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Energy efficiency in transport

The **energy efficiency in transport** is the useful travelled distance, of passengers, goods or any type of load; divided by the total energy put into the transport propulsion means. The energy input might be rendered in several different types depending on the type of propulsion, and normally such energy is presented in liquid fuels, electrical energy or food energy.[1][2] The energy efficiency is also occasionally known as **energy intensity**.[3] The inverse of the energy efficiency in transport, is the **energy consumption in transport.**

Energy efficiency in transport is often described in terms of fuel consumption, fuel consumption being the reciprocal of fuel economy.[2] Nonetheless, fuel consumption is linked with a means of propulsion which uses liquid fuels, whilst energy efficiency is applicable to any sort of propulsion. To avoid said confusion, and to be able to compare the energy efficiency in any type of vehicle, experts tend to measure the energy in the International System of Units, i.e., joules.

Therefore, in the International System of Units, the energy efficiency in transport is measured in terms of metre per joule, or **m/J**, whilst the energy consumption in transport is measured in terms of joules per metre, or **J/m**. The more efficient the vehicle, the more metres it covers with one joule (more efficiency), or the fewer joules it uses to travel over one metre (less consumption). The energy efficiency in transport largely varies by means of transport. Different types of transport range from some hundred kilojoules per kilometre (kJ/km) for a bicycle to tens of megajoules per kilometre (MJ/km) for a helicopter.

Via type of fuel used and rate of fuel consumption, energy efficiency is also often related to operating cost ($/km) and environmental emissions (e.g. CO_2/km).

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Units of measurement

In the International System of Units, the energy efficiency in transport is measured in terms of metre per joule, or **m/J**. Nonetheless, several conversions are applicable, depending on the unit of distance and on the unit of energy. For liquid fuels, normally the quantity of energy input is measured in terms of the liquid's volume, such as litres or gallons. For propulsion which runs on electricity, normally kW·h is used, while for any type of human-propelled vehicle, the energy input is measured in terms of Calories. It is typical to convert between different types of energy and units.

For passenger transport, the energy efficiency is normally measured in terms of passengers times distance per unit of energy, in the SI, passengers metres per joule (**pax.m/J**); while for cargo transport the energy efficiency is normally measured in terms of mass of transported cargo times distance per unit of energy, in the SI, kilograms metres per joule (**kg.m/J**). Volumetric efficiency with respect to vehicle capacity may also be reported, such as passenger–mile per gallon (PMPG),[4] obtained by multiplying the miles per gallon of fuel by either the passenger capacity or the average occupancy.[5] The occupancy of personal vehicles is typically lower than capacity by a considerable degree[6][7] and thus the values computed based on capacity and on occupancy will often be quite different.

Typical conversions into SI unit

	Joules
litre of petrol	0.3×10^8
US gallon of petrol (gasoline)[8]	1.3×10^8
Imp. gallon of petrol (gasoline)	1.6×10^8
kilocalorie[9][10]	4.2×10^3
kW·h[8]	3.6×10^6
BTU[8]	1.1×10^3

Liquid fuels

Energy efficiency is expressed in terms of fuel economy:[2]

- distance per vehicle per unit fuel volume; e.g., km/L or miles per gallon (US or imperial).
- distance per vehicle per unit fuel mass; e.g., km/kg.[11]
- distance per vehicle per unit energy; e.g., miles per gallon equivalent (mpg-e).

Energy consumption (reciprocal efficiency)[3] is expressed terms of fuel consumption:[2]

- volume of fuel (or total energy) consumed per unit distance per vehicle; e.g. L/100 km or MJ/100 km.
- volume of fuel (or total energy) consumed per unit distance per passenger; e.g., L/(100 passenger·km).
- volume of fuel (or total energy) consumed per unit distance per unit mass of cargo transported; e.g., L/100 kg·km or MJ/t·km.

Electricity

Electricity consumption:

- electrical energy used per vehicle per unit distance; e.g., kW·h/100 km.

Producing electricity from fuel requires much more primary energy than the amount of electricity produced.

Food energy

Energy consumption:

- calories burnt by the body's metabolism per kilometre; e.g., Cal/km.
- calories burnt by the body's metabolism per mile; e.g., Cal/miles.[12]

Overview

In the following table the energy efficiency and energy consumption for different types of passenger land vehicles and modes of transport, as well as standard occupancy rates, are presented. The sources for these figures are in the correspondent section for each vehicle, in the following article. The conversions amongst different types of units, are well known in the art.

For the conversion amongst units of energy in the following table, 1 litre of petrol amounts to 34.2 MJ, 1 kWh amounts to 3.6 MJ and 1 kilocalorie amounts to 4184 J. For the car occupation ratio, the value of 1.2 passengers per automobile[13] was considered. Nonetheless in Europe this value slightly increases to 1.4.[14] The sources for conversions amongst units of measurements appear only of the first row.

