HEMIS®

Polymer Composite Gasoline Tanks

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Introduction

- Purpose
  - To produce marketable polymer gasoline tanks
  - To propose a competitive and appealing business plan

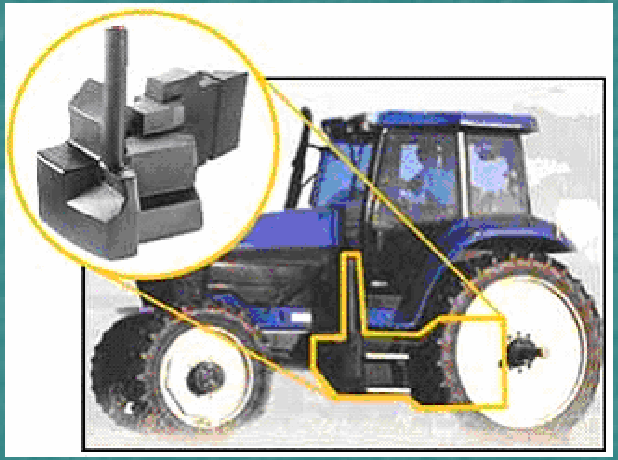
- Project Considerations
  - Current Gas Tanks
  - Safety and Regulations
  - Material Selection
  - Process Design
  - Tank Design
  - Financial Evaluations
  - Risk and Uncertainty

First Stage

- Determine limiting factors
  - Existing gas tanks
    - Cost
    - Quality
  - State and federal regulations
- These factors **must** be met, or surpassed, for successful design and plan

Current Gas Tank Comparison

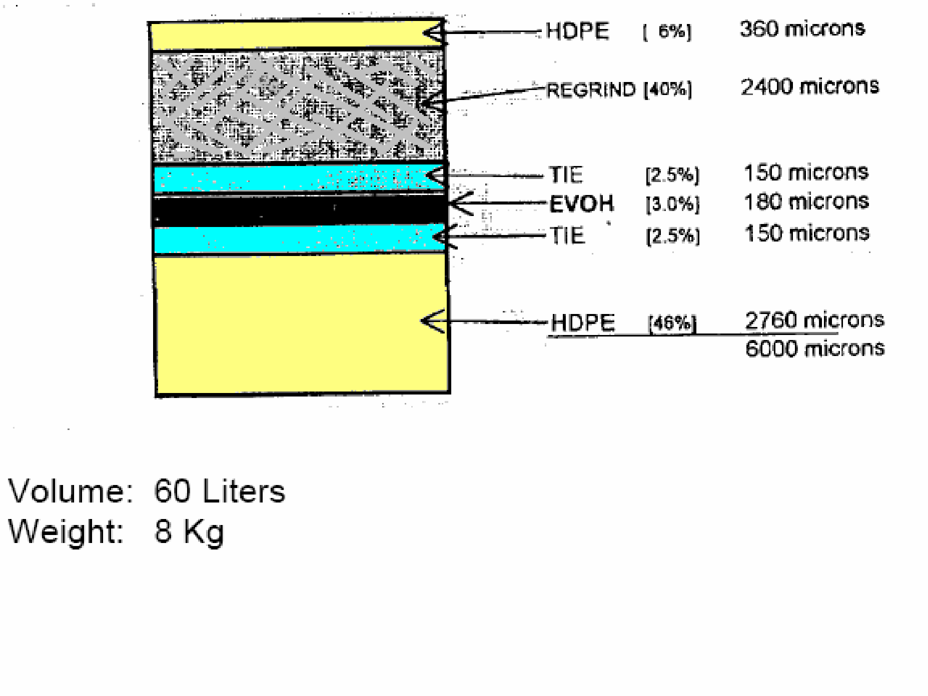
- Plastic
  - Competitive Edge
    - Various materials
    - Possibly recyclable
    - Lightweight
    - Additives and layers
    - Complex geometry
    - Emerging product (Visteon)
  - Current Uses
    - Automobiles
    - Boats
    - Farm equipment
    - Lawn equipment
    - Motorcycles
    - Race Cars



- Steel
  - 20 gauge low Carbon
  - Competitive Edge
    - Historical use
    - Types
    - Strong
    - Low diffusion
    - Recyclable

Cost Comparison

- Visteon
  - Six layer design
    - High density polyethylene structure
    - Ethylene vinyl alcohol barrier layer
    - Linear low density polyethylene adhesive layer
  - Blow molding process
  - Estimated selling price $53.00
    - Sold directly to automobile manufacturer
      - Price based on 15% return on investment



Federal Regulations

- U.S. Department of Transportation
- Federal Motor Vehicle Safety Standards and Regulations, Post Crash Standard No. 301 crash requirements
  - Frontal Barrier
  - Rear Moving
  - Lateral Moving
  - Static Rollover
- Purpose
  - Reduce deaths and injuries

Federal Regulations

- Fuel spillage limits for each crash test
  - 28 g from impact until cessation of motion
  - 142 g in next 5 minutes
  - 25 g per minute in next 25 minutes
- Other requirements
  - Parking brake disengaged
  - Transmission in neutral
  - 90 – 95% full fuel system
    - Including hoses and activated pumps

Federal Regulations

- Vehicle must pass 2 evaporative emissions tests
    - Using SHED (sealed housing for evaporative determination)
  - 2 grams of hydrocarbon in a 24 hr period
    - Includes one hour hot soak test
  - 0.05 g/mi loss test standard under normal driving conditions
- Environmental Protection Agency
  - Extended Evaporative Emissions Test
- Future standard
  - California plans 0.35 g/day "zero emissions" standard
  - Other states will follow

First Stage Summary

- Design
  - Capitalize on advantages
    - Plastic is inexpensive
    - Study numerous material options
    - Additives and layers
  - Improve on possible weak points
    - Strength
    - Diffusion
- Regulations
  - Comparison of mechanical properties of materials
  - Determination of diffusion model
  - Set “near zero” emissions goal
    - Pass all current Federal and State regulations
    - Pass future regulations

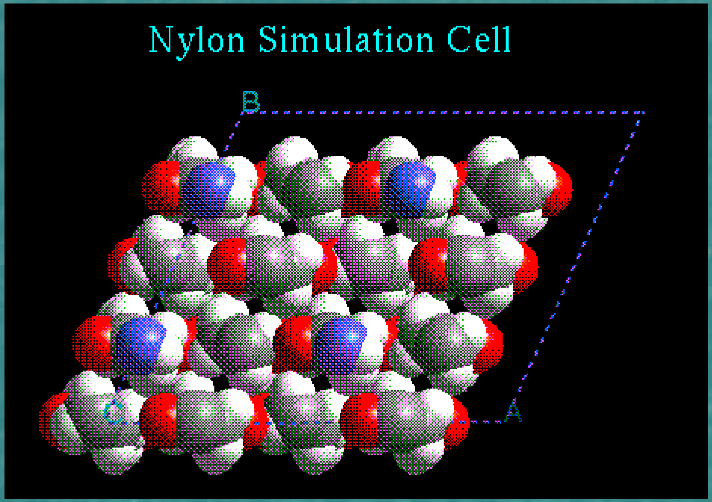
Second Stage

Materials selection

- Identify feasible materials
  - Structure and properties
  - Consider additives
  - Consider multiple layer design
- Mechanical properties
- Diffusion model

Materials Identified

- Selection
  - Based on properties
  - Feasibility of design
- Materials
  - High density polyethylene (HDPE)
  - Nylon
  - Glass filled nylon
  - Epoxies
  - Polyurethane
  - Ethylene vinyl alcohol (EVOH)
  - KYNAR® (polyvinyldenefluoride)
  - Curv® (polypropylene product)

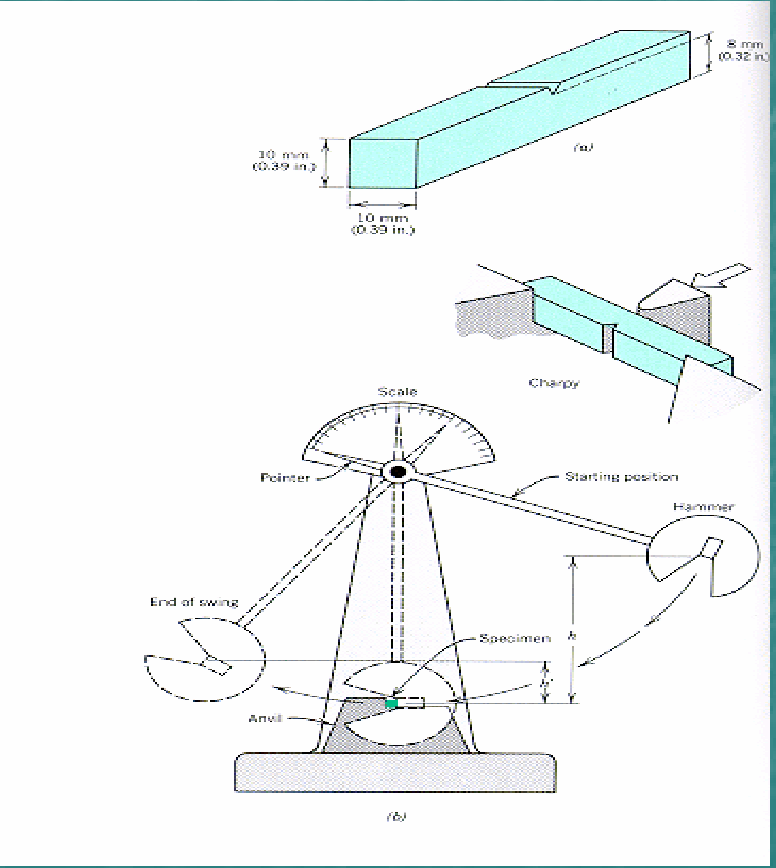


Mechanical Properties

- Tensile strength/Yield strength
- Abrasion resistance
  - Rockwell hardness
- Puncture resistance
  - High speed puncture test
- Flexural strength
- Charpy impact energy

