

Chapter 2

Rail Transportation

2.1 Introduction

Transportation has been a critical issue to the humankind over the centuries, and it has shaped the past, is shaping the present, and will definitely shape the future. Human activities depend essentially on transportation; movement of goods and commodities, persons, and even communication via mail delivery services.

The sources of energy for propelling transportation activities vary throughout history, evolving in parallel with the development of communication systems. This relationship between transportation and communication has important social implications. The railway transport, in particular, is vital in times of crises, emergency situations, and when the military mobilization is necessary. The railway transport has the ability to provide redundancy during emergencies.

In antiquity, special systems were developed to transmit messages, strategic information, and goods within various jurisdictions. The postal transport within the Roman Empire employed the “*cursus publicus*,” special walking couriers, who delivered messages between the postal mansions constructed 40 km apart from the main communication road. The same roads were used for land transport of larger goods by animal-pulled vehicles. This mode of land transport continued until the industrial revolution of the eighteenth century when the invention of steam engine and the rail transport gradually occurred. In its early development stages, rail transport was used in conjunction with mining operations, slowly reaching technological maturity by the mid-nineteenth century. The development of steam locomotive and the invention of the wrought iron rail technology were the two crucial factors that led to the establishment of the modern railway transportation.

The modes of rail transport are very diverse nowadays, as they involve complex operations and infrastructure. This chapter discusses the role of rail in transportation systems, its current status, and the opportunities for sustainable transportation solutions across the sector through clean rail development.

2.2 Rail Transportation Overview

Rail transport is employed to mainly carry passengers and goods (especially cargos), and can run on both single fixed-type and dual-type rails. It essentially covers light rail, heavy rail, and tram as well as funicular and monorail rail means. They provide numerous advantages, ranging from economic to social and energetic to environmental, which makes rail transport the best land transportation option for passengers and goods. It also appears to be the best public transportation option based on several criteria, such as number of passengers carried, congestion-free traffic, reduced amount of fuels and hence reduced amount of emissions per passenger, reduced cost, reduced road accidents, increased safety, increased speed, reduced use of land, better use of existing infrastructure, etc.

Rail transport has a well-established position among the transportation modes for passengers and freight. Figure 2.1 shows a classification of the passenger transportation modes. As well understood, transportation can be done on roads, air, rail, and sea. Passenger air transport differentiates two modes, namely scheduled and charter flight with the overwhelming majority of carriers being jet airplanes. Road transport is the most varied with respect to transportation means, starting from pedestrian, bicycle, motorcycle, automobile, and bus (coach). Rail transport vehicles for passengers can be categorized as: transit (commuter) trains, high-speed rail, and intercity rail, and also includes railcar on the streets in towns.

The maritime passenger transport is less used today due to its slow mode. The most used is the ferry transport, which actually can transport the pedestrians and passengers riding in all types of road vehicles. Cruise ship is mainly used for leisure transport. Figure 2.2 shows five types of freight transportation modes, namely, air, road, rail, maritime, and pipeline. As seen, the freight rail transport differentiates two modes, the unit train and carload. Furthermore, the rail, road, and maritime

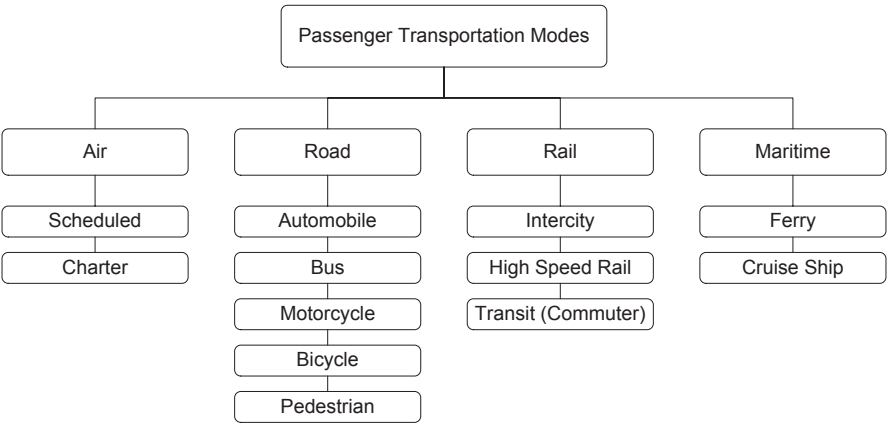


Fig. 2.1 Major passenger transportation modes. (Adapted from [17])

