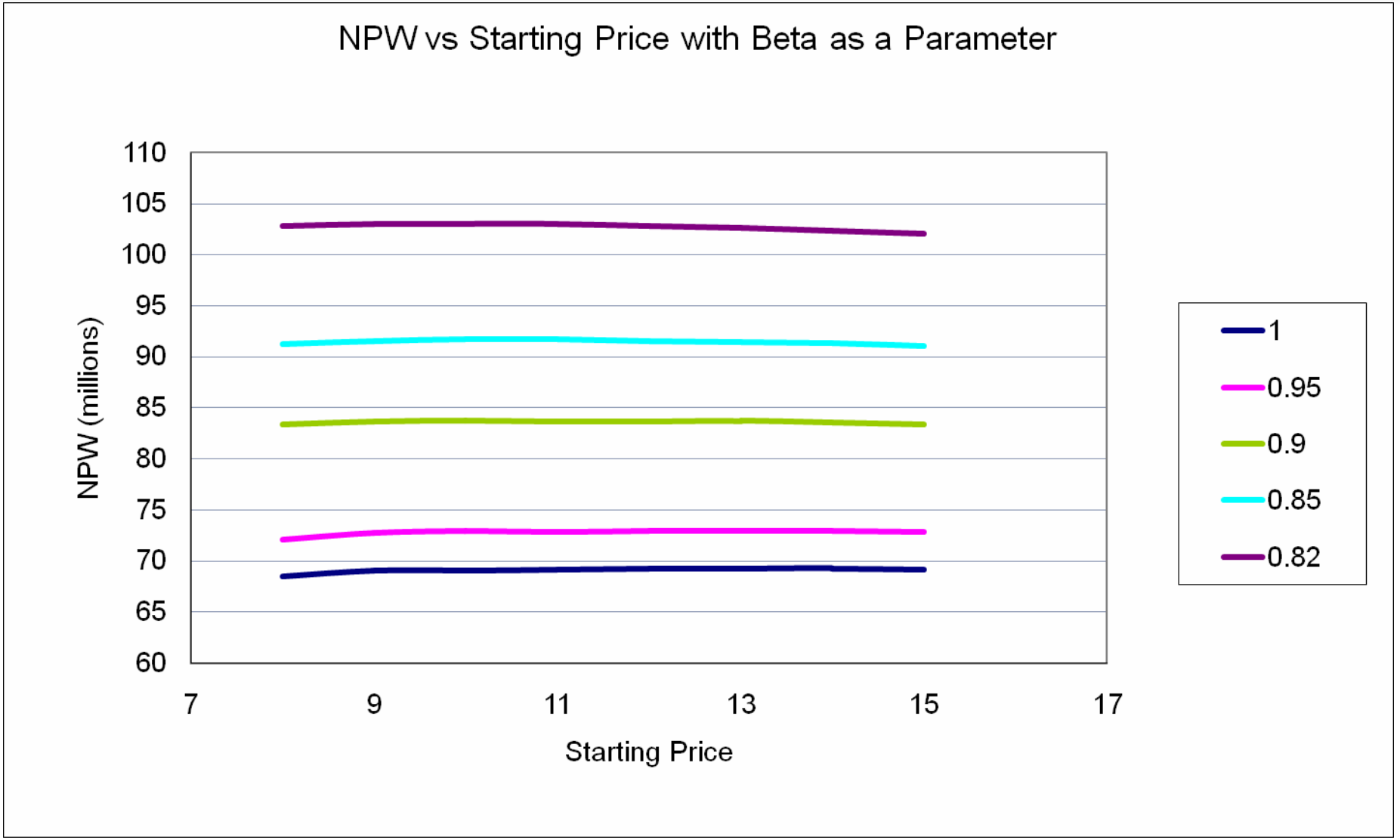
$$a_2 = \$7$$

$$p_{1i} = \$8 \rightarrow \$15$$

$$p_{1\max p} = \$7 \rightarrow \$20$$

Beta	TPC (a_1)
.82	$4.30/bottle
.85	$4.80/bottle
.9	$5.00/bottle
.95	$5.50/bottle
1	$5.50/bottle

