Power-to-weight ratio

From Wikipedia, the free encyclopedia

Power-to-weight ratio (or **specific power** or **power-to-mass ratio**) is a calculation commonly applied to engines and mobile power sources to enable the comparison of one unit or design to another. Power-to-weight ratio is a measurement of actual performance of any engine or power source. It is also used as a measurement of performance of a vehicle as a whole, with the engine's power output being divided by the weight (or mass) of the vehicle, to give a metric that is independent of the vehicle's size. Power-to-weight is often quoted by manufacturers at the peak value, but the actual value may vary in use and variations will affect performance.

The inverse of power-to-weight, weight-to-power ratio (power loading) is a calculation commonly applied to aircraft, cars, and vehicles in general, to enable the comparison of one vehicle's performance to another. Power-to-weight ratio is equal to thrust per unit mass multiplied by the velocity of any vehicle.

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Power-to-weight (specific power)

The power-to-weight ratio (Specific Power) formula for an engine (power plant) is the power generated by the engine divided by the mass. ("Weight" in this context is a colloquial term for "mass". To see this, note that what an engineer means by the "power to weight ratio" of an electric motor is not infinite in a zero gravity environment.)

A typical turbocharged V8 diesel engine might have an engine power of 250 kW (340 hp) and a mass of 380 kg (840 lb),[1] giving it a power-to-weight ratio of 0.65 kW/kg (0.40 hp/lb).

Examples of high power-to-weight ratios can often be found in turbines. This is because of their ability to operate at very high speeds. For example, the Space Shuttle's main engines used turbopumps (machines consisting of a pump driven by a turbine engine) to feed the propellants (liquid oxygen and liquid hydrogen) into the engine's combustion chamber. The original liquid hydrogen turbopump is similar in size to an automobile engine (weighing approximately 352 kilograms (775 lb)) and produces 72,000 hp (53.6 MW)[2] for a power-to-weight ratio of 153 kW/kg (93 hp/lb).

Physical interpretation

In classical mechanics, instantaneous power is the limiting value of the average work done per unit time as the time interval Δt approaches zero.

$$P = \lim_{\Delta t \to 0} \frac{\Delta W(t)}{\Delta t} = \lim_{\Delta t \to 0} P_{\text{avg}}$$

The typically used metrical unit of the power-to-weight ratio is $\frac{W}{kg}$ which equals $\frac{m^2}{s^3}$. This fact allows one to express the power-to-weight ratio purely by SI base units.

Propulsive power

If the work to be done is rectilinear motion of a body with constant mass m , whose center of mass is to be accelerated along a straight line to a speed $|\mathbf{v}(t)|$ and angle ϕ with respect to the centre and radial of a gravitational field by an onboard powerplant, then the associated kinetic energy to be delivered to the body is equal to

$$E_K = \tfrac{1}{2} m |\mathbf{v}(t)|^2$$

where:

m is mass of the body
$|\mathbf{v}(t)|$ is speed of the center of mass of the body, changing with time.

The instantaneous mechanical pushing/pulling power delivered to the body from the powerplant is then

$$P_K = \frac{1}{2}m2|\mathbf{v}(t)| \lim_{\Delta t \to 0} \frac{\Delta|\mathbf{v}(t)|}{\Delta t} = m\mathbf{a}(t) \cdot \mathbf{v}(t) = \mathbf{F}(t) \cdot \mathbf{v}(t) = \tau(t) \cdot \omega(t)$$

where:

$\mathbf{a}(t)$ is acceleration of the center of mass of the body, changing with time.
$\mathbf{F}(t)$ is linear force - or thrust - applied upon the center of mass of the body, changing with time.
$\mathbf{v}(t)$ is velocity of the center of mass of the body, changing with time.
$\tau(t)$ is torque applied upon the center of mass of the body, changing with time.
$\omega(t)$ is angular velocity of the center of mass of the body, changing with time.

In propulsion, power is only delivered if the powerplant is in motion, and is transmitted to cause the body to be in motion. It is typically assumed here that mechanical transmission allows the powerplant to operate at peak output power. This assumption allows engine tuning to trade power band width and engine mass for transmission complexity and mass. Electric motors do not suffer from this tradeoff, instead trading their high torque for traction at low speed. The **power advantage** or **power-to-weight ratio** is then

$$\text{P-to-W} = \frac{|\mathbf{a}(t)||\mathbf{v}(t)|}{|\mathbf{g}|}$$

where:

$|\mathbf{v}(t)|$ is linear speed of the center of mass of the body.

Engine power

The actual useful power of any traction engine can be calculated using a dynamometer to measure torque and rotational speed, with peak power sustained when the transmission and/or operator keeps the product of torque and rotational speed maximised. For jet engines there is often a cruise speed and power can be usefully calculated there, for rockets there is typically no cruise speed, so it is less meaningful.

Peak power of a traction engine occurs at a rotational speed higher than the speed when torque is maximised and at or below the maximum rated rotational speed - Max RPM. A rapidly falling torque curve would correspond with sharp torque and power curve peaks around their maxima at similar rotational speed, for example a small, lightweight engine with a large turbocharger. A slowly falling or near flat torque curve would correspond with a slowly rising power curve up to a maximum at a rotational speed close to Max RPM, for example a large, heavy multi-cylinder engine suitable for cargo/hauling. A falling torque curve could correspond with a near flat power curve across rotational speeds for smooth handling at different vehicle speeds.

Examples

Engines

Heat engines and heat pumps

Thermal energy is made up from molecular kinetic energy and latent phase energy. Heat engines are able to convert thermal energy in the form of a temperature gradient between a hot source and a cold sink into other desirable mechanical work. Heat pumps take mechanical work to regenerate thermal energy in a temperature gradient. Care should be made when interpreting propulsive power, especially for jet engines and rockets, deliverable from heat engines to a vehicle.

Heat Engine/Heat pump type	Peak Power Output		Power-to-weight ratio		Example Use
	SI	English	SI	English	
Wärtsilä RTA96-C 14-cylinder two-stroke Turbo Diesel engine[3]	80,080 kW	108,920 hp	0.03 kW/kg	0.02 hp/lb	Emma Mærsk container ship
Suzuki 538 cc V2 4-stroke gas (petrol) outboard Otto engine[4]	19 kW	25 hp	0.27 kW/kg	0.16 hp/lb	Runabout boats
DOE/NASA/0032-28 Mod 2 502 cc gas (petrol) Stirling engine[5]	62.3 kW	83.5 hp	0.30 kW/kg	0.18 hp/lb	Chevrolet Celebrity[•] 1985
GM 6.6 L Duramax LMM (LYE option) V8 Turbo Diesel engine[1]	246 kW	330 hp	0.65 kW/kg	0.40 hp/lb	Chevrolet Kodiak[•], GMC Topkick[•]
Junkers Jumo 205A opposed-piston two-stroke Diesel engine[6]	647 kW	867 hp	1.1 kW/kg	0.66 hp/lb	Ju 86C-1 airliner, B&V Ha 139 floatplane
GE LM2500+ marine turboshaft Brayton gas turbine[7]	30,200 kW	40,500 hp	1.31 kW/kg	0.80 hp/lb	GTS Millennium cruiseship, QM2 ocean liner
Mazda 13B-MSP Renesis 1.3 L Wankel engine[8]	184 kW	247 hp	1.5 kW/kg	0.92 hp/lb	Mazda RX-8[•]
PW R-4360 71.5 L 28-cylinder supercharged Radial engine	3,210 kW	4,300 hp	1.83 kW/kg	1.11 hp/lb	B-50 Superfortress, Convair B-36
					C-97 Stratofreighter, C-119 Flying Boxcar
					Hughes H-4 Hercules "Spruce Goose"
Wright R-3350 54.57 L 18-c s/c Turbo-compound Radial engine	2,535 kW	3,400 hp	2.09 kW/kg	1.27 hp/lb	B-29 Superfortress, Douglas DC-7
					C-97 S/f prototype, Kaiser-Frazer C-119F
O.S. Engines 49-PI Type II 4.97 cc UAV Wankel engine[9]	0.934 kW	1.252 hp	2.8 kW/kg	1.7 hp/lb	Model aircraft, Radio-controlled aircraft
JetCat SPT10-RX-H UAV turboshaft[10]	9 kW	12 hp	3.67 kW/kg	2.24 hp/lb	Model aircraft, Radio-controlled aircraft
GE LM6000 marine turboshaft Brayton gas turbine[11][12]	44,700 kW	59,900 hp	5.67 kW/kg	3.38 hp/lb	Peaking power plant

Heat Engine/Heat pump type	Peak Power Output		Power-to-weight ratio		Example Use
	SI	English	SI	English	
GE CF6-80C2 Brayton high-bypass turbofan jet engine[12]					Boeing 747[•], 767, Airbus A300
BMW V10 3L P84/5 2005 gas (petrol) Otto engine[13]	690 kW	925 hp	7.5 kW/kg	4.6 hp/lb	Williams FW27 car[•], Formula One auto racing
BMW i4 1.490L M12 engine 1987 gas (petrol) Otto engine [14]	1030 kW	1,400 hp	8.25 kW/kg	5.07 hp/lb	Arrows A10 car[•], Formula One auto racing
GE90-115B Brayton turbofan jet engine[15][16]	83,164 kW	111,526 hp	10.0 kW/kg	6.10 hp/lb	Boeing 777
PWR RS-24 (SSME) Block II H_2 Brayton turbopump [17][18]	63,384 kW	85,000 hp	138 kW/kg	84 hp/lb	Space Shuttle (STS-110 and later) [•]
PWR RS-24 (SSME) Block I H_2 Brayton turbopump[2]	53,690 kW	72,000 hp	153 kW/kg	93 hp/lb	Space Shuttle

- Full vehicle power-to-weight ratio shown below

Electric motors/Electromotive generators

An electric motor uses electrical energy to provide mechanical work, usually through the interaction of a magnetic field and current-carrying conductors. By the interaction of mechanical work on an electrical conductor in a magnetic field, electrical energy can be generated.