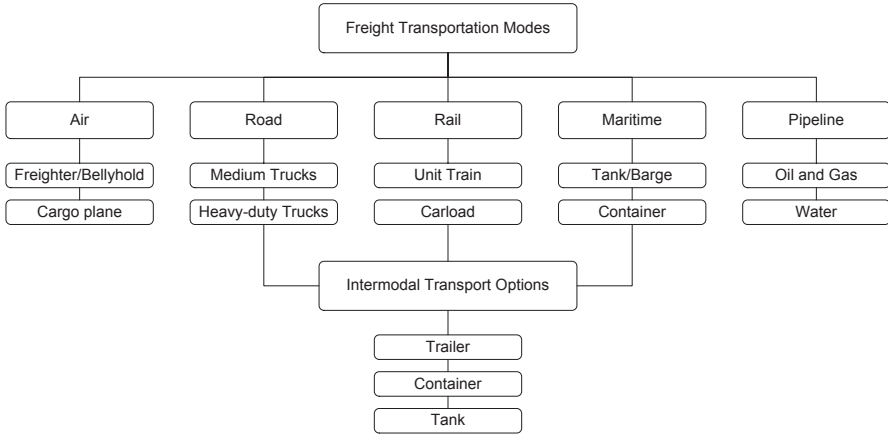


Fig. 2.2 Major freight transportation modes. (Adapted from [17])

transport integrated the unitary in the so-called intermodal transport. Three options are available for the intermodal transport: trailer, container, and tank.

Rail transport appears to be a widely used transportation mode in many countries. As a relevant example, in Germany, railway length is approximately 35,000 km, being the second largest in that country after the long-distance federal roads. Diesel is the primary fuel in North America for railway transport, while several countries, including European countries and Japan, use electricity as a primary source of energy for rail transport. Some developing countries, such as China and India, still use coal as the energy source. The energy consumption for rail transport is in-between the road truck transport and inland and coastal ship transport with approximately 400 kJ/t km.

When we look at the railway sector for the transport of passengers and goods, we observe an increasing use of this mode in almost every country due to the above-mentioned advantages, which may be generalized into four key benefits, namely, safety, rapidity, cost effectiveness, and environmentfriendliness. The growth in rail transport is expected to be doubled in the next decade by considering the economic growth in fast-developing countries, including China, India, and Turkey.

Several countries, such as Turkey, have developed strategic plans to go for speedy trains and started implementing their plans in a massive manner. The high-speed trains represent a complex development involving interdisciplinary aspects related to the prime mover development (with the use of high tech and advanced designs), rolling stock operations, traffic system and signaling, special rail infrastructure, commercial, and managerial issues.

In the subsequent paragraphs, some relevant information on high-speed trains is given, as summarized from Ref. [18]. The high-speed trains run at a speed of over 250 km/h, whereas the speed of conventional trains is limited to about 200 km/h. The high-speed trains currently in use can attain a speed of over 500 km/h; however,

the practical maximum speed in operation is about 350 km/h. The braking distance from a speed of 350 km/h is of about 6.7 km.

It appears that high-speed train has the highest passenger-kilometer carried per unit of energy among all means of land transport. In addition, the land use for high-speed railway is three times smaller than land use of a motorway in terms of hectare per kilometer. Furthermore, all high-speed trains are electric trains operating with single phase current at 15–25 kV with typical frequencies of 50 Hz or 60 Hz. However, the construction and maintenance cost are relatively high. The capital cost of railway infrastructure is in average US\$20 million per km with an annual maintenance of 0.5% of the capital cost in railway. The specific capital cost on high-speed passenger trains is approximately US\$80,000 per passenger seat, and typically a train has 350 seats. The train requires a maintenance cost of US\$4 per km while it travels approximately 400,000 km/year.

