PennState College of Engineering | ENGINEERING DESIGN, TECHNOLOGY, AND PROFESSIONAL PROGRAMS

The Pennsylvania State University
University Park Campus

Freight, Fuel, & Emissions

GE Transportation

EDSGN 100
Section 00#

Design Team 7
007
Fall 2015

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08 Dec 2015

ACKNOWLEDGMENTS

Penn State University

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SECTION 1 EXECUTIVE SUMMARY

The Engineering Design Team 007 has been assigned by GE Transportation to manage locomotive fleet of the city of Pittsadelphia. The fleet currently is composed of 50 tier 2 locomotives, which will be required be replaced with tier 3 or higher upon their failure. The city is also experiencing smog from the exhaust of these locomotives, specifically the chemical NOx, and this problem should be solved as well without affecting the freight import and export of the city.

SECTION 2 INTRODUCTION[1]

2.1 Project Objectives.

Design a cost-effective solution for Pittsadelphia's freight that reduces smog and meets EPA requirements, while still supporting the freight import and export of the city.

2.2 Project Background.

Every day around 165,000 tons of freight travel in or out of Pittsadelphia via rail. Smog from locomotive emissions is a key complaint of city residents. Smog is caused by NOx, which is created from the exhaust of the locomotives. The current Tier 2 locomotives used to haul freight are approaching failure. Upon their failure investments will be required to meet EPA Tier 3 requirements.

2.3 Project Sponsor Background.

GE Transportation solves transportation challenges. GE Transportation builds equipment utilized in the rail, mining, and marine industries. GE's fuel-efficient and lower-emissions freight and passenger locomotives; diesel engines for rail; marine and stationary power applications; signaling and software solutions; drive systems for mining trucks; and value-added services help customers grow. GE Transportation is headquartered in Chicago, IL, and employs approximately 13,000 employees worldwide.

2.4 Project Description.

Each design team should research and 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 requirements: New locomotives are required to meet Tier 3 Emission Standards or higher. Tier 4 Emission Standards are preferable because they will have to met eventually anyways. Tier 4 Standards require that emissions of PM and NOx be further reduced by about 90% [2]

2) Costs: fuel, infrastructure, etc.[3]

The EPA requires the availability of low-sulfur diesel fuel to enable catalytic aftertreatment methods. The sulfur limit is 15 ppm as of June 2012. By rail most materials cost about $2.50 per ton-mile. Trucks (depending on size) average about $7 per ton-mile. Barges (depending on size) average about $0.75 per ton-mile.

3) Freight throughput/capacity

Train- 100 tons/ 3500 bushels/ 30240 gallons per car, train can fit 100 cars (10,000 tons per train). Truck- 26 tons/ 910 bushels/ 7865 gallons per large semi-truck. Barge- 1500 tons/ 52500 bushels/ 453600 gallons

4) Public opinion

Trucks are most popular because they are fastest and most common currently, but trains and barges can be implemented if they are managed efficiently enough.

5) On time delivery

While trucks are the fastest of the 3 options, all 3 have the potential to deliver freight on time if they are managed efficiently.

2.5 Project Freight Requirements.

165,000 tons of freight or minerals via rail

2.6 Transportation Mode Comparisons.

a. Trucks. Low cost and capacity (⅓), very bad impact for the environment (0/3), but fast (⅔). Images refer to Figure 2.

b. Barges. Very cheap and good for the environment (3/3), good capacity (⅔), but slow (0/3). Images refer to Figure 3.

c. Railroad. Good cost and environmental impact (⅔), great capacity (3/3), but slow (⅓). Images refer to Figure 4.