Electric motor type	Weight		Peak Power Output		Power-to-weight ratio		Example Use
	SI	English	SI	English	kW/kg	hp/lb	
Panasonic MSMA202S1G AC servo motor [19]	6.5 kg	14 lb	2 kW	2.7 hp	0.31 kW/kg	0.19 hp/lb	Conveyor belts, Robotics
Toshiba 660 MVA water cooled 23kV AC turbo generator	1,342 t	2,959,000 lb	660 MW	890,000 hp	0.49 kW/kg	0.30 hp/lb	Bayswater, Eraring Coal Power stations
Canopy Tech. Cypress 32 MW 15 kV AC PM generator[20]	33,557 kg	73,981 lb	32 MW	43,000 hp	0.95 kW/kg	0.58 hp/lb	Electric Power stations
Toyota Brushless AC Nd Fe B PM motor[21]	36.3 kg	80 lb	50 kW	67 hp	1.37 kW/kg	0.84 hp/lb	Toyota Prius[•] 2004
Himax HC6332-250 Brushless DC motor[22]	0.45 kg	0.99 lb	1.7 kW	2.3 hp	3.78 kW/kg	2.30 hp/lb	Radio controlled cars
Hi-Pa Drive HPD40 Brushless DC wheel hub motor[23]	25 kg	55 lb	120 kW	160 hp	4.8 kW/kg	2.92 hp/lb	Mini QED HEV, Ford F150 HEV
ElectriFly GPMG4805 Brushless DC[24]	1.48 kg	3.3 lb	8.4 kW	11.3 hp	5.68 kW/kg	3.45 hp/lb	Radio-controlled aircraft
YASA-400 Brushless AC[25]	24 kg	53 lb	165 kW	221 hp	6.875 kW/kg	4.18 hp/lb	Electric Vehicle, Drive eO
ElectriFly GPMG5220 Brushless DC[26]	0.133 kg	0.29 lb	1.035 kW	1.388 hp	7.78 kW/kg	4.73 hp/lb	Radio-controlled aircraft
Remy HVH250-090-POC3 Brushless DC[27]	33.5 kg	74 lb	297 kW	398 hp	8.87 kW/kg	5.39 hp/lb	Electric Vehicle
EMRAX268 Brushless AC[28]	19.9 kg	44 lb	200 kW	270 hp	10.05 kW/kg	6.12 hp/lb	Battery Electric Air Plane

- Full vehicle power-to-weight ratio shown below

Fluid engines and fluid pumps

Fluids (liquid and gas) can be used to transmit and/or store energy using pressure and other fluid properties. Hydraulic (liquid) and pneumatic (gas) engines convert fluid pressure into other desirable mechanical or electrical work. Fluid pumps convert mechanical or electrical work into movement or pressure changes of a fluid, or storage in a pressure vessel.

Fluid Powerplant type	Dry Weight		Peak Power Output		Power-to-weight ratio	
	SI	English	SI	English	SI	English
PlatypusPower Q2/200 hydroelectric turbine[29]	43 kg	95 lb	2 kW	2.7 hp	0.047 kW/kg	0.029 hp/lb
PlatypusPower PP20/200 hydroelectric turbine[29]	330 kg	728 lb	20 kW	27 hp	0.060 kW/kg	0.037 hp/lb
Atlas Copco LZL 35 pneumatic motor[30]	20 kg	44.1 lb	6.5 kW	8.7 hp	0.33 kW/kg	0.20 hp/lb
Atlas Copco LZB 14 pneumatic motor[31]	0.30 kg	0.66 lb	0.16 kW	0.22 hp	0.53 kW/kg	0.33 hp/lb
Bosch 0 607 954 307 pneumatic motor[32]	0.32 kg	0.71 lb	0.1 kW	0.13 hp	0.31 kW/kg	0.19 hp/lb
Atlas Copco LZB 46 pneumatic motor[33]	1.2 kg	2.65 lb	0.84 kW	1.13 hp	0.7 kW/kg	0.43 hp/lb
Bosch 0 607 957 307 pneumatic motor[32]	1.7 kg	3.7 lb	0.74 kW	0.99 hp	0.44 kW/kg	0.26 hp/lb
SAI GM7 radial piston hydraulic motor[34]	300 kg	661 lb	250 kW	335 hp	0.83 kW/kg	0.50 hp/lb
SAI GM3 radial piston hydraulic motor[35]	15 kg	33 lb	15 kW	20 hp	1 kW/kg	0.61 hp/lb
Denison GOLD CUP P14 axial piston hydraulic motor[36]	110 kg	250 lb	384 kW	509 hp	3.5 kW/kg	2.0 hp/lb
Denison TB vane pump[37]	7 kg	15 lb	40.2 kW	53.9 hp	5.7 kW/kg	3.6 hp/lb

Thermoelectric generators and electrothermal actuators

A variety of effects can be harnessed to produce thermoelectricity, thermionic emission, pyroelectricity and piezoelectricity. Electrical resistance and ferromagnetism of materials can be harnessed to generate thermoacoustic energy from an electric current.

Thermoelectric Powerplant type	Dry Weight		Peak Power Output		Power-to-weight ratio		Example Use
Teledyne ^{238}Pu GPHS-RTG 1980 [38][39]	56 kg	123 lb	285 W	0.39 hp	5.09 W/kg	0.003 hp/lb	Galileo probe, New Horizons probe
Boeing ^{238}Pu MMRTG MSL[39]	44.1 kg	97.2 lb	123 W	0.16 hp	2.79 W/kg	0.002 hp/lb	Mars Science Laboratory
HZ-20 thermoelectric module	0.115 kg	0.254 lb	19 W	0.025 hp	165 W/kg	0.098 hp/lb	Hi-Z Technology Inc.

Electrochemical (galvanic) and electrostatic cell systems

(Closed cell) batteries

All electrochemical cell batteries deliver a changing voltage as their chemistry changes from "charged" to "discharged". A nominal output voltage and a cutoff voltage are typically specified for a battery by its manufacturer. The output voltage falls to the cutoff voltage when the battery becomes "discharged". The nominal output voltage is always less than the open-circuit voltage produced when the battery is "charged". The temperature of a battery can affect the power it can deliver, where lower temperatures reduce power. Total energy delivered from a single charge cycle is affected by both the battery temperature and the power it delivers. If the temperature lowers or the power demand increases, the total energy delivered at the point of "discharge" is also reduced.

Battery discharge profiles are often described in terms of a factor of battery capacity. For example, a battery with a nominal capacity quoted in ampere-hours (Ah) at a C/10 rated discharge current (derived in amperes) may safely provide a higher discharge current - and therefore higher power-to-weight ratio - but only with a lower energy capacity. Power-to-weight ratio for batteries is therefore less meaningful without reference to corresponding energy-to-weight ratio and cell temperature. This relationship is known as Peukert's law.[40]