Land Passenger Transport means

Energy Efficiency and Consumption of Land Passenger Transport means

Mode of transport	Energy Efficiency					Energy consumption					Average number of passengers per vehicle	Energy Efficiency	Energy consumption
	mpg(US) of petrol	mpg(imp) of petrol	km/L of petrol	km/MJ	m/J	L(petrol)/ 100 km	kWh/100 km	Cal/km	MJ/100 km	J/m		(m·pax)/J	J/(m·pax)
Human propelled													
Walking				4.55[15]	0.00455[16]			52.58[17]	22.00[18]	220[19]	1.0	0.00455	220
Velomobile				55.56	0.05556		0.50[20][21]	4.30	1.80	18	1.0	0.05556	18
Bicycle				9.09	0.00909			26.29	11.00	110[22][15]	1.0	0.00909	110
Motor assist													
Motorised bicycle	670.36	805.07	285.00	8.33	0.00833	0.35	3.33	28.68	12.00	120	1.0	0.00833	120
Electric kick scooter				24.87	0.02487		1.12[23]	9.61	4.00	40	1.0	0.02487	40
Automobile													
Solar Car	1200.65	1441.92	510.45	14.93	0.01493	0.20	1.86[24]	16.01	6.70	67	1.0	0.01493	67
GEM NER	212.81	255.58	90.48	2.65	0.00265	1.11	10.50	90.34	37.80	378	1.2[13]	0.00317	315
General Motors EV1	97.15	116.68	41.30	1.21	0.00121	2.42	23.00[25]	197.90	82.80	828	1.2[13]	0.00145	690
Chevrolet Volt	99.31	119.27	42.22	1.23	0.00123	2.37	22.50[25]	193.59	81.00	810	1.2[13]	0.00148	675
Daihatsu Charade	83.80	100.63	35.63	1.04	0.00104	2.81	26.67	229.45	96.00	960	1.2[13]	0.00125	800
Volkswagen Polo	61.88	74.31	26.31	0.77	0.00077	3.80[26]	36.11	310.71	130.00	1300	1.2[13]	0.00092	1083
SEAT Ibiza 1.4 TDI Ecomotion	61.88	74.31	26.31	0.77	0.00077	3.80[27]	36.11	310.71	130	1300	1.2[13]	0.00092	1083
Cadillac CTS-V	13.82[28]	16.60	5.88	0.17	0.00017	17.02	161.67	1391.01	582.00	5820	1.2[13]	0.00021	4850
Bugatti Veyron	9.79[28]	11.75	4.16	0.12	0.00012	24.04	228.33	1964.63	822.00	8220	1.2[13]	0.00015	6850
Nissan Leaf	119.89	143.98	50.97	1.49	0.00149	1.96	18.64[29]	160.37	67.10	671	1.2[13]	0.00179	559
Toyota Prius	56.06	67.32	23.83	0.70	0.00070	4.20	39.86[30]	342.97	143.50	1435	1.2[13]	0.00084	1196
Tesla Model S	129.54	155.57	55.07	1.61	0.00161	1.82	17.25[31]	148.42	62.10	621	1.2[13]	0.00193	517
Buses													
MCI 102DL3	6.03[32]	7.24	2.56	0.07	0.00007	39.04	370.83	3190.73	1335.00	13350	11.0[33]	0.00082	1214
Proterra Catalyst 40' E2				0.23[34][note 1]	0.00023		121.54	1044.20	437.60	4376	11.0[33]	0.00319	313
Trains													
Urban rail												0.00231	432[35]
CR400AF (cn)											~	0.00150	667
JR East (jp)											~	0.01091	92[36]
CP-Lisbon (pt)											27.7%[37]	0.01304	77[38]
Basel (ch)											~50.0%[39]	0.00215	465[40]

1. The range used is the midpoint of the effective operating range.

Land transport means

Walking


Nordic walkers

A 68 kg (150 lb) person walking at 4 km/h (2.5 mph) requires approximately 210 kilocalories (880 kJ) of food energy per hour, which is equivalent to 4.55 km/MJ.[15] 1 US gal (3.8 L) of petrol contains about 114,000 British thermal units (120 MJ)[41] of energy, so this is approximately equivalent to 360 miles per US gallon (0.65 L/100 km).

Velomobile

Velomobiles have the highest energy efficiency of any known mode of personal transport because of their small frontal area and aerodynamic shape. At a speed of 50 km/h (31 mph), the velomobile manufacturer WAW claims that only 0.5 kW·h (1.8 MJ) of energy per 100 km is needed to transport the passenger (= 18 J/m). This is around $^{1}/_{5}$ (20%) of what is needed to power a standard upright bicycle without aerodynamic cladding at same speed, and $^{1}/_{50}$ (2%) of that which is consumed by an average fossil fuel or electric car (the velomobile efficiency corresponds to 4700 miles per US gallon, 2000 km/L, or 0.05 L/100 km).[21] Real energy from food used by human is 4–5 times more.[42] Unfortunately their energy use advantage over bicycles is smaller with decrease of speed and disappear at around 10 km/h where power needed for velomobile and triathlon bike is almost the same[43]

