EDSGN 100,
Submitted to Wallace

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EXECUTIVE SUMMARY

Philadelphia is the fifth biggest city in the U.S. and the second biggest city in the East coast side; population of Philadelphia is over 1.5 million. Since Philadelphia is a huge city, there are a lot of gifted and developed transportation: rail, ship, ground, and air. By rail, the locomotive can go through two freight railroads in Philly. From the ship, there are Delaware River near Philadelphia. In Delaware River, about 2 million metric tons of cargos are handled. Also, Philadelphia have international airport. Not only these, but also cargo trucks can go through interstate highways. However, since all kinds of transportations are handled, rate of pollution is very serious; Philly is ranked as eighth smoggiest region in the United States. Even, 30 days in last year were considered as "hard breathing condition days". Due to serious pollution, residents in Philly are complaining about the pollution by transportations.

In order to solve the problems, GE Transportation wants to make some type of transportation that can alternate already existed transportations. Otherwise, the other option is upgrading the locomotive. After serious evaluation, my group decided to upgrading the locomotive will be effective solution. To reduce the emission rate, my group discussed to find out alternative fuel to replace the coal which produce tons of emission. The answer was liquid natural gas(LNG). It can reduce emission part at maximum rate compared to using coal. Also, vehicles using LNG are already existed; applying to locomotive to use LNG will not be a big hinder.

The risks of locomotive contain various aspects. The hardest part was figuring out the alternative fuel to replace the coal because the customer needs requires to be cheaper and speedy.

To find out the alternative fuel, my group searched over many fuels and compared. Another part of finding the departure locations. Our group needs to search the any places within 500 miles from the Philadelphia. Still the place has the another place nearby to supply the fuel. After several researches, the outcome was the Rolling Hill which not too far away and have a gas station nearby.

Abstract

Concerning with serious pollution and smog rate in Philadelphia, there are possible solutions that minimize the pollution rate. Among the solutions, building eco-friendly locomotive is the one of the most effective solution since there are two freight railroad in Philadelphia that goes to everywhere within the United States. Derived from this idea, nearly zero emission rate locomotive has invented. New locomotive achieves lowest emission rate among existed locomotive overall with using recyclable energies such as liquid natural gas...

Introduction

For past over a month, our team designed a new locomotive for GE Transportation, which runs to Philadelphia from any places that is 500 miles away from Philadelphia. Our project starts from basic research like find proper location for departure where can have a place to supply fuel near. The locomotive requires reducing emission rate at maximum with less expensive cost; it still needs to have larger capacity, fast speed. Additionally, our group tries to fit in to best locations and all locomotives features to maximize the benefits such as using the liquid natural gas maximally and minimize the loss. There is following result in detail:

Mission Statement

This project requires to create new version of locomotive with having lower emission rate; also, this locomotive requires to contain larger capacity with less expensive and faster speed.

Analysis of Customer Needs

#	Imp	Customer Need	Need Statement
1	2	"Philadelphia is looking for the design."	This shipping method is available for citizens in Philadelphia.
2	5	"Reduce smog and meets EPA requirements."	Emission reaches the standard of EPA (Tier 4).
3	4	"Maintain or increase freight capacity."	Capacity is big enough to satisfy the requirement of need in Philadelphia.
4	4	"Cost-effective solution"	Cost of this shipping method is affordable/cheap.
5	3	"effective solution"	Speed of this shipping method is fast enough.

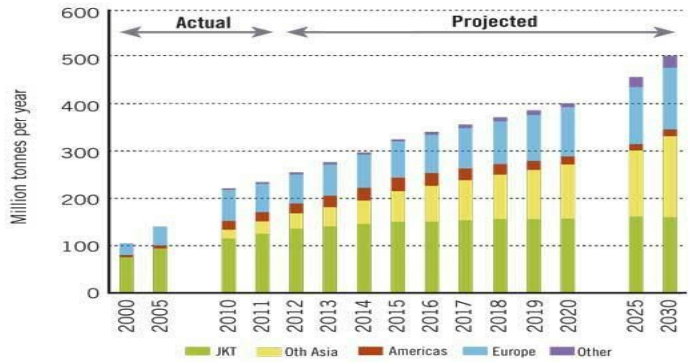
External Researches

Online research

Public opinion

- People around the Philadelphia complained about the smog from the locomotive emission; as the engineers working on reducing the locomotive emission, it has been reduced significantly. However, engineers try to develop the better method to locomotive to have larger capacity and less emission rate. First locomotive they developed, 'Tier 0', was used from 1973 through 1992. During this period, the emission from the locomotive was serious; city residents had critical complains about the smog from the locomotive emission. After Tier 0, through Tier 1 and Tier 2 (period from 1993 through 2011), they reduced significant amount of smog. They reduced more than 50% of emission from the locomotive. It was very great development to environment. Currently, the locomotive is on Tier 4; it is impressive progress compared to Tier 0 since they reduce approximately 80%. Even though the growth is appreciable, engineers are still working on reducing the EPA emission of locomotive.

Fig. 1: Global LNG demand



- Source: Ernst & Young assessment from multiple sources

According to the above graph, we can observe tendency of using liquefied natural gas all over the world.