Battery type	Volts	Temp.	Energy-to-weight ratio	Power-to-weight ratio
Energizer 675 Mercury Free Zinc-air battery[41]	1.4V	21 °C	1,645 kJ/kg to 0.9 V	1.65 W/kg 2.24 mA
GE Durathon™ NaMx A2 UPS Molten salt battery[42]	54.2V	-40–65 °C	342 kJ/kg to 37.8 V	15.8 W/kg C/6 (76 A)
Panasonic R03 AAA Zinc–carbon battery[43][44]	1.5 V	20±2 °C	47 kJ/kg 20 mA to 0.9 V	3.3 W/kg 20 mA
			88 kJ/kg 150 mA to 0.9 V	24 W/kg 150 mA
Eagle-Picher SAR-10081 60Ah 22-cell Nickel–hydrogen battery[45]	27.7 V	10 °C	192 kJ/kg C/2 to 22 V	23 W/kg C/2
			165 kJ/kg C/1 to 22 V	46 W/kg C/1
ClaytonPower 400Ah Lithium-ion battery[46][47]	12V		617 kJ/kg	85.7 W/kg C/1 (175 A)
Energizer 522 Prismatic Zn–MnO_2 Alkaline battery[48]	9 V	21 °C	444 kJ/kg 25 mA to 4.8 V	4.9 W/kg 25 mA
			340 kJ/kg 100 mA to 4.8 V	19.7 W/kg 100 mA
			221 kJ/kg 500 mA to 4.8 V	99 W/kg 500 mA
Panasonic HHR900D 9.25Ah Nickel–metal hydride battery[49]	1.2 V	20 °C	209.65 kJ/kg to 0.7 V	11.7 W/kg C/5
				58.2 W/kg C/1
				116 W/kg 2C
URI 1418Ah replaceable anode Aluminium–air battery model[50][51]	244.8 V	60 °C	4680 kJ/kg	130.3 W/kg (142 A)
LG Chemical/CPI E2 6Ah $LiMn_2O_4$ Lithium-ion polymer battery[52][53]	3.8 V	25 °C	530.1 kJ/kg C/2 to 3.0 V	71.25 W/kg
			513 kJ/kg 1C to 3.0 V	142.5 W/kg
Saft 45E Fe Super-Phosphate Lithium iron phosphate battery[54]	3.3 V	25 °C	581 kJ/kg C to 2.5 V	161 W/kg
			560 kJ/kg 1.14 C to 2.0 V	183 W/kg
			0.73 kJ/kg 2.27 C to 1.5 V	367 W/kg
Energizer CH35 C 1.8Ah Nickel–cadmium battery[55]	1.2 V	21 °C	152 kJ/kg C/10 to 1 V	4 W/kg C/10

Battery type	Volts	Temp.	Energy-to-weight ratio	Power-to-weight ratio
			147.1 kJ/kg 5C to 1 V	200 W/kg 5 C
Firefly Energy Oasis FF12D1-G31 6-cell 105Ah VRLA battery[56]	12 V	25 °C	142 kJ/kg C/10 to 7.2 V	4 W/kg C/10
		-1 8 °C	7 kJ/kg CCA to 7.2V	234 W/kg CCA (625A)
		0 °C	9 kJ/kg CA to 7.2 V	300 W/kg CA (800 A)
Panasonic CGA103450A 1.95Ah $LiCoO_2$ Lithium-ion battery[57]	3.7 V	20 °C	666 kJ/kg C/5.3 to 2.75 V	35 W/kg C/5.3
		0 °C	633 kJ/kg C/1 to 2.75 V	176 W/kg C/1
		20 °C	655 kJ/kg C/1 to 2.75 V	182 W/kg C/1
		20 °C	641 kJ/kg 2C to 2.75 V	356 W/kg 2C
Electric Fuel Battery Corp. UUV 120Ah Zinc–air fuel cell[58]			630 kJ/kg	500 W/kg C/1
Sion Power 2.5Ah Li–S Lithium-ion battery[59]	2.15 V	25 °C	1260 kJ/kg	70 W/kg C/5
			1209 kJ/kg	672 W/kg 2C
Stanford Prussian Blue durable Potassium-ion battery[60]	1.35 V	room	54 kJ/kg	13.8 W/kg C/1
			50 kJ/kg	138 W/kg 10C
			39 kJ/kg	693 W/kg 50C
Maxell / Yuasa / AIST Nickel–metal hydride lab prototype[61]		45 °C		980 W/kg
Toshiba SCiB cell 4.2Ah Li_2TiO_3 Lithium-ion battery[62][63]	2.4 V	25 °C	242 kJ/kg	67.2 W/kg C/1
			218 kJ/kg	4000 W/kg 12C
Ionix Power Systems $LiMn_2O_4$ Lithium-ion battery lab model[64]		lab	270 kJ/kg	1700 W/kg
		lab	29 kJ/kg	4900 W/kg
A123 Systems 26650 Cell 2.3Ah $LiFePO_4$ Lithium ion battery[65][66]	3.3 V	-20 °C	347 kJ/kg C/1 to 2V	108 W/kg C/1
		0 °C	371 kJ/kg C/1 to 2 V	108 W/kg C/1
		25 °C	390 kJ/kg C/1 to 2 V	108 W/kg C/1
		25 °C	390 kJ/kg 27C to 2 V	3300 W/kg 27C

Battery type	Volts	Temp.	Energy-to-weight ratio	Power-to-weight ratio
		25 °C	57 kJ/kg 32C to 2 V	5657 W/kg 32C
Saft VL 6Ah Lithium-ion battery[67]	3.65 V	-20 °C	154 kJ/kg 30C to 2.5 V	41.4 W/kg 30C (180 A)
			182 kJ/kg 1C to 2.5 V	67.4 W/kg 1C
		25 °C	232 kJ/kg 1C to 2.5 V	64.4 W/kg 1C
			233 kJ/kg 58.3C to 2.5 V	3757 W/kg 58.3C (350A)
			34 kJ/kg 267C to 2.5 V	17176 W/kg 267C (1.6kA)
			4.29 kJ/kg 333C to 2.5 V	21370 W/kg 333C (2kA)

Electrostatic, electrolytic and electrochemical capacitors

Capacitors store electric charge onto two electrodes separated by an electric field semi-insulating (dielectric) medium. Electrostatic capacitors feature planar electrodes onto which electric charge accumulates. Electrolytic capacitors use a liquid electrolyte as one of the electrodes and the electric double layer effect upon the surface of the dielectric-electrolyte boundary to increase the amount of charge stored per unit volume. Electric double-layer capacitors extend both electrodes with a nanopourous material such as activated carbon to significantly increase the surface area upon which electric charge can accumulate, reducing the dielectric medium to nanopores and a very thin high permittivity separator.

While capacitors tend not to be as temperature sensitive as batteries, they are significantly capacity constrained and without the strength of chemical bonds suffer from self-discharge. Power-to-weight ratio of capacitors is usually higher than batteries because charge transport units within the cell are smaller (electrons rather than ions), however energy-to-weight ratio is conversely usually lower.

Capacitor type	Capacity	Volts	Temp.	Energy-to-weight ratio	Power-to-weight ratio
ACT Premlis Lithium ion capacitor[68]	2000 F	4.0 V	25 °C	54 kJ/kg to 2.0 V	44.4 W/kg @ 5 A
				31 kJ/kg to 2.0 V	850 W/kg @ 10 A
Nesccap Electric double-layer capacitor[69]	5000 F	2.7 V	25 °C	19.58 kJ/kg to 1.35 V	5.44 W/kg C/1 (1.875 A)
				5.2 kJ/kg to 1.35 V	5,200 W/kg[70] @ 2,547A
EEStor EESU barium titanate supercapacitor[71]	30.693 F	3500 V	85 °C	1471.98 kJ/kg	80.35 W/kg C/5
				1471.98 kJ/kg	8,035 W⁄kg 20 C
General Atomics 3330CMX2205 High Voltage Capacitor[72]	20.5 mF	3300 V	? °C	2.3 kJ/kg	6.8 MW/kg @ 100 kA

Fuel cell stacks and flow cell batteries

Fuel cells and flow cells, although perhaps using similar chemistry to batteries, have the distinction of not containing the energy storage medium or fuel. With a continuous flow of fuel and oxidant, available fuel cells and flow cells continue to convert the energy storage medium into electric energy and waste products. Fuel cells distinctly contain a fixed electrolyte whereas flow cells also require a continuous flow of electrolyte. Flow cells typically have the fuel dissolved in the electrolyte.

Fuel cell type	Dry weight	Power-to-weight ratio	Example Use
Redflow Power+BOS ZB600 10kWh ZBB[73]	900 kg	5.6 W/kg (9.3 W/kg peak)	Rural Grid support
Ceramic Fuel Cells BlueGen MG 2.0 CHP SOFC[74]	200 kg	10 W/kg 15 W/kg CHP	
MTU Friedrichshafen 240 kW MCFC HotModule 2006	20,000 kg	12 W/kg	
Smart Fuel Cell Jenny 600S 25W DMFC [75]	1.7 kg	14.7 W/kg	Portable military electronics
UTC Power PureCell 400 kW PAFC[76]	27,216 kg	14.7 W/kg	
GEFC 50V50A-VRB Vanadium redox battery[77]	80 kg	31.3 W/kg (125 W/kg peak)	
Ballard Power Systems Xcellsis HY-205 205 kW PEMFC[78]	2,170 kg	94.5 W/kg	Mercedes-Benz Citaro O530BZ[•]
UTC Power/NASA 12 kW AFC[79]	122 kg	98 W/kg	Space Shuttle orbiter[•]
Ballard Power Systems FCgen-1030 1.2 kW CHP PEMFC[80]	12 kg	100 W/kg	Residential cogeneration
Ballard Power Systems FCvelocity-HD6 150 kW PEMFC[80]	400 kg	375 W/kg	Bus and heavy duty
NASA Glenn Research Center 50 W SOFC[81]	0.071 kg	700 W/kg	
Honda 2003 43 kW FC Stack PEMFC [82][•]	43 kg	1000 W/kg	Honda FCX Clarity[•]
Lynntech, Inc. PEMFC lab prototype[83]	0.347 kg	1,500 W/kg	

