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

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® (polyvinylidene fluoride)
  - 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

Directly related to thickness
Linear relationship

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

\[ U = \text{Total impact energy (J)} \]
\[ U_{\text{des}} = \text{Desired total impact energy} \]
\[ C_{H_i} = \text{Charpy impact strength of material } i \text{ (J/cm}^2\text{)} \]
\[ B_s = \text{thickness of steel tank} \]
\[ D = \text{width of test sample} \]
\[ B = \text{thickness of material needed to make its strength equal to } T_{E_{\text{des}}} \]

\[ U = C_{H_s} B_s D \]
\[ B = \frac{U_{\text{des}}}{C_{H_i} D} \]
## Thickness and Strength

<table>
<thead>
<tr>
<th>Material</th>
<th>Charpy Impact Energy (J/cm²)</th>
<th>Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1020 Steel</td>
<td>16.9</td>
<td>0.912</td>
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<tr>
<td>HDPE</td>
<td>6.8</td>
<td>2.41</td>
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<tr>
<td>Nylon 6</td>
<td>5.2</td>
<td>3.15</td>
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<tr>
<td>Nylon 6 10% glass</td>
<td>0.5</td>
<td>30.95</td>
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<tr>
<td>Nylon 6 20% glass</td>
<td>1.7</td>
<td>9.65</td>
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<tr>
<td>Nylon 6 30% glass</td>
<td>1.8</td>
<td>9.11</td>
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<tr>
<td>Nylon 6/6</td>
<td>3.4</td>
<td>4.82</td>
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<td>1.0</td>
<td>16.40</td>
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<tr>
<td>Nylon 6/6 30% glass</td>
<td>1.7</td>
<td>9.65</td>
</tr>
<tr>
<td>Nylon 12</td>
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<td>6.84</td>
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<tr>
<td>Nylon 12 20% glass</td>
<td>1.6</td>
<td>10.25</td>
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<tr>
<td>Nylon 12 30% glass</td>
<td>1.7</td>
<td>9.65</td>
</tr>
<tr>
<td>Curv</td>
<td>12.0</td>
<td>1.37</td>
</tr>
</tbody>
</table>
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
  
  \[ c = S \times p \]

- \( c = \text{Concentration} \)
- \( S = \text{Henry’s solubility coefficient} \)
- \( p = \text{vapor pressure of gas} \)

- Liquid diffusion negligible
  
  - Surface should be hydrophilic
  - Gasoline is hydrophobic
Fick’s Law of Diffusion

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

- \( N_a \) = Flux out
- \( D_{ab} \) = Diffusion Coefficient
- \( c_a \) = Concentration
- \( z \) = Thickness
Diffusion Resistance Cont.

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

\[
k_c = \frac{D_{ab}}{l} \times (0.332 \times \text{Re}_l^{0.5} \times \text{Sc}^{1/3})
\]
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 = $9.10 \times 10^{-4}$ ft/s
- Overall mass balance yields concentration of $1.25 \times 10^{-10}$ 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**
  \[ C = S \times p \quad P = D_{ab} \times S \]

- **Final Diffusion Model**
  \[ N_{az} = \frac{P \times A \times (p_2 - p_1)}{x} \]
Second Stage Results

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

<table>
<thead>
<tr>
<th>Material</th>
<th>Diffusion Thickness (mm)</th>
<th>Charpy Impact Required (mm)</th>
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</thead>
<tbody>
<tr>
<td>Nylon 6</td>
<td>0.566</td>
<td>3.15</td>
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<tr>
<td>HDPE</td>
<td>7825</td>
<td>2.41</td>
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<td>Curv</td>
<td>8607</td>
<td>1.37</td>
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<tr>
<td>Kynar</td>
<td>0.132</td>
<td>7.46</td>
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<tr>
<td>EVOH</td>
<td>0.033</td>
<td>41.31</td>
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</table>
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 26 gauge mild steel - 48 in for a sample width of 32 inches (6.48 c.u.) |

<table>
<thead>
<tr>
<th>Tanks/yr</th>
<th>Hit/week</th>
<th>Day</th>
<th>Work day/yr</th>
<th>Tanks/ks</th>
<th>Purpose</th>
<th>Impact (ft-lb)</th>
<th>Composition (mm)</th>
<th>Thickness (in)</th>
<th>Total Impact Energy (c.u.)</th>
<th>Heat Capacity (KBTU/hr)</th>
<th>Densify (K BTU/ft³)</th>
<th>Process Temp (%)</th>
<th>Cost ($)</th>
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<tr>
<td>10000</td>
<td>24</td>
<td>360</td>
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### Tank Size Dimensions

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<td>36</td>
<td>340.8</td>
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### Processing Grades