The high-speed trains worldwide increased since 1964, when the first train was put in operation on the line between Osaka and Tokyo; growing from a few hundred kilometers, to 30,000 km in 2014 with prospects to reach over 40,000 km after 2025, with the rail operating up to 15 trains per hour. The high-speed trains are more effective for travels longer than 300 km, for which the actual travel time will be less than half when compared with the conventional transportation vehicles.

The freight railway transport represents the least costly alternative for massive, heavy, bulky commodities, and hazardous materials, being critical to the development of in-land industries. The reason for this fact is not only better energy efficiency and fuel economy of the rail transport with respect to truck transport, but also a better ability to carry massive products. According to the US statistics, the railway transport consumes less than 0.7 L of diesel fuel for 100 km to transport 1 tonne of freight [19]. In addition, the emission factors are better for the rail transport than for the trucking. As of today, if 10% of the freight transported by road trucks are transported by rail freight, then 2.5 millions of carbon dioxide emissions would be mitigated [19].

Most hauled products of the rail freight transport include: grains, corn, soybean, corn syrup, ethanol, traffic control equipment, electro-mechanical equipment, machinery parts, HVAC equipment, lead-acid batteries, construction-related products (including railway pavement materials), drywall, paper products, aluminum, steel, sheet metal, structural steel, tubing, bars, steel profiles, studs, wood, glass, mirrors, office supplies and furniture, paints, solvents, detergents, cement, lime, aggregates and ready mix, automobile and truck repair parts, bottled water, specialty gases, and cars. Coal is the commodity that is mostly transported by the freight-rail. It follows farm products and non-metallic minerals, chemicals, and then food products.

There is a large variety of railcars for freight transport, namely, intermodal container on flat car, intermodal trailer on flat car, intermodal double stack, liquid-bulk tank car, open flat car, hopper car, box car, and cryo-car. Worldwide, an annual growth of few percent in the freight rail transport is remarkable.

It should be noted that the need for new locomotives has decreased by over 20% during the past three decades due to the technological developments and improvements in locomotives and their systems. Such improvements and developments

have helped to improve the overall efficiency by more than 25%. There are even more potential integrated systems to improve the performance of the locomotives further and make them more efficient, cost effective, and environmentally benign. Such novel systems are described in detail in Chap. 6, and the case studies related to these integrated systems are presented in Chap. 8, based on various criteria, such as efficiency, cost and environmental impact.

2.3 Rail Transportation Infrastructure

Clean transport has been identified as a critical area of research in numerous countries, such as Canada, which aims to meet the mobility needs of the country and provide more efficient, more cost effective, and more environment- friendly transportation solutions to the people and goods, at the same time reducing the associated harmful effects on humans and other living species as well as the environment. In recent decades, there has been an overall improvement in the energy efficiency of transport in these countries as well.

To contextualize rail within the global transportation sector, it is important to first introduce the general characteristics of all transport systems, technical, operational, and commercial factors affecting the selection of a certain mode of transportation. Not only the locomotives and their design are important in the railway operation, but also the rail infrastructure, maintenance issues, and ownership (private or state owned companies). The railway system in North America operates as a unitary infrastructure as it allows for interchangeability and interoperability of line-haul locomotives and railcars everywhere across Canada, USA, and Mexico. In North America, the railroads are classified in three classes. If the railway carrier revenue is over US\$250 million yearly (given in 1991 dollar indexed value), then the railroad is denoted as Class I. Some important Class I railways in North America are named here as:

- Union Pacific (UP) railway with more than 31,000 route miles and 8000 locomotives (major freight—fuels)
- Burlington Northern Santa Fe (BNSF) railroad with more than 32,000 route-miles and 7000 locomotives (major freight—consumer products)
- Canadian National (CN) railway with more than 22,000 route-miles
- Canadian Pacific Railway
- CSX Transportation (major freight—coal, coke, and iron)
- Norfolk Southern Railway (major freight—coal, coke, and iron)
- Kansas City Southern Railway
- VIA Rail (in Canada)
- Amtrack (in USA).