1. **Biodiesel (diesel vehicles)**
   - Domestically produced
   - Renewable fuel (from vegetable oils, animal fats, recycled restaurant grease)
   - Similar properties to petroleum diesel, but cleaner-burning
     - Can substitute petroleum directly → US imports 1/3 petroleum and use 2/3 to fuel vehicles
   - Can reduce emission
     - Can reduce up to near zero levels of NOx
   - Less damage → safer
   - Price is more expensive
     - $2.88 for Diesel
     - $2.92 Biodiesel

2. **Electricity (Hybrid & Plug-In Vehicles)**
   - Can be sued to all-electric vehicles
   - Draw electricity directly from the grid and store its batteries
   - Boost fuel efficiency
   - Energy security and emission low

3. **Ethanol (Flexible Fuel Vehicles)**
   - Renewable fuel from corn and plant materials
   - Use is widespread
   - Contains less energy per gallon than gasoline
     - E85(gasoline-ethanol blend containing) reduce 27% less energy per gallon than gasoline
   - Can reduce imported oil and greenhouse gas emissions

- Energy security
  - Ethanol increased up to 10% of gasoline supply
- Lower Emission

4. **Hydrogen (Fuel Cell Vehicles)**
   - Used in a fuel cell
   - Domestic resources
     - From diverse domestic energy sources
     - Promise of offsetting petroleum
   - Emission-free alternative fuel
     - From diverse domestic energy sources
     - Health benefits is very great
       - Using these fuel for transportation
   - Fuel Storage
     - Content by volume is low
       - Requires high pressure
       - Low temp
       - Can be stored compactly

5. **Natural Gas (Natural Gas Vehicles)**
   - Produced gaseous fuel
     - Produced via conventional or renewable
   - Clean burning
     - Must be compressed or liquefied
   - Energy Security
   - Vehicle Performance
     - Similar to gasoline or diesel vehicles
     - Overall less energy content
   - Lower Emission
     - No evaporative emission

6. **Propane (Propane Vehicles)**
   - Liquefied petroleum gas (LPG)
     - PROPANE AUTOGAS
   - Worldwide use
   - Stored as liquid
   - Energy Security
   - Vehicle Availability
     - Can cost more than gasoline vehicle
     - Cost of propane is lower than gasoline
       - Investment can be quick
     - Offers comparable driving range
   - Fuel Economy and Performance
     - Potentially more horsepower
     - Low maintained costs
   - Public Health and Environment
     - Reduce harmful pollutant

7. Compressed natural gas (CNG)

- Natural gas under the pressure
  - Clear, odorless, non-corrosive
  - Most vehicles used
    - Can be used in place of gasoline, LPG, diesel fuel
  - Compressed less than 1 percent of volume that occupies
    - Less than liquid natural gas
- CNG combustion reaction produces less toxic products
  - an engine running on petrol for 100 km emits 22 kilograms of CO_2, while covering the same distance on CNG emits only 16.3 kilograms of CO_2
  - due to lessen CO2, it can possibly lessen greenhouse gas emission in future
    - Approximately 28 percent lower than the average gasoline fuel in that market (95.86 gCO_2e/MJ).

- Safer than other fuels
  - Lighter and disperse quickly
  - Prevent leaking → fuel loses X
  - Can be easily mixed with air
  - Less likely ignite -
- Problem
  - Cost and placement
    - Placement
      - Can take space of trunk or pickup truck
    - Cost
      - Lack of cost unity internationally

8. Liquid natural gas (LNG)

a) Converted into liquid

b) Easy to store and transport

1/1600th volume

Higher reduction of volume than CNG

Energy density is higher 2.4 times than CNG

Efficient for long distance

Used to transport into market

c) Odorless, non-corrosive, non toxic

d) Flammable after transferring into gaseous state

e) Liquidification

Removal certain components

1. Heavy hydrocarbon
2. Water
3. Acid gaseous

4. Helium

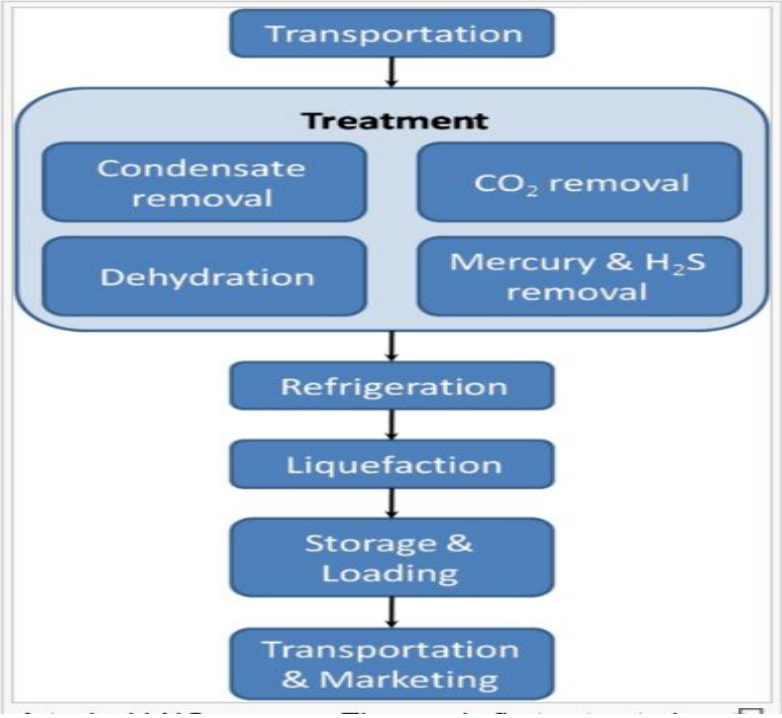
Converting into gaseous via atmospheric pressure by cooling it to approximately −162 °C (−260 °F); maximum transport pressure is set at around 25 kPa (4 psi).