SECTION 3 TRANSPORTATION INFRASTRUCTURE CONDITION AND CAPACITY[4]

3.1 Pennsylvania Roads and Bridges. Roads Condition: Based on the data from 2012, nearly 23% of state owned roadways are rated poor. For those 79000 miles of roadways owned by local governments and other non-state entities, although they are not rated by PennDOT, they would be the same or even worse condition than the state owned roads. As a result, an additional 18000 miles non-state owned roads are rated poor. The total mileage of poor rated roads in Pennsylvania is 27500 miles.[5]

Roads capacity: The capacity of one large semi truck is 26 tons/ 910 bushels/ 7865 gallons.

3.2 Pennsylvania Inland Water Ways.

Inland waterways capacity: The overall capacity can be measured by total commercial tonnage transported. Based on the data from 2012, the total commercial tonnage transported in Pennsylvania is around 35 million tons, which is somewhat higher than the tonnage in 2010, but still significantly lower than historic levels. The capacity of each barge is 1500 tons/ 52500 bushels/ 453600 gallons.

3.3 Pennsylvania Freight Rail System

Freight rail system capacity: the capacity of one rail car is 100 tons/ 3500 bushels/ 30240 gallons. The capacity of 100-car train unit is 10000 tons/ 350000 bushels/ 3024000 gallons.

There are approximately 5145 route-miles of freight railroad operating in Pennsylvania. They are consist of sixty five freight railroads, summarized as follows:

- Four Class I Railroads: CSX, Norfolk Southern, Canadian Pacific (CP Rail), and Bessemer and Lake Erie Railroad Company (owned by Canadian National (CN))
- Two Class II Railroads: Buffalo and Pittsburgh Railroad, and Wheeling and Lake Erie Railroads
- Thirty-two Class III Railroads, also known as short line or local line haul railroads, twenty-seven local switching and terminal railroads.[6]

SECTION 4 STANDARD CAPACITY FOR ALTERNATE TRANSPORTATION MODES

4.1 Cargo Capacity.

Refer to figure 1 to view cargo capacity in tons, bushels, and gallons.

4.2 Equivalent Units.

Refer to figure 1

One barge has the carrying capacity equal to 15 Jumbo Hopper Cars or 58 Large Semis. One 15 barge tow is equal to 2.25 100 Car unit trains or 870 large semis.

4.3 Equivalent Lengths.

One 15 Barge Tow, 0.25 miles, has the equivalent length of 2.25 100 Car Train Units, which is 2.75 miles, or 870 Large Semis, which is 11.5 miles.

SECTION 5 TRANSPORTATION COSTS AND CONCEPT OF OPERATIONS (ConOps)[7]

5.1 Trucks.

In general, truck costs rise with distance at a somewhat less than linear rate. However, for lengths of haul above 50 or 100 miles, truck costs increase only slightly more slowly than length of haul. There are a number of other factors that influence this cost. Including trailer type, configuration, gross vehicle weight (GVW), payload, driver costs, fuel efficiency,...etc.

The cost per mile rise slowly with GVW and payload, but costs per ton-mile drop appreciably. Jack Faucett Associates (JFA) estimated costs for intercity less-than-truckload shipments to average about $2.4 per vehicle-mile of operation. According to the United States department of transportation, trucks cost usually 17.0 cents per ton-mile.

5.2 Barges.

Cost and time analysis for water transport facilities can either be based on the marginal impact on existing rate and service characteristics or the development of fully-allocated system costs and service parameters for representative cargo flows. The more common method is to estimate the underlying cost and transit-time structure, calibrated against available rate and service data. According to the United States department of Transportation, it usually costs 2.0 per ton-mile.[9]

5.3 Railroad.

Rates per ton-mile tend to vary inversely with length of haul, size of shipment, and commodity density. The average rates for the commodities are all between 2 and 4 cents per ton-mile.