Mechanical Properties

- Charpy Impact Energy
  - Resistance to impact
  - Linear with thickness
- Simulates actual impact
- Used to compare materials to steel



Charpy Impact Relation to Thickness

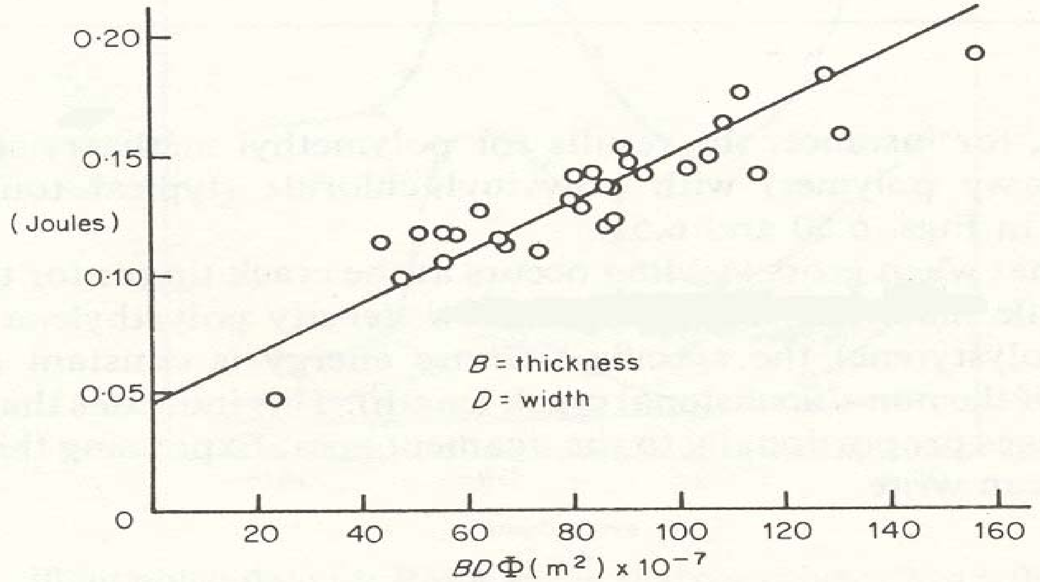


Fig. 6.49. Typical results for cast PMMA sheets obtained on Charpy tests. (After Plati and Williams.[53])

Directly related to thickness

Linear relationship

Thickness Calculation

U=Total impact energy (J)

U_{des}=Desired total impact energy

Ch_i=Charpy impact strength of material i (J/cm²)

B_s=thickness of steel tank

D=width of test sample

B=thickness of material needed to make its strength equal to TE_{des}

$$U = CH_s * B_s * D$$

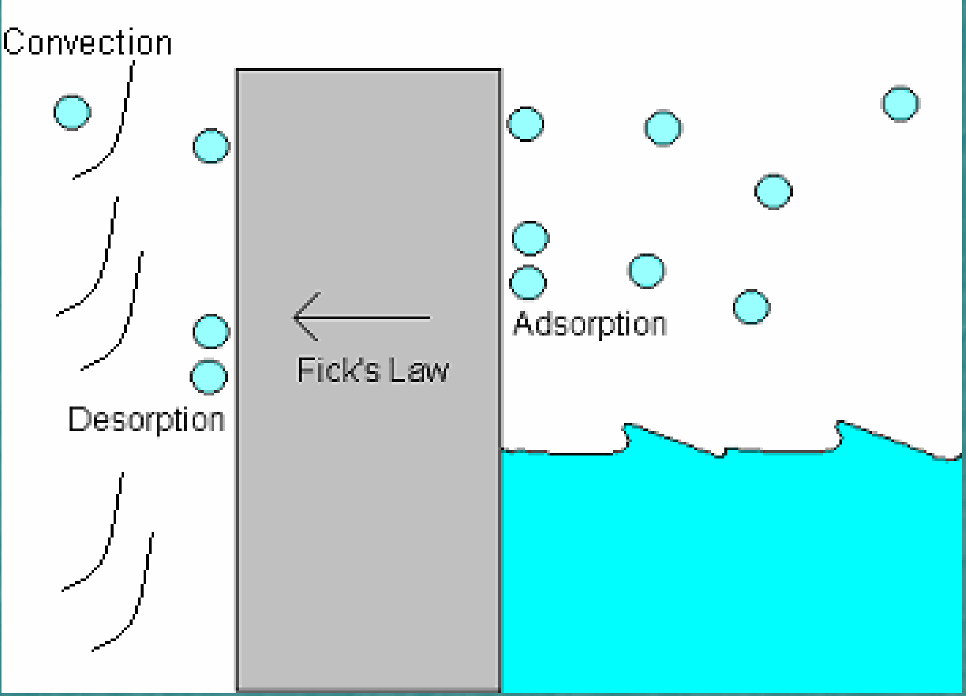
$$B = \frac{U_{des}}{CH_i * D}$$

Thickness and Strength

Material	Charpy Impact Energy (J/cm^2)	Thickness (mm)
1020 Steel	16.9	0.912
HDPE	6.8	2.41
Nylon 6	5.2	3.15
Nylon 6 10% glass	0.5	30.95
Nylon 6 20% glass	1.7	9.65
Nylon 6 30% glass	1.8	9.11
Nylon 6/6	3.4	4.82
Nylon 6/6 20% glass	1.0	16.40
Nylon 6/6 30% glass	1.7	9.65
Nylon 12	2.4	6.84
Nylon 12 20% glass	1.6	10.25
Nylon 12 30% glass	1.7	9.65
Curv	12.0	1.37

Diffusion Model

- Diffusion through walls needs to meet EPA emissions regulations
- One dimensional, steady state diffusion through barrier (hydrophilic) layer needs to be investigated

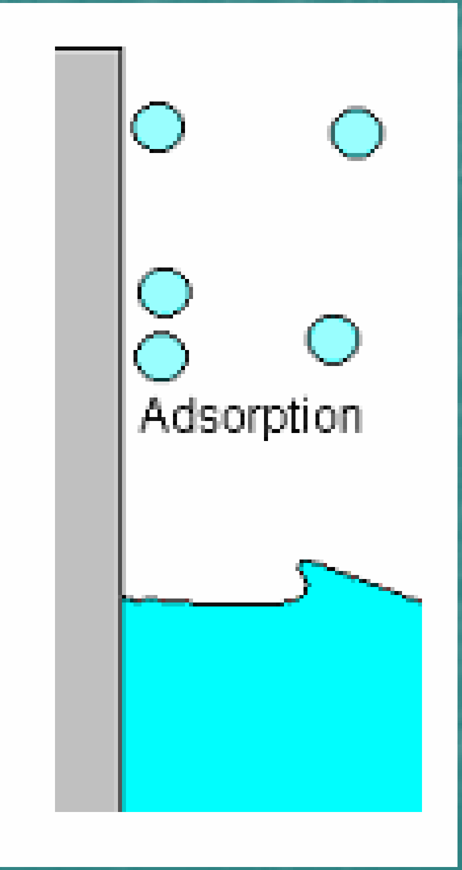


Diffusion Resistances

- Adsorption – Governed by Henry's Law

$$c = S \times p$$

  - c= Concentration
  - S= Henry's solubility coefficient
  - p= vapor pressure of gas
- Liquid diffusion negligible
  - Surface should be hydrophilic
  - Gasoline is hydrophobic

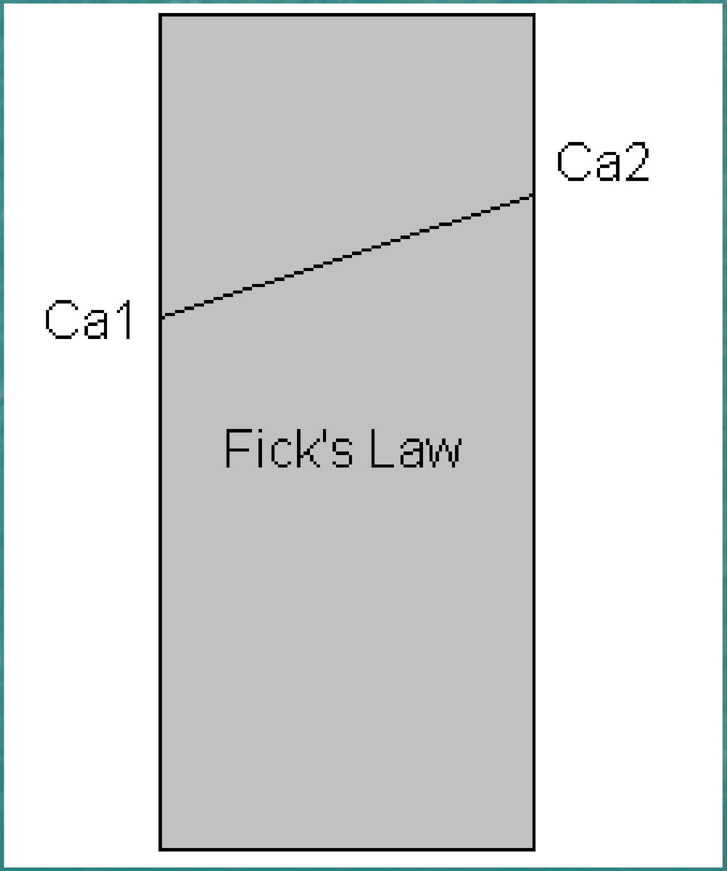


Diffusion Resistance Cont.