Bicycle


A Chinese Flying Pigeon bicycle

A standard lightweight, moderate-speed bicycle is one of the most energy-efficient forms of transport. Compared with walking, a 64 kg (140 lb) cyclist riding at 16 km/h (10 mph) requires about half the food energy per unit distance: 27 kcal/km, 3.1 kW·h (11 MJ) per 100 km, or 43 kcal/mi.[15] This converts to about 732 mpg_{-US} (0.321 L/100 km; 879 mpg_{-imp}).[22] This means that a bicycle will use between 10–25 times less energy per distance travelled than a personal car, depending on fuel source and size of the car. This figure does depend on the speed and mass of the rider: greater speeds give higher air drag and heavier riders consume more energy per unit distance. In addition, because bicycles are very lightweight (usually between 7–15 kg) this means they consume very low amounts of materials and energy to manufacture. In comparison to an automobile weighing 1500 kg or more, a bicycle typically requires 100–200 times less energy to produce than an automobile. In addition, bicycles require less space both to park and to operate and they damage road surfaces less, adding an infrastructural factor of efficiency.

Motorised bicycle

A motorised bicycle allows human power and the assistance of a 49 cm^3 (3.0 cu in) engine, giving a range of 160 to 200 mpg_{-US} (1.5–1.2 L/100 km; 190–240 mpg_{-imp}). Electric pedal-assisted bikes run on as little as 1.0 kW·h (3.6 MJ) per 100 km,[44] while maintaining speeds in excess of 30 km/h (19 mph). These best-case figures rely on a human doing 70% of the work, with around 3.6 MJ (1.0 kW·h) per 100 km coming from the motor. This makes an electric bicycle one of the most efficient possible motorised vehicles, behind only a motorised velomobile.

Electric kick scooter


Electric kick scooters, part of a scooter-sharing system, in San Jose, California.

Electric kick scooters, such as those used by scooter-sharing systems like Bird or Lime, typically have a maximum range of under 30 km (19 mi) and a maximum speed of roughly 15.5 mph (24.9 km/h).[23] Intended to fit into a last mile niche and be ridden in bike lanes, they require little skill from the rider. Because of their light weight and small motors, they are extremely energy-efficient with a typical energy efficiency of 1.1 kW·h (4.0 MJ) per 100 km[45] (1904 MPGe 810 km/l 0.124 l/100 km), even more efficient than bicycles and walking. However, as they must be recharged frequently, they are often collected overnight with motor vehicles, somewhat negating this efficiency. The lifecycle of electric scooters is also notably shorter than that of bicycles, often reaching only a single digit number of years.

Human power

To be thorough, a comparison must also consider the energy costs of producing, transporting and packaging of fuel (food or fossil fuel), the energy incurred in disposing of exhaust waste, and the energy costs of manufacturing the vehicle. This last can be significant given that walking requires little or no special equipment, while automobiles, for example, require a great deal of energy to produce and have relatively short lifespans. In addition, any comparison of electric vehicles and liquid-fuelled vehicles must include the fuel consumed in the power station to generate the electricity. In the UK for instance the efficiency of the electricity generation and distribution system is around 0.40.

Automobiles

The automobile is an inefficient vehicle compared to other modes of transport. This is because the ratio between the mass of the vehicle and the mass of the passengers is much higher when compared to other modes of transport.

Bugatti Veyron

Automobile fuel efficiency is most commonly expressed in terms of the volume of fuel consumed per one hundred kilometres (L/100 km), but in some countries (including the United States, the United Kingdom and India) it is more commonly expressed in terms of the distance per volume fuel consumed (km/L or miles per gallon). This is complicated by the different energy content of fuels such as petrol and diesel. The Oak Ridge National Laboratory (ORNL) states that the energy content of unleaded petrol is 115,000 British thermal unit (BTU) per US gallon (32 MJ/L) compared to 130,500 BTU per US gallon (36.4 MJ/L) for diesel.[46]

A second important consideration is the energy costs of producing energy. Bio-fuels, electricity and hydrogen, for instance, have significant energy inputs in their production. Hydrogen production efficiency are 50–70% when produced from natural gas, and 10–15% from electricity. The efficiency of hydrogen production, as well as the energy required to store and transport hydrogen, must to be combined with the vehicle efficiency to yield net efficiency.[47] Because of this, hydrogen automobiles are one of the least efficient means of passenger transport, generally around 50 times as much energy must be put into the production of hydrogen compared to how much is used to move the car.

A third consideration to take into account when calculating energy efficiency of automobiles is the occupancy rate of the vehicle. Although the consumption per unit distance per vehicle increases with increasing number of passengers, this increase is slight compared to the reduction in consumption per unit distance per passenger. This means that higher occupancy yields higher energy efficiency per passenger. Automobile occupancy varies across regions. For example, the estimated average occupancy rate is about 1.3 passengers per car in the San Francisco Bay Area,[48] while the 2006 UK estimated average is 1.58.[49]

Fourth, the energy needed to build and maintain roads is an important consideration, as is the energy returned on energy invested (EROEI). Between these two factors, roughly 20% must be added to the energy of the fuel consumed, to accurately account for the total energy used.