- Full vehicle power-to-weight ratio shown below

Photovoltaics

Photovoltaic Panel type	Power-to-weight ratio
Thyssen Solartec 128W Nanocrystalline Si Triplejunction PV module[84]	6 W/kg
Suntech/UNSW HiPerforma PLUTO220-Udm 220W Ga-F22 Polycrystalline Si PV module[85]	13.1 W/kg STP
	9.64 W/kg nominal
Global Solar PN16015A 62W CIGS polycrystalline thin film PV module[86]	40 W/kg
Able (AEC) PUMA 6 kW GaInP2/GaAs/Ge-on-Ge Triplejunction PV array[87]	65 W/kg
Current spacecraft grade	~77 W/kg[88]
ITO/InP on Kapton foil	2000 W/kg[89]

Vehicles

Power-to-weight ratios for vehicles are usually calculated using curb weight (for cars) or wet weight (for motorcycles), that is, excluding weight of the driver and any cargo. This could be slightly misleading, especially with regard to motorcycles, where the driver might weigh 1/3 to 1/2 as much as the vehicle itself. In the sport of competitive cycling athlete's performance is increasingly being expressed in VAMs and thus as a power-to-weight ratio in W/kg. This can be measured through the use of a bicycle powermeter or calculated from measuring incline of a road climb and the rider's time to ascend it.[90]

Utility and practical vehicles

Most vehicles are designed to meet passenger comfort and cargo carrying requirements. Different designs trade off power-to-weight ratio to increase comfort, cargo space, fuel economy, emissions control, energy security and endurance. Reduced drag and lower rolling resistance in a vehicle design can facilitate increased cargo space without increase in the (zero cargo) power-to-weight ratio. This increases the role flexibility of the vehicle. Energy security considerations can trade off power (typically decreased) and weight (typically increased), and therefore power-to-weight ratio, for fuel flexibility or drive-train hybridisation. Some utility and practical vehicle variants such as hot hatches and sports-utility vehicles reconfigure power (typically increased) and weight to provide the perception of sports car like performance or for other psychological benefit. Rail locomotives require high mass to maintain adhesive traction on the rails, therefore improving the power-to-weight ratio by reducing mass is not necessarily beneficial. However choice of rail locomotive traction system (i.e. AC VFD over DC) can support improved power-to-weight ratio by reducing mass for the same adhesion.

Notable low ratio

Vehicle	Power	Vehicle Weight	Power to Weight ratio
Benz Patent Motorwagen 954 cc 1886[91]	560 W / 0.75 bhp	265 kg / 584 lb	2.1 W/kg / 779 lb/hp
Stephenson's Rocket 0-2-2 steam locomotive with tender 1829[92]	15 kW / 20 bhp	4,320 kg / 9524 lb	3.5 W/kg / 476 lb/hp
CBQ Zephyr streamliner diesel locomotive with railcars 1934[93]	492 kW / 660 bhp	94 t / 208,000 lb	5.21 W/kg / 315 lb/hp
Alberto Contador's Verbier climb 2009 Tour de France on Specialized bike[90]	420 W / 0.56 bhp	62 kg / 137 lb	6.7 W/kg / 245 lb/hp
Force Motors Minidor Diesel 499 cc auto rickshaw[94][95]	6.6 kW / 8.8 bhp	700 kg / 1543 lb	9 W/kg / 175 lb/hp
PRR Q2 4-4-6-4 steam locomotive with tender 1944	5,956 kW / 7,987 bhp	475.9 t / 1,049,100 lb	12.5 W/kg / 131 lb/hp
Mercedes-Benz Citaro O530BZ H_2 fuel cell bus 2002[96]	205 kW / 275 bhp	14,500 kg / 32,000 lb	14.1 W/kg / 116 lb/hp
TGV BR Class 373 high-speed Eurostar Trainset 1993	12,240 kW / 16,414 bhp	816 t / 1,798,972 lb	15 W/kg / 110 lb/hp
General Dynamics M1 Abrams Main battle tank 1980[97]	1,119 kW / 1500 bhp	55.7 t / 122,800 lb	20.1 W/kg / 81.9 lb/hp
BR Class 43 high-speed diesel electric locomotive 1975	1,678 kW / 2,250 bhp	70.25 t / 154,875 lb	23.9 W/kg / 69 lb/hp
GE AC6000CW diesel electric locomotive 1996	4,660 kW / 6,250 bhp	192 t / 423,000 lb	24.3 W/kg / 68 lb/hp
BR Class 55 Napier Deltic diesel electric locomotive 1961	2,460 kW / 3,300 bhp	101 t / 222,667 lb	24.4 W/kg / 68 lb/hp
International CXT 2004[98]	164 kW / 220 bhp	6,577 kg / 14500 lb	25 W/kg / 66 lb/hp
Ford Model T 2.9 L flex-fuel 1908	15 kW / 20 bhp	540 kg / 1,200 lb	28 W/kg / 60 lb/hp
TH!NK City 2008[99]	30 kW / 40 bhp	1038 kg / 2,288 lb	28.9 W/kg / 56.9 lb/hp
Messerschmitt KR200 Kabinenroller 191 cc 1955	6 kW / 8.2 bhp	230 kg / 506 lb	30 W/kg / 50 lb/hp
Wright Flyer 1903	9 kW / 12 bhp	274 kg / 605 lb	33 W/kg / 50 lb/hp
Tata Nano 624 cc 2008	26 kW / 35 bhp	635 kg / 1,400 lb	41.0 W/kg / 40 lb/hp
Bombardier JetTrain high-speed gas turbine-electric locomotive 2000[100]	3,750 kW / 5,029 bhp	90,750 kg / 200,000 lb	41.2 W/kg / 39.8 lb/hp

Vehicle	Power	Vehicle Weight	Power to Weight ratio
Suzuki MightyBoy 543 cc 1988	23 kW / 31 bhp	550 kg / 1,213 lb	42 W/kg / 39 lb/hp
Mitsubishi i MiEV 2009[101]	47 kW / 63 bhp	1,080 kg / 2,381 lb	43.5 W/kg / 37.8 lb/hp
Holden FJ 2,160 cc 1953[102]	44.7 kW / 60 bhp	1,021 kg / 2,250 lb	43.8 W/kg / 37.5 lb/hp
Chevrolet Kodiak/GMC Topkick LYE 6.6 L 2005[1][103]	246 kW / 330 bhp	5126 kg / 11,300 lb	48 W/kg / 34.2 lb/hp
DOE/NASA/0032-28 Chevrolet Celebrity 502 cc ASE Mod II 1985[5]	62.3 kW / 83.5 bhp	1,297 kg / 2,860 lb	48.0 W/kg / 34.3 lb/hp
Suzuki Alto 796 cc 2000	35 kW / 46 bhp	720 kg / 1,587 lb	49 W/kg / 35 lb/hp
Land Rover Defender 2.4 L 1990[104]	90 kW / 121 bhp	1,837 kg / 4,050 lb	49 W/kg / 33 lb/hp

Common power

Vehicle	Power	Vehicle Weight	Power to Weight ratio
Toyota Prius 1.8 L 2010 (petrol only)[105]	73 kW / 98 bhp	1,380 kg / 3,042 lb	53 W/kg / 31 lb/hp
Bajaj Platina Naked 100 cc 2006[106]	6 kW / 8 bhp	113 kg / 249 lb	53 W/kg / 31 lb/hp
Subaru R2 type S 2003[107]	47 kW / 63 bhp	830 kg / 1,830 lb	57 W/kg / 29 lb/hp
Ford Fiesta ECOnetic 1.6 L TDCi 5dr 2009[108]	66 kW / 89 bhp	1,155 kg / 2,546 lb	57 W/kg / 29 lb/hp
Volvo C30 1.6D DRIVe S/S 3dr Hatch 2010[109]	80 kW / 108 bhp	1,347 kg / 2,970 lb	59.4 W/kg / 27.5 lb/hp
Ford Focus ECOnetic 1.6 L TDCi 5dr Hatch 2009 [110]	81 kW / 108 bhp	1,357 kg / 2,992 lb	59.7 W/kg / 27 lb/hp
Ford Focus 1.8 L Zetec S TDCi 5dr Hatch 2009 [111]	84 kW / 113 bhp	1,370 kg / 3,020 lb	61 W/kg / 27 lb/hp
Honda FCX Clarity 4 kg Hydrogen 2008[112]	100 kW / 134 bhp	1,600 kg / 3,528 lb	63 W/kg / 26 lb/hp
Hummer H1 6.6 L V8 2006[113]	224 kW / 300 bhp	3,559 kg / 7,847 lb	63 W/kg / 26 lb/hp
Audi A2 1.4 L TDI 90 type S 2003[114]	66 kW / 89 bhp	1,030 kg / 2,270 lb	64 W/kg / 25 lb/hp
Opel/Vauxhall/Holden/Chevrolet Astra 1.7 L CTDi 125 2010[115]	92 kW / 123 bhp	1,393 kg / 3,071 lb	66 W⁄kg / 24.9 lb⁄hp
Mini (new) Cooper 1.6D 2007[116]	81 kW / 108 bhp	1,185 kg / 2,612 lb	68 W/kg / 24 lb/hp
Toyota Prius 1.8 L 2010 (electric boost)[105]	100 kW / 134 bhp	1,380 kg / 3,042 lb	72 W/kg / 23 lb/hp
Ford Focus 2.0 L Zetec S TDCi 5dr Hatch 2009 [117]	100 kW / 134 bhp	1,370 kg / 3,020 lb	73 W/kg / 23 lb/hp
General Motors EV1 electric car Gen II 1998[118]	102.2 kW / 137 bhp	1,400 kg / 3,086 lb	73 W/kg / 23 lb/hp
Toyota Venza I4 2.7 L FWD 2009[119]	136 kW / 182 bhp	1,706 kg / 3,760 lb	80 W/kg / 20.7 lb/hp
Ford Focus 2.0 L Zetec S 5dr Hatch 2009[120]	107 kW / 143 bhp	1,327 kg / 2,926 lb	81 W/kg / 20 lb/hp
Fiat Grande Punto 1.6 L Multijet 120 2005[121]	88 kW / 118 bhp	1,075 kg / 2,370 lb	82 W/kg / 20 lb/hp
Mini (classic) 1275GT 1969	57 kW / 76 bhp	686 kg / 1,512 lb	83 W/kg / 20 lb/hp