- Fick's Law of Diffusion

$$N_{az} = D_{ab} \times \frac{dc_a}{dz}$$

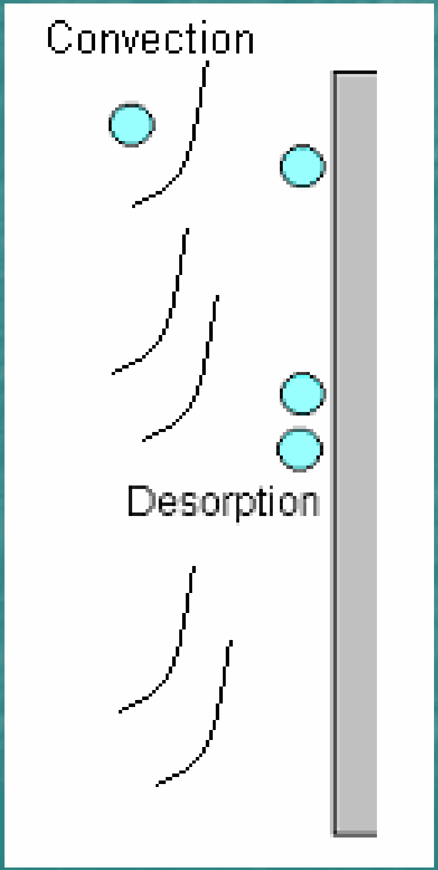
- Na = Flux out
- D_{ab}= Diffusion Coefficient
- Ca= Concentration
- z= Thickness



Diffusion Resistance Cont.

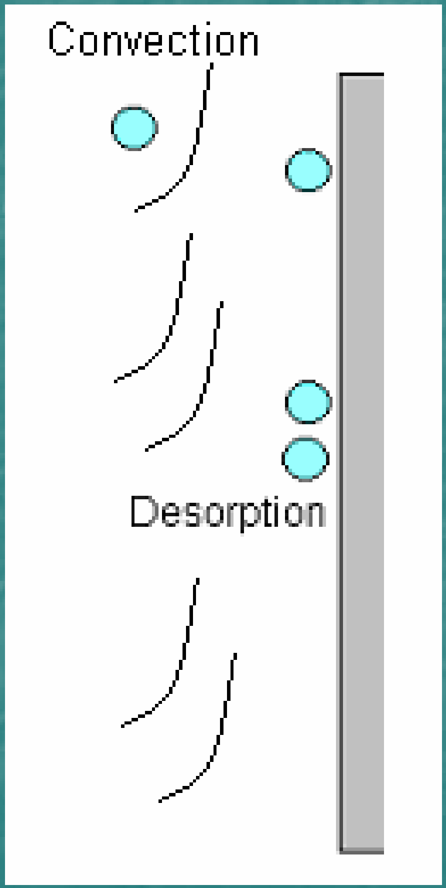
- Desorption/ Convection
  - Desorption governed by Henry’s Law
  - Correlation for Convective Mass Transfer Coefficient

$$k_c = \frac{D_{ab}}{l} \times (0.332 \times \mathrm{Re}_l^{0.5} \times Sc^{1/3})$$



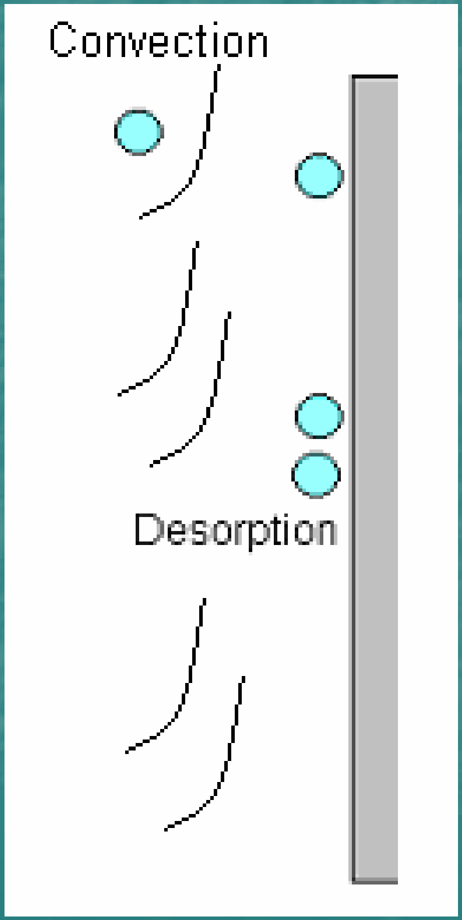
Diffusion Resistance Cont.

- Assumptions for Local Reynold's Number
  - Pressure = 1 atm
  - Temperature= 300 K
  - Natural Convection = 0.0833 ft/s
- Local Length for Correlation = 0.833 ft



Diffusion Resistance Cont.

- Convective Mass Transfer Coefficient = 9.10×10^{-4} ft/s
- Overall mass balance yields concentration of 1.25×10^{-10} mol/cm^3
- Negligible concentration, no boundary layer resistance



Diffusion Model

- New Term- Permeability

$$P = D_{ab} \times S$$

- D_{ab}= Diffusion Coefficient
- S= Henry's Solubility Coefficient
- Why introduce permeability???
  - Fewer terms will simplify the final equation

Diffusion Model

- Integrated Fick's Law

$$N_{az} = \frac{D_{ab} \times (c_{a2} - c_{a1})}{x}$$

- Substituting Henry's Law, and Permeability

$$C = S \times p \qquad P = D_{ab} \times S$$

- Final Diffusion Model

$$N_{az} = \frac{P \times A \times (p_2 - p_1)}{x}$$

Second Stage Results

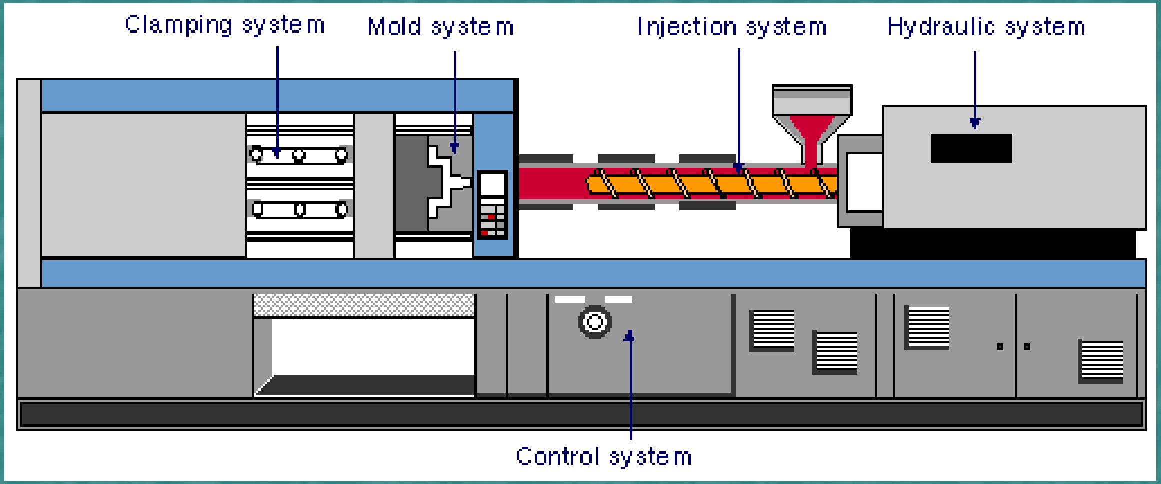
Material	Diffusion Thickness (mm)	Charpy Impact Required (mm)
Nylon 6	0.566	3.15
HDPE	7825	2.41
Curv	8607	1.37
Kynar	0.132	7.46
EVOH	0.033	41.31

- Nylon cannot be used alone
  - Needs polar barrier
- Tank will require 2 layers
  - Barrier- EVOH
  - Structural- Curv®, HDPE, or Nylon 6

