The Materials Which Make Up an Automobile

Understanding the Upstream Processes and Burdens Associated with Materials and Parts Production

TPP 123

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Group Assignment

- The task for each group will be:
  - Propose a vehicle design which suits the goals of your interest group
    
    Note: Design changes will be limited to changing the material from which the body-in-white is made
  
  - Propose a policy which will promote the development and adoption of your proposed vehicle

- Tools for detailed analysis
  - Cost models
  - Environmental Inventory
  - Inventory evaluation tools
Why Do We Care About Material?

- Choice of material impacts the
  - Manufacturing process
  - Product performance
  - Cost
  - Environmental impact?

- Three materials are the prime candidates for use in automotive bodies
  - Actually three groups of materials
    - Steel
      - *The current dominant material*
    - Aluminum
    - Polymer composites
      - *Ester Resin with Glass Fiber Reinforcement*

Materials Matter -- Energy Use Primary / Secondary

- The choice of material and its source can have a big impact on the environmental impact of the product

<table>
<thead>
<tr>
<th>Material</th>
<th>Energy for Primary Prod (MJ/kg)</th>
<th>Energy for Secondary Prod (MJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>189</td>
<td>27</td>
</tr>
<tr>
<td>Cu</td>
<td>100</td>
<td>45</td>
</tr>
<tr>
<td>Steel</td>
<td>40</td>
<td>18</td>
</tr>
<tr>
<td>Mg</td>
<td>285</td>
<td>27</td>
</tr>
<tr>
<td>Lead</td>
<td>41</td>
<td>8</td>
</tr>
<tr>
<td>Polyester</td>
<td>96</td>
<td>50</td>
</tr>
<tr>
<td>PP</td>
<td>74</td>
<td>42</td>
</tr>
</tbody>
</table>
What is in an automobile?

- Steel 59%
- Iron 13%
- Glass 3%
- Rubber 4%
- Other 3%
- Plastics 8%
- Aluminum 7%
- Other Nonferrous 3%

Why Care About Automobile Recycling

- Autos are significant consumers of resources
  - Aluminum 19%
  - Lead 70%
  - Platinum 41%
  - Rubber >60%
  - Iron 35%
  - Steel 14%
What is Steel?

Steel is Iron with a small amount of Carbon (~<1%)

Iron makes up 5% of earth's crust
- Steel first used ~1400 BC by Chalybes, SE of Black Sea

Two major steps:
- Make Iron
  - Blast Furnace
- Make Steel
  - Basic Oxygen Furnace (BOF)
Making Steel Step One - Blast Furnace

- **Raw Materials**
  - Iron Ore
    - Usually iron oxides
  - Coke
  - Limestone
    (and/or other fluxes)

- **What is happening?**
  - Carbon in coke serves as reducing agent
  - \( \text{Fe}_2\text{O}_3 + 3\text{CO} \rightarrow 2\text{Fe} + 3\text{CO}_2 \)

### Inputs (kg)
- Ore 1600
- Coke 450
- Limestone 190

### Outputs (kg)
- Top Gas 2300
- Blast Furnace
- Iron 1000
- Slag 300

Making Steel Step Two - Basic Oxygen Furnace

- **Must reduce the amount of carbon in the iron**

- **Raw Materials**
  - Pig Iron
    - From blast furnace
  - Scrap
  - Limestone
    and other fluxes

- **Dissolved carbon is oxidized**

- **Releases about .25g particulates/ kg steel**

### Inputs (kg)
- Iron 865
- Scrap 170
- Limestone 80

### Outputs (kg)
- Top Gas ~150 (CO₂)
- Steel 1000
- BOF
How Do We Make Aluminum?

- Aluminum makes up 8% of the earth’s crust
  - Al production process discovered in 1886
- Bauxite is the primary ore
  - 40-60% Alumina
- Two major steps:
  - Extract Alumina from Bauxite
    - Bayer Process
  - Electrolytically reduce Aluminum from Alumina
    - Hall-Heroult Process

Making Aluminum Step One - Bayer Process

- Because bauxite contains many minerals, the alumina must be extracted.
- Alumina is preferentially dissolved in NaOH
- Al(OH)$_3$ is precipitated out
- Al(OH)$_3$ is calcined to Al$_2$O$_3$
- Remaining caustic sludge is referred to as red mud
  - Iron oxides give reddish color

To Produce 1000kg of Al

<table>
<thead>
<tr>
<th></th>
<th>Bauxite</th>
<th>NaOH</th>
<th>Limestone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4-5000 kg</td>
<td>400 kg</td>
<td>90 kg</td>
</tr>
</tbody>
</table>

Bayer Process

Alumina

Al$_2$O$_3$ 1900kg

Process Releases

<table>
<thead>
<tr>
<th></th>
<th>per Kg Al$_2$O$_3$</th>
<th>per Kg Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particulates</td>
<td>100g</td>
<td>200g</td>
</tr>
<tr>
<td>Red Mud</td>
<td>1.75kg</td>
<td>3.5kg</td>
</tr>
</tbody>
</table>
Making Aluminum Step Two - Hall-Heroult Process

- Aluminum in alumina is electrolytically reduced
  - Anodes are made of carbon
  - Electrolyte, called cryolite, is mixture of $\text{AlF}_3$ & $\text{Na}_3\text{AlF}_6$