Vehicle	Power	Vehicle Weight	Power to Weight ratio
Opel/Vauxhall/Holden/Chevrolet Astra 2.0 L CTDi 160 2010[122]	118 kW / 158 bhp	1,393 kg / 3,071 lb	85 W⁄kg / 19.4 lb⁄hp
Ford Focus 2.0 auto 2007[123]	104.4 kW / 140 bhp	1,198 kg / 2,641 lb	87.1 W/kg / 19 lb/hp
Subaru Legacy/Liberty 2.0R 2005[124]	121 kW / 162 bhp	1,370 kg / 3,020 lb	88 W/kg / 19 lb/hp
Subaru Outback 2.5i 2008[125]	130.5 kW / 175 bhp	1,430 kg / 3,153 lb	91 W/kg / 18 lb/hp
Smart Fortwo 1.0 L Brabus 2009[126]	72 kW / 97 bhp	780 kg / 1,720 lb	92 W/kg / 18 lb/hp
Toyota Venza V6 3.5 L AWD 2009[119]	200 kW / 268 bhp	1,835 kg / 4,045 lb	109 W/kg / 15 lb/hp
Toyota Venza I4 2.7 L FWD 2009[119] with Lotus mass reduction[127]	136 kW / 182 bhp	1,210 kg / 2,667 lb	112.2 W/kg / 14.7 lb/hp
Toyota Hilux V6 DOHC 4 L 4×2 Single Cab Pickup ute 2009[128]	175 kW / 235 bhp	1,555 kg / 3,428 lb	112.5 W/kg / 14.6 lb/hp
Toyota Venza V6 3.5 L FWD 2009[119]	200 kW / 268 bhp	1,755 kg / 3,870 lb	114 W/kg / 14.4 lb/hp

Performance luxury, roadsters and mild sports

Increased engine performance is a consideration, but also other features associated with luxury vehicles. Longitudinal engines are common. Bodies vary from hot hatches, sedans (saloons), coupés, convertibles and roadsters. Mid-range dual-sport and cruiser motorcycles tend to have similar power-to-weight ratios.

Vehicle	Power	Vehicle Weight	Power to Weight ratio
Honda Accord sedan V6 2011	202 kW / 271 bhp	1630 kg / 3593 lb	124 W/kg / 13.26 lb/hp
Mini (new) Cooper 1.6T S JCW 2008[129]	155 kW / 208 bhp	1205 kg / 2657 lb	129 W/kg / 13 lb/hp
Mazda RX-8 1.3 L Wankel 2003	173 kW / 232 bhp	1309 kg / 2888 lb	132 W/kg / 12 lb/hp
Holden Statesman/Caprice / Buick Park Avenue / Daewoo Veritas 6 L V8 2007[130]	270 kW / 362 bhp	1891 kg / 4170 lb	143 W/kg / 12 lb/hp
Kawasaki KLR650 Gasoline DualSport 650 cc	26 kW / 35 bhp	182 kg / 401 lb	143 W/kg / 11 lb/hp
NATO HTC M1030M1 Diesel/Jet fuel DualSport 670 cc[131]	26 kW / 35 bhp	182 kg / 401 lb	143 W/kg / 11 lb/hp
Harley-Davidson FLSTF Softail Fat Boy Cruiser 1,584 cc 2009[132]	47 kW / 63 bhp	324 kg / 714 lb	145 W/kg / 11.3 lb/hp
BMW 7 Series 760Li 6 L V12 2006[133]	327 kW / 439 bhp	2250 kg / 4960 lb	145 W/kg / 11 lb/hp
Subaru Impreza WRX STi 2.0 L 2008[134]	227 kW / 304 bhp	1530 kg / 3373 lb	148 W/kg / 11 lb/hp
Honda S2000 roadster 1999	183.88 kW / 240 bhp	1250 kg / 2723 lb	150 W/kg / 11 lb/hp
GMH HSV Clubsport / GMV VXR8 / GMC CSV CR8 / Pontiac G8 6 L V8 2006[135]	317 kW / 425 bhp	1831 kg / 4037 lb	173 W/kg / 9.5 lb/hp
Tesla Roadster 2011[136]	215 kW / 288 bhp	1235 kg / 2723 lb	174 W/kg / 9.5 lb/hp

Sports vehicles and aircraft

Power-to-weight ratio is an important vehicle characteristic that affects the acceleration and handling - and therefore the driving enjoyment - of any sports vehicle. Aircraft also depend on high power-to-weight ratio to achieve sufficient lift.

Vehicle	Power	Vehicle Weight	Power to Weight ratio
Lotus Elise SC 2008	163 kW / 218 bhp	910 kg / 2006 lb	179 W/kg / 9.20 lb/hp
Ferrari Testarossa 1984	291 kW / 390 bhp	1506 kg / 3320 lb	193 W/kg / 8.51 lb/hp
Citroën DS3 WRC rally car 2011[137]	235 kW / 315 bhp	1200 kg / 2,645.5 lb	196 W/kg / 8.40 lb/hp
Artega GT[138]	220 kW / 300 bhp	1100 kg / 2425 lb	200 W/kg / 8.08 lb/hp
Lotus Exige GT3 2006[139]	202.1 kW / 271 bhp	980 kg / 2160 lb	206 W/kg / 7.97 lb/hp
Chevrolet Corvette C6 2008[140]	321 kW / 430 bhp	1441 kg / 3177 lb	223 W/kg / 7.39 lb/hp
Nissan GT-R R35 3.6L Turbo V6[141]	406 kW / 545 bhp	1779 kg / 3922 lb[142]	228 W/kg / 7.20 lb/hp
Dodge Charger SRT Hellcat 6.2L Hemi V8[141]	527 kW / 707 bhp	2075 kg / 4575 lb	254 W/kg / 6.47 lb/hp
Chevrolet Corvette C6 Z06[140]	376 kW / 505 bhp	1421 kg / 3133 lb	265 W/kg / 6.2 lb/hp
Porsche 911 GT2 2007	390 kW / 523 bhp	1440 kg / 3200 lb	271 W/kg / 6.1 lb/hp
Lamborghini Murciélago LP 670-4 SV 2009[143]	493 kW / 661 bhp	1550 kg / 3417 lb	318 W/kg / 5.17 lb/hp
Mercedes-Benz C-Coupé DTM touring car 2012[144]	343 kW / 460 bhp	1110 kg / 2,447 lb	309 W/kg / 5.32 lb/hp
Sector111 Drakan Spyder[145]	321 kW / 430 bhp	907 kg / 2000 lb	354 W/kg / 4.65 lb/hp
McLaren F1 GT 1997[146]	467.6 kW / 627 bhp	1220 kg / 2690 lb	403 W/kg / 4.3 lb/hp
BAC Mono 2011[147]	213 kW / 285 bhp	540 kg / 1190 lb	394 W/kg / 4.18 lb/hp
Porsche 918 Spyder[148]	661 kW / 887 bhp	1656 kg / 3650 lb	399 W/kg / 4.16 lb/hp
Lancia Delta S4 group B 1985[149]	350 kW / 480 bhp	890 kg / 1,962 lb	393 W/kg / 4.08 lb/hp
Ariel Atom 3S 2014[150]	272 kW / 365 bhp	639 kg / 1400 lb	426 W/kg / 3.84 lb/hp
Bombardier Dash 8 Q400 turboprop airliner[151]	7,562 kW / 10,142 bhp	17,185 kg / 37,888 lb	440 W/kg / 3.7 lb/hp