The railroads categorized under Class II are destined to freight transport of mid-sized revenue, greater than US\$37 million per year but smaller than US\$433 for

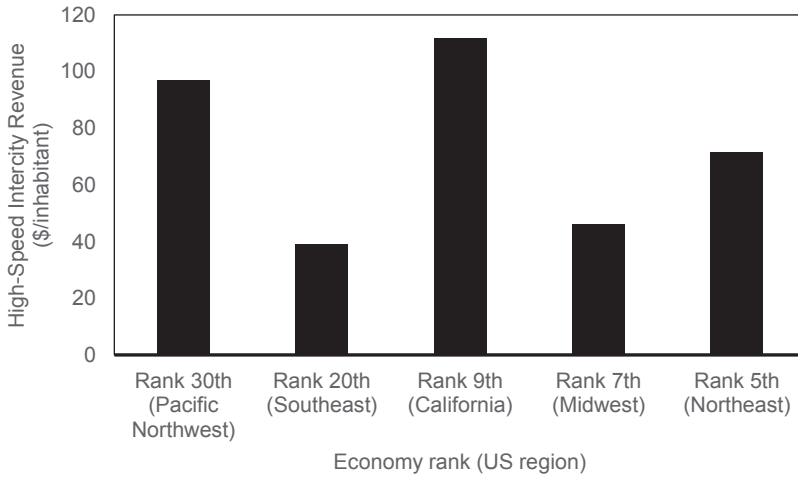


Fig. 2.3 A specific high-speed intercity revenue of railway operator correlated with the worldwide economy of the USA region. (Data from [19])

three consecutive years. The Class III railroads are of short distance with revenues less than US\$20 million per year.

The freight-rail transportation in USA carries 16% of the total freight tonnage representing 28% of total tonne-km or approximately 6% of the total freight which has been valued at US\$600 billion in the year 2000 [19]. It is recognized that the freight-rail transport will enhance by 50% by 2020 with respect to today. The average length for rail-freight transport is approximately 1000 km at a cargo cost, which is three times lower than for trucking. Regarding the passenger rail transport, this increased steadily during the years. The speed of intercity railway is of over 200 km/h in North America with more than 1500 track-km in USA. Figure 2.3 shows a correlation between the railway revenue for the high-speed intercity passenger transport in the USA and the rank of the economy.

The Canadian locomotive fleet is made up of nearly 3000 locomotives servicing the freight and passenger transportation operations (Table 2.1). Freight locomotives and operations make up the majority of rail operations, representing more than

Table 2.1 Canadian locomotive fleet for 2011. (Source: [20])

Locomotive fleet	2978
Freight operations	2731
Passenger operations	247
Diesel fueled	2933
EPA emission limit compliant	1433
Tier 0/0+	517/170
Tier1/1+	111/94
Tier 2	541

EPA Environmental Protection Agency

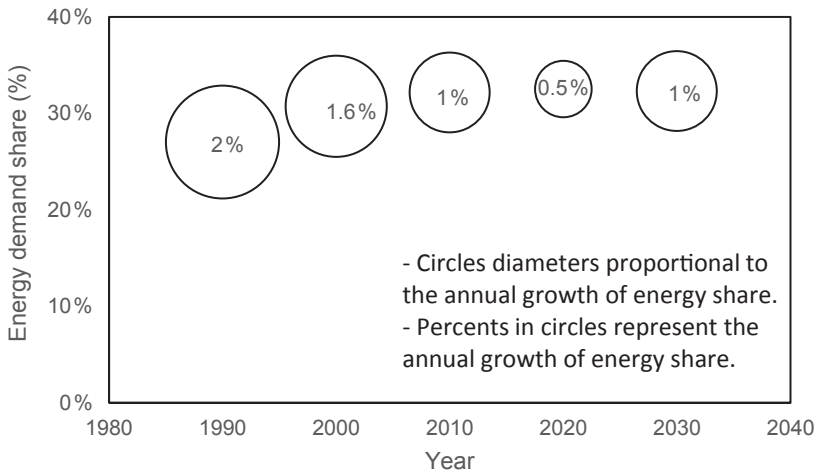


Fig. 2.4 Annual share of energy demand for transportation sector in Europe. (Historical records and predictions until 2030; data from [21])

90% of the Canadian locomotive fleet. The fleet is almost entirely of diesel-electric locomotives, operating with either two-stroke or four-stroke prime mover diesel engines that are coupled with an electric alternator/generator to convert shaft power to electric and power the traction motors and control systems.