Finally, vehicle energy efficiency calculations would be misleading without factoring the energy cost of producing the vehicle itself. This initial energy cost can of course be depreciated over the life of the vehicle to calculate an average energy efficiency over its effective life span. In other words, vehicles that take a lot of energy to produce and are used for relatively short periods will require a great deal more energy over their effective lifespan than those that do not, and are therefore much less energy efficient than they may otherwise seem. Hybrid and electric cars use less energy in their operation than comparable petroleum-fuelled cars but more energy is used to manufacture them, so the overall difference would be less than immediately apparent. Compare, for example, walking, which requires no special equipment at all, and an automobile, produced in and shipped from another country, and made from parts manufactured around the world from raw materials and minerals mined and processed elsewhere again, and used for a limited number of years. According to the French energy and environment agency ADEME,[50] an average motor car has an embodied energy content of 20,800 kWh and an average electric vehicle amounts to 34,700 kWh. The electric car requires nearly twice as much energy to produce, primarily due to the large amount of mining and purification necessary for the rare earth metals and other materials used in lithium-ion batteries and in the electric drive motors. This represents a significant portion of the energy used over the life of the car (in some cases nearly as much as energy that is used through the fuel that is consumed, effectively doubling the car's per-distance energy consumption), and cannot be ignored when comparing automobiles to other transport modes. As these are average numbers for French automobiles and they are likely to be significantly larger in more auto-centric countries like the United States and Canada, where much larger and heavier cars are more common.

Driving practices and vehicles can be modified to improve their energy efficiency by about 15%.[51][52]

On a percentage basis, if there is one occupant in an automobile, between 0.4–0.6% of the total energy used is used to move the person in the car, while 99.4–99.6% (about 165 to 250 times more) is used to move the car.

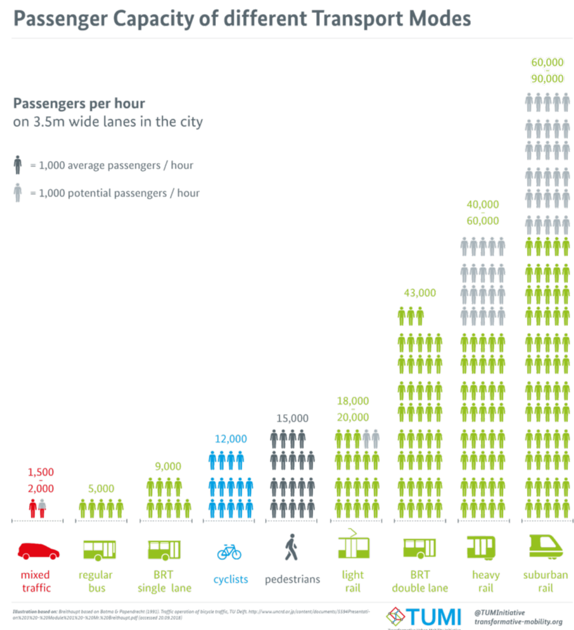
Example consumption figures

Two American solar cars in Canada

- Solar cars use no externally supplied fuel other than sunlight, charging the batteries entirely from built-in solar panels, and typically use less than 3 kW·h per 100 miles (67 kJ/km or 1.86 kW·h/100 km). These cars are not designed for passenger or utility use and would not be practical as such due to speed, payload, and inherent design.[24]
- The four passenger GEM NER uses 169 Wh/mi (203 mpg-e; 10.5 kW·h/100 km),[25] which equates to 2.6 kW·h/100 km per person when fully occupied, albeit at only 24 mph (39 km/h).
- The General Motors EV1 was rated in a test with a charging efficiency of 373 Wh-AC/mile or 23 kWh/100 km[53] approximately equivalent to 2.6 L/100 km (110 $\text{mpg}_{\text{-imp}}$; 90 $\text{mpg}_{\text{-US}}$) for petroleum-fuelled vehicles.
- Chevrolet Volt in full electric mode uses 36 kilowatt-hours per 100 miles (810 kJ/km; 96 mpg-e), meaning it may approach or exceed the energy efficiency of walking if the car is fully occupied with 4 or more passengers, although the relative emissions produced may not follow the same trends if analysing environmental impacts.
- The Daihatsu Charade 993cc turbo diesel (1987–1993) won the most fuel efficient vehicle award for going round the United Kingdom consuming an average of 2.82 L/100 km (100 $\text{mpg}_{\text{-imp}}$). It was surpassed only recently by the VW Lupo 3 L which consumes about 2.77 L/100 km (102 $\text{mpg}_{\text{-imp}}$). Both cars are rare to find on the popular market. The Daihatsu had major problems with rust and structural safety which contributes to its rarity and the quite short production run.
- The Volkswagen Polo 1.4 TDI Bluemotion and the SEAT Ibiza 1.4 TDI Ecomotion, both rated at 3.8 L/100 km (74 $\text{mpg}_{\text{-imp}}$; 62 $\text{mpg}_{\text{-US}}$) (combined) were the most fuel efficient petroleum-fuelled cars on sale in the UK as of 22 March 2008.[54][26][27]
- Honda Insight – achieves 48 $\text{mpg}_{\text{-US}}$ (4.9 L/100 km; 58 $\text{mpg}_{\text{-imp}}$) under real-world conditions.[55]
- Honda Civic Hybrid- regularly averages around 45 $\text{mpg}_{\text{-US}}$ (5.2 L/100 km; 54 $\text{mpg}_{\text{-imp}}$).
- 2012 Cadillac CTS-V Wagon 6.2 L Supercharged, 14 $\text{mpg}_{\text{-US}}$ (17 L/100 km; 17 $\text{mpg}_{\text{-imp}}$).[28]