Third Stage

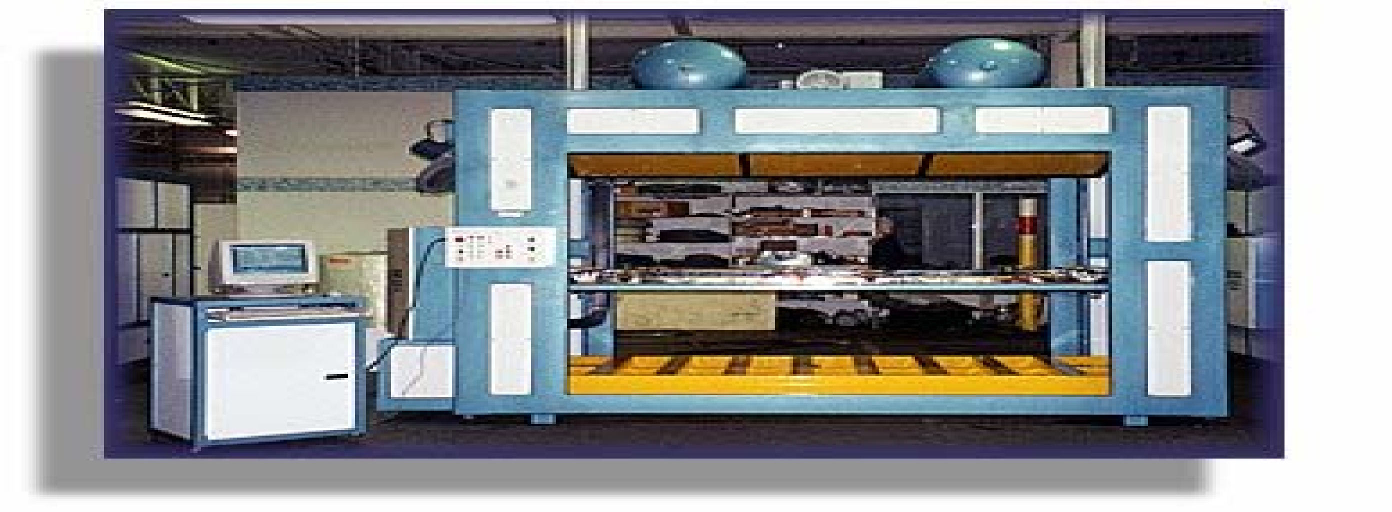
- Process selection
  - Identify and analyze feasible processes
    - Injection Molding
    - Stamping
    - Rotational Molding
    - Blow Molding
  - Match materials with processes
- Compare Returns on investment (ROI)
- Choose process
  - Based on profitability

Injection Molding



- Advantages
  - Self contained process
- Disadvantages
  - High equipment cost
  - Tanks will have seams
- Compatible materials
  - HDPE
  - Nylon

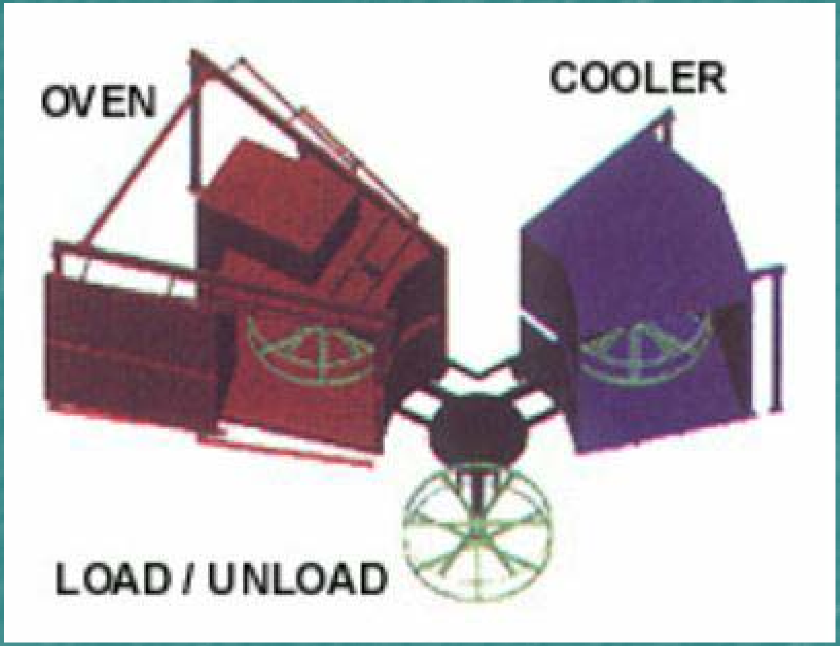
Stamping



- Advantages
  - Simple process
  - Low cycle times
  - Low maintenance
- Disadvantages
  - Cannot produce complex shapes
  - Tanks must contain seams
- Compatible materials
  - HDPE
  - Nylon
  - Curv®

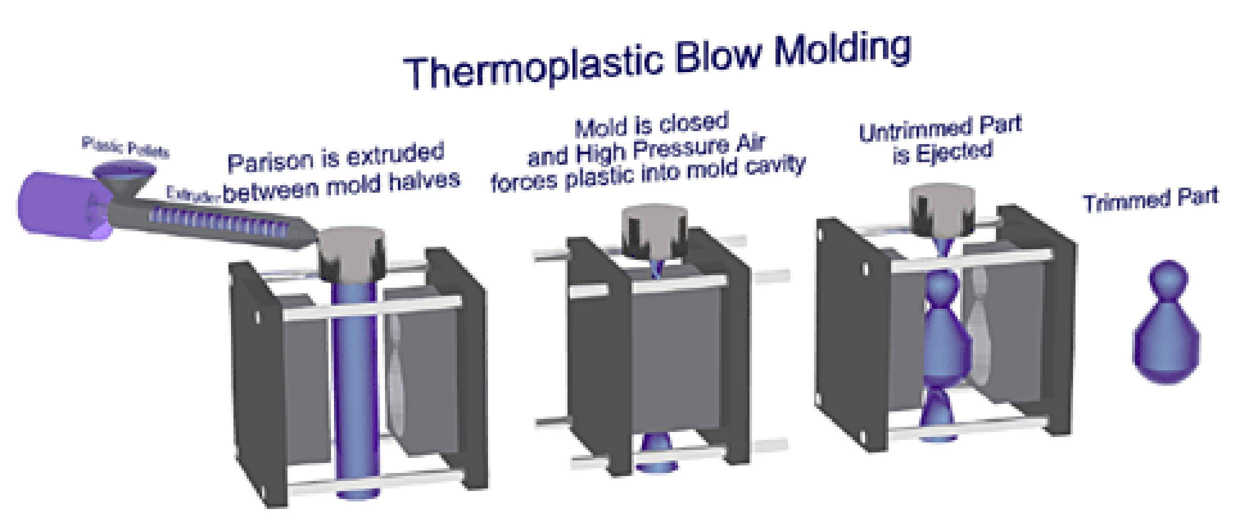
Rotational Molding

- Advantages
  - Complex geometry
  - Seamless
  - Stress free corners
- Disadvantages
  - Larger labor needed
  - Lower production volumes
  - High utilities
  - Large machinery



- Compatible Materials
  - Nylon
  - HDPE

Blow Molding



- Advantages
  - Large volumes
  - Low cycle times
- Disadvantages
  - Loss of trimmed material
    - 20 - 30 % of total part
  - High pressure
- Compatible Materials
  - Nylon
  - HDPE

Process Spreadsheet

Stamping with Glass-filled Nylon and polypropylene

Total Impact Energy for 20 gage 1020 steel = 47.0 J for a sample width of 12 inches (30.48 cm)

Tanks/yr	Hrs/work day	Work days/yr	Tanks/hr	Polymer	Charpy Impact (J/cm²)	Comparison w (mm)	Thickness (mm)	Tot Impact Evergy (J)	Heat Capacity (J/g-°C)	Density (kg/m³)	Process Temp (°C)	Cost ($/lb)
500,000	24	320	65	HDPE	6.8	304.8	2.41	50	2.2	956	110	0.51
				10% Nylon 6	0.53	304.8	30.95	50	2.7	1210	205	0.25
				20% Nylon 6	1.7	304.8	9.65	50	2.3	1240	205	0.29
				30% Nylon 6	1.8	304.8	9.11	50	1.9	1350	200	0.36
				Nylon 6	5.2	304.8	3.15	50	1.6	1120	160	0.20
				20% Nylon 12	1.6	304.8	10.25	50	1.8	1180	160	0.33
				30% Nylon 12	1.7	304.8	9.65	50	1.6	1290	168	0.38
				20% Nylon 6,6	1	304.8	16.40	50	2.0	1250	205	0.37
				30% Nylon 6,6	1.7	304.8	9.65	50	1.8	1350	220	0.43
				Nylon 66	3.4	304.8	4.82	50	2.2	1120	200	0.24
				Nylon 12	2.4	304.8	6.84	50	1.0	1040	140	0.26
				KYNAR	2.2	304.8	7.46	50				

Tank inner dimensions

Length (cm)	Width (cm)	Height (cm)	Vol Tank (cm³)	Vol Tank (gal)
62.1	40.8	25.4	64355.5	17.0
62.1	40.8	25.4	64355.5	17.0
62.1	40.8	25.4	64355.5	17.0
62.1	40.8	25.4	64355.5	17.0
62.1	40.8	25.4	64355.5	17.0
62.1	40.8	25.4	64355.5	17.0
62.1	40.8	25.4	64355.5	17.0
62.1	40.8	25.4	64355.5	17.0
62.1	40.8	25.4	64355.5	17.0
62.1	40.8	25.4	64355.5	17.0
62.1	40.8	25.4	64355.5	17.0