The railway industry has a great growth potential. Major transportation corridors continue to develop. The capital expenditures were US\$54 billion in the USA for the 1990 decade, of which 67% is infrastructure investment and the rest equipment. Although the capital expenditures with respect to revenue are four times higher than all manufacturing processes, the investment is safer [19]. Since the rail transportation sector is predicted to grow, the associated energy demand with this activity must increase. In Ref. [21], it is shown that not only energy but also the energy share of transportation sector in general with respect to other sectors of activity is predicted to steadily increase. This fact is illustrated graphically as shown in Fig. 2.4. The share of rail transport with respect to other transportation mode is predicted to be around 6.5% in Europe. However, the railroad transport is predicted to grow and double in every year until 2030, as shown in Fig. 2.5.

2.4 Rail Transportation Challenges

Projections of Canada’s green house gas (GHG) emissions for 2020 based on current emission reduction strategies exceed the Copenhagen target level by more than 100 megatons (Fig. 2.6). Significant effort is necessary in order to close this gap. Fossil fuel combustion is the primary source of GHG emissions—approximately 75% of total GHG emissions [22]—mainly from stationary and transportation combustion sources.

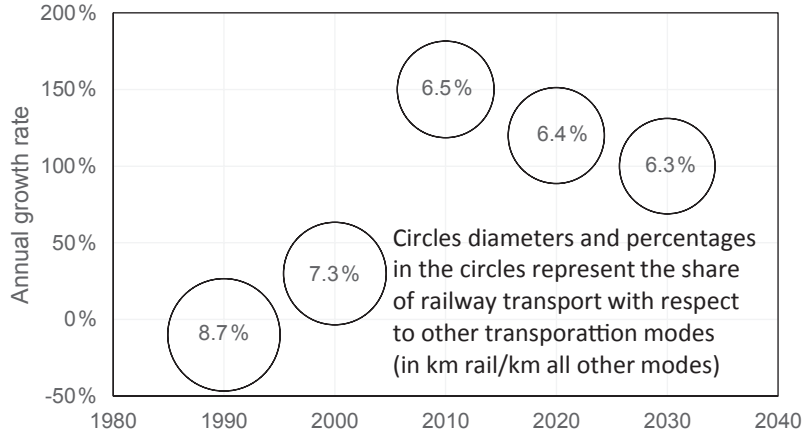


Fig. 2.5 Annual growth rate and the share of rail transport versus other transportation modes in Europe. (Data from [21])

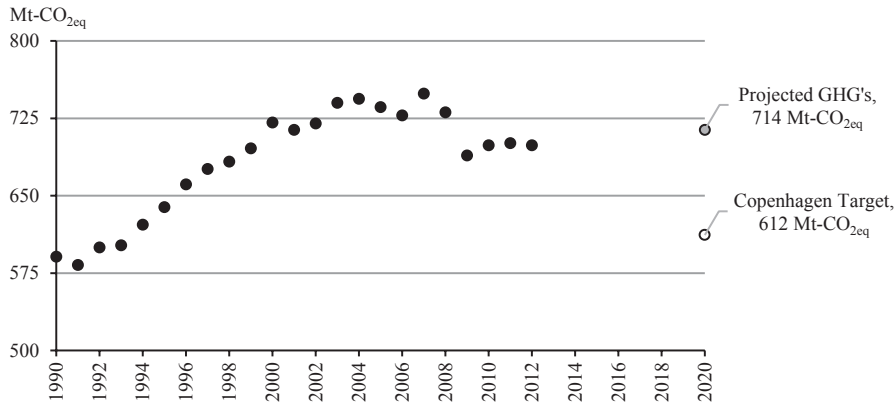


Fig. 2.6 Total GHG emissions in Canada. (Data from [23])

The distribution of GHG emissions by sector and transportation-specific modes is shown in Fig. 2.7. With the considerable role of passenger car fuel combustion in emission levels, commuter transit—which effectively addresses traffic congestion and reduces pressures on infrastructure—is still reliant on the use of fossil fuels, and this results in GHG emissions. However, when placed in context with other forms of transportation, rail transit represents only a small percentage of the total GHG emissions in the Canadian landscape, making it a worthwhile endeavor to consider viable alternatives that are environmentally benign and/or neutral.