- 2012 Bugatti Veyron, 10 mpg_{-US} (24 L/100 km; 12 mpg_{-imp}).[28]
- 2018 Honda Civic: 36 mpg_{-US} (6.5 L/100 km; 43 mpg_{-imp})[56]
- 2017 Mitsubishi Mirage: 39 mpg_{-US} (6.0 L/100 km; 47 mpg_{-imp})[57]
- 2017 Hyundai Ioniq hybrid: 55 mpg_{-US} (4.3 L/100 km; 66 mpg_{-imp})[58]
- 2017 Toyota Prius: 56 mpg_{-US} (4.2 L/100 km; 67 mpg_{-imp}) (Eco trim)[30]
- 2018 Nissan Leaf: 30 kWh (110 MJ)/100 mi (671 kJ/km) or 112 MPGe[29]
- 2017 Hyundai Ioniq EV: 25 kWh (90 MJ)/100 mi (560 kJ/km) or 136 MPGe[59]

Trains



Trains are in general one of the most efficient means of transport for freight and passengers. An inherent efficiency advantage is the low friction of steel wheels on steel rails compared especially to rubber tires on asphalt. Efficiency varies significantly with passenger loads, and losses incurred in electricity generation and supply (for electrified systems),[60][61] and, importantly, end-to-end delivery, where stations are not the originating final destinations of a journey.

Actual consumption depends on gradients, maximum speeds, and loading and stopping patterns. Data produced for the European MEET project (Methodologies for Estimating Air Pollutant Emissions) illustrate the different consumption patterns over several track sections. The results show the consumption for a German ICE high-speed train varied from around 19 to 33 kW·h/km (68–119 MJ/km; 31–53 kW·h/mi). The data also reflects the weight of the train per passenger. For example, TGV double-deck Duplex trains use lightweight materials, which keep axle loads down and reduce damage to track and also save energy.[62]

The specific energy consumption of the trains worldwide amounts to about 150 kJ/pkm (kilojoule per passenger kilometre) and 150 kJ/tkm (kilojoule per tonne kilometre) (ca. 4.2 kWh/100 pkm and 4.2 kWh/100 tkm) in terms of final energy. Passenger transportation by rail systems requires less energy than by car or plane (one seventh of the energy needed to move a person by car in an urban context,[35]). This is the reason why, although accounting for 9% of world passenger transportation activity (expressed in pkm) in 2015, rail passenger services represented only 1% of final energy demand in passenger transportation.[63][64]

Freight

Energy consumption estimates for rail freight vary widely, and many are provided by interested parties. Some are tabulated below.

Country	Year	Fuel economy (weight of goods)	Energy Intensity
USA[65]	2007	185.363 km/L (1 short ton)	*energy/mass-distance*
USA[66]	2018	473 miles/gallon (1 ton)	*energy/mass-distance*
UK[67]	—	87 t·km/L	0.41 MJ/t·km (LHV)

Passenger

Country	Year	Train efficiency	Per passenger-km (kJ)	Note
China[68]	2018	9.7 MJ (2.7 kWh) /car-km	137 kJ/passenger-km (at 100% load)	CR400AF@350 km/h Beijing-Shanghai PDL 1302 km average
Japan[69]	2004	17.9 MJ (5.0 kWh)/car-km	350 kJ/passenger-km	JR East average
Japan[70]	2017	1.49 kWh/car-km	≈92 kJ/passenger-km[36]	JR East Conventional Rail
EC[71][72]	1997	18 kW·h/km (65 MJ/km)		
USA[73][74]		1.125 mpg-US (209.1 L/100 km; 1.351 mpg-imp)	468 passenger-miles/US gallon (0.503 L/100 passenger-km)	
Switzerland[75]	2011	2300 GWhr/yr	470 kJ/passenger-km	
Basel, Switzerland[40][76]		1.53 kWh/vehicle-km (5.51 MJ/vehicle-km)	85 kJ/passenger-km (150 kJ/passenger-km at 80% average load)	
USA[77]	2009		2,435 BTU/mi (1.60 MJ/km)	
Portugal[38]	2011	8.5 kW·h/km (31 MJ/km; 13.7 kW·h/mi)	77 kJ/passenger-km	

Braking losses


N700 Series Shinkansen uses regenerative braking

Stopping is a considerable source of inefficiency. Modern electric trains like the *Shinkansen* (the *Bullet Train*) use regenerative braking to return current into the catenary while they brake. A Siemens study indicated that regenerative braking might recover 41.6% of the total energy consumed. The Passenger Rail (Urban and Intercity) and Scheduled Intercity and All Charter Bus Industries Technological and Operational Improvements – FINAL REPORT states that "Commuter operations can dissipate more than half of their total traction energy in braking for stops." and that "We estimate head-end power to be 35 percent (but it could possibly be as high as 45 percent) of total energy consumed by commuter railways."[78] Having to accelerate and decelerate a heavy train load of people at every stop is inefficient despite regenerative braking which can recover typically around 20% of the energy wasted in braking. Weight is a determinant of braking losses.