f) High cost for production than CNG

Need to store in cryogenic tanks

1. Cryogenic tanks
   a) Production and behavior of materials at very low temperatures.
2. Widespread used

g) Storage



- **After treatment system**

After treatment system (ATS) is required for a dual fuel locomotive; engine of the locomotive can run both natural gas and diesel fuel simultaneously. By applying a dual fuel system, it can reduce the level of emission and save tremendous of fuel costs. Approximately, one locomotive can save $ 300,000 per year. Also aspect of environment is benefited; it can drop emission rate of CO, hydrocarbons, and non-methane below Tier 3. Emission level of Tier 3 reduces up to 80% compared to Tier 0 – it indicated ATS will be innovative development. GE is expected a dual fuel locomotive will be conducted in 2015 and produce finalized a dual locomotive in one year later. Tier 4 locomotive (using a dual fuel locomotive) will be materialized no later than 2016. Tier 4 locomotive expected to reduce emission rate over 80% of all pollutants.

Tier 4 compared with Tier 0

	Tier 0	**Tier 3**	Tier 4	**Reduction rate**
HC (g/hp-hr)	2.10	0.60	0.14	93.33%
NOx (g/bhp-hr)	11.8	5.0	1.3	88.98%
PM (g/bhp-hr)	0.26	0.1	0.03	88.46%
CO (g/bhp-hr)	8.0	2.4	2.4	70%

Smoke (percentage)	30 / 40 / 50	20 / 40 / 50	-	-

Diesel-filter method

In diesel exhaust, NOx and particulate matter are called “Soot”. A diesel particulate filter can remove up to 90% all soot particulates produced from the exhaust gas process. There will be more quantity of nitrogen increases if fewer soot particulates are produced in the combustion process. Thus, adding this after-treatment method is necessary to fulfill the emission requirement.

Benefits

- Consume as little space as possible
- Serve on a long period of time
- Easily replace the engine with a new version to conform with new emission standards
- Diesel particulate filter also acts as a silencer.

NH3 based

This after-treatment method has to be generated on-board from a suitable reductant since transporting pure ammonia is not advisable.

Limitations of the method:

• Reliable urea injection

• Uniform ammonia distribution in the exhaust

• NOx neutral SCR-catalyst heating-up strategy

• Dosing strategy

• Ammonia slip

• Vehicle package

• System costs

High NOx conversion efficiencies can only be achieved using the SCR technology with NO2 ratios of about 50% in the exhaust as well as significant ammonia storage on the SCR catalyst. This requires a sophisticated control strategy to avoid ammonia slip. Besides that, the evaporation and mixing of the liquid urea/water solution has to be guaranteed under 5 such low exhaust temperature conditions. Furthermore it has to be taken into account, that an SCR catalyst cannot be positioned really close-coupled to the turbocharger outlet, as there is always a certain length in the exhaust line required for the urea injection and appropriate mixing.

Exhaust gas recirculation

Introduction:

It's a technology designed to reduce significant amount of NOx in most diesel engines. However, this technique needed to be combined with other changes to avoid sudden raise in fuel consumption, such as

- reductions in lubricating oil consumption,
- increases in fuel injection pressure,

- increased use of diesel oxidation catalysts, and
- increased intake manifold boost pressure.

A little bit on the background:

Table: Commercial Application of EGR Systems on Diesel Engines

Commercial Application of EGR Systems on Diesel Engines

Emission Legislation	NOx Limit	Areas of EGR Application
Light-Duty Vehicles		
Euro 1/2 (1992/96)	NOx+HC = 0.97-0.7 g/km	Introduced in DI and larger IDI Euro 1 engines, EGR (non-cooled) became the main NOx reduction strategy in nearly all Euro 2 vehicles.
Euro 3/4 (2000/05)	NOx= 0.5-0.25 g/km	Cooled EGR introduced in larger size Euro 3 engines, and became the standard in Euro 4 and later diesel passenger cars and light trucks.
Heavy-Duty Engines		
US 2004 (2002-04)	NOx ≈ 2 g/bhp-hr	Cooled EGR introduced on heavy-duty truck and bus engines by most manufacturers (Cummins, Volvo/Mack, DDC, International). Miller-type intake valve timing was the alternative technology to EGR (Caterpillar).
Euro IV (2005)	NOx = 3.5 g/kWh	EGR introduced by some manufacturers of heavy-duty truck and bus engines