NPW with Perfect Information



Summary of Parameters Imperfect Information

$D = 500{,}000$ $\quad$ $D' = 600{,}000$

$Y \approx \$3{,}000{,}000$ $\quad$ $Y' \approx \$3{,}600{,}000$

$\alpha = 1$ $\quad$ $\rho = .75$

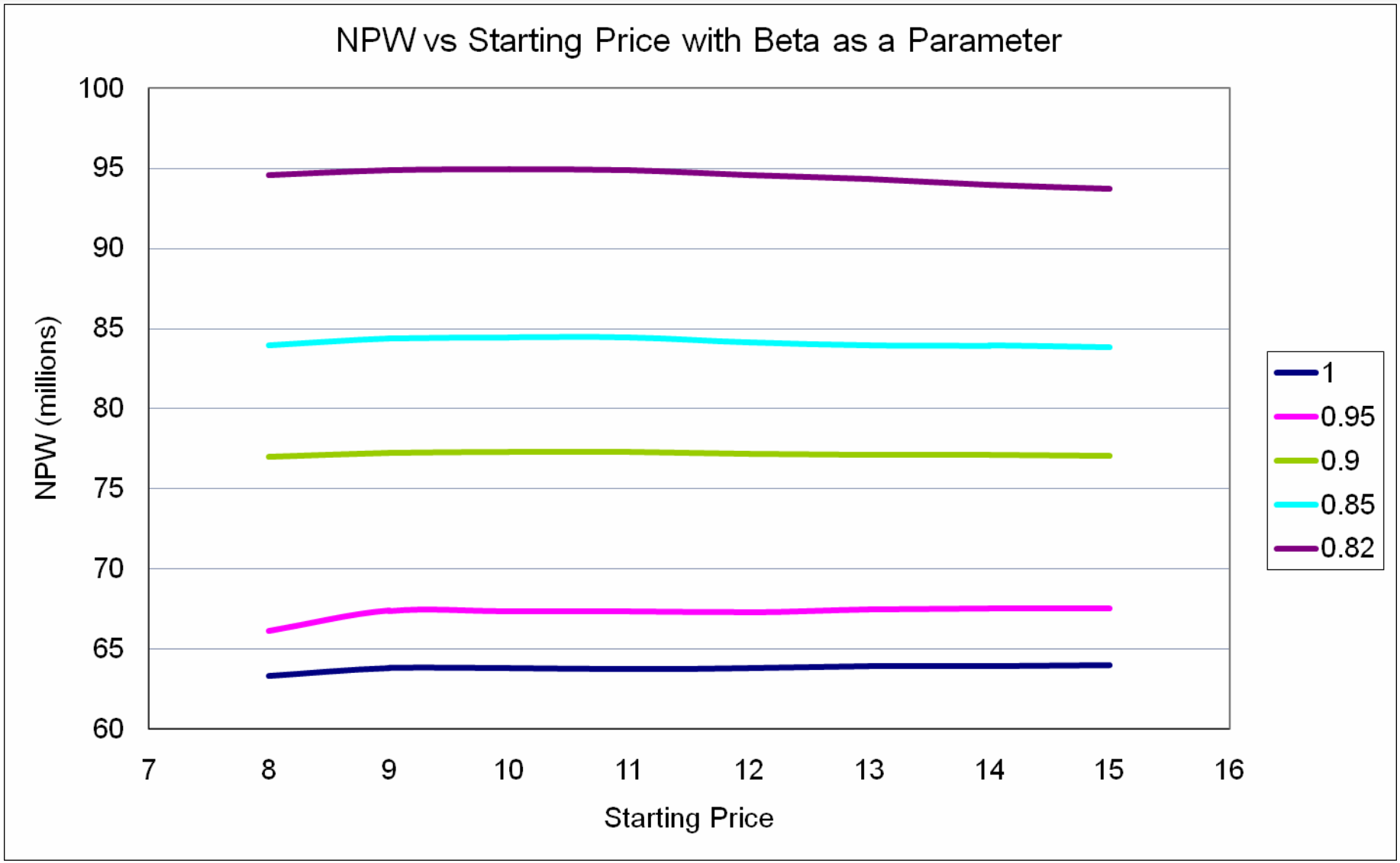
$p_{2i} = \$12.13$ $\quad$ $p_{1i} = \$8 \rightarrow \$15$

