AGENDA

- Background of University of Michigan Transit
- Problem Statement
- Case Studies
  - Ann Arbor Transit Authority (AATA)
  - Washington Metropolitan Area Transit Authority (Metro)
- Emissions Analysis
- Financial Analysis
- Recommendation
Quick Facts

- Operate campus bus service 360 days a year
- Entire fleet consists of 60 buses
- 120,000 annual service hours
- Carried 5.8 million passenger trips in fiscal year 2007

Environmental Initiatives (implemented in 2003)

- Using B-20 ultra-low sulfur biodiesel fuel
- Installing particulate filters
- Recycling engine fluids
## POLLUTANTS OF DIESEL EXHAUST

- **Regulated**

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Environmental and Health Affects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particulate Matter (PM)</td>
<td>Affect respiratory health and carry toxic substances into the lungs and bloodstream</td>
</tr>
<tr>
<td>Oxides of Nitrogen (NO(_x))</td>
<td>Irritates and damages lung tissue&lt;br&gt;Combines with water to form acid rain&lt;br&gt;NO(_2) forms ground level ozone (smog)</td>
</tr>
<tr>
<td>Hydrocarbons (HC)</td>
<td>React with NO(_2) to produce ozone&lt;br&gt;Methane is a principal HC in CNG</td>
</tr>
<tr>
<td>Carbon Monoxide (CO)</td>
<td>Binds with hemoglobin in blood impairing it’s ability transport oxygen</td>
</tr>
</tbody>
</table>

- **Unregulated: CO\(_2\)**
CASE STUDY
AATA

Quick facts about AATA
- Local public transit system for the greater Ann Arbor – Ypsilanti Area
- Entire fleet of 69 busses
- 5.6 million passengers per year
- Increase in ridership on the average of 8 percent per year

Environmental Initiatives
- Service 20 hybrid electric buses by March 2008
- Long term goal of replacing entire fleet
- Using 5% ULSD biodiesel in 2006
- Grade school essay competition
- On bus advertising
CASE STUDY
AATA HYBRID ELECTRIC BUSES

BENEFITS

- With the addition of 20 hybrid buses, AATA will save 811,200 gallons of fuel ($2.5 million) over the next 12 years
- 50% better acceleration than conventional buses
- Reducing maintenance costs by 30% to 50%
- Reduction in PM, CO, and hydrocarbons of up to 90%
- Reduction of NO by 50%
CASE STUDY
Washington Metropolitan Area Transit Authority (Metro)

Quick facts about Metro

- Fifth largest bus network in the United States
- Public transit system for the District of Columbia and Maryland and Virginia suburbs
- Entire fleet of approximately 1,470 busses
- 131.5 million passengers per year
CASE STUDY
Washington Metropolitan Area Transit Authority (Metro)

Environmental Initiatives

- Currently run CNG buses, Hybrid buses, and Advanced Diesel Technology buses
- Clean Fleet project – update current buses for improved emissions without total fleet replacement
- Long term goals
  - Add additional 100 hybrid buses per year for 5 years to reduce average fleet age
  - Add additional 25 CNG buses
  - Fuel Cell Program – demonstration fuel cell buses
CASE STUDY
Washington Metropolitan Area Transit Authority (Metro)

**Metro Bus Benefits**

- With the completion of the Clean Fleet Program visible exhaust has been reduced by 90% by all buses

- Clean Natural Gas Buses provide the best emissions of all currently operated buses

- Currently the Hybrid Buses are getting to 20% - 30% fuel savings over Metro’s diesel average and better mileage between maintenance stops
## CASE STUDY

### Metro Bus vs. Bus Comparison

<table>
<thead>
<tr>
<th>Legend</th>
<th>DIESEL</th>
<th>CNG</th>
<th>HYBRID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best</td>
<td><img src="diesel.png" alt="Image" /></td>
<td><img src="cng.png" alt="Image" /></td>
<td><img src="hybrid.png" alt="Image" /></td>
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<td>Worst</td>
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<table>
<thead>
<tr>
<th>Category</th>
<th>DIESEL</th>
<th>CNG</th>
<th>HYBRID</th>
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</thead>
<tbody>
<tr>
<td>Capital Cost-Vehicle</td>
<td><img src="diesel.png" alt="Image" /></td>
<td><img src="cng.png" alt="Image" /></td>
<td><img src="hybrid.png" alt="Image" /></td>
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<tr>
<td>Capital Cost-Facilities</td>
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<td><img src="cng.png" alt="Image" /></td>
<td><img src="hybrid.png" alt="Image" /></td>
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<td>Operating Cost-Vehicle</td>
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<td><img src="cng.png" alt="Image" /></td>
<td><img src="hybrid.png" alt="Image" /></td>
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<td>Operating Cost-Facilities</td>
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<tr>
<td>Fuel Economy</td>
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<td>Reliability</td>
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<tr>
<td>Emissions</td>
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<td><img src="cng.png" alt="Image" /></td>
<td><img src="hybrid.png" alt="Image" /></td>
</tr>
</tbody>
</table>