5.4 Most Economical Transportation Solution.

After comparing all three solutions, we recommend that the railroad transportation is the best solution. The capacity of barges is the largest compared to trucks and railroad but barges are also dependent on trucks, the cost would be higher after consideration. The fuel needed to start the barge would also cost more and be unfriendly to the environment. Also, the periods of low water and floods needs to be considered, this makes the where and when unpredictable, this makes it hard to transport for every season and weather condition. Although trucks can travel almost anywhere at anytime, it is not the best choice because not only it is too expensive, but also it is inconvenient due to the traffic lights and jams. Railroad is the best solution because it is not only fuel-efficient, it also goes on a high speed and non-stop. We could also make it environmental friendly by using alternative elements. Overall, Railroad is the most ideal solution.

[Prove a complete systems model image of the most economical transportation solution selected.]

SECTION 6 EPA DIESEL EMISSION STANDARDS[8]

6.1 Background.

The Environmental Protection Agency started evaluating and regulating gaseous emissions from the heavy-duty highway use of diesel engines and particle emissions in the 1970s. The information provided by this assessment was useful in developing EPA's understanding of the implications on public health due to the exposure to diesel engines and can use this evidence to take action to control the exhaust emissions. US emission standards for railway locomotives apply to newly manufactured and remanufactured railroad locomotives and engines. There are two standards that have been adopted by the EPA:

- *Tier 0-2 standards:* The first emission regulation for railroad locomotives was adopted on 17 December 1997. Tier 0-2 standards are met through engine design methods, without the use of exhaust gas aftertreatment.
- *Tier 3-4 standards:* A regulation signed on 14 March 2008 introduced more stringent emission requirements. Tier 3 standards, to be met by engine design methods, become effective from 2011/12. Tier 4 standards, which are expected to require exhaust gas aftertreatment technologies, become effective from 2015.

6.2 Tier 0-2 Standards.

Three separate sets of emission standards have been adopted, termed Tier 0, Tier 1, and Tier 2. The applicability of the standards depends on the date a locomotive is first manufactured, as follows:

Tier 0—The first set of standards applies (effective 2000) to locomotives and locomotive engines originally manufactured from 1973 through 2001, any time they are manufactured or remanufactured.

Tier 1—These standards apply to locomotives and locomotive engines originally manufactured from 2002 through 2004. These locomotives and locomotive engines are required to meet the Tier 1 standards at the time of the manufacture and each subsequent remanufacture.

Tier 2—This set of standards applies to locomotives and locomotive engines originally manufactured in 2005 and later. Tier 2 locomotives and locomotive engines are required to meet the applicable standards at the time of original manufacture and each subsequent remanufacture.

The Tier 0-2 Line-Haul Locomotive Emission Standards are listed in Table 1 and the Switch Locomotive Emission Standards are listed in Table 2.

6.3 Tier 3-4 Standards

Tier 3—Near-term engine-out emission standards for newly-built and remanufactured locomotives. Tier 3 standards are to be met using engine technology.

Tier 4—Longer-term standards for newly-built and remanufactured locomotives. Tier 4 standards are expected to require the use of exhaust gas aftertreatment technologies, such as particulate filters for PM control, and urea-SCR for NOx emission control.

The emission standards are summarized in Figure 4 and Figure 5. The Tier 0-2 standards apply to existing locomotives of the indicated manufacture years (MY) at the time they are remanufactured, beginning from the effective date. The Tier 3-4 standards apply to locomotives of the indicated manufacture years at the time they are newly built or remanufactured.

The Tier 3-4 Line-Haul Locomotive Emission Standards are listed in Table 1 and the Switch Locomotive Emission Standards are listed in Table 2.

SECTION 7 DIESEL ENGINE EXHAUST EMISSIONS (DEEE)

7.1 Diesel Emission Chemistry.

a. NOx.

NOx (mono-nitrogen oxides NO and NO_2) is produced from reactions with nitrogen, oxygen and hydrocarbons during combustion at high temperature. Therefore, areas of high traffic such as cities have high nitrogen oxide emission, contributing to air pollution. Vehicles contribute to nitrogen oxide emission from the breathing of the engine. When NOx reactions with volatile organic compounds in the presence of sunlight, it forms photochemical smog, contributing tremendously to air pollution.[10]

b. Particulate Matter (PM).