Vehicle	Power	Vehicle Weight	Power to Weight ratio
Ferrari LaFerrari[152]	708 kW / 950 bhp	1585 kg / 3495 lb	447 W/kg / 3.68 lb/hp
McLaren P1 2013[153]	673 kW / 903 bhp	1490 kg / 3280 lb	452 W/kg / 3.63 lb/hp
Supermarine Spitfire Fighter aircraft 1936	1,096 kW / 1,470 bhp	2,309 kg / 5,090 lb	475 W/kg / 3.46 lb/hp
Messerschmitt Bf 109 Fighter aircraft 1935	1,085 kW / 1,455 bhp	2,247 kg / 4,954 lb	483 W/kg / 3.40 lb/hp
Thunderbolt Land speed record car	3504 kW / 4700 bhp	7 t / 15432 lb	500 W/kg / 3.28 lb/hp
Ferrari FXX 2005	597 kW / 801 bhp	1155 kg / 2546 lb	517 W/kg / 3.18 lb/hp
Polaris Industries Assault Snowmobile 2009[154]	115 kW / 154 bhp	221 kg / 487 lb	523 W/kg / 3.16 lb/hp
Audi R10 TDI Le Mans Prototype 2006 [155]	485 kW / 650 bhp	925 kg / 2,039 lb	524 W/kg / 3.13 lb/hp
Ultima GTR 720 2006[156]	536.9 kW / 720 bhp	920 kg / 2183 lb	583 W/kg / 3.03 lb/hp
Honda CBR1000RR 2009	133 kW / 178 bhp	199 kg / 439 lb	668 W/kg / 2.46 lb/hp
Ariel Atom 500 V8 2011	372 kW / 500 bhp	550 kg / 1212 lb	676.3 W/kg / 2.47 lb/hp
BMW S1000RR 2009	144 kW / 193 bhp	207.7 kg / 458 lb	693.3 W/kg / 2.37 lb/hp
Peugeot 208 T16 Pikes Peak 2013	652 kW / 875 bhp	875 kg / 1930 lb	745 W/kg / 2.21 lb/hp
Koenigsegg One:1 2015	1000 kW / 1341 bhp	1310 kg / 2888 lb	763 W/kg / 2.15 lb/hp
Nissan R90C Group C 1990[157]	746 kW / 1000 bhp	900 kg / 1984 lb	829 W/kg / 1.98 lb/hp
Ducati 1199 Panigale R (WSB) 2012	151 kW / 202 bhp	165 kg / 364 lb	915 W/kg / 1.80 lb/hp
KillaCycle Drag racing electric motorcycle	260 kW / 350 bhp	281 kg / 619 lb	925 W/kg / 1.77 lb/hp
MTT Turbine Superbike 2008[158]	213.3 kW / 286 bhp	227 kg / 500 lb	940 W/kg / 1.75 lb/hp
Vyrus 987 C3 4V V supercharged motorcycle 2010[159]	157.3 kW / 211 bhp	158 kg / 348.3 lb	996 W/kg / 1.65 lb/hp

Vehicle	Power	Vehicle Weight	Power to Weight ratio
Kawasaki H2R Motorcycle 2015[160]	223 kW / 300 bhp	216 kg / 476 lb	1032 W/kg / 1.43 lb/hp
BMW Williams FW27 Formula One 2005[161]	690 kW / 925 bhp	600 kg / 1323 lb	1150 W/kg / 1.58 lb/hp
Honda RC211V MotoGP 2004-6	176.73 kW / 237 bhp	148 kg / 326 lb	1194 W/kg / 1.37 lb/hp
Boeing 747-300[11] at Mach 0.84 cruise, 35,000 ft altitude	245 MW / 328,656 bhp	178.1 t / 392,800 lb	1376 W/kg / 1.20 lb/hp
John Force Racing Funny Car NHRA Drag Racing 2008[162]	5,963.60 kW / 8,000 bhp	1043 kg / 2,300 lb	5717 W/kg / 0.30 lb/hp

Human

Power to weight ratio is important in cycling, since it determines acceleration and the speed during hill climbs. Since a cyclist's power to weight output decreases with fatigue, it is normally discussed with relation to the length of time that he or she maintains that power. A professional cyclist can produce over 20 W/kg as a 5-second maximum.[163]

See also

- Thrust-to-weight ratio
- Specific output
- Vehicle metrics
- Energy density
- Engine power
- Propulsive efficiency
- von Kármán–Gabrielli diagram

References

1. "General Motors 2009 Data Book" (PDF). September 5, 2008.
2. Ryan, Richard. "Lessons in Systems Engineering - The SSME Weight Growth History" (PDF). NASA.
3. "The world's most powerful Engine enters service" (Press release). Wärtsilä. 2006-09-12. Retrieved 2010-01-12.
4. "Suzuki Marine - DF25 - Features and Specifications". Suzuki. Retrieved January 12, 2010.
5. Noel P. Nightingale (October 1986). "Automotive Stirling Engine - Mod II Design Report" (PDF). NASA Lewis Research Center. Retrieved July 16, 2010.
6. Jane's 1989, p. 294.
7. "LM2500+ Marine Gas Turbine" (PDF). GE Aviation. Retrieved 2010-01-25.
8. "Mazda - What Is A Rotary Engine?". Mazda. Retrieved January 12, 2010.
9. "UAV Wankel Engines". O.S. Engines. Retrieved 2010-01-08.

10. http://www.jetcatusa.com/rc-turbines/turbine-details/spt10_rx_h/. Retrieved 2015-11-17. Missing or empty `|title=` (help)
11. "LM6000 Marine Gas Turbine" (PDF). GE Aviation. Retrieved 2010-01-25.
12. "GE's LM6000 Demonstrates Outstanding Reliability And Availability In First Two Years Of Commercial Service". GE Aviation. Retrieved 2010-01-25.
13. "BMW engines". All Formula One Info. Retrieved 2010-01-08.
14. "BMW engines". All Formula One Info. Retrieved 2010-01-08.
15. "Model GE90-115B". GE Aviation. Retrieved 2010-01-08.
16. **(French)** Jean-Claude Thevenin, *Le turboréacteur, moteur des avions à réaction*, AAAF, June 2004 (3rd edition).
17. "NASA Fact Sheet: Space Shuttle Main Engine (SSME) Enhancements" (PDF). Marshall Space Flight Center, Huntsville, Alabama: NASA. March 2002. Archived from the original (PDF) on 2008-10-26.
18. "High Performance Liquid Hydrogen Turbopumps". NASA. 1999-02-01. Retrieved 2010-01-08.
19. "Panasonic MINAS-A4 AC Servo - Motor Specifications and Ratings 200V MSMA" (PDF). Retrieved 2010-01-26.
20. "Cypress HPL Series Permanent Magnet Motors - Product Brochure" (PDF). Canopy Technologies, LLC. Retrieved 2010-01-26.
21. Jewell, Geraint (2009-09-11). "Permanent Magnet Machines and Actuators" (PDF). *Symposium on Materials for a Sustainable Future*. Birmingham, England: Magnetic Materials Group, University of Birmingham. pp. 11–18. Retrieved 2010-05-14.
22. "Himax Brushless Outrunner Motor HC6332-250" (PDF). Maxx Products International, Inc. Retrieved 2010-01-28.
23. "Hi-Pa Drive". PML Flightlink. Archived from the original on April 10, 2009. Retrieved 2010-03-02.
24. "Great Planes ElectriFly RimFire 65cc 80-85-160 Brushless Outrunner Electric Motor" (PDF). Retrieved 2015-06-23.
25. "YASA-400 Electric Motor Specification". Retrieved 2015-07-01.
26. "Great Planes ElectriFly AMMO Inrunner Brushless Motors". Retrieved 2015-06-23.
27. "HVH250 R3" (PDF). Retrieved 2016-01-19.
28. "EMRAX268". Retrieved 2015-06-22.
29. "Platypus Power Micro Hydro Electric Generator - Specifications". Platypus Power. Retrieved 2010-01-15.
30. "Atlas Copco Air motor catalogue, page 52 - Product data at air pressure 6.3 bar (91 psi) - LZL 35 Unrestricted" (PDF). Atlas Copco. Retrieved 2011-09-21.
31. "Atlas Copco Tools - LZB 14 Technical data". Atlas Copco. Retrieved 2011-09-21.
32. "Bosch Production Tools - Air Tools - Motors". Bosch. Retrieved 2010-01-15.
33. "Atlas Copco Tools - LZB 46 Technical data". Atlas Copco. Retrieved 2011-09-21.
34. SAI. "GM Series - GM7 Hydraulic Motor" (PDF). SAI. Retrieved 2010-01-14.
35. SAI. "GM03 Motor - Extremely Compact Unit" (PDF). SAI. Retrieved 2010-01-14.
36. Parker Hannifin Corporation. "Denison GOLD CUP Product Catalog" (PDF). Parker Hannifin Corporation. Retrieved 2012-10-31.
37. Denison Hydraulics. "TB Vane-Type Single Pump" (PDF). Parker Hannifin Corporation. Retrieved 2012-10-31.
38. Bennett, G.L. (2006). "Space Nuclear Power" (PDF). Federation of American Scientists.
39. Caillat, T. (August 2006). "Development of a New Generation of High-Temperature Thermoelectric Unicouples for Space Applications" (PDF). NASA, JPL and Caltech.
40. Peukert, W. (1897). "Über die Abhängigkeit der Kapazität von der Entladestromstärke bei Bleiakkumulatoren". *Elektrotechnische Zeitschrift*. **20**.
41. "Product Datasheet - Energizer 675 ZnAir" (PDF). Energizer Holdings. 2010-02-15. Retrieved 2010-09-20.
42. "GE Durathon Batteries - NaMx Battery System for Telecom Applications" (PDF). Pennsylvania State University. 2010-09-17. Retrieved 2011-11-24.
43. "Zinc Carbon Batteries" (PDF). Panasonic. August 2009. Retrieved February 5, 2010.
44. Matsushita Battery Industrial Co., Ltd.;Matsushita Electric Industrial Co., Ltd. (June 25, 1998). "Specification for Zinc-Carbon Dry Battery R03(NB)" (PDF). Panasonic.
45. EaglePicher Technologies, LLC (February 6, 2003). "Nickel Hydrogen (NiH_2) Batteries - Single Pressure Vessel" (PDF). University of Padua. Retrieved February 5, 2010.
46. Clayton Power (2010). "Lithium Ion Battery Packs". Clayton Power. Retrieved 2010-10-05.