Buses


The Bus Rapid Transit of Metz uses a diesel-electric hybrid driving system, developed by Belgian Van Hool manufacturer.[79]

- In July 2005, the average occupancy for buses in the UK was stated to be 9 passengers per vehicle.[33]
- The fleet of 244 40-foot (12 m) 1982 New Flyer trolley buses in local service with BC Transit in Vancouver, Canada, in 1994/95 used 35,454,170 kWh for 12,966,285 vehicle km, or 9.84 MJ/vehicle km. Exact ridership on trolleybuses is not known, but with all 34 seats filled this equates to 0.32 MJ/passenger km. It is quite common to see people standing on Vancouver trolleybuses. This is a service with many stops per kilometre; part of the reason for the efficiency is the use of regenerative braking.
- A commuter service in Santa Barbara, California, USA, found average diesel bus efficiency of 6.0 mpg-US (39 L/100 km; 7.2 mpg-imp) (using MCI 102DL3 buses). With all 55 seats filled this equates to 330 passenger mpg; with 70% filled, 231 passenger mpg.[32]
- In 2011 the fleet of 752 buses in the city of Lisbon had an average speed of 14.4 km/h and an average occupancy of 20.1 passengers per vehicle.[80]
- Battery electric buses combine the high efficiency of a trolleybus with the flexibility of a diesel bus. Major manufacturers include BYD and Proterra.

Other

- NASA's Crawler-Transporter was used to move the Space Shuttle from storage to the launch pad. It uses diesel and has one of the highest fuel consumption rates on record, 150 US gallons per mile (350 l/km; 120 imp gal/mi).[81]

Air transport means

Aircraft

A principal determinant of energy consumption in aircraft is drag, which must be opposed by thrust for the aircraft to progress.

- Drag is proportional to the lift required for flight,[82] which is equal to the weight of the aircraft. As induced drag increases with weight, mass reduction, with improvements in engine efficiency and reductions in aerodynamic drag, has been a principal source of efficiency gains in aircraft, with a rule-of-thumb being that a 1% weight reduction corresponds to around a 0.75% reduction in fuel consumption.[82]
- Flight altitude affects engine efficiency. Jet-engine efficiency increases at altitude up to the tropopause, the temperature minimum of the atmosphere;

at lower temperatures, the Carnot efficiency is higher.[82] Jet engine efficiency is also increased at high speeds, but above about Mach 0.85 the airframe aerodynamic losses increase faster.

- Compressibility effects: beginning at transonic speeds of around Mach 0.85, shockwaves form increasing drag.
- For supersonic flight, it is difficult to achieve a lift to drag ratio greater than 5, and fuel consumption is increased in proportion.

Passenger airplanes averaged 4.8 l/100 km per passenger (1.4 MJ/passenger-km) (49 passenger-miles per gallon) in 1998. On average 20% of seats are left unoccupied. Jet aircraft efficiencies are improving: Between 1960 and 2000 there was a 55% overall fuel efficiency gain (if one were to exclude the inefficient and limited fleet of the DH Comet 4 and to consider the Boeing 707 as the base case).[85] Most of the improvements in efficiency were gained in the first decade when jet craft first came into widespread commercial use. Compared to advanced piston engine airliners of the 1950s, current jet airliners are only marginally more efficient per passenger-mile.[86] Between 1971 and 1998 the fleet-average annual improvement per available seat-kilometre was estimated at 2.4%. Concorde the supersonic transport managed about 17 passenger-miles to the Imperial gallon; similar to a business jet, but much worse than a subsonic turbofan aircraft. Airbus puts the fuel rate consumption of their A380 at less than 3 l/100 km per passenger (78 passenger-miles per US gallon).[87]

Solar Impulse 2, a solar aircraft

The mass of an aircraft can be reduced by using light-weight materials such as titanium, carbon fibre and other composite plastics. Expensive materials may be used, if the reduction of mass justifies the price of materials through improved fuel efficiency. The improvements achieved in fuel efficiency by mass reduction, reduces the amount of fuel that needs to be carried. This further reduces the mass of the aircraft and therefore enables further gains in fuel efficiency. For example, the Airbus A380 design includes multiple light-weight materials.

Concorde fuel efficiency comparison (assuming jets are filled to capacity)

Aircraft	Concorde[83]	Boeing 747-400[84]
Passenger-miles/imperial gallon	17	109
Passenger-miles/US gallon	14	91
Litres/100 passenger-km	16.6	3.1

Airbus has showcased wingtip devices (sharklets or winglets) that can achieve 3.5 percent reduction in fuel consumption.[88][89] There are wingtip devices on the Airbus A380. Further developed Minix winglets have been said to offer 6 percent reduction in fuel consumption.[90] Winglets at the tip of an aircraft wing smooth out the wing-tip vortex (reducing the aircraft's wing drag) and can be retrofitted to any airplane.[90]

NASA and Boeing are conducting tests on a 500 lb (230 kg) "blended wing" aircraft. This design allows for greater fuel efficiency since the whole craft produces lift, not just the wings.[91] The blended wing body (BWB) concept offers advantages in structural, aerodynamic and operating efficiencies over today's more conventional fuselage-and-wing designs. These features translate into greater range, fuel economy, reliability and life cycle savings, as well as lower manufacturing costs.[92][93] NASA has created a cruise efficient STOL (CESTOL) concept.

