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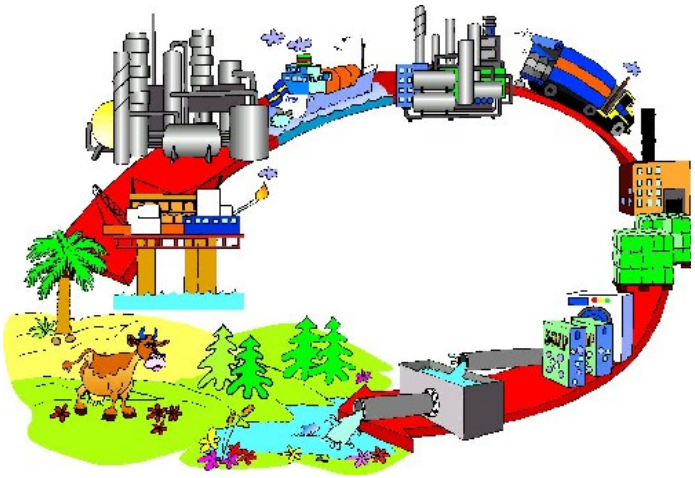
Environmental Life Cycle Assessment
PSE 476 / WPS 576

Lecture 9: Transportation

Richard Venditti



Fall 2016

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Transportation in LCA

- Almost every product has a distribution and transportation phase of life.
  - Distribution: all activities not involved in moving but required to facilitate the transfer of a product to its final end user
  - Transportation: movement of materials or energy between operations at different locations
- Sometimes transportation is at the focus of the study, or is significant
- Other times transportation is negligible and the LCA practitioner should not be distracted by transportation details
  - Environmental LCA, Ciambrone, 1997.

Distribution

- Warehouse or other storage
  - Indoors, outdoors, refrigerated, secured….
- Wholesaling operations
- Repackaging
- Retailing operations
- Other supporting activities

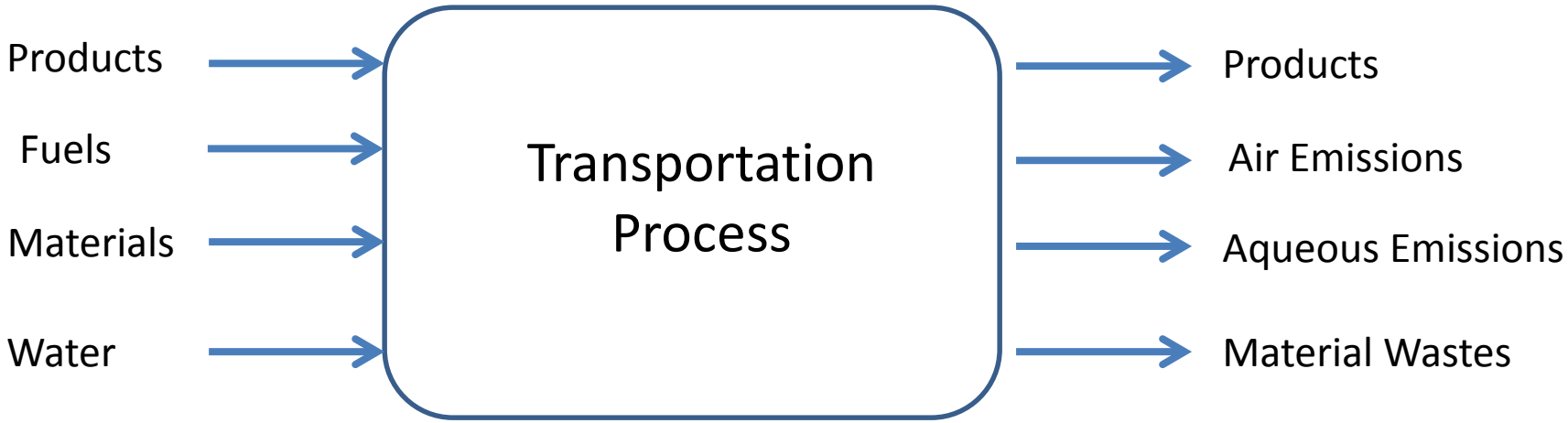
Common Modes of Transportation

- Fixed Transportation systems
  - Pipeline
  - Electrical Power Lines
  - Electronic

- Movable Transportation systems-batch carriers
  - Airplane
  - Railroad
  - Truck
  - Automotive
  - Bus
  - Barge
  - Freighter
  - Tanker

Plains All American Pipeline (PAA) has announced plans to construct two new Delaware Basin pipelines and related gathering systems. The 60 mi., 16 in. State Line pipeline will connect Culberson County to Wink, Texas. State Line will connect Delaware Basin production to the existing network of PAA Permian Basin assets. The pipeline will be capable of transporting up to 150,000 bbl/d of batched crude oil and condensate. (42 gallons in a bbl, oil barrel) - https://www.oilonline.com/news/midstream/paa-announces-pipeline-additions

Transportation model format



Materials = oils, lubricants, antifreeze, rags, ropes, tires, filters, belts, hoses,…

Air emissions: CO_2, methane, nitrous oxide, hydrofluorocarbons (HFC)…

Table 10-1. Elements of the Transportation Lifecycle

	Vehicle Cycle	Fuel Cycle	Infrastructure Cycle
Upstream Emissions	**Upstream Vehicle Cycle** Raw material (e.g., ore for steel or aluminum; petroleum for plastics) extraction, processing, production, and transport; manufacture of finished materials and components; intermediate parts transportation; assembly of parts and vehicles; distribution to retail locations	**Upstream Fuel Cycle** Exploration, drilling, production, and pumping; agricultural activities for biomass; production activities for other energy sources; crude oil/gas/material transport; refining and processing into motor fuel; product transport, intermediate, wholesale, and retail storage; retail product sales and dispensing	**Upstream Infrastructure Cycle** Raw material production and transport (e.g., asphalt, cement, and steel); desequestration (clear-cutting) of land; construction activities
Direct (Operating) Emissions	**Direct Vehicle Cycle** Tire wear; engine oil and other lubricant and fluid use; parts replacement; other operations and maintenance activities	**Direct Fuel Cycle** Fuel combustion; fuel evaporation [This element is the only one covered under traditional transportation emissions analyses.]	**Direct Infrastructure Cycle** Resurfacing; repainting and striping; pothole repair; plowing, street cleaning, other operations and maintenance activities
Downstream Emissions	**Downstream Vehicle Cycle** Disposal of vehicles, including possible recycling of parts; tire disposal and possible incineration	**Downstream Fuel Cycle** Disposal and possible recycling of oil products	**Downstream Infrastructure Cycle** Disposal and possible recycling of certain infrastructure raw materials; potential reclamation of land (e.g., rails-to-trails)

http://www.epa.gov/otaq/climate/420r06003.pdf

Transportation

- Typically reported on the basis of **cargo weight transported times distance**
- Be careful, this method is based on the assumption that the transportation is weight limited, if a system is volume limited, this calculation should be checked
- Common units
  - Tonne*km
  - Ton*mile