Although the rail sector is not a significant contributor in terms of total transportation sector GHG emissions, the locomotive fleet is fueled almost entirely by diesel fuel. Between 2009 and 2010, diesel consumption by railway operations increased

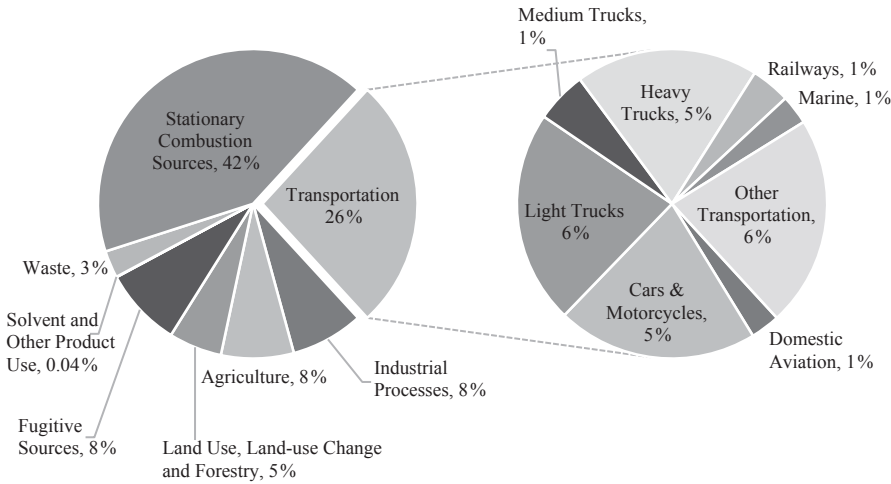


Fig. 2.7 GHG distribution by sector and mode of transportation, 2012. (Data from [24])

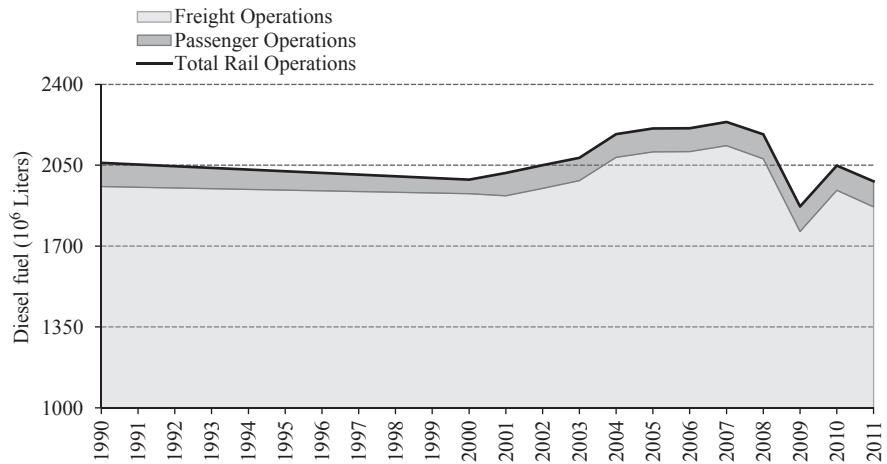


Fig. 2.8 Diesel fuel consumption by rail operation. (Data from [20])

significantly, from 1.87 billion litres of fuel to over 2 billion, due to increased freight operations (Fig. 2.8).