Provided by Metro: Bus Technology Selection: FY08-11, Executive Summary
CASE STUDY FINDINGS

- Large and small bus systems are taking climate change into account when upgrading fleets
- Leads to local, national, and international exposure about the seriousness of climate change
- Larger bus systems act as a resource for smaller bus systems
- Some buses systems are already investing in the future like Metro is doing to develop fuel cell buses
EMISSION AND FUEL ECONOMY MEASUREMENT

- Emissions Test Cycles
  - Simulated driving conditions performed on a chassis dynamometer
  - Strongly dependant on bus route and operation
    - Central Business District (CBD)
    - Manhattan Cycle
    - Orange County Transit Authority (OCTA)

<table>
<thead>
<tr>
<th></th>
<th>CBD</th>
<th>Manhattan</th>
<th>OCTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNG</td>
<td>3.75</td>
<td>2.39</td>
<td>3.52</td>
</tr>
<tr>
<td>ULSD</td>
<td>4.10</td>
<td>2.82</td>
<td>4.14</td>
</tr>
<tr>
<td>Diesel Hybrid</td>
<td>5.17</td>
<td>3.86</td>
<td>4.90</td>
</tr>
<tr>
<td>B20 Biodiesel</td>
<td>4.04</td>
<td>2.78</td>
<td>4.08</td>
</tr>
</tbody>
</table>
EMISSION ANALYSIS
UM EMISSION TEST CYCLE

Commuter Northbound
- Measured values between stops
  - Distance
  - Time
- Results
  - Average Speed 19 m.p.h.
  - Max Speed 37 m.p.h.
  - Duration 720 Seconds
  - Length 3.9 miles
  - Share of idle 38%

Conclusion
- Predominately suburban
  - Similar to OCTA Cycle
  - Higher average speed than urban Manhattan Cycle (6.8 m.p.h.)
Orange County Bus Cycle (OCTA)

- Developed by West Virginia University
- Based on driving patterns of urban busses in the Los Angeles, California area
  - Average Speed 12.5 m.p.h.
  - Max Speed 40.9 m.p.h.
  - Duration 1909 seconds
  - Length 6.6 miles
  - Share of idle 21%

![Graph showing fuel economy and GHG emissions for different fuel types.](chart.png)
EMISSION ANALYSIS
UM HYBRID-ELECTRIC ADOPTION

- Over 50,000 gallons less fuel consumed annually
  - 17% decrease
  - Approximately 500 metric tons less CO₂
### Table 18: Projected annual emissions from the national transit bus fleet in 2009

<table>
<thead>
<tr>
<th>Number of Buses</th>
<th>CO tons</th>
<th>NMHC tons</th>
<th>CH₄ tons</th>
<th>NOₓ tons</th>
<th>PM tons</th>
<th>CO₂ tons</th>
<th>Fuel Consumed thousands of gallons</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Annual Emissions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel</td>
<td>50,003</td>
<td>9,577</td>
<td>1,667</td>
<td>53,981</td>
<td>843</td>
<td>6,289,918</td>
<td>573,989</td>
</tr>
<tr>
<td>CNG/LNG</td>
<td>10,064</td>
<td>1,331</td>
<td>364</td>
<td>6,902</td>
<td>7,229</td>
<td>9</td>
<td>1,003,149</td>
</tr>
<tr>
<td>Diesel Hybrid</td>
<td>1,525</td>
<td>12</td>
<td>2</td>
<td>489</td>
<td>1</td>
<td>107,814</td>
<td>9,805</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>61,592</td>
<td>10,920</td>
<td>2,032</td>
<td>6,902</td>
<td>61,699</td>
<td>853</td>
<td>7,400,881</td>
</tr>
</tbody>
</table>