47. Clayton Power (2010). "Complete Power Systems - 24VDC/230VAC". Clayton Power. Retrieved 2010-10-05.
48. "Product Datasheet - Energizer 522 9V" (PDF). Energizer Holdings. Retrieved February 4, 2010.
49. "Nickel Metal Hydride Batteries - Individual Data Sheet - HHR900D" (PDF). Panasonic. August 2005. Retrieved February 5, 2010.
50. Yang, Shaohua & Harold Knickle (2002). "Design and analysis of aluminum/air battery system for electric vehicles". *Journal of Power Sources*. **112** (1): 162–173. Bibcode:2002JPS...112..162Y. doi:10.1016/S0378-7753(02)00370-1. ISSN 0378-7753.
51. Zhang, Xin, Shao Hua Yang, and Harold Knickle (2004). "Novel operation and control of an electric vehicle aluminum/air battery system". *Journal of Power Sources*. **128** (2): 331–342. Bibcode:2004JPS...128..331Z. doi:10.1016/j.jpowsour.2003.09.058. ISSN 0378-7753.
52. LG Chem. (2005-03-24). "E2 General Information" (PDF). Lucky Goldstar Chemical Ltd. p. 1. Retrieved 2010-10-01.
53. LG Chem. (2009-01-12). "Press Release - LG Chem Battery Cells to Power Chevrolet Volt" (PDF). Lucky Goldstar Chemical Ltd., CompactPower division. p. 3. Retrieved 2010-10-01.
54. JCI-SAFT (June 2010). "Rechargeable LiFePO4 lithium-ion battery Super-Phosphate VL 45E Fe Very High Energy cell" (PDF). SAFT Batteries. Retrieved 2010-10-01.
55. "Product Datasheet - Energizer CH35 C" (PDF). Energizer Holdings. Retrieved February 4, 2010.
56. "Microcell Technology AGM Deep Cycle Group 31 Battery" (PDF). FireFly Energy, Inc. 2009. Retrieved February 4, 2010.
57. "Lithium Ion Batteries - Individual Data Sheet - CGA103450A" (PDF). Panasonic. January 2007. Archived from the original (PDF) on March 27, 2009. Retrieved February 4, 2010.
58. "Mission Extended - Advanced Zinc-Air Battery Technology" (PDF). Electric Fuel Battery Corporation. 2003-03-30. Retrieved 2010-09-15.
59. "Sion Power - LiS Spec Sheet" (PDF). Sion Power. October 3, 2008. Retrieved 11 September 2010.
60. Pasta, Mauro; Colin D. Wessells; Nian Liu; Johanna Nelson; Matthew T. McDowell; Robert A. Huggins; Michael F. Toney; Yi Cui (2014-01-06). "Full open-framework batteries for stationary energy storage". *Nature Communications*. **5**. Bibcode:2014NatCo...5E3007P. doi:10.1038/ncomms4007. Retrieved 2014-08-01.
61. Fukunaga, Hiroshi; Kishimi, Mitsuhiro; Matsumoto, Nobuaki; Tanaka, Toshiki; Kishimoto, Tomonori; Ozaki, Tetsuya; Sakai, Tetsuo (2006). "Improvement of Nickel Metal Hydride Battery with Non-foam Nickel Electrode for Hybrid Electric Vehicles Applications". *Electrochemistry*. Japan. **75** (5): 385–393. ISSN 1344-3542. Retrieved February 4, 2010.
62. "Rechargeable Battery SCiB - Description". Toshiba Corporation. Retrieved 2010-09-11.
63. "Rechargeable Battery SCiB - Specifications". Toshiba Corporation. Retrieved 2010-09-11.
64. "Lithium Ion Battery Research". Ionix Power Systems. Retrieved February 4, 2010.
65. "A123Systems Products". A123 Systems. Retrieved February 4, 2010.
66. "High Power Lithium Ion ANR26650M1A - Datasheet" (PDF). A123 Systems. Archived from the original (PDF) on June 1, 2010. Retrieved February 4, 2010.
67. JCI-Saft (June 2009). "Rechargeable lithium-ion battery VL 6A Very High Power cell" (PDF). SAFT Batteries. Retrieved 2010-10-02.
68. "Typical Characteristics of Premlis". Advanced Capacitor Technologies, Inc. Retrieved September 9, 2010.
69. "Nesccap Ultracapacitor Products - EDLC - Prismatic" (PDF). Nesscap Co., Ltd. Retrieved September 10, 2010.
70. "Nesccap Ultracapacitor (EDLC)". Nesscap Co., Ltd. Retrieved September 10, 2010.
71. US patent 7466536 (https://worldwide.espacenet.com/textdoc?DB=EPODOC&IDX=US7466536), Weir; Richard Dean & Nelson; Carl Walter, "Utilization of poly(ethylene terephthalate) plastic and composition-modified barium titanate powders in a matrix that allows polarization and the use of integrated-circuit technologies for the production of lightweight ultrahigh electrical energy storage units (EESU)", published 16 December 2008, issued 16 December 2008, assigned to EEStor, Inc
72. "SERIES CMX - Self-Healing Energy Storage Capacitors". Retrieved 12 August 2012.
73. "Redflow Power+BOS ZB600 Stand Alone Power System" (PDF). Redflow. March 2010. Retrieved September 11, 2010.
74. "BlueGen Modular Generator - Power + Heat" (PDF). Ceramic Fuel Cells Ltd. Retrieved February 4, 2010.
75. "The Jenny fuel cell by SFC". Smart Fuel Cell AG. Retrieved February 4, 2010.

