# Design Project 2:
## Creating a More Sustainable Future through Locomotive Design

Current Situation, Pittsdelphia:

• Approx 165,000-tons of freight or minerals (coal, etc) per day travel in or out of the port city of Pittsdelphia via rail.

• Smog from locomotive emissions is a key complaint of city residents. Smog is generated from engine emitted NOx. (https://en.wikipedia.org/wiki/NOx)

• Tier 2 locomotives used to haul freight are approaching age for overhaul, at which time investments will be required to meet EPA Tier 3 requirements

Pittsdelphia must continue to meet EPA requirements, but is looking for a cost effective solution which reduces smog, while maintaining or increasing freight capacity.

Suggestions have been made to address locomotive emissions (i.e. smog)

1) Upgrade the locomotive fleet to meet more recent emissions guidelines set by the EPA. A few options may exist to meet the new guidelines
    - Sell existing fleet and purchase new locomotives
    - Upgrade fleet with exhaust aftertreatment hardware
    - Utilize alternate fuels (Biodiesel, CNG, LNG, etc) which may produce less Nox
2) Alternate freight shipping
    - By sea
    - By air
    - By ground- trucking

Problem Statement: Evaluate the suggestions made for fleet upgrade or alternate shipping methods. For upgrades, consider physical constraints of new hardware, as well as fuel storage requirements. Provide your recommendations, commenting on impact to…

1. Emissions/Regulatory req'ts
2. Costs- fuel, infrastructure, etc
3. Freight throughput / capacity
4. Public opinion
5. On time delivery

**Mission Statement:** Freight Optimization GE

| | |
|---|---|
| Product Description | A modified or replaced locomotive or alternative form of transportation that reduces the emissions and maintains consumer satisfaction and is cost effective |
| Key Business Goals | Utilize the best freight hauling option to increase efficiency of transportation while following pre existing constraints |
| Primary Market | GE Transportation |

| | |
|---|---|
| Secondary Market | Freight Transportation companies, Government |
| Assumptions | Variable transportation range, 165,000 tons shipped, 15 trains per day w/ 3 mineral (12k ton, 3 loc.) 12 freight (7k ton, 2 loc), possibilities of alternative fuel types and or alternative shipping methods |
| Stakeholders | GE, Freight Transportation companies, railway lines |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Locomotive Emissions | | | | | | | | | |
| | | | | | | | | | |
| Tier | Nox (g)/(hp*hr) | Nox/300 Miles (g) | NO kg/300 | PM g/(hp*hr) | PM / 300 miles (g) | PM kg/300 miles | | | Conversion Factor |
| 2 | 5.5 | 185625 | 185.625 | 0.2 | 6750 | 6.75 | | | 33750 |
| 3 | 5.5 | 185625 | 185.625 | 0.11 | 3712.5 | 3.7125 | | | 0.001 |
| 4 | 1.3 | 43875 | 43.875 | 0.025 | 843.75 | 0.84375 | | | |

