

## Polymer Composite Gasoline Tanks

Lucio Boccacci Jaime Erazo Nick Harm Zack McGill Ryan Posey

University of Oklahoma

#### 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



Volume: 60 Liters Weight: 8 Kg



# 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.<sup>53</sup>)

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/cm<sup>2</sup>)  $B_s$ =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 <sup>2</sup> )	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



Fick's Law of Diffusion

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

Na = Flux out
 D<sub>ab</sub>= Diffusion Coefficient
 Ca= Concentration
 z= Thickness



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

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



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



 Convective Mass Transfer Coefficient = 9.10 x 10<sup>-4</sup> ft/s
 Overall mass balance yields concentration of 1.25 x 10<sup>-10</sup> mol/cm<sup>3</sup>

 Negligible concentration, no boundary layer resistance



#### **Diffusion Model**

#### New Term- Permeability

 $P = D_{ab} \times S$ 

D<sub>ab</sub>= 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  $C = S \times p$   $P = D_{ab} \times S$ 

Final Diffusion Model

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

#### Thermoplastic Blow Molding



Advantages

 Large volumes
 Low cycle times

 Disadvantages

 Loss of trimmed material
 20 - 30 % of total part
 High pressure

Compatible MaterialsNylonHDPE

## Process Spreadsheet

Stamping with 0	Glass-filled Nylon and	polypropylene										
					Total Impact Energy for 2	0 gage 1020 steel – 41	7.0 J for a sample widtl	h of 12 inches (30.48 cm)				
Tanks/yr 500,000	Hrs/work day 24	Work days/yr 320	Tanks/hr 85	Polymer HDPE 10% Nylon 6 20% Nylon 6 0% Nylon 5 20% Nylon 12 30% Nylon 12 20% Nylon 5,6 30% Nylon 5,6	Charpy Impact (J/cm <sup>2</sup> ) 6.8 0.63 1.7 1.8 5.2 1.6 1.7 1.7 1.7	Comparison w (mm) 304.8 304.8 304.8 304.8 304.8 304.8 304.8 304.8 304.8 304.8	Thickness (mm)           2.41           30.95           9.65           9.11           3.15           10.25           9.66           16.40           9.65	Tot Impact Evergy (J) 50 50 50 50 50 50 50 50 50 50 50 50	Heat Capacity (J/g.°C) 2.2 2.7 2.3 1.9 1.6 1.8 1.8 2.0 1.8	Density (kg/m <sup>2</sup> ) 956 1210 1240 1350 1120 1180 1290 1250 1350	Process Temp (°C) 110 205 205 200 160 160 160 160 205 220	Cost (\$/lb) 0.51 0.25 0.29 0.36 0.20 0.33 0.38 0.37 0.43
				Nylon bb Nylon 12 KYNAR	3.4 2.4 2.2	304.8 304.8 304.8	4.82 6.84 7.46	50 50 50	1.0	1120	140	0.26