Showing details for *Transport, train, diesel powered*

Back to Results

Activity | Modelling | Admin Info | Exchanges

Inputs

Flow	Category	Type	Unit	Amount	Comment
Diesel, at refinery	root/Flows	ProductFlow	l	6.48e-03	

Outputs

Carbon dioxide, fossil	air/unspecified	ElementaryFlow	kg	1.89e-02	
Carbon monoxide, fossil	air/unspecified	ElementaryFlow	kg	4.91e-05	
Dinitrogen monoxide	air/unspecified	ElementaryFlow	kg	4.75e-07	
Methane, fossil	air/unspecified	ElementaryFlow	kg	9.05e-07	
Nitrogen oxides	air/unspecified	ElementaryFlow	kg	4.99e-04	
NMVOC, non-methane volatile organic compounds, unspecified	air/unspecified	ElementaryFlow	kg	1.85e-05	
Particulates, > 2.5 um, and < 10um	air/unspecified	ElementaryFlow	kg	1.24e-05	
Sulfur oxides	air/unspecified	ElementaryFlow	kg	4.19e-06	
transport, train, diesel powered	root/Flows	ProductFlow	t*km	1.00e+00	

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Ton*mile Calc.

- A truck drives 400 miles carrying 1000 lb of equipment. It then makes a trip in which it carries 5000 lb of equipment 85 miles. How many Ton*miles are required?

- If the GWP emissions are 0.094 kgCO_2/tonne*km how much emissions are generated? (1 km is .62 miles, 1 kg is 2.2. lb)

Ton*mile Calculation

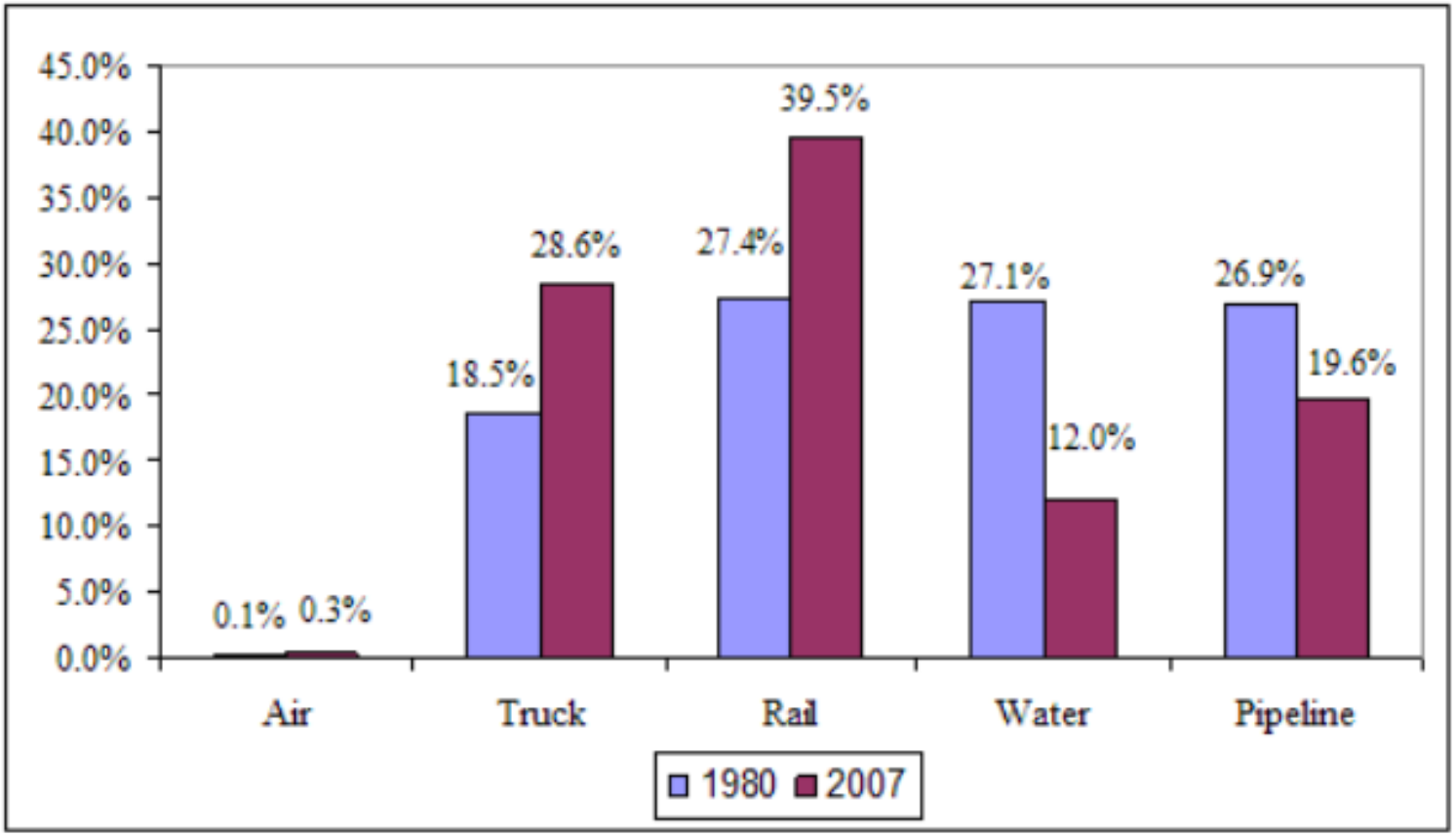
- A truck is carrying 140 ft^3 of steel (density of 6 gram/cm^3) 500 miles from New Orleans to Dallas. The truck can carry a maximum amount of weight of 40,000 lb. Calculate the transportation load in ton*miles. Is the truck volume or mass limited?

tonne*km Calculation

- A diesel powered train is carrying 500 tonnes of hay 1000 km, what is the GWP of this transportation? Include fossil based CO2 and methane, CH4 in the calculation only.

Modes of Transportation for Freight

Figure 3. Shares of Domestic Ton-Miles by Mode, 1980 and 2007



Source: National Transportation Statistics, 2010, Bureau of Transportation Statistics, U.S. Department of Transportation, Table 1-46b.

Types of Trucks

- Single Truck: a truck consisting of one frame which holds the engine, driving compartment and cargo bay.