Tank outer dimensions / **Processing quanties**

Polymer	Length (cm)	Width (cm)	Height (cm)	Vol Pol/Tank (cm³)	Vol Pol/hr (cm³/hr)	Vol Pol/hr (m³/hr)	Vol Pol/day (m³/day)	Mass Pol/day (kg/day)	Tank Weight (lbs/tank)	Cost ($/tank)	Cost ($/yr)
HDPE	62.58247646	41.28247646	25.88247646	2513.4	163636.0	0.16	3.9	3754.46	5.29	$2.70	$1,349,622.35
10% Nylon 6	68.29026395	46.99026395	31.59026395	37017.0	2409959.3	2.41	57.8	55294.11	98.66	$24.66	$12,332,197.12
20% Nylon 6	64.02990582	42.72990582	27.32990582	10418.9	678315.6	0.68	16.3	15563.27	28.46	$8.25	$4,126,262.46
30% Nylon 6	63.92268883	42.62268883	27.22268883	9814.3	638951.3	0.64	15.3	14660.10	29.18	$10.51	$5,253,024.14
Nylon 6	62.73093075	41.43093075	26.03093075	3298.9	214774.7	0.21	5.2	4927.79	8.14	$1.63	$813,835.19
20% Nylon 12	64.15052493	42.85052493	27.45052493	11102.8	722840.3	0.72	17.3	16584.85	28.86	$9.52	$4,761,499.01
30% Nylon 12	64.02990582	42.72990582	27.32990582	10418.9	678315.6	0.68	16.3	15563.27	29.60	$11.25	$5,624,843.88
20% Nylon 6,6	65.3808399	44.0808399	28.6808399	18303.9	1191661.6	1.19	28.6	27341.48	50.40	$18.65	$9,323,308.69
30% Nylon 6,6	64.02990582	42.72990582	27.32990582	10418.9	678315.6	0.68	16.3	15563.27	30.98	$13.32	$6,660,999.33
Nylon 66	63.06495291	41.76495291	26.36495291	5087.3	331204.7	0.33	7.9	7599.16	12.55	$3.01	$1,506,021.19
Nylon 12	63.46701662	42.16701662	26.76701662	7278.8	473881.0	0.47	11.4	10872.73	16.67	$4.34	$2,167,611.14

Equipment Cost

Storage Tank (m³)	Storage Tank Cost ($)	Auger (lbs/hr)	Auger Cost ($)	Number Stamps	Stamp Cost ($)	Conveyors	Conveyor Cost ($)	Cutters	Cutter Cost ($)	Extruder/Dies	Die Cost ($)	Extruder Cost ($)
5.89	$14,541	344.16	$172	4.00	$500,000	8.00	$28,800	4.00	$12,000	4.00	$1,100,000	$240,000
86.76	$37,592	5068.63	$2,534									
24.42	$26,727	1426.63	$713									
23.00	$26,215	1343.84	$672									
7.73	$16,872	451.71	$226									
26.02	$27,272	1520.28	$760									
24.42	$26,727	1426.63	$713									
42.90	$31,556	2506.30	$1,253									
24.42	$26,727	1426.63	$713									
11.92	$20,584	696.59	$348									
17.06	$23,654	996.67	$498									

Polymer	Tot. Equip. Cost ($)
HDPE	**$1,934,473**
10% Nylon 6	**$1,959,886**
20% Nylon 6	**$1,947,201**
30% Nylon 6	**$1,946,647**
Nylon 6	**$1,936,858**
20% Nylon 12	**$1,947,792**
30% Nylon 12	**$1,947,201**
20% Nylon 6,6	**$1,952,570**
30% Nylon 6,6	**$1,947,201**
Nylon 66	**$1,940,692**
Nylon 12	**$1,943,912**

Utilities

Stamp (kWh/yr)	Heaters (kWh/yr)	Conveyor (kWh/yr)	Sprayer (kWh/yr)	Cutter (kWh/yr)	Extruder (kWh/yr)	Dies (kWh/yr)	Total Energy (kWh/yr)
2,150,400	393,216	30,720	92,160	153,600	1,843,200	1,666,667	6,329,963

Inside Coating

Zero emissions (0.3g/day)

Material	ZE Thickness (mm)	Volume (cm³/tank)	Weight (lbs/tank)	Cost ($/lb)	Cost ($/tank)	Cost ($/yr)	Density (g/cm³)	Weight Coating (lbs/yr)	Vol Coating (ft³/yr)	Vol Coating (m³/yr)
EVALCA EVOH	0.3	305.5	0.80	$2.65	$2.12	$1,060,962	1.19	400,362.9	5,394.1	152.7
KYNAR® 1000 HD	0.5	509.1	1.98	$10.50	$20.84	$10,421,211	1.77	992,496.3	8,990.1	254.6

Adhesive Layer

Material	ZE Thickness (mm)	Volume (cm³/tank)	Weight (lbs/tank)	Cost ($/lb)	Cost ($/tank)	Cost ($/yr)	Density (g/cm³)	Weight Coating (lbs/yr)	Vol Coating (ft³/yr)	Vol Coating (m³/yr)
Adhesive LLDPE	0.1	101.8	0.27	$0.46	$0.12	$61,389	1.19	133,454.3	1,798.0	50.9

Rivet Costs

Material	Rivets/tank	Rivet Cost ($/rivet)	Rivet Cost ($/tank)	Rivet Cost ($/yr)
Steel	24.0	0.1174	$2.82	$1,408,800.00

Total Material Cost

Polymer	Structural ($/tank)	Structural ($/yr)	Other Materials ($/tank)	Other Materials ($/yr)	Total Cost ($/tank)	Total Cost ($/yr)
HDPE	$2.70	1,349,622	$5.06	$2,531,151	$7.76	$3,880,773
10% Nylon 6	$24.66	12,332,197			$29.73	$14,863,348
20% Nylon 6	$8.25	4,126,262			$13.31	$6,657,413
30% Nylon 6	$10.51	5,253,024			$15.57	$7,784,175
Nylon 6	$1.63	813,835			$6.69	$3,344,986
20% Nylon 12	$9.52	4,761,499			$14.59	$7,292,650
30% Nylon 12	$11.25	5,624,844			$16.31	$8,155,995
20% Nylon 6,6	$18.65	9,323,309			$23.71	$11,854,459
30% Nylon 6,6	$13.32	6,660,999			$18.38	$9,192,150
Nylon 66	$3.01	1,506,021			$8.07	$4,037,172
Nylon 12	$4.34	2,167,611			$9.40	$4,698,762

Process Spreadsheet Cont.

- Input
  - Plant capacity, annual working days, daily working hours
- Output
  - Material costs
  - Equipment costs
  - Utility costs
  - Tank specifications

Financial Evaluation

Year ending at time	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	Row Sum
1. Land, 10^6\$ (see notes)		0.00	0.00	0.00										0.00	0.00
2. Fixed Capital Investment, 10^6\$		-0.47	-1.13	-1.64											-3.24
3. Working Capital, 10^6\$ (see notes)				-0.47										0.47	0.00
4. Salvage Value, 10^6\$														0.00	0.00
5. Total Capital Investment, 10^6\$		-0.47	-1.13	-2.11											-3.71
6. Annual Investment, 10^6\$					0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7. Start-up cost, 10^6\$					-0.32										
8. Operating rate, fraction of capacity					0.50	0.75	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
9. Annual sales, 10^6\$					10.50	15.75	18.90	21.00	21.00	21.00	21.00	21.00	21.00	21.00	192.15
10. Annual Total Product Cost, depreciation not included, 10^6\$					-12.42	-14.99	-16.72	-18.02	-18.38	-18.74	-19.12	-19.50	-19.89	-20.29	-178.07
11. Annual depreciation factor, 1/y					0.20	0.320	0.192	0.115	0.115	0.058					
12. Annual depreciation, 10^6\$/y					0.65	1.04	0.62	0.37	0.37	0.19					3.24
13. Annual Gross Profit, 10^6\$					-2.89	-0.28	1.56	2.61	2.25	2.07	1.88	1.50	1.11	0.71	10.52
14. Annual Net Profit, 10^6\$					-2.89	-0.28	1.02	1.70	1.46	1.35	1.22	0.97	0.72	0.46	5.73
15. Annual operating cash flow, 10^6\$					-2.25	0.76	1.64	2.07	1.84	1.53	1.22	0.97	0.72	0.46	8.96
16. Total annual cash flow, 10^6\$	0.00	-0.47	-1.13	-2.11	-2.25	0.76	1.64	2.07	1.84	1.53	1.22	0.97	0.72	0.46	5.26
17. Cumulative cash position, 10^6\$	0.00	-0.47	-1.60	-3.71	-5.95	-5.20	-3.56	-1.49	0.35	1.88	3.10	4.08	4.80	5.26	
Profitability measures, time value of money NOT included:															
18. Return on investment, ave. %/y	15.5														
19. Payback period, y	3.6														
20. Net return, 10^6\$	0.44	at m_{ar} =	3.7	%/y											
Profitability measures including time value of money, with ANNUAL END-OF-YEAR cash flows and discounting															
21. Present worth factor	1.11	1.08	1.04	1.00	0.96	0.93	0.90	0.87	0.83	0.80	0.78	0.75	0.72	0.70	
22. Present worth of annual cash flows, 10^6\$	0.00	-0.51	-1.17	-2.11	-2.17	0.70	1.47	1.79	1.53	1.23	0.95	0.73	0.52	0.32	3.30
23. Net present worth, 10^6\$ =	3.30	at discount rate=	3.7	%/y											
24. Discounted cash flow rate of return, DCFR, %/y =	15.2	To get DCFR, go to "Tools" and function "Solver." Set target cell as \$R\$41, to be made = 0 by changing cell \$C\$39. Solver must be rerun after a change on any sheet.													
Iterated discount rate= 0.152															
25. Present worth factor	1.53	1.33	1.15	1.00	0.87	0.75	0.65	0.57	0.49	0.43	0.37	0.32	0.28	0.24	
26. Present worth of annual cash flows, 10^6\$	0.00	-0.63	-1.30	-2.11	-1.95	0.57	1.07	1.18	0.91	0.66	0.45	0.31	0.20	0.11	-0.52
Profitability measures including time value of money, with CONTINUOUS cash flows and discounting															
27. Present worth factor	1.14	1.09	1.06	1.02	0.98	0.95	0.91	0.88	0.85	0.82	0.79	0.76	0.73	0.71	
28. Present worth of annual cash flows, 10^6\$	0.00	-0.52	-1.19	-2.15	-2.21	0.72	1.50	1.82	1.56	1.25	0.97	0.74	0.53	0.33	3.36
29. Net present worth, 10^6\$ =	3.36	at discount rate=	3.6	%/y											
30. Discounted cash flow rate of return, DCFR, %/y =	14.1	To get DCFR, go to "Tools" and function "Solver." Set target cell as \$R\$51, to be made = 0 by changing cell \$C\$49. Solver must be rerun after a change on any sheet.													
Iterated discount rate= 0.141															
31. Present worth factor	1.64	1.43	1.24	1.07	0.93	0.81	0.70	0.61	0.53	0.46	0.40	0.35	0.30	0.26	
32. Present worth of annual cash flows, 10^6\$	0.00	-0.67	-1.39	-2.26	-2.09	0.61	1.15	1.26	0.97	0.70	0.49	0.34	0.22	0.12	-0.56