		(Scania, MAN); used in competition to urea-SCR technology.
Japan 2005	NOx = 2.0 g/kWh	EGR introduced by some manufacturers of heavy-duty truck and bus engines (Hino, Isuzu); used in competition to urea-SCR technology.
US 2007	NOx ≈ 1 g/bhp-hr	EGR used on heavy-duty truck and bus engines by all manufacturers.
Euro V (2008)	NOx = 2 g/kWh	EGR continues to be used in some products by several OEMs (Scania and MAN), however, no OEM relies solely on EGR. Urea-SCR is still the competing technology.
US 2010	NOx = 0.2 g/bhp-hr	EGR combined with NOx credits allows one heavy-duty diesel engine manufacturer (Navistar) to certify engines to a 0.5 g/bhp-hr NOx level. All other manufacturers rely on a combination of EGR and urea-SCR.
Euro VI (2013)	NOx = 0.4 g/kWh	Most manufacturers intend to use a combination of EGR and urea-SCR. The competing technology is urea-SCR without EGR (Iveco).
Nonroad Engines		
US Tier 3 (2006)	NOx = 4.0 g/kWh	Cooled EGR engines introduced by John Deere. A number of other

		manufacturers used internal EGR.
US Tier 4i / EU Stage IIIB (2011)	NOx ≈ 2 g/kWh	Cooled EGR introduced by a number of nonroad engine manufacturers; used in competition to urea-SCR technology.
IMO Tier III (2016)	NOx = 3.4 to 1.96 g/kWh	EGR will be used in some two-stroke low-speed marine diesel engine applications (MAN Diesel & Turbo). Ammonia-SCR is an important competing technology.

How it works:

The components of the exhaust gases mainly are carbon dioxide, nitrogen, etc.; therefore the mixture has higher specific heat than atmospheric air. Fresh air after entering the combustion chamber will get displaced with carbon dioxide and water vapor present in engine exhaust, thus, lower the amount of needed oxygen and effective air-fuel ratio. Also, mixing exhaust gases with intake air will increase specific heat, reducing the temperature of flame -> Reducing rate of NOx formation reactions. The EGR % is the mass percent of the recirculated exhaust (MEGR) in the total intake mixture (MI).

At lower load, diesel engines can tolerate a higher EGR ratio because recirculating exhaust gases contain high concentration of oxygen and low concentration of carbon dioxide and water vapors. At higher loads, the amount of oxygen is reduced and the inert constituents start dominating along with increased exhaust temperature, thus producing more smoke compared with lower load

Piston design:

Requirements:

- High power output
- High thermal efficiency and low specific fuel consumption
- Smooth engine operation Smooth engine operation
- Reduced exhaust pollutants.

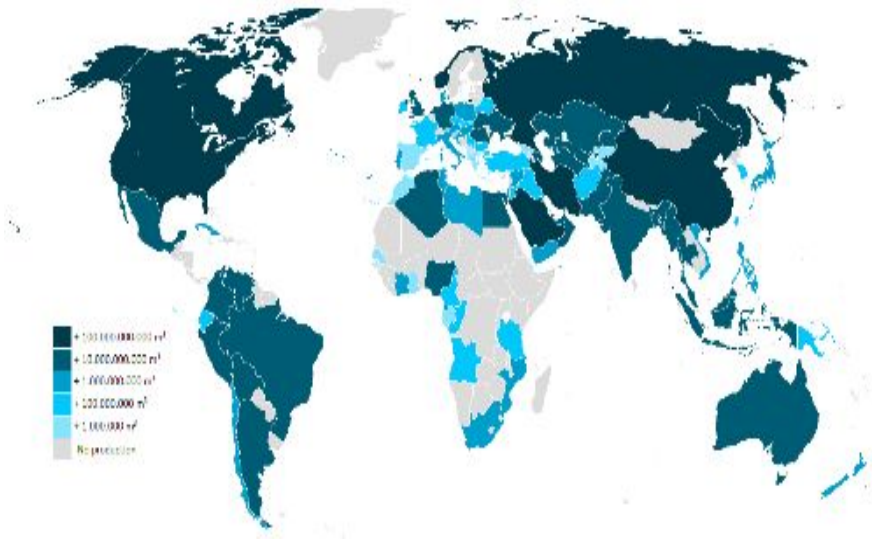
For higher power input:

- High compression ratio.
- Small or no excess air
- Complete utilization of the air –no dead pockets. no dead pockets
- An optimum degree of turbulence.
- High Volumetric Efficiency
- High thermal efficiency
- High compression ratio
- A small heat loss during combustion.
- Good scavenging of the exhaust gases

Smooth engine operation requires:

- Moderate rate of pressure rise during combustion.
- Absence of detonation which in turn means
- Compact combustion chamber:
- Proper location of the spark plug and exhaust valve
- Satisfactory cooling of the spark plug and of exhaust valve head which is the hottest region of the combustion chamber.

- Reduced exhaust pollutants



Concept generation and selection

- **Comparison between four kinds of shipping methods**

		Concepts							
		A		**B**		**C**		**D**	
		Train		Ship		Truck		Airplan	
Selection Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Wed S**
Cost	25%	4	1	5	1.25	3	0.75	1	0
Environmental Friendly	30%	4	1.2	5	1.5	2	0.6	2	
Capacity	25%	5	1.25	4	1	3	0.75	2	
Time	15%	3	0.45	1	0.15	4	0.6	5	0
Availability	5%	5	0.25	2	0.1	5	0.25	2	
	Total Score	4.15		4		2.95		2.2	
	Rank	1		2		3		4	
	Continue ?	Yes		No		No		No	

- GE is a big company that involves many kinds of shipping methods business, so our group wants to analyze good and bad of them to sift a best methods. We valued the importance of each need statement at first, and then summarize five selection criteria for judgment between four kinds of shipping methods. After processing concept selection, we choose train as a priority.