Length (cm) 62.1 62.1 62.1 62.1 62.1 62.1 62.1 62.1 62.1 62.1 62.1 62.1 62.1	Width (cm)           4D.8	Tank inner dimensions           Height (cm)           25 4           25 5 4           25 5 4           25 5 4           25 5 4	Vol Tank (cm <sup>3</sup> ) 64355.5 64355.5 64355.5 64355.5 64355.5 64355.5 64355.5 64355.5 64355.5 64355.5 64355.5	Vol Tank (gal) 17.0 17.0 17.0 17.0 17.0 17.0 17.0 17.0 17.0 17.0 17.0 17.0 17.0 17.0								
62.1	40.8	25.4 Tank outer dimensions	64355.5	17.0			Processing quanties					
Polymer HDPE 10% Nylon 6 20% Nylon 6 30% Nylon 6 20% Nylon 12 30% Nylon 12 30% Nylon 12 30% Nylon 5,6 30% Nylon 6,6 Nylon 66 Nylon 66	Length (cm) 62 56247646 68 29026395 64 02905892 63 92260883 62 73093075 64 15052493 64 15052493 64 3000399 64 3000399 64 30290582 63 3000399 64 02990582 63 06495291 63 06495291 64 06495291 64 06495291 65 06495291 60 06495	Width (cm) 41 (26247646 46 (99026396 42 (72990582) 42 (52960882) 41 (43093075 42 (85052493) 42 (85052493) 42 (72990682) 44 (72990682) 41 (764952691) 41 (764952691)	Height (cm) 26.86247646 31.59026396 27.32290582 27.22288883 26.0393075 27.45052493 27.45052493 28.6903999 28.690399 29.5905 20.5905 20.590	Vol Pol/Lank (cm*) 2513.4 37017.0 10418.9 9814.3 3298.9 11102.8 10418.9 16303.9 10418.9 10418.9 5087.3 7079.9	Vol Pol/hr (cm*/hr) 2409969 3 5709569 3 5709569 3 5709569 3 570956 3 570957 3 570957 3 570957 3 570957 5 570957 5 57095757 5 57095757 5 57095757 5 57095757 5 5700575757575	Vol Pol/hr (m?hr) 0.16 2.41 0.68 0.64 0.21 0.72 0.68 1.19 0.68 0.33 0.47	Vol Połday (m² day) 3.9 67.8 16.3 5.2 17.3 16.3 28.6 16.3 28.6 16.3 7.9	Mass Pol/day, (kg/day) 3754, 46 55294, 11 16563, 27 14650, 10 4927, 79 16584, 85 16653, 27 27341, 48 16563, 27 27341, 48 16553, 27 7599, 16 1699, 16	Tank Weight (fbstank) 529 58 66 29 18 29 18 29 18 29 86 29 80 50 40 50 40 50 40 50 57	Cost (\$/tank) \$2.70 \$24.66 \$8.25 \$10.51 \$1.63 \$9.52 \$11.25 \$18.65 \$13.32 \$3.01 \$4.24	Cost (\$/yr) \$1,349,622,35 \$12,332,197.12 \$4,126,262.46 \$5,253,024.14 \$613,835.19 \$4,761,499.01 \$4,761,499.01 \$6,662,48,43,88 \$9,323,308,69 \$6,660,999.33 \$1,506,021,19 \$7,215,611,14 \$2,151,611,14 \$2,151,611,14 \$2,151,611,14 \$2,151,611,14 \$2,151,611,14 \$2,151,611,14 \$2,151,611,14 \$2,151,611,14 \$2,151,611,14 \$2,151,611,14 \$2,151,611,14 \$3,151,611,14 \$3,151,611,14 \$4,151,611,14 \$4,151,611,14 \$4,151,611,14 \$4,151,611,14 \$4,151,611,14 \$4,151,611,14 \$4,151,611,14 \$4,151,611,14 \$4,151,611,14 \$4,151,611,14 \$4,151,611,14 \$4,151,611,14 \$4,151,145,14 \$4,151,145,145,145,145,145,145,145,145,14	
States Tank (m <sup>3</sup> )	Starage Tenk Cert (f)	Equipment Cost	20.70701002	Number Stewart	47 3001.0	0.47	Commune Cont (f)	10072.73	Cuttor Cost (\$)		\$2,107,011.14	Entruder Cost (8)