76. "UTC Power - Model 400 PureCell System" (PDF). South Windsor, Connecticut, United States: UTC Power. 2008. Retrieved February 4, 2010.
77. "GEFC 50V50A-VRB Vanadium Redox Battery Stack". GEFC. 2010. Retrieved February 5, 2010.
78. "Transportation Fuel Cells - Technical Info." (PDF). Fuel Cells 2000. Retrieved 2010-07-24. External link in `|publisher=` (help)
79. "Space Orbiter". UTC Power. 2008. Retrieved February 5, 2010.
80. "PEM Fuel Cell Product Portfolio" (PDF). Ballard Power Systems. Retrieved February 4, 2010.
81. "High Power Density Solid Oxide Fuel Cell" (PDF). NASA Glenn Research Center. Retrieved June 24, 2015.
82. "Press Information Honda Fuel Cell Power FCX" (PDF). Honda. December 2004. Retrieved February 4, 2010.
83. Murphy, O.J.; Cisar, A.; Clarke, E. (1998). "Low-cost light weight high power density PEM fuel cell stack". *Proceedings of the Symposium on Batteries and Fuel Cells for Portable Applications and Electric Vehicles*. INIST. pp. 3829–3840.
84. "Thyssen-Solartec - The photovoltaic roof and façade system" (PDF). Thyssen Solartec. Retrieved 2010-02-13.
85. "Suntech HiPerforma Module PLUTO220-Udm PLUTO215-Udm" (PDF). Suntech Power. Retrieved 2010-03-09.
86. "GlobalSolar Product Catalog - Power the Possibilities". Global Solar. Retrieved 2010-03-09.
87. "A Heritage-Technology Rigid Substrate Solar Array for Traditional Applications" (PDF). Able Engineering Company, Inc. Retrieved 2010-02-13.
88. Rocket and spacecraft propulsion By Martin J. L. Turner (https://books.google.com/books?id=ja1ROyh4yPYC&pg=RA1-PA180&lpg=RA1-PA180&dq=solar+panels+spacecraft+kg&source=bl&ots=sQKXYoTEg0&sig=wFkCMoPlauHp7-ryD0F3fljOTEA&hl=en&ei=kbM6St6mKdKhjAfx5KijDQ&sa=X&oi=book_result&ct=result&resnum=2)
89. http://apl.aip.org/resource/1/applab/v95/i22/p223503_s1
90. "What is VAM and How to Calculate it?". Cycling Fitness. 2009-07-24. Retrieved 2010-06-25.
91. "1886 Benz Patent Motorwagen". *Los Angeles Times*. Tribune Company. 2006-06-01.
92. Karwatka, Dennis (ed.). "Robert Stephenson and 19th-Century Transportation Technology". *Encyclopædia Britannica*. Retrieved 2010-01-08.
93. Cobb, Harold M. (June 2006). "The Burlington Zephyr Stainless Steel Train". *Advanced Materials & Processes*: 24–28. Retrieved 2010-01-12.
94. *Minidor Diesel 3-seater* (PDF), Force Motors, archived from the original (PDF) on October 10, 2008, retrieved 2010-01-08
95. "Balaji Force Minidor Autorickshaw". Balaji Force. Retrieved 2010-01-08.
96. Ally, Jamie; Pryor, Trevor (2007-04-25). "Life-cycle assessment of diesel, natural gas and hydrogen fuel cell bus transportation systems". *Journal of Power Sources*. Research Institute for Sustainable Energy, Murdoch University, Perth, Western Australia, Australia: Elsevier. **170** (2): 401–411. doi:10.1016/j.jpowsour.2007.04.036. ISSN 0378-7753.
97. "Abrams Tank Fact File for the United States Army". US Army. Archived from the original on 2013-11-15. Retrieved 2011-02-19.
98. Leno, Jay (March 2005). "A Tonka Toy comes to life--really big life.". Popular Mechanics.
99. "TH!NK City - Specifications - Technical Data". TH!NK Global. Retrieved 2010-09-13.
100. "Bombardier Transportation - Rail Vehicles - Intercity/Highspeed - JetTrain". June 2000. Retrieved 2010-07-24.
101. "About i MiEV". Mitsubishi Motors. July 2008. Retrieved 2010-06-03.
102. "Holden FJ Technical Specifications". Unique Cars and Parts. Retrieved 2010-01-08.
103. Quiroga, Tony (November 2005). "GMC TopKick C4500 by Monroe Truck Equipment - Specs; Hummer This". Car And Driver. Retrieved 2010-01-15.
104. "Land Rover Defender 4×4 110 2.4D Hard Top 5dr". What Car?. Retrieved 2010-01-08.
105. "Toyota Prius 2010 Performance & Specifications". Toyota. Retrieved 2010-01-08.
106. "Details of Bajaj Platina 100 cc". AutoIndia. Retrieved 2010-01-08.
107. "2003 Subaru R2 S Technical specifications". Car Folio. Retrieved 2010-01-08.
108. "Ford Fiesta Hatchback 1.6 TDCi Econetic 5dr". What Car?. Retrieved 2010-01-08.
109. "Volvo C30 - a Four-Seat Sports Coupé with High Performance". Volvo. Retrieved 2010-03-16.
110. "Ford Focus Hatchback 1.6 TDCi 110 DPF ECOnetic 5dr". What Car?. Retrieved 2010-01-08.

111. "Ford Focus Hatchback 1.8 TDCi Zetec S 5dr". What Car?. Retrieved 2010-01-08.
112. "The History of the Honda FCX Clarity, Fuel Cell Electric Vehicle FCEV". Honda. Retrieved 2010-01-08.
113. "2006 HUMMER H1 specifications". InternetAutoguide.com. Retrieved 2010-01-08.
114. "2003 Audi A2 1.4 TDi Technical specifications". Car Folio. Retrieved 2010-01-08.
115. "Vauxhall Astra Hatchback 1.7 CDTi 125 Elite 5dr". What Car?. Retrieved 2010-07-09.
116. "Mini Cooper Hatchback 1.6D 3dr". What Car?. Retrieved 2010-01-08.
117. "Ford Focus Hatchback 1.8 TDCi Style 5dr". What Car?. Retrieved 2010-01-08.
118. "1998 GM EV1 GenII Lead-Acid 2 door fixed-head coupe technical specifications". Car Folio. Retrieved 2012-08-09.
119. "Toyota Venza Performance & Specs". Toyota Motor North America. 2010. Retrieved 2010-11-06.
120. "Ford Focus Hatchback 2.0 Zetec S 5dr". What Car?. Retrieved 2010-01-08.
121. "Fiat Grande Punto Hatchback 1.6 Multijet 120 Sporting 5dr". What Car?. Retrieved 2010-01-08.
122. "Vauxhall Astra Hatchback 2.0 CDTi 160 Elite 5dr". What Car?. Retrieved 2010-07-09.
123. "2007 Ford Focus 2.0 Automatic (US) Technical specifications". Retrieved 2010-01-08.
124. "2005 Subaru Legacy 2.0R Technical specifications". Retrieved 2010-01-08.
125. "2008 Subaru Legacy Outback 2.5i Technical specifications". Retrieved 2010-01-08.
126. "Smart Fortwo Cabriolet 1.0 97 Brabus Xclusive (07-09) 2dr". What Car?. Retrieved 2010-01-08.
127. "An Assessment of Mass Reduction Opportunities for a 2017–2020 Model Year Vehicle Program" (PDF). International Council on Clean Transportation.
128. "Toyota HiLux 4×2 Utes 2009" (PDF). Toyota. Retrieved 2010-01-21.
129. "Mini Cooper Hatchback 1.6T S John Cooper Works 3dr". What Car?. Retrieved 2010-01-08.
130. "2007 Holden WM Caprice". Topspeed. Retrieved 2010-01-08.
131. *M1030M1 JP8/Diesel Military Motorcycle* (PDF), Hayes Diversified Technologies, retrieved 2009-02-28
132. "2009 Harley-Davidson FLSTF Softail Fat Boy Preview". Topspeed. Retrieved 2010-01-26.
133. "The new BMW 760i; The new BMW 760Li; Contents." (PDF) (Press release). BMW. March 2009. Retrieved 2010-01-08.
134. Edmunds, Dan. "Full Test: 2008 Subaru Impreza WRX STI". edmunds InsideLine. Retrieved 2010-01-08.
135. "Vauxhall VXR8 Saloon 6.2 V8 Bathurst 4dr". What Car?. Retrieved 2010-01-08.
136. "Roadster Features and Specifications". Tesla Motors, Inc.. Retrieved 2011-07-31.
137. "Citroën DS3 RRC: A new addition to the family!". Retrieved 24 October 2012.
138. Vijayenthiran, Viknesh. "Artega GT now on sale". Motor Authority. Retrieved 2010-01-08.
139. "2006 Lotus Exige GT3 Technical specifications". Car Folio. Retrieved 2010-01-08.
140. "2008 Chevrolet Corvette". MSN Autos. Retrieved 2010-01-08.
141. "Is Nissan GTR Beating Hellcat Charger a Big Deal?". Allpar. Retrieved 2015-09-24.
142. "gt-r versions-specs". Nissan. Retrieved 2015-09-24.
143. "Press Release - Lamborghini Murciélago LP 670-4 SuperVeloce – the new king of the bulls - is even more powerful, lighter and faster" (PDF). MotorStars. Retrieved 2010-03-24.
144. mercedes-benz.com. "The New 2012 Mercedes-Benz C-Coupé DTM". mercedes-benz.com. Retrieved 9 September 2011.
145. "Sector111 Project Dragon (Drakan Spyder)". sector111. Retrieved 2014-11-20.
146. "1997 McLaren F1 GT Technical specifications". Car Folio. Retrieved 2010-01-08.
147. "BAC Mono review". *Autocar*. Retrieved 19 May 2014.
148. "Porsche 918 Spyder". car and driver. 2015. Retrieved 2016-09-24.
149. Mastrostefano, Raffaele, ed. (January 1985). "Sempre Più Integrali" [More and More All-Wheel Drives]. *Quattroruote* (in Italian). Milan, Italy: Editoriale Domus. **30** (351): 182–183.
150. "2014 Ariel Atom 3S". sector111. Retrieved 2014-11-20.
151. "Bombardier Dash 8 Q400 Specifications". Bombardier Aerospace. 1997. Retrieved 2010-07-24.
152. "Ferrari LaFerrari". car and driver. 2015. Retrieved 2016-09-24.
153. Steve Sutcliffe (7 May 2014). "McLaren P1 Review". Autocar. Retrieved 7 May 2014.
154. "2009 Polaris 800 Assault RMK146 Snowmobile Specifications & Price". Polaris Industries. Retrieved 2010-01-19.
155. Michael J. Fuller. "2006 Audi R10". Mulsanne's Corner.
156. "Ultima GTR 720 (2006 - date)". SupercarWorld. Retrieved 2010-01-08.
157. Lis, Alan. "The One That Got Away". *Racecar Engineering*. Chelsea Magazines.
158. "The MTT Turbine Superbike" (PDF). Marine Turbine. Retrieved 2010-01-08.

159. "2010 Vyrus 987 Review". Motorcycle.com. Retrieved 2010-04-14.
160. "Kawasaki H2R". F1 Technical. Retrieved 2015-02-03.
161. "Williams FW27". F1 Technical. Retrieved 2010-01-12.
162. "John Force - Funny Car Legend". Automobile Magazine. Retrieved 2010-09-10.
163. http://home.trainingpeaks.com/blog/article/power-profiling

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- Measurespeed.com - Power to Weight Ratio Calculator (http://measurespeed.com/power-to-weight-ratio-calculator.php)

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