Fine particles in diesel exhaust (e.g. soot) is produced through the spark ignition of engines in vehicles. Particulate matter presents health concerns such as heart and lung cancer as well as mental functioning. [11]

c. CO_2.

Carbon dioxide, along with carbon monoxide, and nitrogen oxides make up the main components of the gas in a diesel engine. CO2 is a greenhouse gas and thus the emission of CO2 from locomotives contributes to global warming as well as air pollution.[12]

d. Hydrocarbons (HC).

Petroleum-derived diesel is made up of 75% saturated hydrocarbons and 25% aromatic hydrocarbons. The operation of engines occurs in enclosed spaces such as underground mines, buildings, tunnels, warehouses, etc., where carbon monoxide can accumulate and thus produce an atmosphere that can cause headaches, dizziness, and lethargy. Along with the choking sensation and eye irritation that is caused by hydrocarbons (and aldehydes), hydrocarbons are a major contributor to the characteristic diesel smell. Hydrocarbons also contribute negatively to the environment causing smog and an acid rain. [13]

7.2 Diesel Emission Reduction Strategies.

Two areas that can contribute to diesel emission reduction is through engine modification, which reduces unwanted diesel emission, and exhaust control technologies which removes the gases from the exhaust.

Homogenous Charge Compression Ignition (HCCI) - HCCI is an example of an engine modification. A lot of engine modifications come with a trade off (decreasing the emission of one gas while increasing the other). HCCI is a method of breaking through the NOx-PM trade-off barrier through the combustion process. Fuel is injected into a heated intake air stream outside of the cylinder (port fuel injection), allowing for greater mixing of air and fuel. The enhanced mixing prevents formation of the fuel-rich zones where particulates form. The difference is when the cylinder compresses, multiple ignitions are generated instead of a single flame, resulting in a lower peak flame temperature and reduced NOx emissions. [14]

Diesel Particulate Filters (DPFs)- DPFs is an example of an exhaust control technology that captures soluble organic and soot in particulate matter (PM). DPF's are often made of ceramic monoliths or woven fibers, and with time, will require changing.

7.3 Alternate Fuels.

Biodiesel (BD) is an alternative fuel derived from liquid feedstock such as vegetable oils and animal fats. A major source of biodiesel in the U.S. come from soybeans. Through chemical processing of pure biodiesel which can blend with petroleum (20:80 respectively) only requires minor changes to the engine. Biodiesel has a higher oxygen content than diesel and virtually no sulfur or aromatics, resulting in PM reductions.[15]

Dimethyl Ether (DME) is another alternative fuel that can be synthesized from virtually any carbonaceous feedstock such as natural gas, coal, and renewable biomass. Currently, DME is manufactured through dehydration of methanol. The product is a partially oxidized, virtually sulfur and aromatics-free gas with no carbon-carbon bonds. This allows for significant PM reduction.

7.4 Human Health Issues.

Toxics - Exhaust emission reduction technologies such as particulate traps include metal-based fuel additives such as cerium, copper, iron, sodium, platinum, and lithium. The use of fuel additives is a simple, passive regeneration strategy being demonstrated successfully worldwide. However, having metal compounds in fuels causes potential effects on human health even at relatively low levels of use. Many metals are toxic and cause changes in emissions that increase

exhaust toxicity by increasing dioxins and size of particles in emission. Although this may not be true of all additives and the filter may recapture most of the additive, health concerns should be considered.

Ultrafine Particulates- Through research, even the smallest of particles in emission (ultrafine and nanoparticles) can potentially be the most hazardous under the health impact category. Early studies indicate that diesel engines emit large numbers particles with a small size range.[16]

SECTION 8 LOCOMOTIVE FLEET UPGRADE

8.1 Alternatives.

i. Sell existing fleet and purchase new locomotives
ii. Upgrade fleet with exhaust after-treatment hardware
iii. Utilize alternate fuels (Biodiesel, CNG, LNG, etc.) which may produce less NOx.