Third Stage Summary

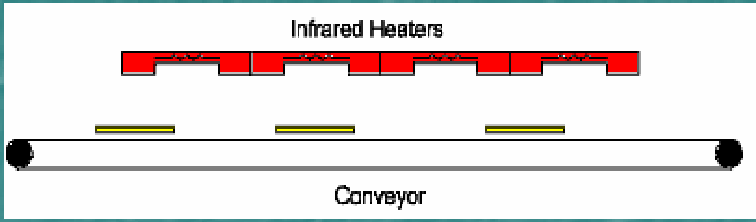
Process	TCI ($million)	ROI (%)
Blow Molding HDPE	10.0	5.2
Injection Molding HDPE	43.5	-15.3
Rotomolding HDPE	11.1	-16.5
Stamping Curv	3.6	15.5
Stamping HDPE	9.0	-9.0

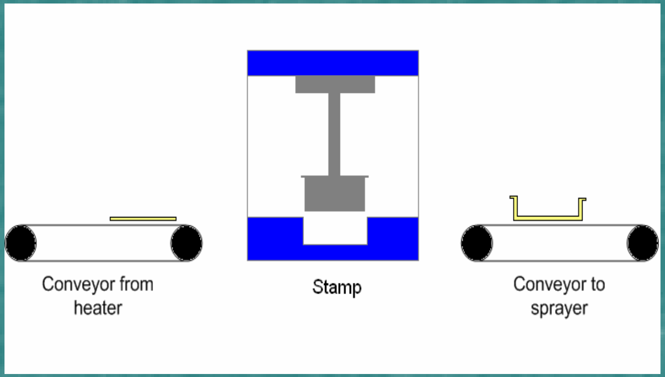
- Nylon excluded
  - Similar in cost and application to HDPE
  - HDPE stronger, lighter
- Stamping Curv
  - Smallest TCI
  - Best ROI

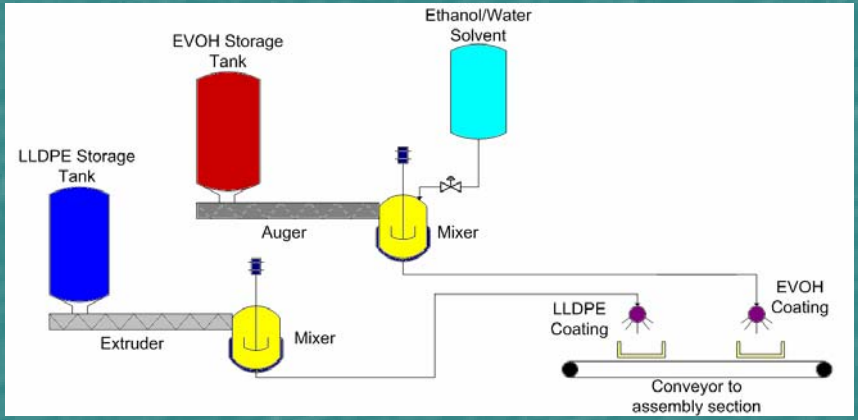
Fourth Stage

- Detailed design
  - Process
  - EVOH Layer
  - Joining tank halves
  - Gas tank design
    - Wall layers and thicknesses

Stamping Process Diagram







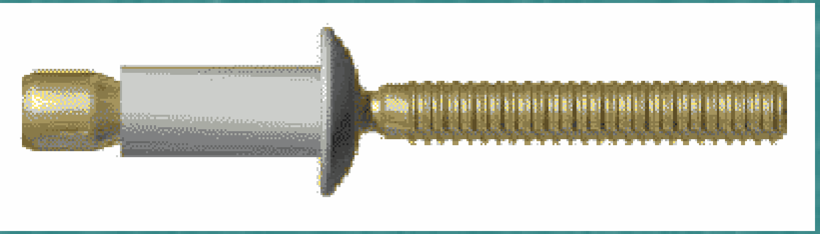
- Tank halves produced separately
- Flanges on each half used to join together

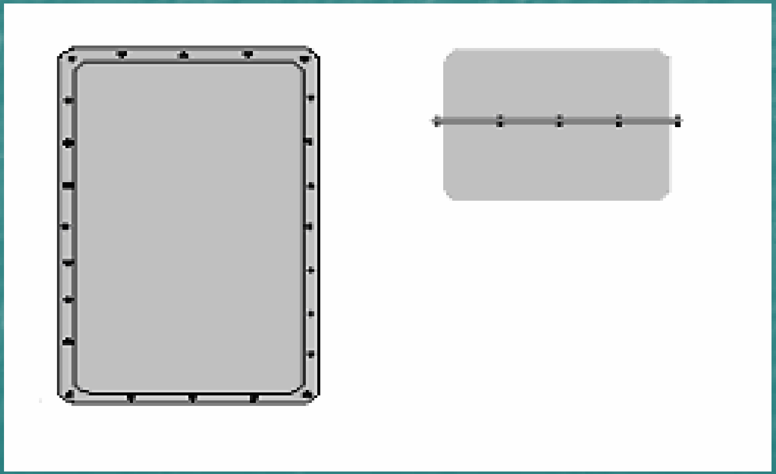
EVOH Layer

- Adhesive
  - Linear Low Density Polyethylene (LLDPE)
- Made by spraying EVOH
- Zero-emission standards
  - **35 micron EVOH layer minimum requirement**
  - 140 micron EVOH layer will be used
- Process
  - Mix with solvent
    - Ethanol – 80/20 solvent/water
    - 40 wt% solvent mixture
  - Spray on the tank
  - Solvent evaporates

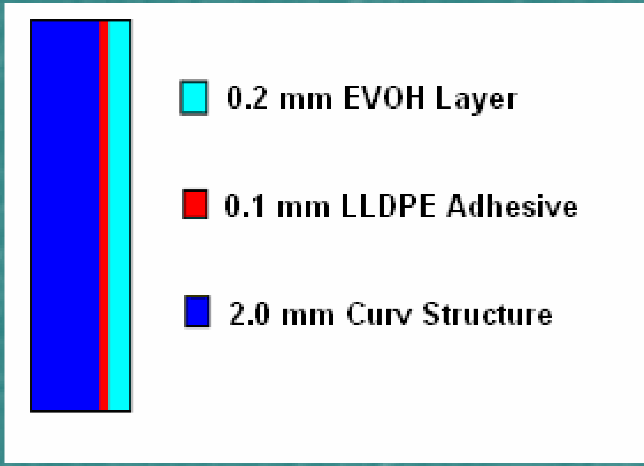
Joining Halves

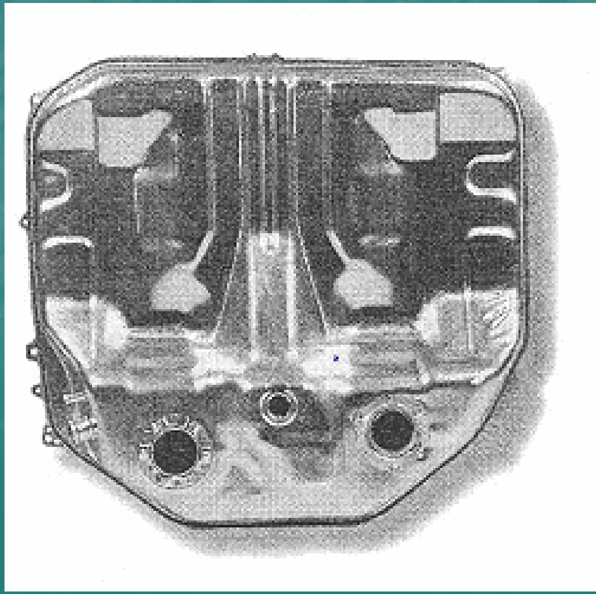
- Heat flanges on side
- Press together
- Steel Rivets