The emission of atmospheric pollutants leads to other harmful effects on the environment besides the global warming. These are illustrated in Fig. 2.9. There may be pollutant emissions, accidents, hazards, ecosystem degradation through air and water pollution, animal poisoning, greenhouse gas emission, carbon monoxide leakages, stratospheric ozone depletion, emission of hydrocarbon, CO, SO₂, NO_x, volatile organic compounds (VOCs), particulate matter (PM), and other aerosols. In average, the CO emissions are of 1.6 g/kWh, hydrocarbons of 0.81 g/kWh, NO_x of 9.5 g/kWh, PM of 0.22 g/kWh [17].

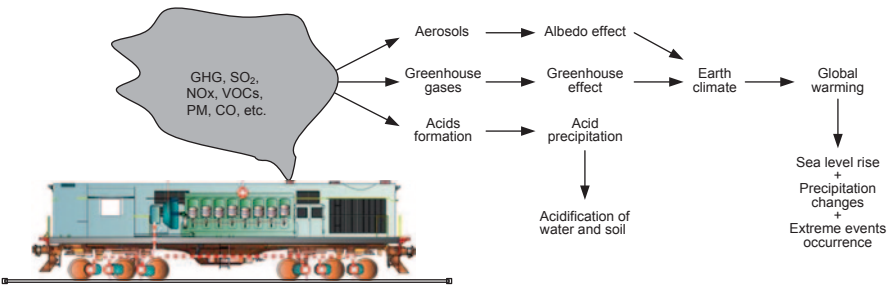


Fig. 2.9 Environmental pollution and effects from diesel combustion

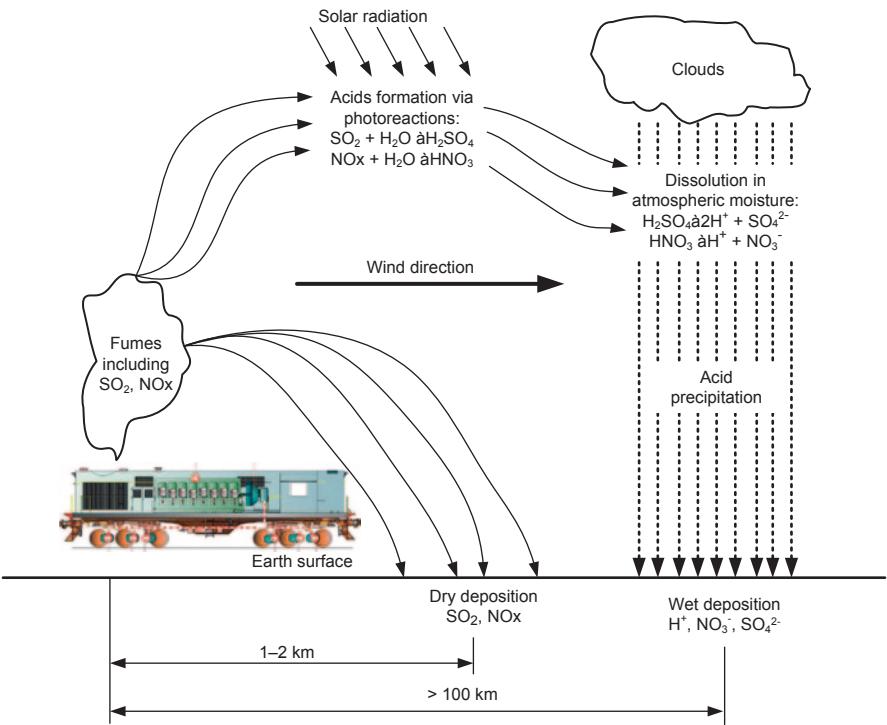


Fig. 2.10 Mechanism of rail transportation-related acid precipitation

A detail of acid formation in the atmosphere and acid deposition on land and sea is illustrated in Fig. 2.10. Acid precursors produced mainly from the combustion of fossil fuels, especially coal and oil, and the smelting of non-ferrous ores can be transported long distances through the atmosphere (by winds and currents) and deposited on ecosystems.

The majority of SO₂ and NO_x emissions come from fossil fuel combustion sources. Dry deposition of SO₂ and NO_x creates opportunity for acid formation at soil level or in the sea. Direct deposition occurs at places 1–2 km distant from the emission source. Acid precursors that travel to high levels of the atmosphere involve in

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