To Produce 1000kg of Al

<table>
<thead>
<tr>
<th></th>
<th>Alumina</th>
<th>C Anodes</th>
<th>Cryolite</th>
</tr>
</thead>
<tbody>
<tr>
<td>1900kg</td>
<td>450kg</td>
<td>20kg</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>per Kg Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2</td>
<td>1.6kg</td>
</tr>
<tr>
<td>Particulates</td>
<td>1.4g</td>
</tr>
<tr>
<td>SO2</td>
<td>8g</td>
</tr>
<tr>
<td>NOx</td>
<td>3g</td>
</tr>
<tr>
<td>HF</td>
<td>.25g</td>
</tr>
<tr>
<td>Fluorocarbons</td>
<td>some</td>
</tr>
<tr>
<td>Electricity</td>
<td>60MJ</td>
</tr>
</tbody>
</table>

Process Releases

<table>
<thead>
<tr>
<th></th>
<th>Kg Released per Kg Produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2</td>
<td>12</td>
</tr>
<tr>
<td>SO2</td>
<td>10</td>
</tr>
<tr>
<td>NOx</td>
<td>8</td>
</tr>
<tr>
<td>NM VOC</td>
<td>6</td>
</tr>
<tr>
<td>Dust</td>
<td>4</td>
</tr>
</tbody>
</table>

How Do These Two Compare?

- Emissions per kg of product
  - Kilograms released for each kilogram produced

Emissions from Production
What If We Look at an Entire Product?

- Emissions from two different BIW designs
  - Aluminum is still mostly worse

![Graph showing Emissions from Production](image1)

Why Look at Aluminum?

- Trade offs in other parts of vehicle life cycle
  - Major reduction of BIW weight
    - Steel - 250 kg
    - Aluminum - 141 kg
  - Reduces vehicle fuel use and emissions

![Graph showing Total Emissions](image2)
Polymer Usage in the Car

- Polymer usage has been growing in the car for 40 years

![Graph showing polymer usage in the car over time.](image)

How are polymers used?

<table>
<thead>
<tr>
<th>Part</th>
<th>Main Plastics Types</th>
<th>Weight in Avg Car (Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bumpers</td>
<td>PP, ABS, PC</td>
<td>10</td>
</tr>
<tr>
<td>Seats</td>
<td>PUR, PP, PVC,</td>
<td>13</td>
</tr>
<tr>
<td>Dashboard</td>
<td>PP, ABS, PA, PC, PE</td>
<td>15</td>
</tr>
<tr>
<td>Fuel systems</td>
<td>PE, POM, PA, PP</td>
<td>7</td>
</tr>
<tr>
<td>Body (including panels)</td>
<td>PP, PPE, UP</td>
<td>6</td>
</tr>
<tr>
<td>Under the hood components</td>
<td>PA, PP, PBT</td>
<td>9</td>
</tr>
<tr>
<td>Interior Trim</td>
<td>PP, ABS, PET, POM, PVC</td>
<td>20</td>
</tr>
<tr>
<td>Electrical components</td>
<td>PP, PE, PBT, PA, PVC</td>
<td>7</td>
</tr>
<tr>
<td>Exterior Trim</td>
<td>ABS, PC, PBT, ASA, PP</td>
<td>4</td>
</tr>
<tr>
<td>Lighting</td>
<td>PP, PC, ABS, PMMA, UP</td>
<td>5</td>
</tr>
<tr>
<td>Upholstery</td>
<td>PVC, PUR, PP, PE</td>
<td>8</td>
</tr>
<tr>
<td>Other reservoirs</td>
<td>PP, PE, PA</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>105</td>
</tr>
</tbody>
</table>
Polymer Processing

- Due to variety it is difficult to settle on one process
- Key steps:
  - Extraction
  - Distillation
  - Cracking
    - Yield of 85 - 95% -- product out / feedstock in
  - Polymerization
    - Yield of 99%
  - Forming

Automobile Production / Manufacturing

- Automobiles are Mass-Production Products
- What Does This Mean?
  - Annual Production Volumes On The Order Of 100,000
  - Production Rated On The Order Of 60-75 units/hour
  - Have To Be Affordable To A Large Market
- Contrast With Airplanes
  - Annual Production Volumes Less Than 1000
  - Production Rates On The Order Of 1/day
  - Specialized Markets
- These Differences Lead To Different Processing Requirements
What is Next?

- At this point, for both steel and aluminum, we are left with a large block of material called a billet.
- Before final processing, billets are flattened using rollers until they become sheets.
- Compared to the previous steps, the energy used and environmental releases are small.

Final Processing

- Current steel body parts are almost entirely made using one forming process - stamping.
- Metal sheets are pressed between two interlocking dies.
Metal Stamping

- Stamping is useful for both steel and aluminum
- Aluminum tends to require
  - Slower line rates
  - More aggressive lubrication
  - More rejects
- Why is stamping useful?
  - Fast cycle times
  - Approx. Seconds

Polymer Forming

*In comparing material alternatives, we will look at polymer alternatives*

- For cost modeling, we will look at one processing method - Sheet Molding using Sheet Molding Compound (SMC)
- SMC is made up of thermoset resin and glass fiber reinforcement
- SMC is pressed between two interlocking molds
Polymers Sheet Molding

- **Advantages of SMC**
  - Low equipment and tooling costs
  - Increased design flexibility
- **Disadvantages**
  - Long cycle times
    - *Polymer must be reacted to make part solid*
    - *Reaction is initiated using heat*
    - *To ensure dimensional control - reaction occurs in mold*
    - *Molding equipment tied up during reaction*
  - Requires different joining techniques