Types of Trucks

- Combination truck
  - A vehicle composed of two or more separate units, a tractor (powered unit, semi-truck) and a trailer (unpowered unit, semi-trailer).
  - *Semi-truck, tractor-trailer, 18 wheeler.* An articulated (jointed) combination vehicle, commonly composed of a 10-wheeled tractor and an 8-wheeled trailer

Single and Combination Trucks

Table 4-1. 2003 Vehicle Registrations, Vehicle Miles Traveled, and Fuel Use for Heavy-Duty

Type of Truck	# of Vehicles	%	VMT (millions)	%	Fuel Use (million gallons)	%
Single-Unit	5,666,933	72%	77,562	35%	10,690	28%
Combination	2,245,085	28%	138,322	64%	26,895	72%

Source: Federal Highway Administration, U.S. Department of Transportation, 2004. *Highway Statistics 2003*. Washington, DC. Table VM-1.

http://www.epa.gov/otaq/climate/420r06003.pdf

Gross vehicle weight rating

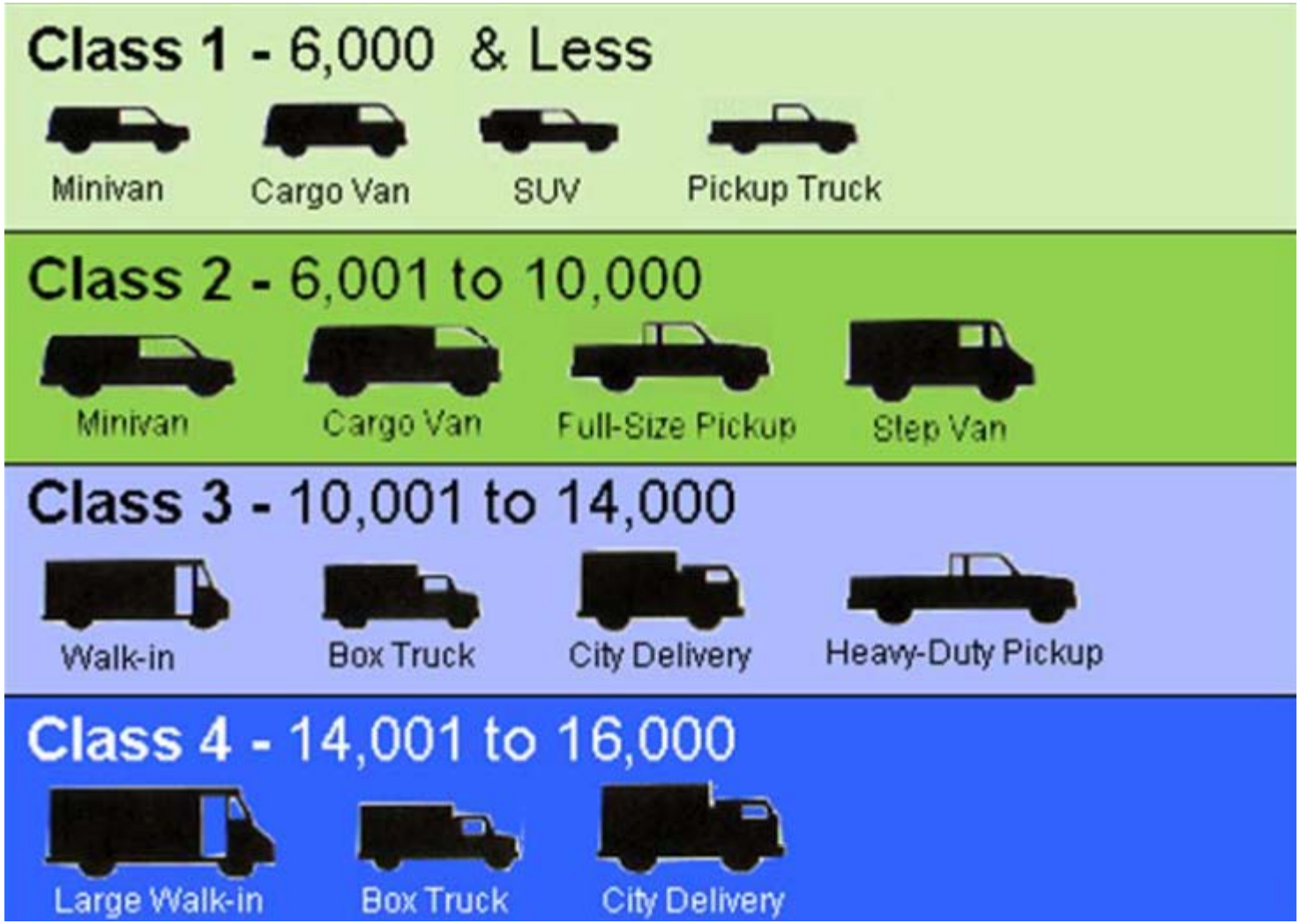
The gross vehicle weight rating of a truck (also gross vehicle mass, GVWR, GVM) is the maximum operating weight/mass of a vehicle as specified by the manufacturer including the vehicle's chassis, body, engine, engine fluids, fuel, accessories, driver, passengers and cargo *but excluding that of any trailers.*

Gross vehicle weight is the weight of the vehicle plus the weight of any optional accessories, cargo and passengers. This changes as people and cargo get in and out of the truck.