<table>
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<tr>
<th>Grades</th>
<th>Length (in)</th>
<th>Width (in)</th>
<th>Height (in)</th>
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### Equipment Cost

<table>
<thead>
<tr>
<th>Storage Tank (cc)</th>
<th>Storage Tank Cost (i)</th>
<th>Impact (K BTU)</th>
<th>Impact Cost (i)</th>
<th>Number Stamps</th>
<th>Stamp Cost (i)</th>
<th>Corrosive</th>
<th>Corrosive Cost (i)</th>
<th>Cathode</th>
<th>Cathode Cost (i)</th>
<th>Extra Cost (i)</th>
<th>Total Cost (i)</th>
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<tr>
<td>340.8</td>
<td>$12,840</td>
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<td>$500,000</td>
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<td>4.00</td>
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### Total Equipment Cost

<table>
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<tr>
<th>Total Equipment Cost (i)</th>
<th>$15,681.67</th>
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### Utilities

<table>
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<tr>
<th>Stamp (Watt-hr)</th>
<th>Batters (Watt-hr)</th>
<th>Corrosive (Watt-hr)</th>
<th>Springer (Watt-hr)</th>
<th>Cathode (Watt-hr)</th>
<th>Corrosive (Watt-hr)</th>
<th>Batters (Watt-hr)</th>
<th>Total Energy (Watt-hr)</th>
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<tr>
<td>40</td>
<td>60</td>
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<td>60</td>
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<td>60</td>
<td>40</td>
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</table>

### Insulation

<table>
<thead>
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<th>Stamp (Watt-hr)</th>
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<th>Cathode (Watt-hr)</th>
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<th>Batters (Watt-hr)</th>
<th>Total Energy (Watt-hr)</th>
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<td>60</td>
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### Total Material Cost

<table>
<thead>
<tr>
<th>Total Material Cost (i)</th>
<th>$1,400,000.00</th>
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### Polymeric Materials

<table>
<thead>
<tr>
<th>Polymeric Material</th>
<th>Stamped (in.)</th>
<th>Stamped (in.)</th>
<th>Other Materials (in.)</th>
<th>Other Materials (in.)</th>
<th>Total Cost (i)</th>
<th>Total Cost (i)</th>
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<td>400</td>
<td>$40,000</td>
<td>$40,000</td>
</tr>
</tbody>
</table>
Process Spreadsheet Cont.

- **Input**
  - Plant capacity, annual working days, daily working hours

- **Output**
  - Material costs
  - Equipment costs
  - Utility costs
  - Tank specifications
# Financial Evaluation

## Financial Evaluation

<table>
<thead>
<tr>
<th>Year ending at time</th>
<th>-3</th>
<th>-2</th>
<th>-1</th>
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<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>Flow Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Land, 10% (see notes)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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</tr>
<tr>
<td>2. Fixed Capital Investment, 10%</td>
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<td>-0.47</td>
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<td>0.00</td>
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<td></td>
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<tr>
<td>3. Working Capital, 10% (see notes)</td>
<td>0.43</td>
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<td>-1.64</td>
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<td>-3.24</td>
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<tr>
<td>4. Salvage Value, 10%</td>
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<td>-3.71</td>
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<td>5. Total Capital Investment, 10%</td>
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</tr>
<tr>
<td>6. Annual Investment, 10%</td>
<td>0.43</td>
<td>-11.18</td>
<td>-1.64</td>
<td>-0.47</td>
<td>-0.47</td>
<td>0.00</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>-3.71</td>
<td></td>
</tr>
<tr>
<td>7. Operating cost, 10%</td>
<td>0.43</td>
<td>-11.18</td>
<td>-1.64</td>
<td>-0.47</td>
<td>-0.47</td>
<td>0.00</td>
<td>0.00</td>
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<td>0.00</td>
<td>0.00</td>
<td>-3.71</td>
<td></td>
</tr>
<tr>
<td>8. Sales, 10%</td>
<td>0.43</td>
<td>-11.18</td>
<td>-1.64</td>
<td>-0.47</td>
<td>-0.47</td>
<td>0.00</td>
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<td>0.00</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>-3.71</td>
<td></td>
</tr>
<tr>
<td>9. Annual Total Product Cost, 10%</td>
<td>0.43</td>
<td>-11.18</td>
<td>-1.64</td>
<td>-0.47</td>
<td>-0.47</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>-3.71</td>
<td></td>
</tr>
<tr>
<td>10. Cumulative net cash flow, 10%</td>
<td>0.43</td>
<td>-11.18</td>
<td>-1.64</td>
<td>-0.47</td>
<td>-0.47</td>
<td>0.00</td>
<td>0.00</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>-3.71</td>
<td></td>
</tr>
</tbody>
</table>