- **Comparison between three options**

Plan 1: Sell existing Tier II locomotive and purchase new Tier IV locomotive

- Cost of Engine:

Sell out Tier II $1.5 M + Buy Tier IV $4M = Total cost of equipment: $2.5M

- Cost of Fuel (diesel)/day: $648326.2
- Effective interest rate of Tier IV: 1-3%

Present price: $4M 10 years later price ≈ $4.88M

- Emission (reach standard of Tier IV): 0.03 g/hp-hr PM 1.3 g/hp-hr NOx
- Speed: 75 mph

Plan 2: Upgrade Tier II locomotive to Tier III with exhaust after-treatment hardware

- Cost of Engine:

Tier II→Tier III $750K + Aftertreatment (Diesel Exhaust After-Treatment System Using Ammonia) $100K = Total Cost $850K

- Cost of Fuel (diesel)/day: $588082.1
- Effective interest rate of Tier III: 2-3%

Present price: $3M 10 years later price ≈ $3.84M

- Emission (reach standard of Tier IV): 0.1 g/hp-hr PM 5.5 g/hp-hr NOx
- Speed: 68 mph

Plan 3: Utilize alternate fuels which may produce less NOx

We compare three kinds of fuel: diesel, liquefied natural gas, and compressed natural gas. When a coal train, which is 38 tons, with 117 tons coal, travels 500 miles:

		Coal Train	
		Full	Empty
Diesel	Amount Consumed (gallon)	12765.96	2321.08
	Cost ($)	31914.9	5802.7
	Weight (lbs)	95744.7	17408.1
	Space Occupancy (ft^3)	1706.68	310.3
Liquefied Natural Gas	Amount Consumed (gallon)	19847.45	3608.62
	Cost ($)	7938.98	1443.45
	Weight (lbs)	69466.08	12630.17
	Space Occupancy (ft^3)	2653.4	482.44
Compressed Natural Gas	Amount Consumed (gallon)	13555972.47	2464718.41
	Cost ($)	135559.72	24647.18
	Weight (lbs)	81335	14788
	Space Occupancy (ft^3)	1812295.72	329507.81

Use a concept selection to summarize data:

	Concepts		
	A	B	C
Selection Criteria			

	Diesel	Liquefied Natural Gas	Compressed Natural Gas
Environmental Friendly	-	+	+
Cost	0	+	-
Weight	-	+	0
Occupancy	+	0	-
Easy to store	+	-	0
Sum +'s	2	3	1
Sum 0's	1	1	2
Sum -'s	2	1	2
Net Score	0	2	-1
Rank	2	1	3
Continue?	No	Yes	No

- Finally, we evaluate liquefied natural gas as the best fuel. Compared to diesel, most of emission of liquefied natural gas is CO2 and H2O, which is more environment friendly. Also, LNG has a lighter weight. Although its' occupancy is larger than diesel, the difference is not much. The obvious disadvantage is difficulty of storing LNG, but new technology can overcome it in the future. Another fuel, compressed natural gas, is seemed that it has low price per gallon. Nevertheless, because of low energy released from combustion, CNG will occupy large space and in fact total price of it is highest.
- Also, effective interest rate of natural gas is 3.25% and effective interest rate of diesel is 3.5%. For an individual or a company, the lower effective interest rate is better.

- Cost of Engine:

Locomotive upgrade $1M + Fueling Station $1B = Total Cost: $1001K

- Cost of Fuel (liquefied natural gas)/day: $141291.7
- Emission (reach standard of Tier IV): ≈0 g/hp-hr PM ≈0 g/hp-hr NOx
- Speed: 50 mph

Concept selection between three options

		Concepts					
		Plan 1		**Plan 2**		**Plan 3**	
Selection Criteria (10 years)	**Weight**	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Cost	25%	2	0.5	3	0.75	4	1
Environmental Friendly	40%	4	1.6	2	0.8	5	2
On Time Delivery	20%	5	1	4	1	3	0.6
Public Opinion	15%	4	0.6	3	0.45	4	0.6
	Total Score	3.7		3		4.2	
	Rank	2		3		1	
	Continue ?	No		No		Yes	