http://en.wikipedia.org/wiki/Gross_vehicle_weight_rating

Types of Trucks

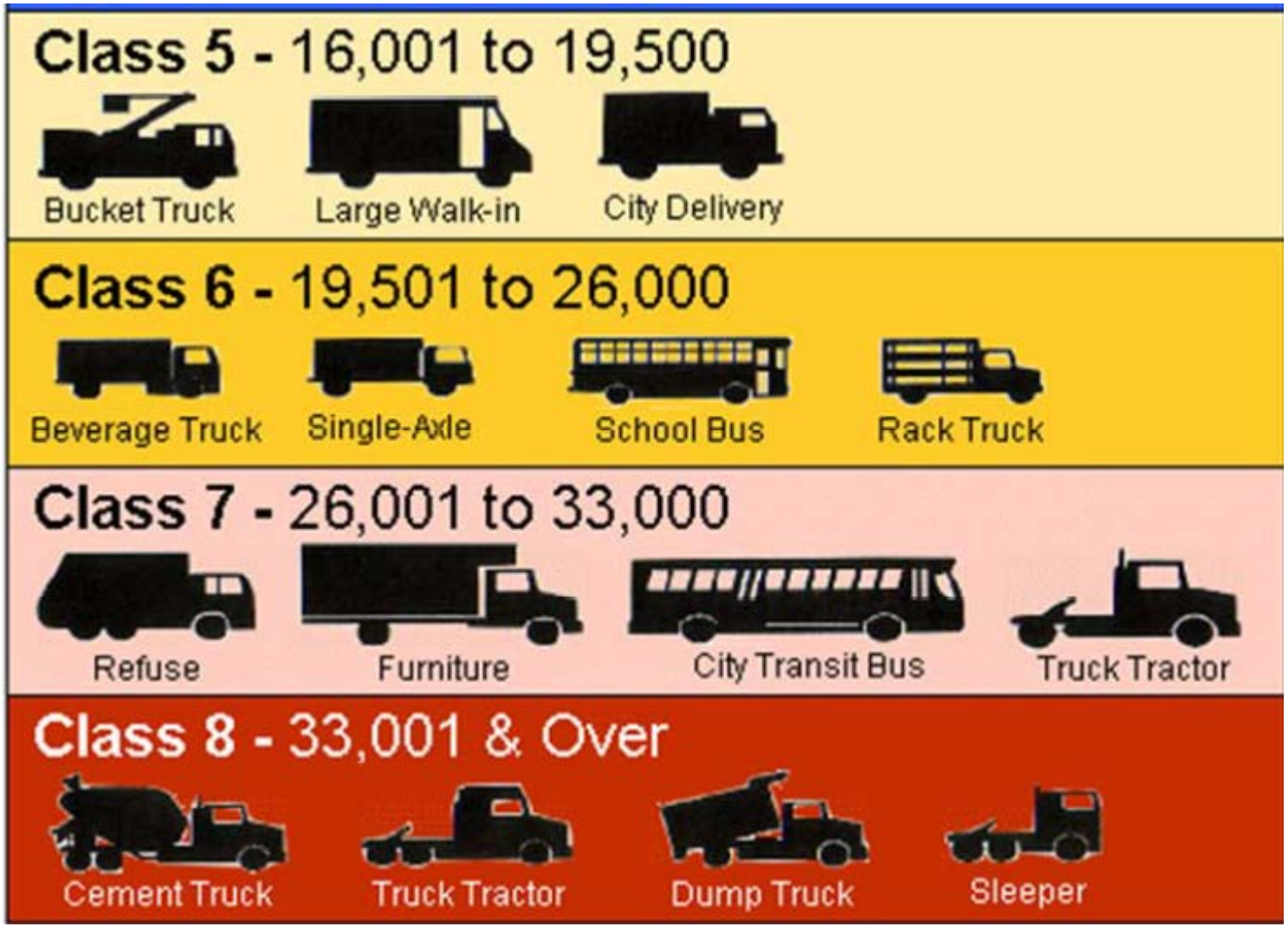
- Gross vehicle weight rating, in lbs



cta.ornl.gov/vtmarketreport/pdf/chapter3_heavy_trucks.pdf

Types of Trucks

- Gross vehicle weight rating in lbs



Gross trailer weight rating

Trailers have their own specific gross vehicle weight ratings that, similar to the tow vehicle's GVWR should never be exceeded.

Gross trailer weight is the actual weight of the trailer after the cargo has been loaded.

Also there are limits per wheel axle.

http://en.wikipedia.org/wiki/Gross_vehicle_weight_rating

Semi-trailer truck or tractor trailer or 18 wheeler, Class 8 trucks

In the United States, 80,000 pounds (36,287 kg) is the maximum allowable legal gross vehicle weight for trailer without a permit

Typical sizes of a trailer are

13 ft to 13.5 ft tall
8.5 feet wide
53 feet long

An empty 35,000 pound tractor trailer can thus haul 45,000 pounds if it is weight and not volume limited.

http://en.wikipedia.org/wiki/Gross_vehicle_weight_rating

How to calculate if a truck is weight or volume limited and how much it can carry.

1. Determine the cargo volume of the truck
2. Identify the maximum cargo weight allowable.
3. Assume the truck is full, what would the theoretical cargo weight be? Theoretical weight=cargo volume*density

4. If the mass of contents of the full truck is greater than the allowable weight, mass limited.
   - Weight equals maximum cargo weight.
   - Volume of cargo = maximum cargo weight/density

5. If the mass of contents of the full truck is less than the allowable weight, volume limited.
   - Weight=cargo volume*density cargo.

http://en.wikipedia.org/wiki/Gross_vehicle_weight_rating

Example Problem

1. A truck trailer has a weight of 35,000 lb empty and a GVWR for the trailer of 80,000 lbs
2. The cargo space is 53 by 8.5 by 13 ft.
3. Is it weight or volume limited if the cargo density is 5 lb_m/ft^3 ?
4. How much cargo can it carry in lbs?
5. How much volume will the cargo occupy?

Typical loads and Fuel Consumption

Class	Applications	Gross Weight Range (lbs.)	Empty Weight Range (lbs.)	Typical Payload Capacity Max (lbs.)	Typical Fuel Economy Range in 2007 (mpg)	Typical Fuel Consumed (gallons per thousand ton-miles)
1c	Cars *only*	3,200 - 6,000	2,400 - 5,000	250 - 1,000	25-33	69.0
1t	Minivans, Small SUVs, Small Pick-Ups	4,000 - 6,000	3,200 - 4,500	250 - 1,500	20-25	58.8
2a	Large SUVs, Standard Pick-Ups	6,001 - 8,500	4,500 - 6,000	250 - 2,500	20-21	38.5
2b	Large Pick-Ups, Utility Van, Multi-Purpose, Mini-Bus, Step Van	8,501 - 10,000	5,000 - 6,300	3,700	10-15	38.5
3	Utility Van, Multi-Purpose, Mini-Bus, Step Van	10,001 - 14,000	7,650 - 8,750	5,250	8-13	33.3
4	City Delivery, Parcel delivery, Large Walk-in, Bucket, Landscaping	14,001 - 16,000	7,650 - 8,750	7,250	7-12	23.8
5	City Delivery, Parcel Delivery, Large Walk-in, Bucket, Landscaping	16,001 - 19,500	9,500 - 10,800	8,700	6-12	25.6

cta.ornl.gov/vtmarketreport/pdf/chapter3_heavy_trucks.pdf

Typical loads and Fuel Consumption

Class	Applications	Gross Weight Range (lbs.)	Empty Weight Range (lbs.)	Typical Payload Capacity Max (lbs.)	Typical Fuel Economy Range in 2007 (mpg)	Typical Fuel Consumed (gallons per thousand ton-miles)
4	City Delivery, Parcel delivery, Large Walk-in, Bucket, Landscaping	14,001 - 16,000	7,650 - 8,750	7,250	7-12	23.8
5	City Delivery, Parcel Delivery, Large Walk-in, Bucket, Landscaping	16,001 - 19,500	9,500 - 10,800	8,700	6-12	25.6
6	City Delivery, School Bus, Large Walk-in, Bucket	19,501 - 26,000	11,500 - 14,500	11,500	5-12	20.4
7	City Bus, Furniture, Refrigerated, Refuse, Fuel Tanker, Dump, Tow, Concrete, Fire Engine, Tractor-Trailer	26,001 - 33,000	11,500 - 14,500	18,500	4-8	18.2
8a	Straight trucks, e.g., Dump, Refuse, Concrete, Furniture, City Bus, Tow, Fire Engine	33,001 - 80,000	20,000 - 34,000	20,000 - 50,000	2.5-6	8.7
8b	Combination trucks, e.g., Tractor-Trailer: Van, Refrigerated, Bulk Tanker, Flat Bed,	33,001 - 80,000	23,500 - 34,000	40,000 - 54,000	4-7.5	6.5