Options:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Individual Groups | beginning with 50 Tier II | | | | | | |
| max freight | | 50 Locomotives (sell all tier II) | Cost ($M) | Freight Capacity (tons) | Mineral | Freight | Emissons (PM kg/300miles) | Emisson of Tier II at Locomotive Level (PM kg/300miles) |
| max emissons | max emissons | buy 50 tier III | 37.5 | 199000 | 16 | 1 | 185.625 | 337.5 |
| max cost | max cost/min emmisons | buy 50 tier IV | 125 | 199000 | 16 | 1 | 42.1875 | 337.5 |
| max emissons | min cost/max emissons | after-treatment all | 5 | 199000 | 16 | 1 | 185.625 | 337.5 |
| | | 25 tier III + 25 tier IV | 81.25 | 199000 | 16 | 1 | 113.90625 | 337.5 |
| | | 24 tier III + 26 tier IV | 83 | 199000 | 16 | 1 | 111.0375 | 337.5 |
| | | 26 tier III + 24 tier IV | 79.5 | 199000 | 16 | 1 | 116.775 | 337.5 |
| | | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 49 Lomotives (sell all tier II) | | | | | | |
| | max emissons | buy 49 tier III | 35.25 | 194000 | 15 | 2 | 181.9125 | 330.75 |
| | max cost/min emmisons | tier IV | 121 | 194000 | 15 | 2 | 41.34375 | 330.75 |
| | min cost/max emissons | after-treatment all | 3.4 | 194000 | 15 | 2 | 181.9125 | 330.75 |
| | | 25 tier III + 24tier IV | 78.75 | 194000 | 15 | 2 | 113.0625 | 330.75 |
| | | 24tier III + 25 tier IV | 80.5 | 194000 | 15 | 2 | 110.19375 | 330.75 |
| | | | | | | | | |
| | | 48 Locomotives (sell all tier II) | | | | | | |
| | max emissons | buy 48 tier III | 33 | 192000 | 16 | 0 | 178.2 | 324 |
| | max cost/min emmisons | tier IV | 117 | 192000 | 16 | 0 | 40.5 | 324 |
| | min cost/max emissons | after-treatment all | 1.8 | 192000 | 16 | 0 | 178.2 | 324 |
| | | 24 tier III + 24 tier IV | 78 | 192000 | 16 | 0 | 109.35 | 324 |
| | | | | | | | | |
| | | 47 Locomotives (sell all tier II) | | | | | | |
| | max emissons | buy 47 tier III | 30.75 | 187000 | 15 | 1 | 174.4875 | 317.25 |
| | max cost/min emmisons | tier IV | 113 | 187000 | 15 | 1 | 39.65625 | 317.25 |
| | min cost/max emissons | after-treatment all | 0.2 | 187000 | 15 | 1 | 174.4875 | 317.25 |
| | | 24 tier III + 23 tier IV | 75.5 | 187000 | 15 | 1 | 108.50625 | 317.25 |
| | | 23tier III + 24tier IV | 77.25 | 187000 | 15 | 1 | 105.6375 | 317.25 |
| | | | | | | | | |
| | | 46 Locomotives (sell all tier II) | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | max emissons | buy 46 tier III | 28.5 | 182000 | 14 | 2 | 170.775 | 310.5 |
| | max cost/min emmisons | tier IV | 109 | 182000 | 14 | 2 | 38.8125 | 310.5 |
| | min cost/max emissons | after-treatment all | -1.4 | 182000 | 14 | 2 | 170.775 | 310.5 |
| | | 23 tier III + 23 tier IV | 74.75 | 182000 | 14 | 2 | 104.79375 | 310.5 |
| | | | | | | | | |
| | | 45 Locomotives (sell all tier II) | | | | | | |
| | max emissons | buy 45 tier III | 26.25 | 180000 | 15 | 0 | 167.0625 | 303.75 |
| | max costmin emmisons | tier IV | 105 | 180000 | 15 | 0 | 37.96875 | 303.75 |
| | min cost/max emissons | after-treatment all | -3 | 180000 | 15 | 0 | 167.0625 | 303.75 |
| | | 23 tier III + 22 tier IV | 72.25 | 180000 | 15 | 0 | 103.95 | 303.75 |
| | | 22 tier II + 23 tier IV | 74 | 180000 | 15 | 0 | 101.08125 | 303.75 |
| | | | | | | | | |
| min freight | | 44 Locomotives (sell all tier II) | | | | | | |
| | max emissons | buy 44 tier III | 24 | 175000 | 14 | 1 | 163.35 | 297 |
| min emmisons | max cost | tier IV | 101 | 175000 | 14 | 1 | 37.125 | 297 |
| min cost | min cost/max emissons | after-treatment all | -4.6 | 175000 | 14 | 1 | 163.35 | 297 |
| | | 22 tier III + 22 tier IV | 71.5 | 175000 | 14 | 1 | 100.2375 | 297 |
| | | | | | | | | |
| below set limit of freight | | 43 Locomotives (sell all tier II) | | | | | | |
| | max emissons | buy tier III | 21.75 | 170000 | 13 | 2 | 159.6375 | 290.25 |
| | max cost/min emmisons | tier IV | 97 | 170000 | 13 | 2 | 36.28125 | 290.25 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | min cost/max emissons | after-treatment all | -6.2 | 170000 | 13 | 2 | 159.6375 | 290.25 |
| | | 22 tier III + 21 tier IV | 69 | 170000 | 13 | 2 | 99.39375 | 290.25 |
| | | 21 tier III + 22 tier IV | 70.75 | 170000 | 13 | 2 | 96.525 | 290.25 |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| red | Tier II --> Tier III | | | | | | | |
| blue | Tier II --> Tier IV | | | | | | | |
| green | After-treatment | | | | | | | |
| purple | mix match Tier III+Tier IV | | | | | | | |
| | | | | | | | | |
| | Graph: | | | | | | | |
| | 3 (9) - max amt of emissons | | | | | | | |
| | 6 - min amt of emissons | | | | | | | |
| | 5 - max cost | | | | | | | |
| | 8 - min cost | | | | | | | |
| | | | | | | | | |