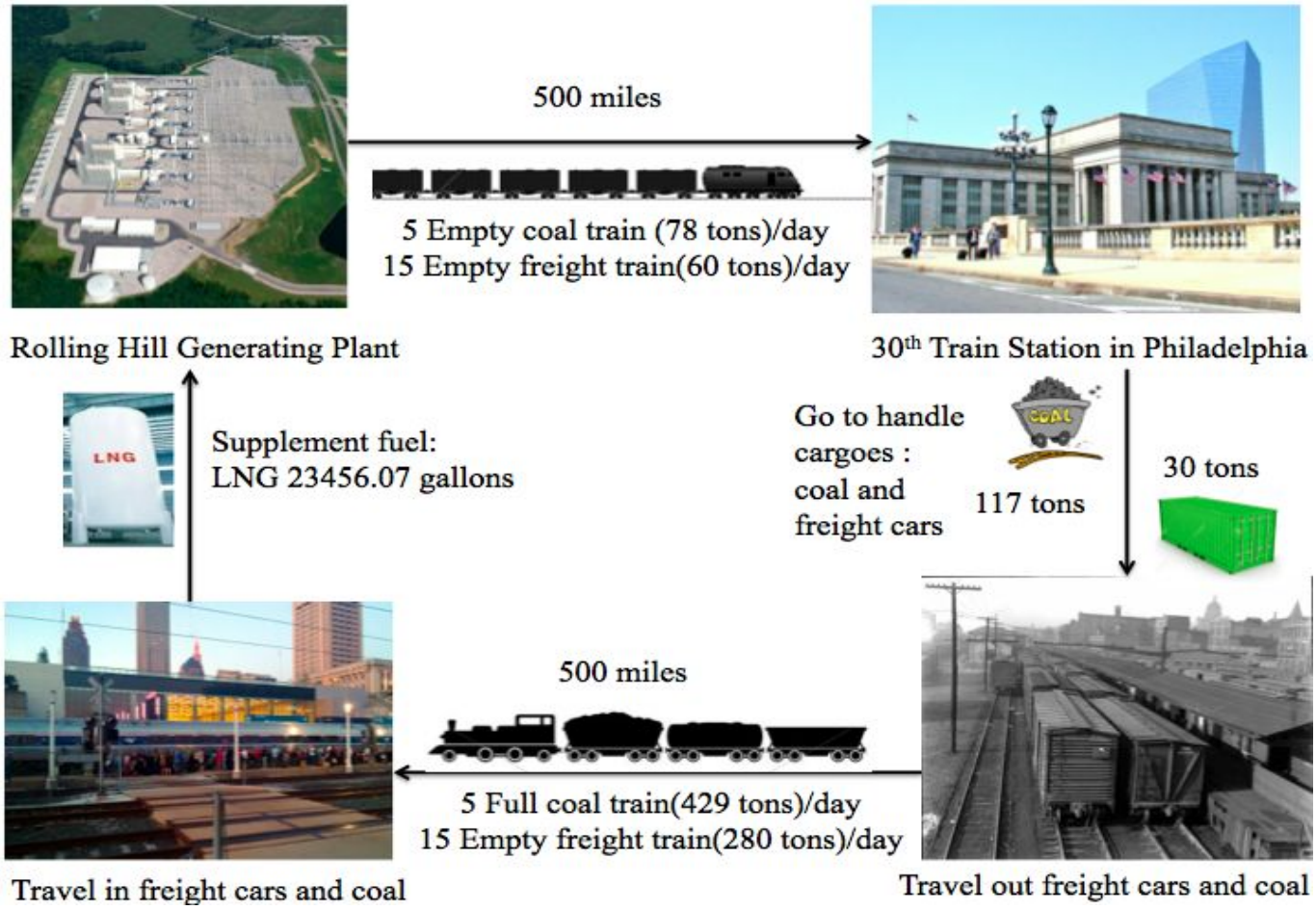
- According to the customer needs, we set four selection criteria for concept selection. Using the way of concept screening, our group decide to choose the third option.

When scoring each criterion, we consider ten years as the standard of time, because managers of big companies like GE should possesses foresight and concentrate on profit of long run. According to our calculation, the extra money paid for the third plan at beginning will be earned back in short years. Difference between plan 3 and plan 1 will be filled in 6 years. And difference between plan 3 and plan 2 will be filled in 7 years. Since then, plan 3 will be the most cost-effective.

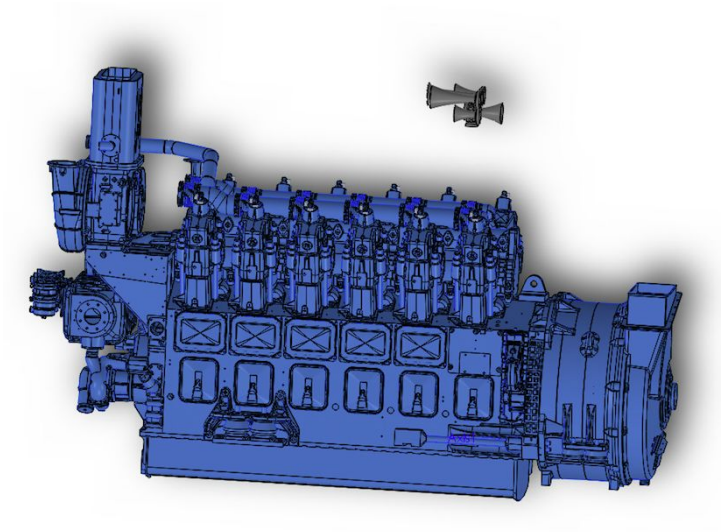
METRIC & MATRIX OF LAST CHOICE

Metric #	Need #	Metric	Unit	Value
1	2	NOx Emission	g/hp-hr	≈0
2	2	PM Emission	g/hp-hr	≈0
3	4	Cost of fuel	$/day	141291.7
4	4	Total Cost for engine	$	1001k
5	5，2	Speed	mph	50
6	5，2	Horsepower	hp	4500
7	3	Capacity	ton	105