Source:

The National Academies, *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles*, 2010. http://www.nap.edu/catalog.php?record_id=12845

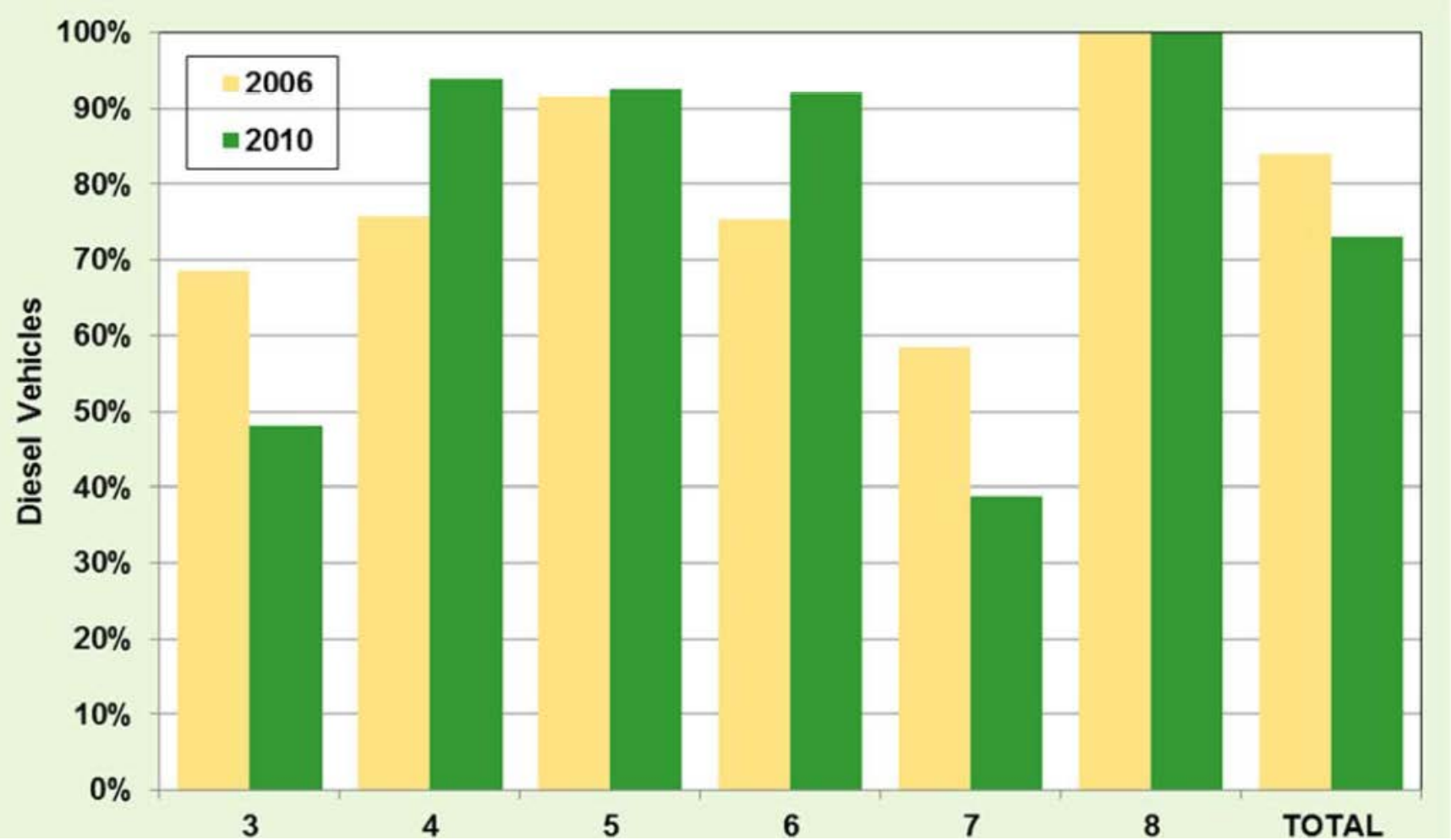
Efficiency of Class 8 trucks by weight range

TABLE 11. Fuel Efficiency of Class 8 Trucks by Vehicle Weight Range on Flat Terrain

Weight Range (Pounds)	Average Weight (Pounds)	Distance Traveled (Miles)	Fuel Consumed (Gallons)	Fuel Efficiency (Miles per Gallon)	Fuel Efficiency (Ton-miles per Gallon)	Average Speed (Miles per Hour)
20,000-30,000	21,222	51.4	5.4	9.5	101	65.0
30,000-40,000	34,285	505.9	53.0	9.5	164	65.0
40,000-50,000	44,911	537.8	58.7	9.2	206	65.0
50,000-60,000	55,468	541.2	63.3	8.6	237	64.9
60,000-70,000	66,558	1,356.9	171.9	7.9	263	65.0
70,000-80,000	73,248	1,363.1	172.3	7.9	290	65.0

cta.ornl.gov/vtmarketreport/pdf/chapter3_heavy_trucks.pdf

% Diesel vs Gasoline Trucks



Ward's Automotive Group, Motor Vehicle Facts and Figures 2011, Southfield, MI, 2011. http://wardsauto.com