Storage         Tank (m)           5.89         86.76           24.42         23.00           7.73         26.02           24.42         24.42           42.90         24.42           11.92         17.06	Storage         Tank Cost (s)           \$14         \$41           \$37         \$92           \$26         \$16           \$16         \$72           \$26         \$21           \$27         \$22           \$26         \$27           \$26         \$27           \$26         \$27           \$27         \$27           \$23         \$56           \$23         \$564	Auger (best) 344.16 5068.83 1428.63 1343.84 461.71 1520.83 1428.63 2506.30 1428.63 696.69 996.67	Auger Cost (s) \$172 \$2,634 \$713 \$672 \$226 \$760 \$7763 \$7783 \$1,253 \$7,13 \$348 \$498	4.00	stamp Cost (s) \$600,000	8.00	\$28,800	4.00	\$12,000	4.00	bie Cost (s) \$1,100,000	\$240,000
Polymer HDPE 10% Nylon 6 20% Nylon 6 30% Nylon 6 20% Nylon 12 30% Nylon 12 30% Nylon 5,6 30% Nylon 6,6 30% Nylon 6,6 Nylon 66 Nylon 66	101. Equip. Cost (3) \$1,959,886 \$1,959,886 \$1,947,201 \$1,946,647 \$1,936,858 \$1,947,792 \$1,947,201 \$1,952,570 \$1,947,201 \$1,940,692 \$1,940,692											
Nylon 12	\$1,943,912	Utilities	Su source (MANIb (cu)	Cuttor (IAMb (m)	Extender (k)A/h (m)	Dies (b)Mb (us)	Total Engravit (MMb (m)					
2,150,400	393,216	30,720	92,160	153,600	1,843,200	1,666,667	6,329,963					
Material EVALCA EVOH KYNAR® 1000 HD	Zero emissions (0.3g/day) ZE Thickness (mm) 0.3 0.5	Inside Coating Volume (cm <sup>2</sup> /tank) 305.5 509.1 Adhesive Layer	Weight (lbs/tank) 0.80 1.98	Cost (\$/lb) \$2.65 \$10.50	Cost (\$/tank) \$2.12 \$20.84	Cost (\$/yr) \$1,060,962 \$10,421,211	Density (g/cm²) 1.19 1.77	Weight Coating (lbs/yr) 400,362.9 992,496.3	Vol Coating (ft²/yr) 5,394.1 8,990.1	Vol Coating (m²/yr) 152.7 254.6		
Material Adhesive LLDPE	ZE Thickness (mm) 0.1	Volume (cm²/tank) 101.8	Weight (lbs/tank) 0.27	Cost (\$/lb) \$0.46	Cost (\$/tank) \$0.12	Cost (\$/yr) \$61,389	Density (g/cm²) 1.19	Weight Coating (lbs/yr) 133,454.3	Vol Coating (ftº/yr) 1,798.0	Vol Coating (m²/yr) 50.9		
Material	Rivets/tank	Rivet Costs Rivet Cost (\$/rivet)	Rivet Cost (\$/tank)	Rivet Cost (\$/yr)								
Palemor	Z4.U Structural (©tank)	U. 1174 Total Material Cost Structural (\$/wt)	0 Other Materials (\$/towb)	other Materiale (\$2.00	Total Cort (\$/tank)	Total Cost (\$/w)						
HDPE 10% Nylon 6	\$2.70 \$24.66	1,349,622 12,332,197	\$5.06	\$2,531,151	\$7.76 \$29.73	\$3,880,773 \$14,863,348						
20% Nylon 6 30% Nylon 6	\$8.25 \$10.51	4,126,262			\$13.31 \$15.57	\$6,657,413 \$7,784,175						
Nylon 6 20% Nylon 12	\$1.63 \$9.52	813,835			\$6.69 \$14.59	\$3,344,986 \$7,292,660						
30% Nylon 12 20% Nylon 6,6 30% Nylon 6,6 Nylon 6,6	\$11.25 \$18.65 \$13.32 \$3.01	5,624,844 9,323,309 6,660,999 1,506,021			\$16.31 \$23.71 \$18.38 \$8.07	\$8,155,995 \$11,854,459 \$9,192,150 \$4,037,172						
Nylon 12	\$4.34	2,167,611	l	1	\$9.40	\$4,698,762		L	I	I	I	