Final Gas Tank Design



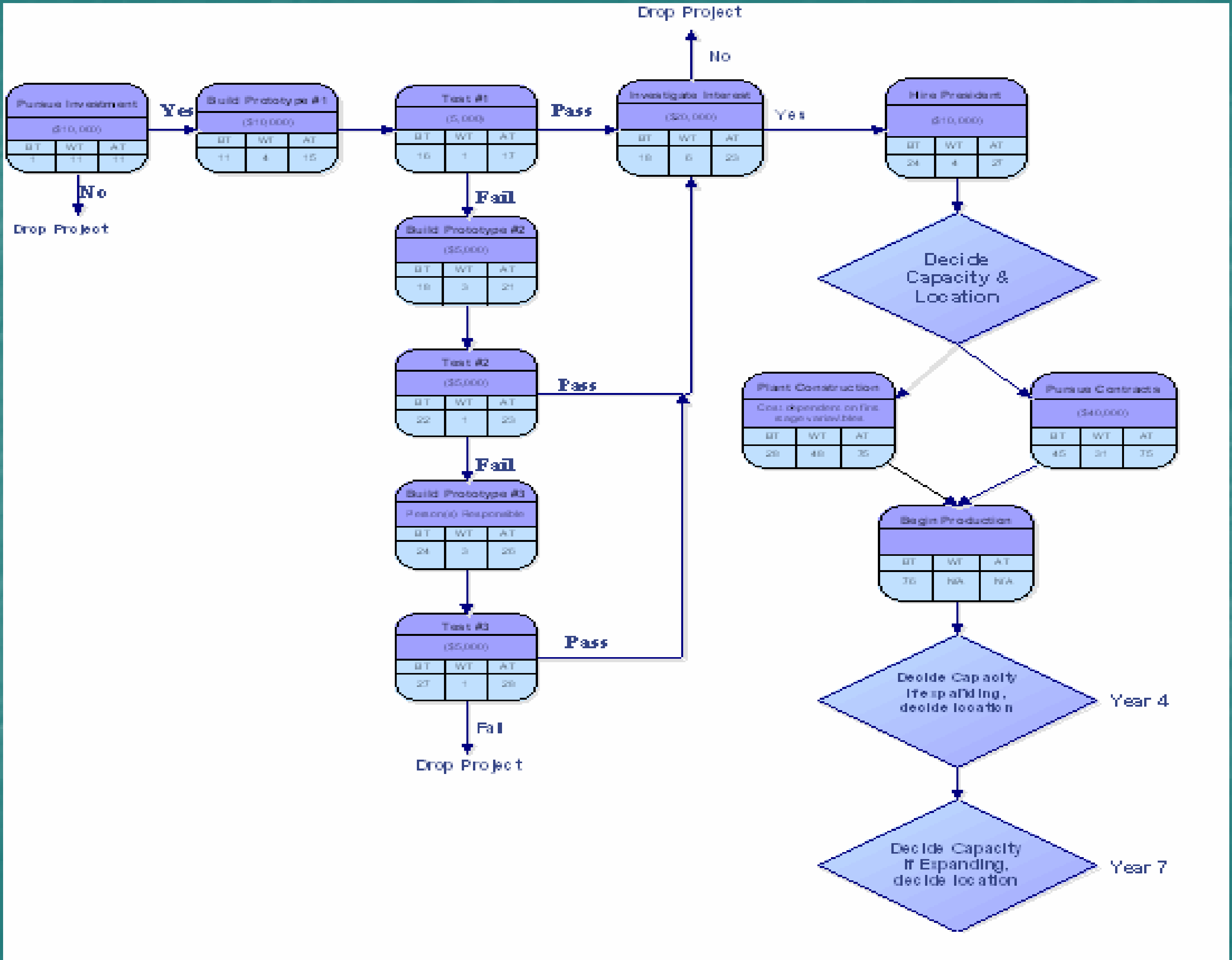


- Constant wall thickness
- Dimensions/Shape
  - Dependent on contract
  - Variability in dimensions:
    - 30 - 36 inches in length
    - 22 - 28 inches in width
    - 7 - 10 inches in height

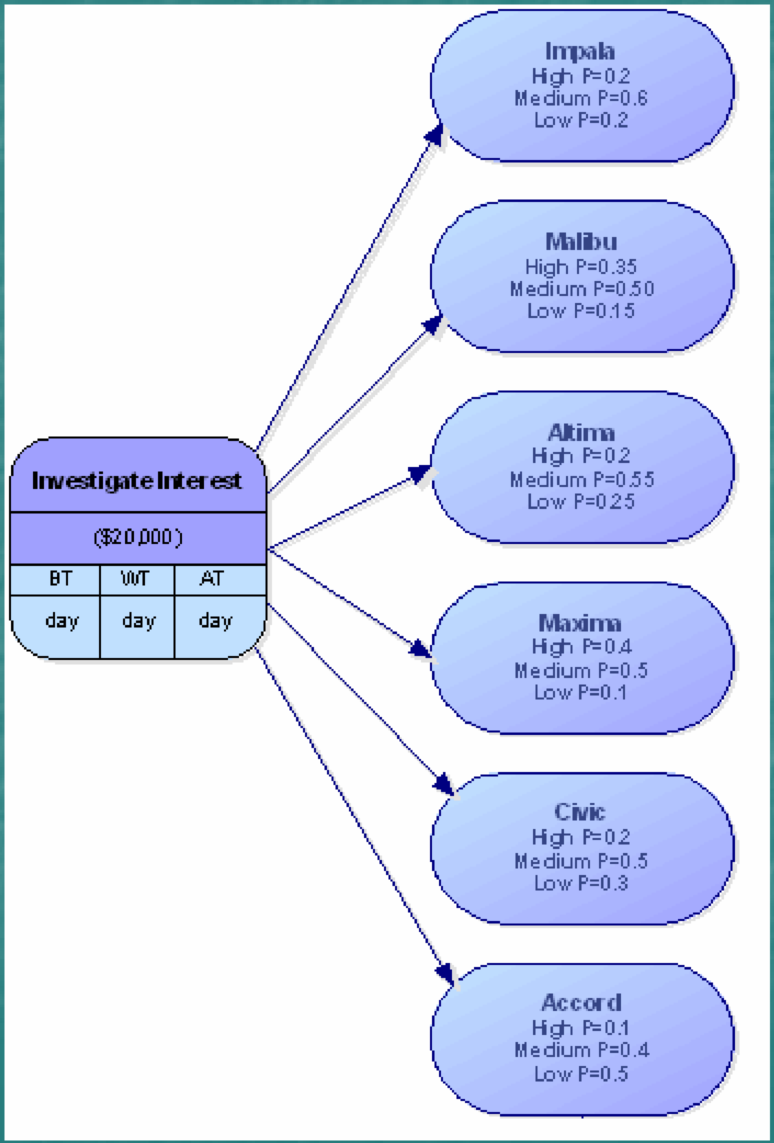
Final Stage

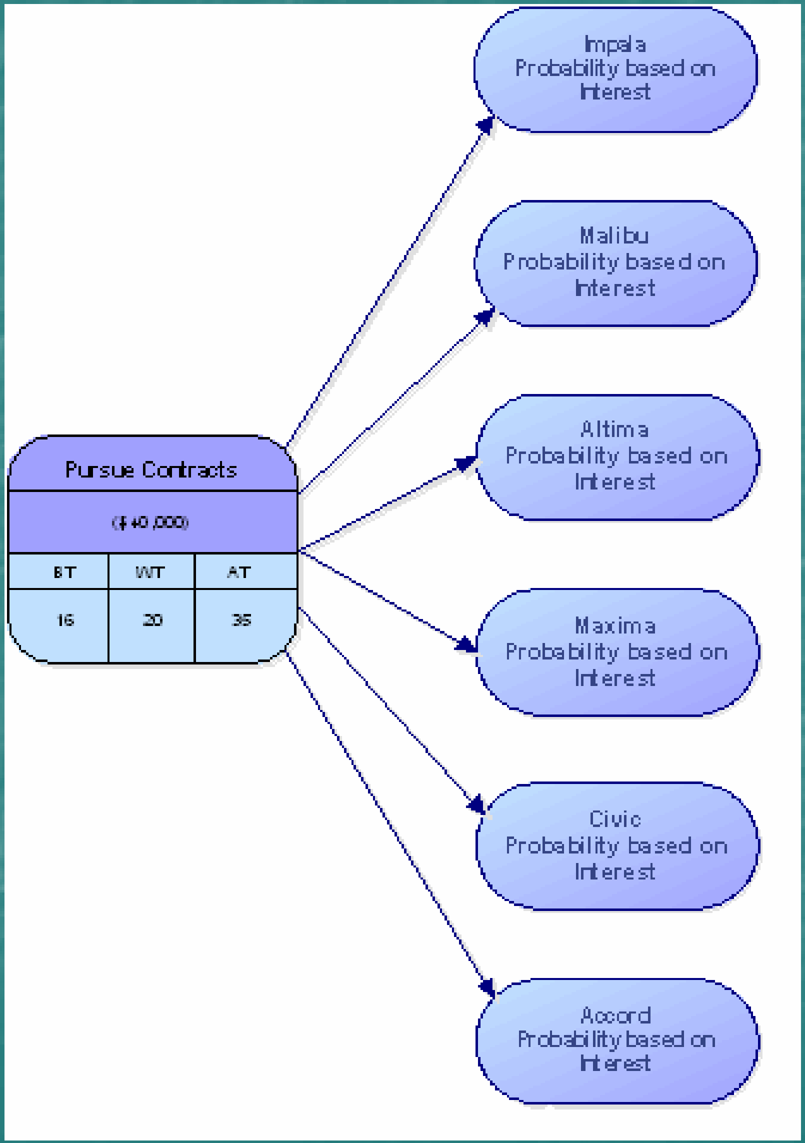
- Develop business plan
  - Strategy
    - Program Evaluation and Review Technique (PERT diagram)
  - Risk and Uncertainty
  - Optimal location