$p_{2\max p} = \$7 \rightarrow \$20$ $\quad$ $p_{1\max p} = \$7 \rightarrow \$20$

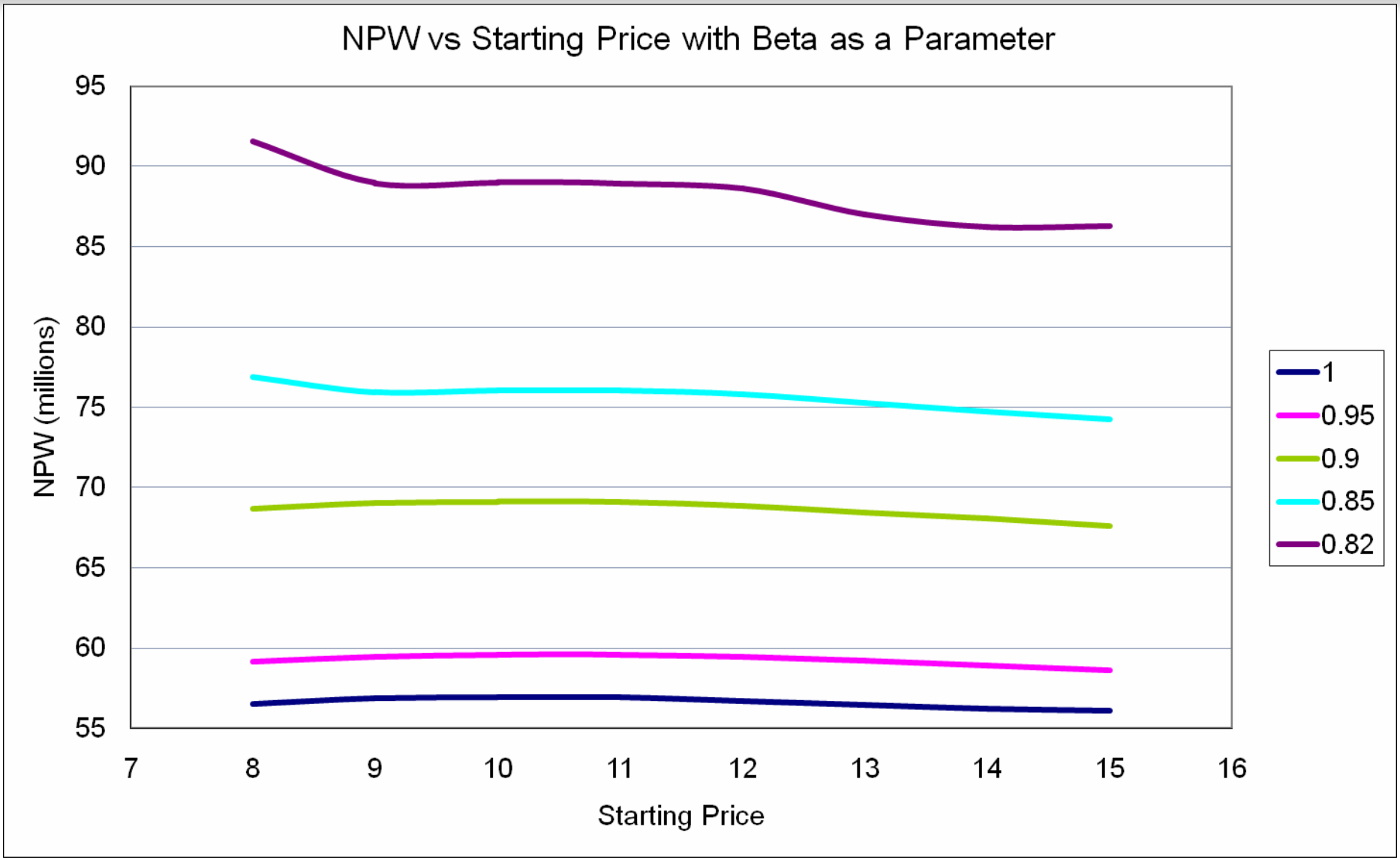
$a_2 = \$7$

Beta	TPC (a_1)
.82	$4.30/bottle
.85	$4.80/bottle
.9	$5.00/bottle
.95	$5.50/bottle
1	$5.50/bottle

NPW with Imperfect Information



NPW with Imperfect Information



Any Question?