#### Process Spreadsheet Cont.

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

#### **Financial Evaluation**

																Row
	Year ending at time	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	Sum
1. Land, 1	0 <sup>6</sup> \$ (see notes)		0.00	0.00	0.00										0.00	0.00
2. Fixed C	apital Investment, 10 <sup>6</sup> \$		-0.47	-1.13	-1.64											-3.24
3. Working	Capital, 10 <sup>6</sup> \$ (see notes)				-0.47										0.47	0.00
4. Salvage	Value, 10 <sup>6</sup> \$														0.00	0.00
5. Total Ca	pital Investment, 10 <sup>6</sup> \$		-0.47	-1.13	-2.11											-3.71
6. Annual I	nvestment, 10 <sup>6</sup> \$					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 <sup>6</sup> \$					-0.32										
8. Operatin	ig 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 s	sales, 10 <sup>6</sup> \$					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,					-12/12	-14 99	-16 72	-18.02	-18 38	-18 74	-19 12	-19 50	-19.89	-20.29	-178.07
depreciatio	n <u>not</u> included,10 <sup>6</sup> \$					-12.42	-14.55	-10.72	-10.02	-10.00	-10.74	-10.12	-10.00	-10.00	-20.25	-170.07
11. Annual	depreciation factor, 1/y					0.20	0.320	0.192	0.115	0.115	0.058					
12. Annual	depreciation, 10°\$/y					0.65	1.04	0.62	0.37	0.37	0.19					3.24
13. Annual	Gross Profit, 10°\$					-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°\$					-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 <sup>6</sup> \$					-2.25	0.76	1.64	2.07	1.84	1.53	1.22	0.97	0.72	0.46	8.96
16. Total a	nnual cash flow, 10 <sup>6</sup> \$	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. Cumula	ative cash position, 10 <sup>6</sup> \$	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	
Profitabili	ty measures, time value	of mon	ey <u>NOT</u>	include	d:											
18. Return	on investment, ave. %/y	15.5														
19. Paybac	ck period, y	3.6														
20. Net ret	urn, 10 <sup>6</sup> \$	0.44	at m <sub>ar</sub> =	3.7	%/y											
Profitability measures including time value of money, with ANNUAL END-OF-YEAR cash flows and discounting																
Profitabili	ty measures including ti	me valı	ie of mo	ney, wi	th ANNU	JAL END	OF-YEA	R cash :	flows ar	id disco	unting					
Profitabili 21. Presen	<b>ty measures including ti</b> t worth factor	me valu 1.11	1.08	ney, wi 1.04	th ANNU 1.00	0.96	OF-YEA 0.93	R cash : 0.90	flows ar 0.87	0.83	unting 0.80	0.78	0.75	0.72	0.70	
Profitabili 21. Presen 22. Presen	<b>ty measures including ti</b> t worth factor t worth of annual cash	<u>me valu</u> 1.11 0.00	1.08	ney, wi 1.04 -1.17	th ANNU 1.00 -2.11	0.96	0F-YEA 0.93 0.70	R cash 1 0.90	flows ar 0.87 1 79	0.83	unting 0.80 1.23	0.78	0.75	0.72	0.70	3 30
Profitabili 21. Presen 22. Presen flows, 10 <sup>6</sup> \$	ty measures including ti t worth factor t worth of annual cash	me valu 1.11 0.00	<u>ie of mo</u> 1.08 -0.51	ney, wi 1.04 -1.17	th ANNU 1.00 -2.11	JAL END 0.96 -2.17	0F-YEA 0.93 0.70	<u>R cash 1</u> 0.90 1.47	flows ar 0.87 1.79	0.83 1.53	unting 0.80 1.23	0.78 0.95	0.75 0.73	0.72 0.52	0.70 0.32	3.30
Profitabili 21. Presen 22. Presen flows, 10 <sup>6</sup> \$ 23. Net pre	<b>ty measures including ti</b> t worth factor t worth of annual cash esent worth, 10 <sup>6</sup> \$ =	<u>me valı</u> 1.11 0.00 <b>3.30</b>	1.08 1.08 -0.51 at disco	ney, wi 1.04 -1.17 unt rate=	th ANNU 1.00 -2.11 3.7	JAL END 0.96 -2.17 %/y	OF-YEA 0.93 0.70	<u>R cash 1</u> 0.90 1.47	flows ar 0.87 1.79	0.83 1.53	unting 0.80 1.23	0.78 0.95	0.75 0.73	0.72 0.52	0.70 0.32	3.30