cta.ornl.gov/vtmarketreport/pdf/chapter3_heavy_trucks.pdf

Modes of Transportation for Freight

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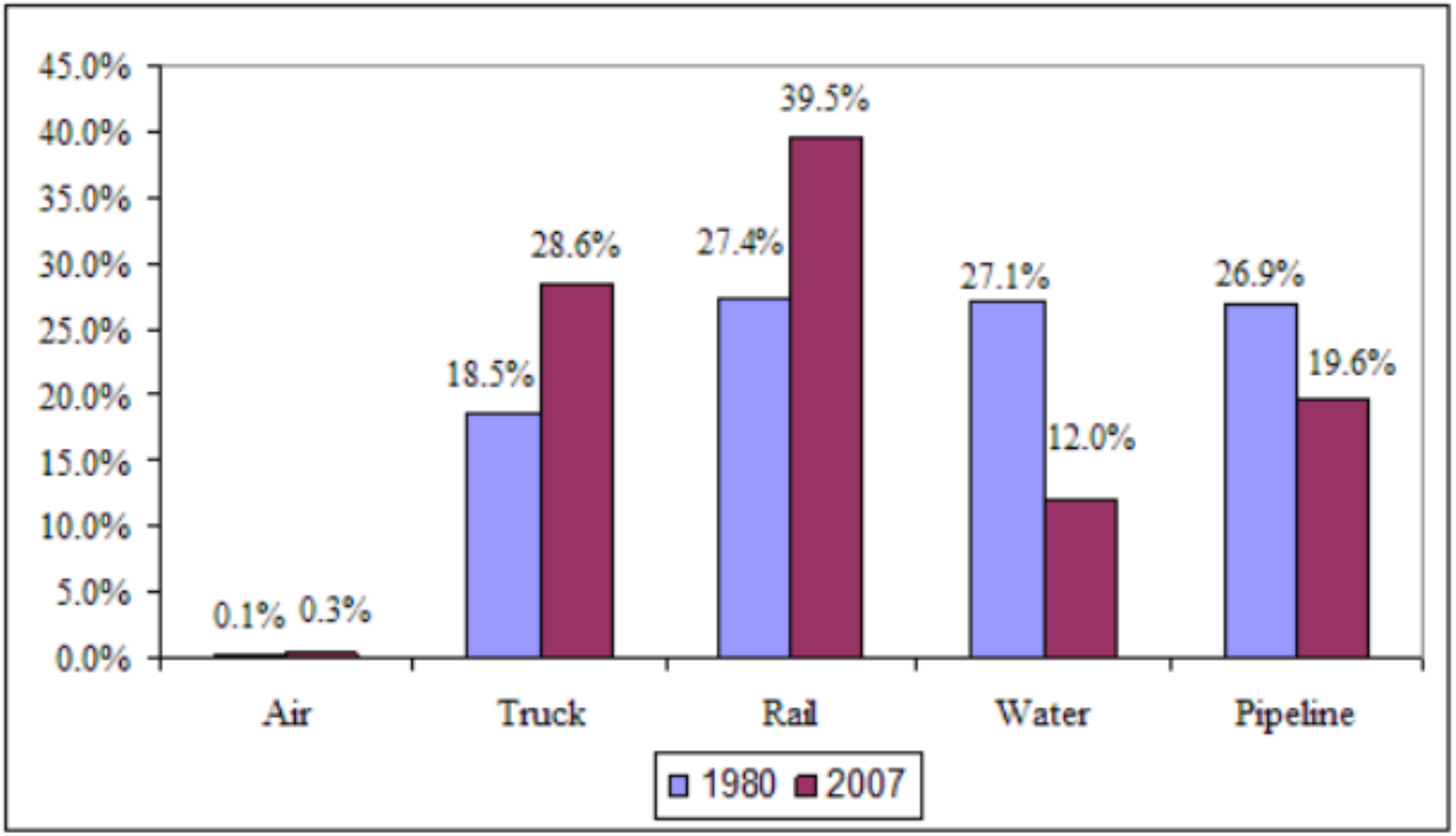


Source: National Transportation Statistics, 2010, Bureau of Transportation Statistics, U.S. Department of Transportation, Table 1-46b.

Tonnage of shipments by mode of transportation

Table 2-1 (standard units - millions of tons)

Table in Excel format

	2007				2010			
	Total	Domestic	Exports[2]	Imports[2]	Total	Domestic	Exports[2]	Imports[2]
Total	**18,879**	**16,851**	**655**	**1,372**	**18,313**	**16,394**	**762**	**1,156**
Truck	12,778	12,587	95	97	12,490	12,309	95	86
Rail	1,900	1,745	61	93	1,776	1,645	57	74
Water	941	504	55	381	860	464	67	328
Air, air & truck	13	3	4	6	12	2	4	5
Multiple modes & mail	1,424	419	399	606	1,380	400	496	485
Pipeline	1,507	1,328	4	175	1,494	1,321	6	167
Other & unknown	316	266	36	14	302	253	37	11

http://ops.fhwa.dot.gov/freight/freight_analysis/nat_freight_stats/docs/11factsfigures/table2_2.htm

Value of shipments by mode of transportation

Billions of 2007 dollars

	2007				2010			
	Total	Domestic	Exports[2]	Imports[2]	Total	Domestic	Exports[2]	Imports[2]
Total	**16,651**	**13,457**	**1,196**	**1,997**	**16,065**	**13,032**	**1,217**	**1,816**
Truck	10,780	10,225	267	287	10,515	10,000	263	252
Rail	512	374	45	93	427	306	41	79
Water	339	158	14	167	343	146	15	182
Air, air & truck	1,077	151	422	505	999	123	409	466
Multiple modes & mail	2,879	1,639	396	844	2,739	1,562	434	743
Pipeline	723	658	4	61	719	655	6	58
Other & unknown	341	252	48	41	323	240	48	35

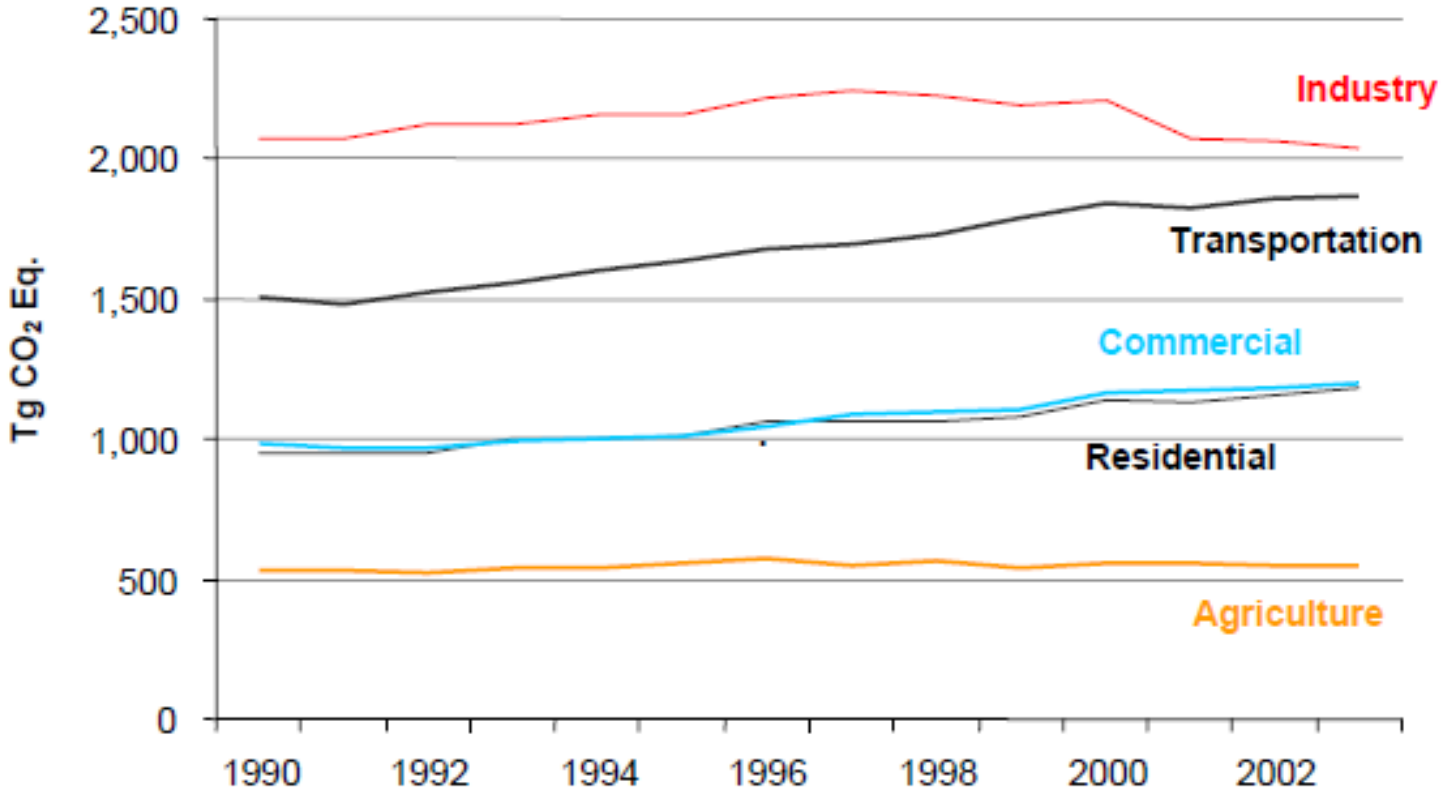
http://ops.fhwa.dot.gov/freight/freight_analysis/nat_freight_stats/docs/11factsfigures/table2_2.htm