8.2 Existing Fleet Make-Up. {NOTE: Assume: (i) fleet consists of the following locomotives and (ii) locomotives are rebuilt at 750,000 mile intervals.}

No. of Existing Locomotives	Locomotive Group Designation	Assumed Existing Locomotive Mileage Range	Assumed Existing Diesel Type
10	A	<150,000	Tier 2
10	B	>150,000 and <300,000	Tier 2
10	C	>300,000 and <450,000	Tier 2
10	D	>450,000 and < 600,000	Tier 2
10	E	>600,000 and <750,000	Tier 2

8.3 Investment Data[17].

- Diesel locomotive upgrade: The investment of upgrading Tier II -> Tier III is $750k, and the After-treatment investment is $100k.
- New locomotive investment: Two types of new locomotives are Tier III and Tier IV, and the investment of each type of new locomotive is: $3M for Tier III and $4M for Tier IV locomotive.
- Alternative Fuels: The investment for locomotive fuel upgrade is $ 1M, and the investment of Fueling station is $1B

8.4 Upgrade Strategy[18]

i) Upgrading locomotive model from Tier ii to Tier iii: Based on the investment data, each locomotive upgrading will cost $750k, which is relatively cheap comparing to other options. However Tier ii locomotives are only upgraded to Tier iii, not replaced by new locomotives Tier iii or Tier iv, they might get functional problems once the locomotives reach the useful life. Besides, this method has little infection on reducing pollution.

ii) Upgrading the after treatment hardware on Tier ii: The advantages and disadvantages to this option is obvious. First it is very cheap, and can largely reduce the pollution. However, it has to be an additional upgrading, which comes with other major locomotive upgrading or replacement. Only upgrading the after treatment hardware while still keeping the Tier ii locomotives is just not efficient.

iii) Purchasing new Tier 3 or Tier 4 locomotives: replacing the Tier ii locomotives to the newest locomotive models will advance significantly in performance, energy efficiency, and more environmental friendly. The downside of this strategy is that the cost is relatively high.

iv) Upgrading locomotives to use alternative fuels and upgrading fueling station: This strategy largely reduces the pollution, and it is a radical cure in long-term perspective. When upgrading the locomotives to use alternative fuels, the fueling stations have to keep up with the locomotives, which makes the price very high.

8.5 Upgrade Schedule and Costs.

Best solution: Replace all 50 Tier ii locomotives to Tier iv. Group C and D will be equipped with after-treatment hardwares. Consider the upgrading might take a few years, another short-term solution that can be implemented immediately is upgrading 20 locomotives of group A and B from Tier ii to Tier iii with after-treatment hardware. (More specific upgrade schedule and Costs please see Section 9. Conclusions)

SECTION 9 SUMMARY

Upon reaching their minimum useful life[19] (750,000 miles or 10 years), locomotives should be either sold or used for scrap parts and replaced with Tier 4 locomotives ($4M each) rather than Tier 3 (3$M each) because of the relatively small price difference for a large difference in NOx emission (5.5 to 1.3 g/bhp·hr)[20]. The replacement of all 50 Tier 2 locomotives will cost $200M, but this cost will be spread over a few years at least (depending on how heavily the locomotives are used and how quickly they reach the end of their minimum useful life.) The smog problem in Pittsadelphia will be greatly diminished by this reduction in NOx emissions, which will please the public. Of the current 50 Tier 2 locomotives, groups C and D will be equipped with after-treatment (100K each), as a temporary solution to reduce NOx emissions. Data shows that an advanced exhaust aftertreatment system lasts about 3,000 hours before it begins to degrade[21]. Assuming that the rails in Pittsadelphia are at least Class 3, meaning the trains can travel at 40 mph[22], group C locomotives (with 300,000 miles already) will need 4 aftertreatment systems each and group D (with 450,000 miles already) will need 3 aftertreatment systems each before they read 750,000 miles and are replaced with new locomotives. The total of 70 aftertreatment systems will cost $7M, but it will also be spread over years as the aftertreatment systems reach begin to degrade and have to be replaced. The 20 locomotives in groups A and B will be upgraded from tier 2 to tier 3 for $750K each for $15M. This be the only part of the solution to be implemented immediately. Our solution will cost a total of $222M upon completion, but the majority of the process will occur gradually and the cost will be spread out as well.