### Average Emissions Levels per Bus

<table>
<thead>
<tr>
<th></th>
<th>CO g/mile</th>
<th>NMHC g/mile</th>
<th>CH₄ g/mile</th>
<th>NOₓ g/mile</th>
<th>PM g/mile</th>
<th>CO₂ g/mile</th>
<th>Fuel Economy mile/gal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>4.31</td>
<td>0.75</td>
<td>24.32</td>
<td>0.38</td>
<td>2,833</td>
<td>3.51</td>
<td></td>
</tr>
<tr>
<td>CNG/LNG</td>
<td>2.98</td>
<td>0.81</td>
<td>15.45</td>
<td>0.02</td>
<td>2,245</td>
<td>3.22</td>
<td></td>
</tr>
<tr>
<td>Diesel Hybrid</td>
<td>0.18</td>
<td>0.03</td>
<td>7.22</td>
<td>0.02</td>
<td>1,592</td>
<td>6.26</td>
<td></td>
</tr>
</tbody>
</table>


- **100% Hybrid Electric Buses**
  - 2.8 million metric tons CO₂ savings
FINANCIAL ANALYSIS
ASSUMPTIONS

- 36 year financial analysis
- 20 buses every 12 years
- Qualified for Clean Fuels Formula Grant Program
- Capital costs
  - Infrastructure
  - Cost of buses
- Operating costs
  - Compression electricity
  - Maintenance
  - Battery replacement – 3 to 5 years
  - Fuel
- Discount rate ~ 5% above inflation
FINANCIAL ANALYSIS

FUEL COSTS

- Used Federal Transit Authority estimates for fuel costs
- Used Orange County Bus Cycle mile per gallon estimates
- Used University of Michigan Transit data for miles per year

<table>
<thead>
<tr>
<th>Michigan Buses</th>
<th>CNG</th>
<th>ULSD</th>
<th>B-20</th>
<th>Diesel Hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miles per gallon</td>
<td>3.52</td>
<td>4.14</td>
<td>4.08</td>
<td>4.90</td>
</tr>
<tr>
<td>Miles per year</td>
<td>759,000</td>
<td>759,000</td>
<td>759,000</td>
<td>759,000</td>
</tr>
<tr>
<td>Mile per bus per year</td>
<td>12,650</td>
<td>12,650</td>
<td>12,650</td>
<td>12,650</td>
</tr>
</tbody>
</table>

FINANCIAL ANALYSIS

TOTAL COSTS WITHOUT GRANT

- CNG: $39.0 M
- ULSD: $36.9 M
- B-20: $37.9 M
- Hybrid Buses: $46.7 M

2008 USD

- New Project Costs
- Old Project Costs
FINANCIAL ANALYSIS
TOTAL COSTS WITH GRANT

2008 USD

- CNG: 24.0 M
- ULSD: 36.9 M
- B-20: 22.9 M
- Hybrid Buses: 31.7 M
RECOMMENDATIONS
EMISSIONS AND FINANCIAL

2008 USD

<table>
<thead>
<tr>
<th></th>
<th>CNG</th>
<th>ULSD</th>
<th>B-20</th>
<th>Hybrid Buses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Project Costs</td>
<td>62,927</td>
<td>36.9 M</td>
<td>22.9 M</td>
<td>64,839</td>
</tr>
<tr>
<td>OCTA GHG Emissions</td>
<td>24.0 M</td>
<td>63,610</td>
<td>31.7 M</td>
<td>63,883</td>
</tr>
</tbody>
</table>
RECOMMENDATIONS
B-20 CARBON NEUTRAL

- 23.3M
- 23.6 M
- 29.5M
- 32.7M
- 35.9M
- 55.4M

2008 USD

Price of Mton CO2

Carbon Neutral
Capital Cost
RECOMMENDATIONS

- **Business as usual – B-20**
  - Lowest cost, highest emissions

- **Compressed natural gas**
  - Second lowest cost, second most emissions

- **Hybrid Buses**
  - Highest cost, lowest emissions

- **Business as usual – B-20 carbon neutral**
  - Buy carbon credits to offset emissions
  - Cost of carbon credits ~ $10 per metric ton
  - Total carbon neutral cost ~ $650,000 for 36 year period
  - Total cost ~ 23.6 M for the 36 year period
QUESTIONS?