USLCI Database

- Determine the fossil fuel CO2 emissions for an airplane, diesel train, and diesel combination truck:

Transportation GWP Emissions

Figure 2-1. U.S. Greenhouse Gas Emissions by End-Use Economic Sector, 1990–2003

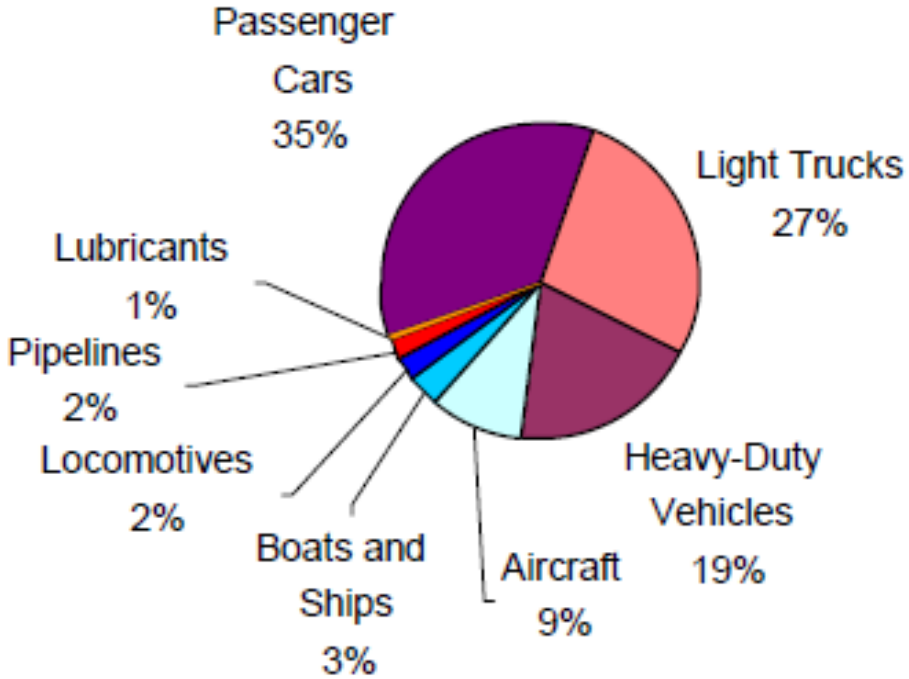


Source: Derived from U.S. Environmental Protection Agency, 2005. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2003.* Washington, DC, Table 2-16.

http://www.epa.gov/otaq/climate/420r06003.pdf

Transportation GWP Emissions

Figure 2-2. 2003 Transportation Greenhouse Gas Emissions, by Source



Source: U.S. Environmental Protection Agency, 2005. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2003*. Washington, DC. Table 2-9

Transportation GWP Emissions

Mode	kg CO_2/tonne*km
Air Cargo*	0.564
Truck	0.094
Rail	0.022
Marine (Ocean)	0.019
Inland Freshwater	0.033

US LCI Database except for * fluglaerm.de/hamburg/klima.htm

Other environmental issues

- The transport industry releases several million tons of gases each year into the atmosphere. These include
  - lead (Pb),
  - carbon monoxide (CO),
  - carbon dioxide (CO2; not a pollutant),
  - methane (CH4),
  - nitrogen oxides (NOx),
  - nitrous oxide (N2O),
  - chlorofluorocarbons (CFCs),
  - perfluorocarbons (PFCs),
  - silicon tetraflouride (SF6),
  - benzene and volatile components (BTX),
  - heavy metals (zinc, chrome, copper and cadmium)
  - and particulate matters (ash, dust).

http://people.hofstra.edu/geotrans/eng/ch8en/conc8en/ch8c1en.html

Other environmental issues

- Climate
- Toxic air pollutants are associated with **cancer, cardiovascular, respiratory and neurological diseases**. Carbon monoxide (CO) when inhale affects bloodstream, reduces the availability of oxygen and can be extremely harmful to public health.
- An emission of nitrogen dioxide (NO2) from transportation sources **reduces lung function**, affects the respiratory immune defense system and increases the risk of respiratory problems.
- The emissions of sulphur dioxide (SO2) and nitrogen oxides (NOx) in the atmosphere form various acidic compounds that when mixed in cloud water creates **acid rain**.

http://people.hofstra.edu/geotrans/eng/ch8en/conc8en/ch8c1en.html

Other environmental issues

- **Air Quality**
- The reduction of natural visibility by smog has a number of adverse impacts on the quality of life and the attractiveness of tourist sites.
- Particulate emissions in the form of dust emanating from vehicle exhaust as well as from non-exhaust sources such as vehicle and road abrasion have an impact on air quality.
- The physical and chemical properties of particulates are associated with health risks such as respiratory problems, skin irritations, eyes inflammations, blood clotting and various types of allergies.

http://people.hofstra.edu/geotrans/eng/ch8en/conc8en/ch8c1en.html

Health

Current scientific evidence links short-term NO_2 exposures, ranging from 30 minutes to 24 hours, with adverse respiratory effects including airway inflammation in healthy people and increased respiratory symptoms in people with asthma.

Also, studies show a connection between breathing elevated short-term NO_2 concentrations, and increased visits to emergency departments and hospital admissions for respiratory issues, especially asthma.