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Figures

Figure 1

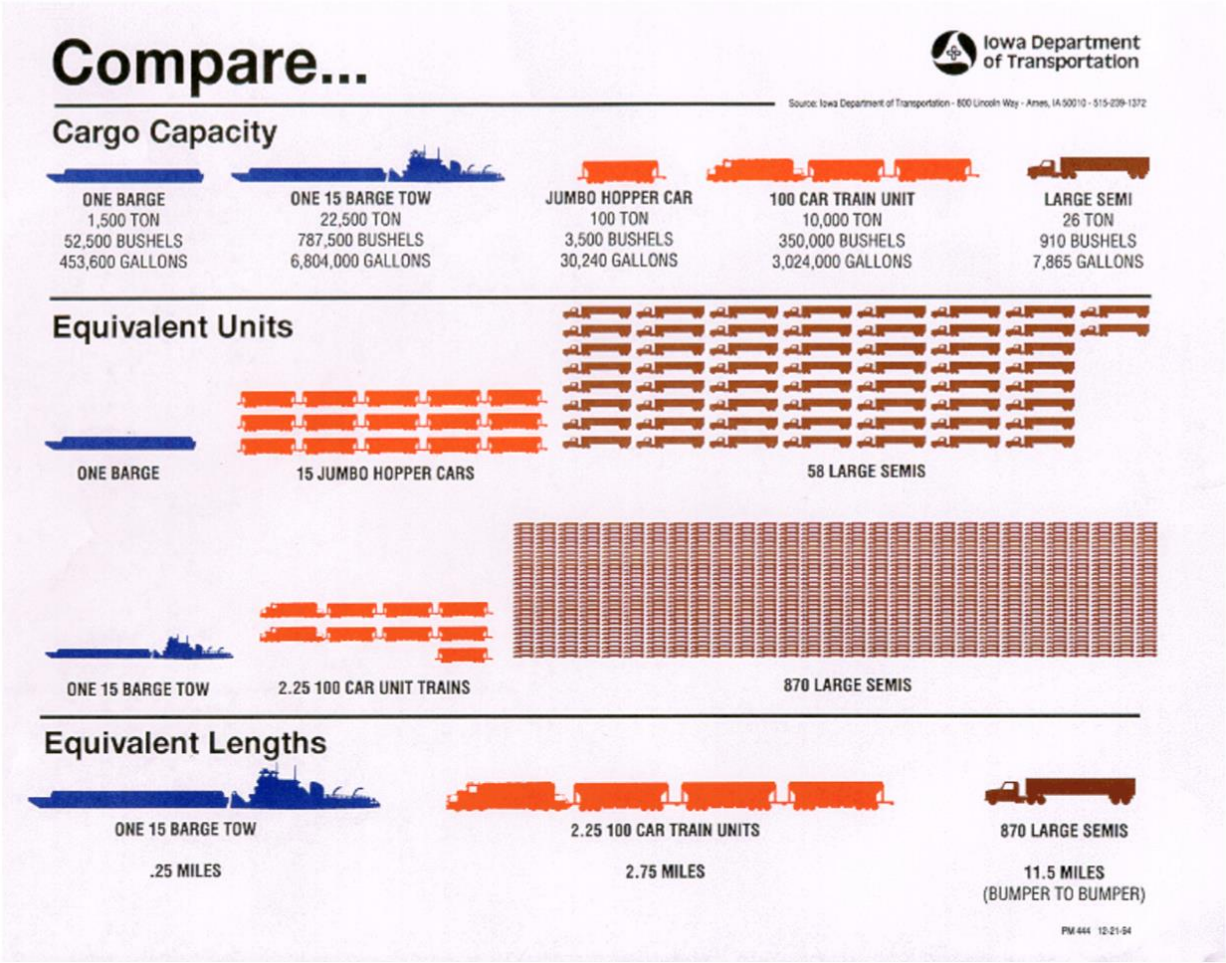
Compare...
Iowa Department of Transportation
Cargo Capacity
ONE BARGE
1,500 TON
52,500 BUSHELS
453,600 GALLONS
ONE 15 BARGE TOW
22,500 TON
787,500 BUSHELS
6,804,000 GALLONS
JUMBO HOPPER CAR
100 TON
3,500 BUSHELS
30,240 GALLONS
100 CAR TRAIN UNIT
10,000 TON
350,000 BUSHELS
3,024,000 GALLONS
LARGE SEMI
26 TON
910 BUSHELS
7,865 GALLONS
Equivalent Units
ONE BARGE
15 JUMBO HOPPER CARS
58 LARGE SEMIS
ONE 15 BARGE TOW
2.25 100 CAR UNIT TRAINS
870 LARGE SEMIS
Equivalent Lengths
ONE 15 BARGE TOW
.25 MILES
2.25 100 CAR TRAIN UNITS
2.75 MILES
870 LARGE SEMIS
11.5 MILES
(BUMPER TO BUMPER)

