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?

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

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

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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

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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
  - Slag 300
  - Iron 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 .25g particulates/ kg steel**

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

- **Outputs (kg)**
  - Top Gas \(\sim 150\) (\(\text{CO}_2\))
  - Slag
  - Steel 1000
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>
</tr>
<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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</tbody>
</table>

Bayer Process

Al₂O₃ 1900kg

Process Releases

<table>
<thead>
<tr>
<th>Particulates</th>
<th>per Kg Al₂O₃</th>
<th>per Kg Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>100g</td>
<td>200g</td>
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<tr>
<td>1.75kg</td>
<td>3.5kg</td>
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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>
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<tbody>
<tr>
<td>1900kg</td>
<td>450kg</td>
<td>20kg</td>
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Hall-Heroult Process

Aluminum 1000kg

Process Releases

<table>
<thead>
<tr>
<th>CO₂</th>
<th>per Kg Al</th>
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</thead>
<tbody>
<tr>
<td>1.6kg</td>
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</table>

<table>
<thead>
<tr>
<th>Particulates</th>
<th>per Kg Al</th>
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<tbody>
<tr>
<td>1.4g</td>
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</table>

<table>
<thead>
<tr>
<th>SO₂</th>
<th>per Kg Al</th>
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</thead>
<tbody>
<tr>
<td>8g</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NOₓ</th>
<th>per Kg Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>3g</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HF</th>
<th>per Kg Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>.25g</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fluorocarbons</th>
<th>per Kg Al</th>
</tr>
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<tbody>
<tr>
<td>some</td>
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</table>

<table>
<thead>
<tr>
<th>Electricity</th>
<th>per Kg Al</th>
</tr>
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<tbody>
<tr>
<td>60MJ</td>
<td></td>
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</tbody>
</table>
How Do These Two Compare?

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

![Emissions from Production Graph](image)

What If We Look at an Entire Product?

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

![Emissions from Production Graph](image)
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 Graph]

<table>
<thead>
<tr>
<th></th>
<th>Steel BIW</th>
<th>Al BIW</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2</td>
<td>10,000</td>
<td>100</td>
</tr>
<tr>
<td>SO2</td>
<td>1,000</td>
<td>10</td>
</tr>
<tr>
<td>NOx</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>NM VOC</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Dust</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

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Cambridge, Massachusetts
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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.

![Billet to Sheet Diagram]

Final Processing

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

![Stamping Press Diagram]
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