Fraunhofer Institute for Manufacturing Engineering and Applied Materials Research (IFAM) have researched a shark skin imitating paint that would reduce drag through a riblet effect.[94] Aircraft are a major potential application for new technologies such as aluminium metal foam and nanotechnology such as the shark skin imitating paint.

Air France Airbus A380-800

Propeller systems, such as turboprops and propfans are a more fuel efficient technology than jets. But turboprops have an optimum speed below about 450 mph (700 km/h).[95] This speed is less than used with jets by major airlines today. With the current high price for jet fuel and the emphasis on engine/airframe efficiency to reduce emissions, there is renewed interest in the propfan concept for jetliners that might come into service beyond the Boeing 787 and Airbus A350XWB. For instance, Airbus has patented aircraft designs with twin rear-mounted counter-rotating propfans.[96] NASA has conducted an Advanced Turboprop Project (ATP), where they researched a variable pitch propfan that produced less noise and achieved high speeds.

Related to fuel efficiency is the impact of aviation emissions on climate.

Small aircraft

- Motor-gliders can reach an extremely low fuel consumption for cross-country flights, if favourable thermal air currents and winds are present.
- At 160 km/h, a diesel powered two-seater Dieselis burns 6 litres of fuel per hour, 1.9 litres per 100 passenger km.[97]
- at 220 km/h, a four-seater 100 hp MCR-4S burns 20 litres of gas per hour, 2.2 litres per 100 passenger km.
- Under continuous motorised flight at 225 km/h, a Pipistrel Sinus burns 11 litres of fuel per flight hour. Carrying 2 people aboard, it operates at 2.4 litres per 100 passenger km.
- Ultralight aircraft Tecnam P92 Echo Classic at cruise speed of 185 km/h burns 17 litres of fuel per flight hour, 4.6 litres per 100 passenger km (2 people).[98] Other modern ultralight aircraft have increased efficiency; Tecnam P2002 Sierra RG at cruise speed of 237 km/h burns 17 litres of fuel per flight hour, 3.6 litres per 100 passenger km (2 people).[99]

Dyn'Aéro MCR4S

- Two-seater and four-seater flying at 250 km/h with old generation engines can burn 25 to 40 litres per flight hour, 3 to 5 litres per 100 passenger km.
- The Sikorsky S-76C++ twin turbine helicopter gets about 1.65 $\text{mpg}_{\text{-US}}$ (143 L/100 km; 1.98 $\text{mpg}_{\text{-imp}}$) at 140 knots (260 km/h; 160 mph) and carries 12 for about 19.8 passenger-miles per gallon (11.9 L per 100 passenger km).

Water transport means

Ships

Queen Elizabeth

Cunard stated that Queen Elizabeth 2 travelled 49.5 feet per imperial gallon of diesel oil (3.32 m/l or 41.2 ft/US gal), and that it had a passenger capacity of 1777.[100] Thus carrying 1777 passengers we can calculate an efficiency of 16.7 passenger miles per imperial gallon (16.9 l/100 p·km or 13.9 p·mpg$_{-US}$).

Queen Elizabeth 2

Cruise ships

MS *Oasis of the Seas* has a capacity of 6,296 passengers and a fuel efficiency of 14.4 passenger miles per US gallon. Voyager-class cruise ships have a capacity of 3,114 passengers and a fuel efficiency of 12.8 passenger miles per US gallon.[101]

Emma Maersk

Emma Maersk uses a Wärtsilä-Sulzer RTA96-C, which consumes 163 g/kW·h and 13,000 kg/h. If it carries 13,000 containers then 1 kg fuel transports one container for one hour over a distance of 45 km. The ship takes 18 days from Tanjung (Singapore) to Rotterdam (Netherlands), 11 from Tanjung to Suez, and 7 from Suez to Rotterdam,[102] which is roughly 430 hours, and has 80 MW, +30 MW. 18 days at a mean speed of 25 knots (46 km/h) gives a total distance of 10,800 nautical miles (20,000 km).

Assuming the Emma Maersk consumes diesel (as opposed to fuel oil which would be the more precise fuel) then 1 kg diesel = 1.202 litres = 0.317 US gallons. This corresponds to 46,525 kJ. Assuming a standard 14 tonnes per container (per teu) this yields 74 kJ per tonne-km at a speed of 45 km/h (24 knots).

Boats

A sailboat, much like a solar car, can locomote without consuming any fuel. A sail boat such as a dinghy using just wind power requires no input energy in terms of fuel. However some manual energy is required by the crew to steer the boat and adjust the sails using lines. In addition energy will be needed for demands other than propulsion, such as cooking, heating or lighting. The fuel efficiency of a single-occupancy boat is highly dependent on the size of its engine, the speed at which it travels, and its displacement. With a single passenger, the equivalent energy efficiency will be lower than in a car, train, or plane.