Figure 2. Typical Diesel Truck and Trailer. [23]

Figure 3. Typical Diesel-Electric locomotive.[24]

Figure 3. Typical Inland Water Ways Barge and Tug.[25]

Tables

Table 1- Line-Haul Locomotive Emission Standards, g/bhp*hr

Tier	MY	Date	HC	CO	NOx	PM
Tier 0[a]	1973-1992[c]	2010[d]	1.00	5.0	8.0	0.22
Tier 1[a]	1993[c]-2004	2010[d]	0.55	2.2	7.4	0.22
Tier 2[a]	2005-2011	2010[d]	0.30	1.5	5.5	0.10[e]
Tier 3[b]	2012-2014	2012	0.30	1.5	5.5	0.10
Tier 4	2015 or later	2015	0.14[f]	1.5	1.3[f]	0.03

a - Tier 0-2 line-haul locomotives must also meet switch standards of the same tier.
b - Tier 3 line-haul locomotives must also meet Tier 2 switch standards.
c - 1993-2001 locomotive that were not equipped with an intake air coolant system are subject to Tier 0 rather than Tier 1 standards.
d - As early as 2008 if approved engine upgrade kits become available.
e - 0.20 g/bhp-hr until January 1, 2013 (with some exceptions).
f - Manufacturers may elect to meet a combined NOx+HC standard of 1.4 g/bhp-hr.

Table 2- Switch Locomotive Emission Standards, g/bhp*hr

Tier	MY	Date	HC	CO	NOx	PM
Tier 0	1973-2001	2010[b]	2.10	8.0	11.8	0.26
Tier 1[a]	2002-2004	2010[b]	1.20	2.5	11.0	0.26
Tier 2[a]	2005-2010	2010[b]	0.60	2.4	8.1	0.13[c]
Tier 3	2011-2014	2011	0.60	2.4	5.0	0.10
Tier 4	2015 or later	2015	0.14[d]	2.4	1.3[d]	0.03

a - Tier 1-2 switch locomotives must also meet line-haul standards of the same tier.
b - As early as 2008 if approved engine upgrade kits become available.
c - 0.24 g/bhp-hr until January 1, 2013 (with some exceptions).
d - Manufacturers may elect to meet a combined NOx+HC standard of 1.3 g/bhp-hr.