### Profitability measures, time value of money not included:

| 18. Return on investment, 10% | 10.52 |
| 19. Payback period, y | 3.5 |
| 20. Net return, 10% | 0.41 at i = 3.7% |

### Profitability measures, time value of money included, with ANNUAL END-OF-YEAR cash flows and discounting

| 21. Present worth factor | 1.11 | 1.68 | 1.94 | 1.00 | 0.95 | 0.93 | 0.90 | 0.87 | 0.83 | 0.80 | 0.75 | 0.75 | 0.72 | 0.70 |
| 22. Present worth of annual cash flows, 10% | 0.00 | -0.51 | -1.17 | -2.11 | -2.17 | -2.70 | 1.47 | 1.79 | 1.63 | 1.23 | 0.95 | 0.73 | 0.62 | 0.32 |
| 23. Net present, 10% | 3.36 at discount rate | 3.7% |

### Discounted cash flow rate of return, DCFR, %

| 24. Discounted cash flow rate of return, DCFR, % | 15.2 |
| 25. Present worth factor | 1.53 | 1.33 | 1.16 | 1.00 | 0.87 | 0.76 | 0.66 | 0.57 | 0.49 | 0.43 | 0.37 | 0.32 | 0.28 | 0.24 |
| 26. Present worth of annual cash flows, 10% | 0.00 | -0.63 | -1.30 | -2.11 | -1.96 | 0.57 | 1.07 | 1.18 | 0.91 | 0.86 | 0.45 | 0.31 | 0.20 | 0.11 |

### Profitability measures, time value of money, with CONTINUOUS cash flows and discounting

| 27. Present worth factor | 1.14 | 1.08 | 1.06 | 1.02 | 0.98 | 0.96 | 0.91 | 0.88 | 0.85 | 0.82 | 0.79 | 0.76 | 0.73 | 0.71 |
| 28. Present worth of annual cash flows, 10% | 0.00 | -0.52 | -1.19 | -2.15 | -2.21 | 0.72 | 1.50 | 1.82 | 1.55 | 1.26 | 0.97 | 0.74 | 0.63 | 0.33 |
| 29. Net present, 10% | 3.36 at discount rate | 3.6% |

### Discounted cash flow rate of return, DCFR, %

| 30. Discounted cash flow rate of return, DCFR, % | 14.1 |
| 31. Present worth factor | 1.64 | 1.43 | 1.24 | 1.07 | 0.83 | 0.61 | 0.70 | 0.61 | 0.53 | 0.46 | 0.40 | 0.35 | 0.30 | 0.26 |
| 32. Present worth of annual cash flows, 10% | 0.00 | -0.67 | -1.30 | -2.26 | -2.09 | 0.61 | 1.15 | 1.25 | 0.97 | 0.70 | 0.43 | 0.34 | 0.22 | 0.12 | -0.58 |
Third Stage Summary

<table>
<thead>
<tr>
<th>Process</th>
<th>TCI ($million)</th>
<th>ROI (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blow Molding HDPE</td>
<td>10.0</td>
<td>5.2</td>
</tr>
<tr>
<td>Injection Molding HDPE</td>
<td>43.5</td>
<td>-15.3</td>
</tr>
<tr>
<td>Rotomolding HDPE</td>
<td>11.1</td>
<td>-16.5</td>
</tr>
<tr>
<td>Stamping Curv</td>
<td>3.6</td>
<td>15.5</td>
</tr>
<tr>
<td>Stamping HDPE</td>
<td>9.0</td>
<td>-9.0</td>
</tr>
</tbody>
</table>

- 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

Investigate Interest
- Impala
  - High: P=0.2
  - Medium: P=0.6
  - Low: P=0.2
- Malibu
  - High: P=0.35
  - Medium: P=0.50
  - Low: P=0.15
- Altima
  - High: P=0.2
  - Medium: P=0.55
  - Low: P=0.25
- Maxima
  - High: P=0.4
  - Medium: P=0.5
  - Low: P=0.1
- Civic
  - High: P=0.2
  - Medium: P=0.5
  - Low: P=0.3
- Accord
  - High: P=0.1
  - Medium: P=0.4
  - Low: P=0.5

Pursue Contracts
- Impala
  - Probability based on interest
- Malibu
  - Probability based on interest
- Altima
  - Probability based on interest
- Maxima
  - Probability based on interest
- Civic
  - Probability based on interest
- Accord
  - Probability based on interest

Investigate Interest ($20,000)
- BT
- MT
- AT
- Day

Pursue Contracts ($40,000)
- BT
- MT
- AT
- 16
- 20
- 35
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

NPV (Millions of Dollars)

Risk

ENPV(0.64) = 3.92

VaR = 1.77
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?