Seaports

Many seaports (e.g. container ports, cruise ports) endeavour to enhance energy efficiency. To ingrain sustainability and to achieve green seaports, many ports started harnessing renewable energy and using innovative technologies, alternative fuels (e.g. LNG, hydrogen, biofuel), smarter power distribution systems, energy consumption measurement systems. Operational strategies (e.g. peak shaving, demand side management), technology usage (e.g. electrification of equipment, cold ironing, energy storage systems), renewable energy, alternative fuels and energy management systems (e.g. smart grid with renewable energy) are gaining popularity.[103]

International transport comparisons

European Public transport

Rail and bus are generally required to serve 'off peak' and rural services, which by their nature have lower loads than city bus routes and inter city train lines. Moreover, due to their 'walk on' ticketing it is much harder to match daily demand and passenger numbers. As a consequence, the overall load factor on UK railways is 35% or 90 people per train:[104]

Conversely, airline services generally work on point-to-point networks between large population centres and are 'pre-book' in nature. Using yield management, overall load factors can be raised to around 70–90%. Intercity train operators have begun to use similar techniques, with loads reaching typically 71% overall for TGV services in France and a similar figure for the UK's Virgin Trains services.[105]

For emissions, the electricity generating source needs to be taken into account.[106][107] [108]

US Passenger transport

The US transport Energy Data Book states the following figures for passenger transport in 2009:[77] These are based on actual consumption of energy, at whatever occupancy rates there were.

Transport mode	Average passengers per vehicle	BTU per passenger-mile	MJ per passenger-kilometre
Rail (intercity Amtrak)	20.9	2,435	1.596
Motorcycles	1.16	2,460	1.61
Rail (transit light & heavy)	24.5	2,516	1.649
Rail (commuter)	32.7	2,812	1.843
Air	99.3	2,826	1.853
Cars	1.55	3,538	2.319
Personal trucks	1.84	3,663	2.401
Buses (transit)	9.2	4,242	2.781
Taxi	1.55	15,645	10.257

US Freight transport

The US transport Energy book states the following figures for freight transport in 2010:[77][109][110][111]

transport mode	Fuel consumption	
	BTU per short ton-mile	kJ per tonne-kilometre
Domestic waterborne	217	160
Class 1 railroads	289	209
Heavy trucks	3,357	2,426
Air freight (approx.)	9,600	6,900

From 1960 to 2010 the efficiency of air freight has increased 75%, mostly due to more efficient jet engines.[112]

1 gal_{-US} (3.785 l, 0.833 gal_{-imp}) of fuel can move a ton of cargo 857 km or 462 nmi by barge, or 337 km (209 mi) by rail, or 98 km (61 mi) by lorry.[113]

Compare:

- Space Shuttle used to transport freight to the other side of the Earth (see above): 40 megajoules per tonne-kilometre.
- Net energy for lifting: 10 megajoules per tonne-kilometre.

Canadian transport

Natural Resources Canada's Office of Energy Efficiency publishes annual statistics regarding the efficiency of the entire Canadian fleet. For researchers, these fuel consumption estimates are more realistic than the fuel consumption ratings of new vehicles, as they represent the real world driving conditions, including extreme weather and traffic. The annual report is called Energy Efficiency Trends Analysis. There are dozens of tables illustrating trends in energy consumption expressed in energy per passenger km (passengers) or energy per tonne km (freight).[114]

French environmental calculator

The environmental calculator of the French environment and energy agency (ADEME) published in 2007 using data from 2005[115] enables one to compare the different means of transport as regards the CO_2 emissions (in terms of carbon dioxide equivalent) as well as the consumption of primary energy. In the case of an electric vehicle, the ADEME makes the assumption that 2.58 toe as primary energy are necessary for producing one toe of electricity as end energy in France (see Embodied energy: In the energy field).

This computer tool devised by the ADEME shows the importance of public transport from an environmental point of view. It highlights the primary energy consumption as well as the CO_2 emissions due to transport. Due to the relatively low environmental impact of radioactive waste, compared to that of fossil fuel combustion emissions, this is not a factor in the tool. Moreover, intermodal passenger transport is probably a key to sustainable transport, by allowing people to use less polluting means of transport.

German environmental costs

Deutsche Bahn calculates the energy consumption of their various means of transportation.[116]

Type	2015
Regional rail passenger transport (MJ/pkm)	0.98
Long-distance rail passenger transport (MJ/pkm)	0.38
Bus service (MJ/pkm)	1.22
Rail freight transport (MJ/tkm)	0.35
Road freight transport (MJ/tkm)	1.31
Air freight (MJ/tkm)	10.46
Ocean freight (MJ/tkm)	0.11

See also

- ACEA agreement
- Alternative fuel vehicle
- Brake-specific fuel consumption
- Corporate average fuel economy (CAFE)
- Emission standard
- Fuel economy in automobiles
- Fuel-management systems
- Gas-guzzler
- Gasoline gallon equivalent
- Life-cycle assessment
- Marine fuel management
- Thrust-specific fuel consumption
- Vehicular metrics
- Transport

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