Pert Diagram



Pert Diagram

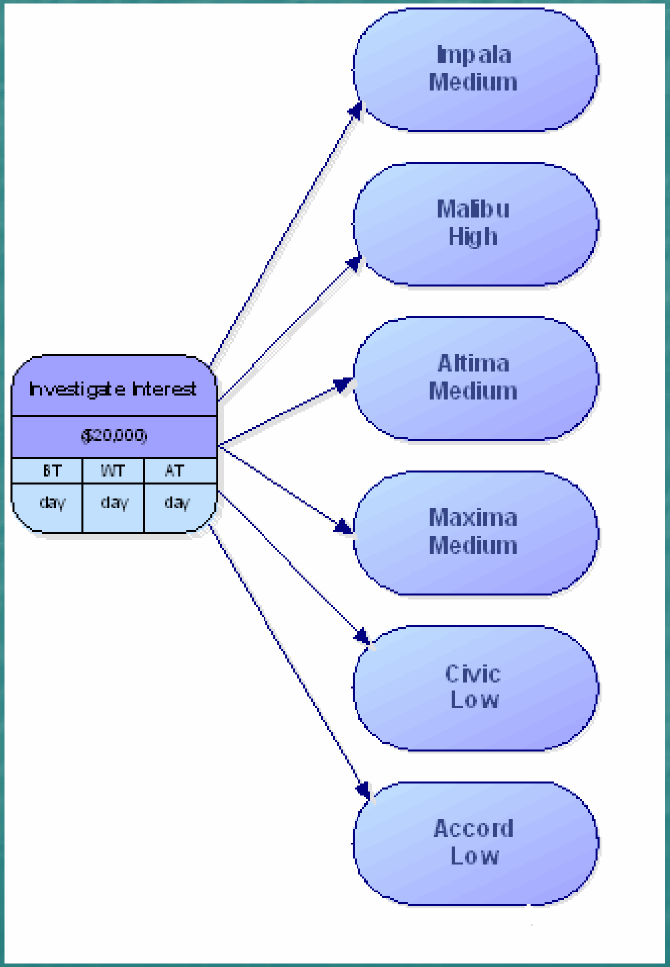


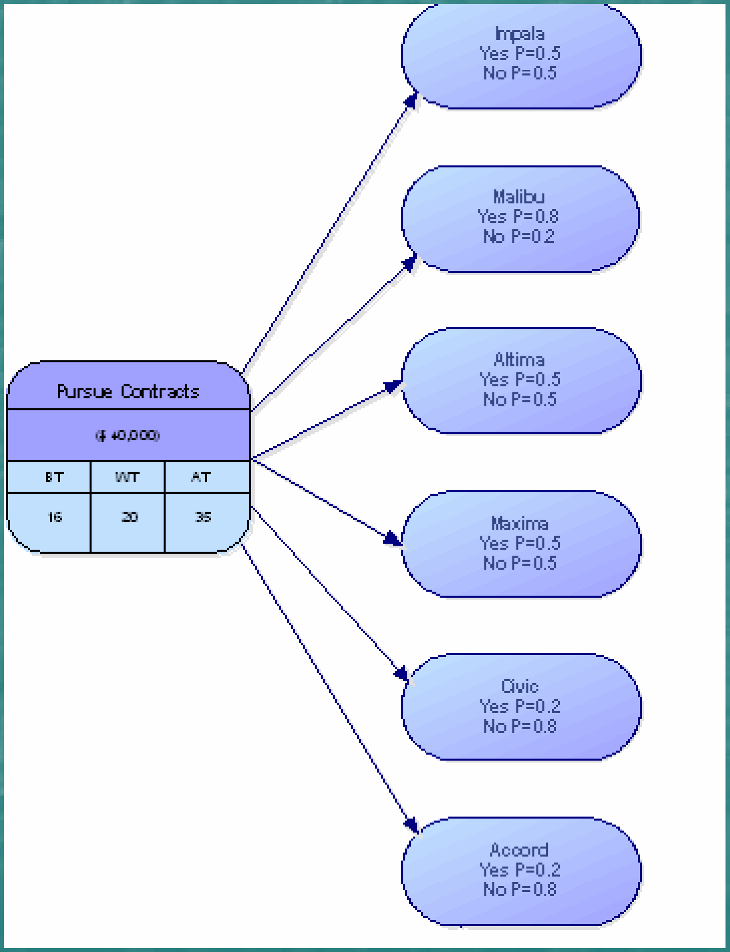


Risk and Uncertainty

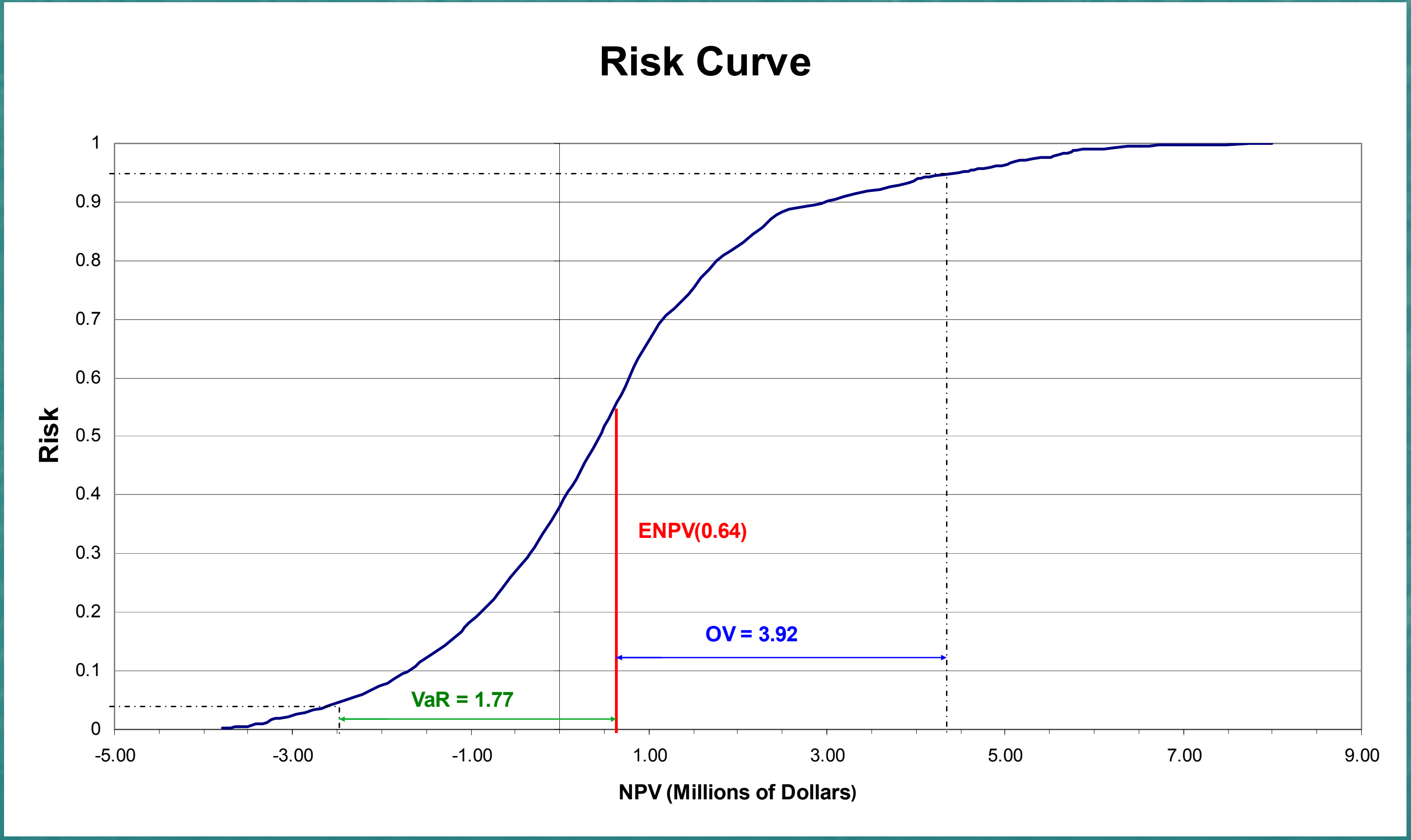
- Determine possible interest levels
- Associate a probability to each level
- Generate random samples for Curv®, EVOH, LLDPE, and rivet prices
- Develop scenarios using possible interests and generated prices
- Calculate the probability and NPV for each scenario

Possible Outcome Example





Risk Curve



Risk Curve
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Risk
ENPV(0.64)
OV = 3.92
VaR = 1.77
-5.00
-3.00
-1.00
1.00
3.00
5.00
7.00
9.00
NPV (Millions of Dollars)

Final Stage Conclusions

- Stamping Curv® with an EVOH barrier
- Total Capital Investment = $3.61 million
- ROI = 15.5 %
- NPV = $3.36 million over 10 year project life

Product Comparison

- Curv®/EVOH
  - $42.00
  - 8.1 lbs
  - Recyclable
  - 2.3 mm wall thickness
- HDPE/EVOH
  - $53.00
  - 17.6 lbs
  - Non-recyclable
  - 4.52 mm wall thickness

Recommendations

- Further analyze risk and uncertainty
- Improve expansion
- Gauge market interest
- Expand automobile models considered

Questions?