Profitabili 21. Presen 22. Presen flows, 10 <sup>6</sup> \$ 23. Net pre	ty measures including to t worth factor t worth of annual cash esent worth, 10°\$ = nted cash flow rate of	<u>me valı</u> 1.11 0.00 <b>3.30</b>	-0.51 at disco	1.04 -1.17 unt rate=	th ANNU 1.00 -2.11 3.7	JAL END 0.96 -2.17 %/y	OF-YEA 0.93 0.70	<u>R cash 1</u> 0.90 1.47	flows ar 0.87 1.79 Set targe	0.83 1.53	0.80 1.23	0.78 0.95	0.75 0.73	0.72 0.52	0.70 0.32	3.30
Profitabili 21. Presen 22. Presen flows, 10 <sup>6</sup> \$ 23. Net pre 24. Discou return, DCF	ty measures including ti t worth factor t worth of annual cash esent worth, 10 <sup>6</sup> \$ = nted cash flow rate of FR %/v =	me valu 1.11 0.00 3.30 15.2	-0.51 at disco To get D	-1.04 -1.17 unt rate= CFR, go ging cell	th ANNU 1.00 -2.11 3.7 to "Too \$C\$39	JAL END 0.96 -2.17 %/y Is" and fu	OF-YEA 0.93 0.70 nction "S	R cash 1 0.90 1.47 Solver."	flows ar 0.87 1.79 Set targe	0.83 0.83 1.53 et cell as	0.80 1.23 \$R\$41, sheet	0.78 0.95 to be ma	0.75 0.73 ide = 0	0.72 0.52	0.70 0.32	3.30
Profitabili 21. Presen 22. Presen flows, 10 <sup>6</sup> \$ 23. Net pre 24. Discou return, DCF	ty measures including ti t worth factor t worth of annual cash esent worth, 10 <sup>6</sup> \$ = nted cash flow rate of =R, %/y = count rate= 0.152	me valu 1.11 0.00 3.30 15.2	ie of mo 1.08 -0.51 at disco To get D by chan	ney, wi 1.04 -1.17 unt rate= OCFR, go ging cell	th ANNU 1.00 -2.11 3.7 to "Too \$C\$39.	JAL END 0.96 -2.17 %/y s" and fu Solver m	OF-YEA 0.93 0.70 nction "S ust be re	R cash 1 0.90 1.47 Solver." erun afte	flows ar 0.87 1.79 Set targe r a chang	od disco 0.83 1.53 et cell as ge on any	0.80 1.23 \$R\$41, / sheet.	0.78 0.95 to be ma	0.75 0.73 de = 0	0.72	0.70	3.30
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Profitabili 21. Presen flows, 10 <sup>6</sup> \$ 23. Net pre 24. Discoureturn, DCP Iterated dis 25. Presen flows, 10 <sup>6</sup> \$ <b>Profitabili</b> 27. Presen flows, 10 <sup>6</sup> \$ 29. Net pre 30. Discoureturn, DCP	ty measures including ti t worth factor t worth of annual cash esent worth, 10°\$ = nted cash flow rate of FR, %/y = count rates 0.152 t worth factor t worth of annual cash ty measures including ti t worth of annual cash esent worth, 10°\$ = nted cash flow rate of FR, %/y =	me valu 1.11 0.00 3.30 15.2 1.53 0.00 me valu 1.14 0.00 3.36 14,1	e of mo 1.08 -0.51 at disco To get D by chan 1.33 -0.63 e of mo 1.09 -0.52 at disco To get D by chan	ney, wi 1.04 -1.17 unt rate= 0CFR, gc ging cell 1.15 -1.30 ney, wi 1.06 -1.19 unt rate= 0CFR, gc ging cell	th ANNU 1.00 -2.11 3.7 to "Too \$C\$39. 1.00 -2.11 th CON 1.02 -2.15 3.6 to "Too \$C\$49.	AL END 0.96 -2.17 %/y s" and fu Solver m 0.87 -1.95 TINUOUS 0.98 -2.21 %/y s" and fu Solver m	OF-YEA 0.93 0.70 nction "S ust be re 0.75 0.57 cash flu 0.95 0.72 nction "S ust be re	R cash 1 0.90 1.47 Solver." erun afte 0.65 1.07 0.91 1.50 Solver." erun afte	flows ar 0.87 1.79 Set targe r a chang 0.57 1.18 I discou 0.88 1.82 Set targe r a chang	et cell as a constant at cell as	unting 0.80 1.23 \$R\$41, / sheet. 0.43 0.66 0.82 1.25 \$R\$51, / sheet.	0.78 0.95 to be ma 0.37 0.45 0.79 0.97	0.75 0.73 de = 0 0.32 0.31 0.76 0.74	0.72 0.52 0.28 0.20 0.20	0.70 0.32 0.24 0.11 0.71 0.33	3.30
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### 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**

EVOH

Coating



Tank halves produced separatelyFlanges 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**



#### 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 R/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