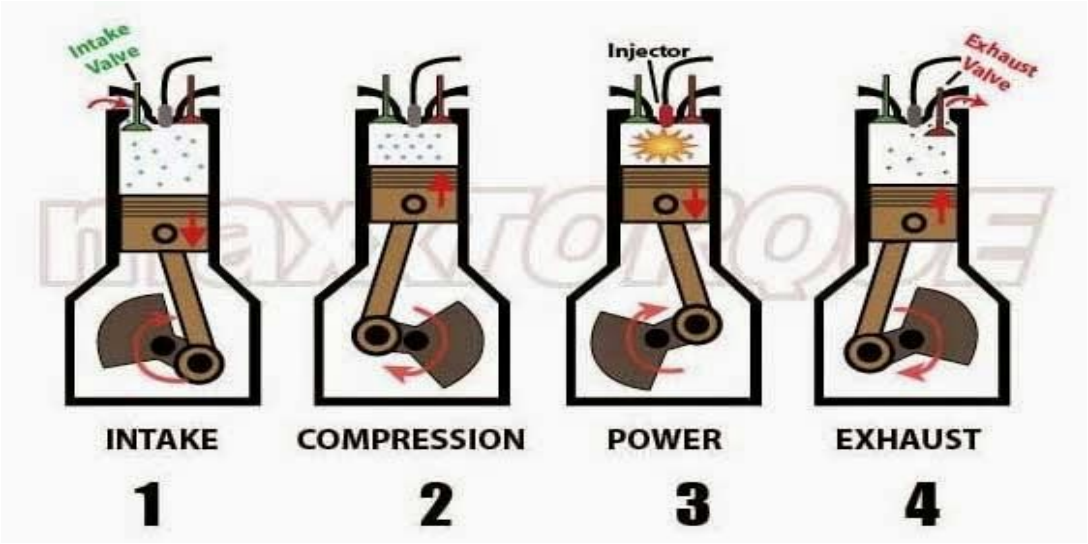
System cycle diagram



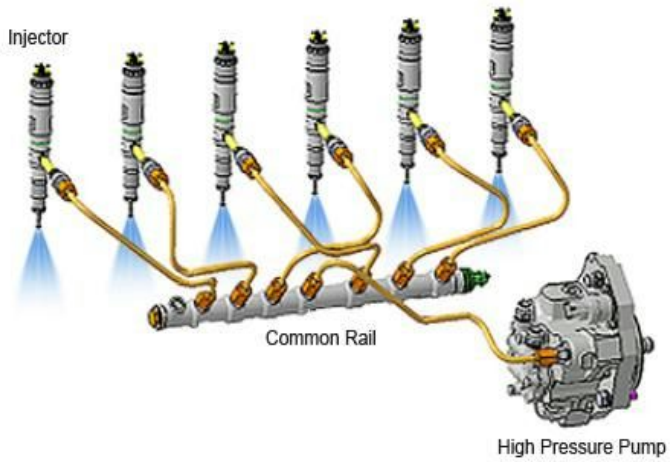
Detailed Design of Engine

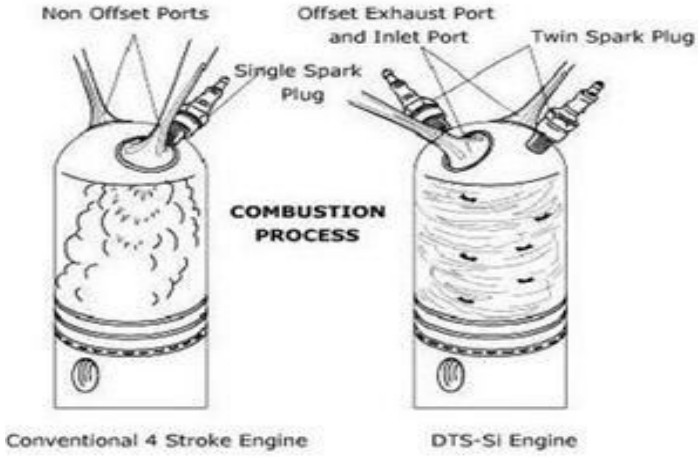


- Main component of natural gas is methane with a little bit nitrogen. According to research, the ignition point of methane is 900-1500 ℃, and ignition point of nitrogen is above 1600 ℃. That means when LNG combust, temperature is not easy to reach nitrogen's ignition point. Still, in order to decrease the small possibility of combustion of nitrogen to the largest extent, we design to add two after- treatments on engine: high pressure common rail and air flow control through valve timing. These two after-treatments allow more air to flow into combustion chamber and help completely burn. Also, abundant oxygen improves efficiency of combustion and decreases emission of carbon dioxide.



High pressure common rail **Air flow control/valve timing control**


Injector
Common Rail
High Pressure Pump


Non Offset Ports
Offset Exhaust Port
and Inlet Port
Twin Spark Plug
Single Spark
Plug
COMBUSTION
PROCESS
Conventional 4 Stroke Engine
DTS-Si Engine

Cost Model

TOTAL cost of engine

Locomotive upgrade $1M

+Fueling Station $1B

= Total Cost: $1001K

cost of fuel (LNG)/day

	Amount Consumed (gallon per trip)		Cost of Fuel ($ per trip)	
	full train	**empty train**	**full train**	**empty train**
Coal Train	19847.45	3608.62	7938.98	1443.45
Freight Train	12954.04	2775.87	5181.62	1110.35

5 coal trains/day + 15 freight trains/day

Total cost of fuel/day: $141291.7

Design

HPCR-High pressure common rail (fuel injection system)

This is considered as the greatest advancement in the past 10 years in engine design.

