ESD.123. Industrial Ecology of the Automobile

Session 3:
Pertinent Manufacturing Processes
or From Dirt to Vehicles

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
What is in an Automobile?

- Plastics 8%  
  - 7.7%
- Aluminum 7%  
  - 6.6%
- Other Nonferrous 3%  
  - 2.4%
- Lead 1%  
  - 0.5%
- Zinc 1%  
  - 0.4%
- Steel 59%  
  - 57.0%
- Iron 13%  
  - 12.0%
- Glass 3%  
  - 3.1%
- Rubber 4%  
  - 4.4%
- Fluids 6%  
  - 2.6%
- Other 3%  
  - 3.2%

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*
Production/Manufacturing Technologies

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

How Do We Make 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

Iron Ore → Coke → Limestone → Blast Furnace → Lime → Iron → Scrap → Basic Oxygen Furnace → Steel
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) | Outputs (kg)
-------------|--------------
Ore 1600     | Top Gas 2300 |
Coke 450     |              |
Limestone 190|              |
Blast Air    | Slag 300     |
Fuel 50      | Iron 1000    |

Inputs (kg) | Outputs (kg)
-------------|--------------
Ore 1600     | Top Gas ~150 (CO₂)
Coke 450     |              |
Limestone 190|              |
Blast Air    | Slag          |
Fuel 50      | Steel 1000   |

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 0.25g particulates/ kg steel
**Does This Account for ALL Important Impacts?**

- **Don't forget feedstocks**
  - Their production may generate significant impacts
  - These impacts are pertinent life cycle effects

- **Consider Coke**
  - Coal is baked down to carbon
  - Releases

<table>
<thead>
<tr>
<th></th>
<th>per Kg Coke</th>
<th>per Kg Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particulates</td>
<td>.25g</td>
<td>100g</td>
</tr>
<tr>
<td>SO₂</td>
<td>1.5g</td>
<td>600g</td>
</tr>
<tr>
<td>NOₓ</td>
<td>.13g</td>
<td>53g</td>
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<tr>
<td>Energy</td>
<td>2.3 MJ</td>
<td>920 MJ</td>
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</table>

**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 Al₂O₃
- Remaining caustic sludge is referred to as red mud
  - Iron oxides give reddish color

To Produce 1000kg of Al

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

Bayer Process

Al₂O₃
1900kg

Process Releases

<table>
<thead>
<tr>
<th>Particulates</th>
<th>per Kg Al₂O₃</th>
<th>per Kg Al</th>
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</thead>
<tbody>
<tr>
<td>100g</td>
<td>200g</td>
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</tr>
<tr>
<td>Red Mud</td>
<td>1.75kg</td>
<td>3.5kg</td>
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</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
    - AlF₃ & Na₃AlF₆

To Produce 1000kg of Al

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

Hall-Heroult Process

Aluminum
1000kg

Process Releases

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

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

What If We Look at an Entire Product?

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

![Total Emissions Chart](chart.png)

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

Polymer 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