NO_2 concentrations in vehicles and near roadways are appreciably higher than those measured at monitors in the current network. In fact, in-vehicle concentrations can be 2-3 times higher than measured at nearby area-wide monitors. Near-roadway (within about 50 meters) concentrations of NO_2 have been measured to be approximately 30 to 100% higher than concentrations away from roadways.

Individuals who spend time on or near major roadways can experience short-term NO_2 exposures considerably higher than measured by the current network. Approximately 16% of U.S housing units are located within 300 ft of a major highway, railroad, or airport (approximately 48 million people). This population likely includes a higher proportion of non-white and economically-disadvantaged people.

Other environmental issues

- **Noise**
- Noise represents the general effect of irregular and chaotic sounds. It is traumatizing for the hearing organ and that may affect the quality of life by its unpleasant and disturbing character. Long term exposure to noise levels above 75dB seriously hampers hearing and affects human physical and psychological wellbeing.
- Transport noise emanating from the movement of transport vehicles and the operations of ports, airports and railyards affects human health, through an increase in the risk of cardiovascular diseases.
- Increasing noise levels have a negative impact on the urban environment reflected in falling land values and loss of productive land uses.

http://people.hofstra.edu/geotrans/eng/ch8en/conc8en/ch8c1en.html

Other environmental issues

- **Water Quality**
- Fuel, chemical and other hazardous particulates discarded from aircraft, cars, trucks and trains or from port and airport terminal operations, such as de-icing, can contaminate rivers, lakes, wetlands and oceans.
- Because demand for shipping services is increasing, marine transport emissions represent the most important segment of water quality inventory of the transportation sector.
- Dredging activities have a two-fold negative impact on the marine environment. They modify the hydrology by creating turbidity that can affect the marine biological diversity. The contaminated sediments and water raised by dredging require spoil disposal sites and decontamination techniques.
- Waste generated by the operations of vessels at sea or at ports cause serious environmental problems, since they can contain a very high level of bacteria that can be hazardous for public health as well as marine ecosystems when discharged in waters
- Ballast waters are required to control ship's stability and draught and to modify their center of gravity in relation to cargo carried and the variance in weight distribution. Ballast waters acquired in a region may contain invasive aquatic species that, when discharged in another region may thrive in a new marine environment and disrupt the natural marine ecosystem.
- Major oil spills from oil cargo vessel accidents are one of the most serious problems of pollution from maritime transport activities. **Soil quality**. The environmental impact of transportation on soil consists of soil erosion and soil contamination.

http://people.hofstra.edu/geotrans/eng/ch8en/conc8en/ch8c1en.html

Other environmental issues

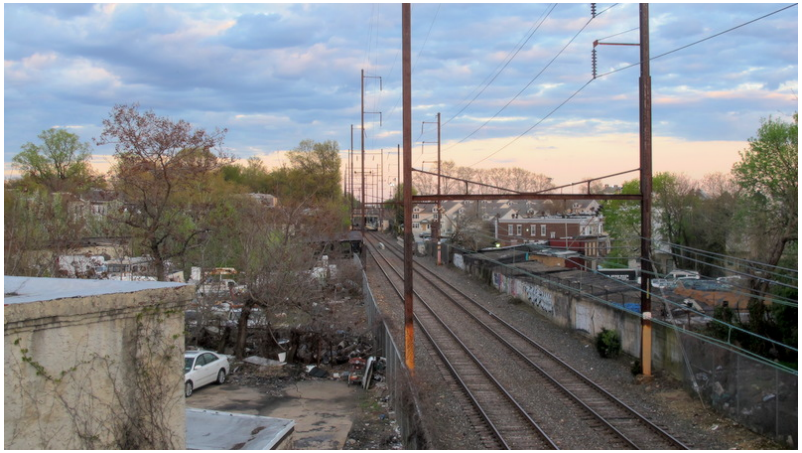
- **Biodiversity**.
- Transportation also influences natural vegetation. The need for construction materials and the development of land-based transportation has led to deforestation.
- Many transport routes have required draining land, thus reducing wetland areas and driving-out water plant species.
- The need to maintain road and rail right-of-way or to stabilize slope along transport facilities has resulted in restricting growth of certain plants or has produced changes in plants with the introduction of new species different from those which originally grew in the areas.
- Many animal species are becoming extinct as a result of changes in their natural habitats and reduction of ranges.

On Tuesday, Washington State Department of Transportation crews broke ground on the state's first animal overpass, a 150-foot wide-bridge surrounded by native trees and planted with vegetation designed to let bears, elk, otters and even mice pass over the ever-busy I-90 expressway.
The $6 million critter crossing will be the first of more than 20 planned overpasses and underpasses spanning the landscape along Washington's central Cascade Mountains, designed to let wandering animals get across a 15-mile stretch while 28,000 cars whiz by every day.
http://www.goodnewsnetwork.org/overpasses-to-let-wildlife-cross-6-lanes-of-highway/

http://people.hofstra.edu/geotrans/eng/ch8en/conc8en/ch8c1en.html

Other environmental issues

- **Land take**.
- Transportation facilities have an impact on the urban landscape. The development of port and airport infrastructure is significant features of the urban and peri-urban built environment.
- Social and economic cohesion can be severed when new transport facilities such as elevated train and highway structures cut across an existing urban community.
- Arteries or transport terminals can define urban borders and produce segregation.
- Major transport facilities can affect the quality of urban life by creating physical barriers, increasing noise levels, generating odors, reducing urban aesthetic and affecting the built heritage.



http://people.hofstra.edu/geotrans/eng/ch8en/conc8en/ch8c1en.html

Other environmental issues

- **Land Requirement and Consumption, land take**
- The main impact of urbanization has been the **expansion of urban land use**, which means that a large city of 5 million inhabitants may stretch over 100 km (including suburbs and satellite cities) and may use an amount of land exceeding 5,000 square km.
- Such large cities obviously **cannot be supported without a vast and complex transport system**.
- Also, modal choice have an important impact on land consumption.
- The preference for road transportation has led to a massive consumption of space with 1.5 to 2.0% of the world's total land surface devoted to the automobile, mainly for roads and parking lots.

http://people.hofstra.edu/geotrans/eng/ch8en/conc8en/ch8c1en.html

Summary

- Fixed transportation systems
- Movable transportation systems -- Batch carriers
- Vehicle cycle
- Fuel cycle
- Infrastructure cycle
- tonne*km
- Ton*mile
- Single truck
- Combination truck
- Gross vehicle weight rating
- Gross vehicle weight rating for trailer

- Weight (mass) limited
- Volume limited
- Modes of transportation
- Fuel efficiency in Ton*mile/gallon
- Transportation GWP Emissions
- Noise
- Biodiversity
- Land take
- Land separation