Benefits:

- **Lower costs** – As the fuel burns more completely, the engine needs less of it to run.
- **Cleaner exhaust** – Less unburned fuel is left behind in the exhaust.
- **Better performance** – Multiple injections during each combustion cycle means that combustion lasts longer, creating more energy and more output

How it works:

The pressure for injection is developed by the high-pressure fuel pump (1), which is mechanically operated by the engine. A common fuel rail (3) connects each injector from the fuel pump; hence where the terminology of Common Rail originated. The design of this system is such that a constant fuel pressure is available at the injector 100% of the time during engine operation thus providing a higher available mean time injection pressure over EUI designs. This feature ensures that fuel droplets are atomized the moment they leave the injector nozzle. As EUI systems must develop the fuel pressure during the injection event, they have a tendency to form larger droplets at the start and end of each injection event. HPCR injection systems are also able to regulate fuel injection pressure based on engine requirements, speed and duty using the engine ECU combined with the fuel pump.

With a large high-speed diesel engine operating at 1400 RPM, the fuel injector is capable of injecting fuel into the combustion chamber in varying quantities depending on the ECU outputs, up

to 1,750 times per minute, or 29 times per second with the fuel exiting the injector tip at speeds in excess of 700 miles per hour.

Valve timing

In a piston engine, valve timing is the precise timing of the opening and closing of the valves. In an internal combustion engine, they appear in the form of poppet valves and in steam engine, they are usually slide valves or piston valves. The fully variable timing state can be achieved only after using computer-operated solenoids to control the exact amount while intake and exhaust valve opening (or close) events take place. Valve timing applications are rather limited due to issues of cost and reliability

This design is very dependent on the levels of velocities of the intake and exhaust gases. When the gases moves at lower speed, the valve should close early to prevent the intake air being pushed back into intake port and manifold. If the velocities increases, the valve will close later to help store more gas into the cylinder. Most VT designs begin to change intake valve timing when intake air velocities begin to increase at 2,500 to 3,500 rpm while the actual operating strategy depends upon the engine design and the speed limitations of the engine.

At high engine speed, valve timing overlap is desirable, since it allows the engine makes use of the slight negative pressure caused by exhaust gases. At lower speed, high valve timing overlap produces a loping idle, thus reducing the engine running compression. Changing the exhaust valve timing can create the “EGR” effect that helps reducing NO emissions in some applications

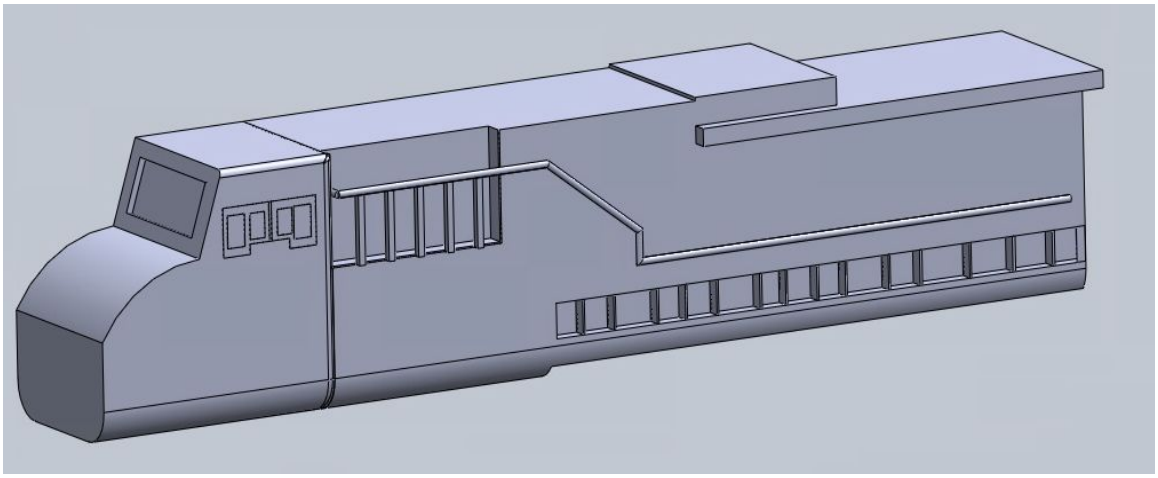
Benefits:

- **Internal exhaust gas recirculation:** By allowing for more direction for internal gases, the system can cut down on emissions
- **Increased torque:** Variable valve timing systems can provide better torque for an engine
- **Better fuel economy:** with more precise handling of engine valves

- **Low RPM Drivability:** When running at lower RPM, the engine uses a camshaft with a profile designed to provide a smooth idle, good fuel economy and better low end power and torque
- **Electronic monitoring and switch:** The engine's computer monitors the operating conditions, decides automatically when to switch to a different camshaft profile
- **High RPM performance.** The high-performance camshaft provides the vehicle with considerably more power at high RPM's.

Model

3D SOLIDWORKS MODEL



- The Solidworks model exhibits the outside appearance of the locomotive.

3D MODEL MADE BY CARDBOARD

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