## Rating Method:

| Options | Emissons (PM kg/300miles) | 5 | Cost ($M) | 4 | Freight Capacity (tons) | 1 | Ranking |
|---|---|---|---|---|---|---|---|
| buy 50 tier III | 185.62500 | 0.7 | 37.50 | 6.1 | 199000 | 10 | 3.79 |
| buy 50 tier IV | 42.18750 | 8.2 | 125.00 | 0.4 | 199000 | 10 | 5.26 |
| after-treatment all | 185.62500 | 0.4 | 5.00 | 8.2 | 199000 | 10 | 4.48 |
| 25 tier III + 25 tier IV | 113.90625 | 4.9 | 81.25 | 2.8 | 199000 | 10 | 4.57 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 24 tier III + 26 tier IV | 111.03750 | 5.2 | 83.00 | 2.5 | 199000 | 10 | 4.6 |
| 26 tier III + 24 tier IV | 116.77500 | 4.6 | 79.50 | 3.4 | 199000 | 10 | 4.66 |
| buy 49 tier III | 181.91250 | 1.3 | 35.25 | 6.4 | 194000 | 9 | 4.11 |
| tier IV | 41.34375 | 8.5 | 121.00 | 0.7 | 194000 | 9 | 5.43 |
| after-treatment all | 181.91250 | 1 | 3.40 | 8.5 | 194000 | 9 | 4.8 |
| 25 tier III + 24tier IV | 113.06250 | 5.5 | 78.75 | 3.7 | 194000 | 9 | 5.13 |
| 24tier III + 25 tier IV | 110.19375 | 5.8 | 80.50 | 3.1 | 194000 | 9 | 5.04 |
| buy 48 tier III | 178.20000 | 1.9 | 33.00 | 6.7 | 192000 | 8 | 4.43 |
| tier IV | 40.50000 | 8.8 | 117.00 | 1 | 192000 | 8 | 5.6 |
| after-treatment all | 178.20000 | 1.6 | 1.80 | 8.8 | 192000 | 8 | 5.12 |
| 24 tier III + 24 tier IV | 109.35000 | 6.1 | 78.00 | 4 | 192000 | 8 | 5.45 |
| buy 47 tier III | 174.48750 | 2.5 | 30.75 | 7 | 187000 | 7 | 4.75 |
| tier IV | 39.65625 | 9.1 | 113.00 | 1.3 | 187000 | 7 | 5.77 |
| after-treatment all | 174.48750 | 2.2 | 0.20 | 9.1 | 187000 | 7 | 5.44 |
| 24 tier III + 23 tier IV | 108.50625 | 6.4 | 75.50 | 4.6 | 187000 | 7 | 5.74 |
| 23tier III + 24tier IV | 105.63750 | 6.7 | 77.25 | 4.3 | 187000 | 7 | 5.77 |
| buy 46 tier III | 170.77500 | 3.1 | 28.50 | 7.3 | 182000 | 6 | 5.07 |
| tier IV | 38.81250 | 9.4 | 109.00 | 1.6 | 182000 | 6 | 5.94 |
| after-treatment all | 170.77500 | 2.8 | -1.40 | 9.4 | 182000 | 6 | 5.76 |
| 23 tier III + 23 tier IV | 104.79375 | 7 | 74.75 | 4.9 | 182000 | 6 | 6.06 |
| buy 45 tier III | 167.06250 | 3.7 | 26.25 | 7.6 | 180000 | 5 | 5.39 |
| tier IV | 37.96875 | 9.7 | 105.00 | 1.9 | 180000 | 5 | 6.11 |
| after-treatment all | 167.06250 | 3.4 | -3.00 | 9.7 | 180000 | 5 | 6.08 |
| 23 tier III + 22 tier IV | 103.95000 | 7.3 | 72.25 | 5.5 | 180000 | 5 | 6.35 |
| 22 tier II + 23 tier IV | 101.08125 | 7.6 | 74.00 | 5.2 | 180000 | 5 | 6.38 |
| buy 44 tier III | 163.35000 | 4.3 | 24.00 | 7.9 | 175000 | 4 | 5.71 |
| tier IV | 37.12500 | 10 | 101.00 | 2.2 | 175000 | 4 | 6.28 |
| after-treatment all | 163.35000 | 4 | -4.60 | 10 | 175000 | 4 | 6.4 |
| **22 tier III + 22 tier IV** | **100.23750** | **7.9** | **71.50** | **5.8** | **175000** | **4** | **6.67** |

## Final Solution:

- a combination of 22 Tier III and 22 Tier IV level locomotives
- 22 of the original Tier II's will be upgraded to Tier III levels
- The Remaining 28 Tier II locomotives will be sold to help purchase 22 Tier IV locomotives

**This solution is effective in the long run and allows for the best correlation between cost, freight weight, and emissions.**