



ET3 Global Alliance 'Space Travel on Earth'

ET3 ENERGY USE OVERVIEW

The energy use calculation of ET3 is not simple as it is with an automobile. The propulsion energy is extremely low (more than 100,000 times better than a car). There are several energy requirements for ET3 that do not exist for an automobile; such as energy to: maintain the vacuum, cycle the airlock, and provide breathable air for the occupants. (The proper ET3 terminology is: "capsule" = the vehicle, and "tube" = the guideway/road/track).

Per cycle energy use:

A) Vacuum Leaks come from the tube surface, the capsules, and airlocks. (Leaks from the tube surface are more or less constant, so for routes with low use, the energy use per trip will be greater.) A old CRT (tube type) television requires a thousand times higher quality vacuum than ET3 to function. A CRT will keep it's vacuum for many years with no significant leaking. Capsule leaking is also very low. The main source of air leaking is from the small clearance between the capsule and the airlock. The energy required for vacuum and airlock cycling is less than 0.1kWh (1.5 cents) per airlock cycle.

B) Acceleration energy is a function of the design speed squared and capsule mass. Assuming a maximum mass of 1200 lb, the acceleration energy to reach the design speed is shown in column "I" of the attached xls file. To reach 300km/h (187mph) takes 0.5kWh; to reach 600km/h (373mph) takes 2.1kWh; to reach 1000km/h (622mph) takes 5.9kWh; to reach 3000km/h (1865mph) takes 53kWh; etc. NOTE: about 90% of the acceleration energy to accelerate can be recovered with 'regenerative braking' when the vehicle slows down.

Per mile energy use:

i) Create the vacuum (initial pump-down). Initial evacuation is at minimum the energy required to move a frictionless piston the length of the tube against atmospheric pressure. For a 60" diameter tube the force required is $\pi \cdot 30 \cdot 30 \cdot 14.7 = 41563$ lb of force. For one mile we have 219.45 million foot pounds of energy, converting to kWh = 82.65kWh per mile of single tube. Pumping efficiency is about 60% so we need 138kWh per mile of 5' diameter tube. This is about \$21 worth of electrical energy (at 15 cents per kWh) per mile of tube, a very small part of construction cost. A typical freeway will carry more than 30,000 vehicles per day, assuming the tube will be serviced once every ten years (it could be once every 100 years) we have a tube vacuum cost of 0.00002 cents per capsule mile. (a tube will carry 300 times this number of capsules, so with higher use, the vacuum cost will drop).

ii) Propulsion energy is a function of magnetic and aerodynamic drag. This depends on the design speed and the degree of evacuation. At 4,000 mph (worst case) it is about 1kWh per thousand miles or about 0.001kWh per mile per 6 seat capsule. This energy is not recoverable, however it helps to reduce leak pumping energy by moving residual air from small leaks through the system. Total per mile energy use is minimized when the energy required to maintain the vacuum and the propulsion energy are equal. At 400mph, the propulsive energy is less than 1/10th as much.

Per hour cost:

Some costs depend on time -- so they convert to per mile cost with the inverse of design speed.

1) HTSM (maglev) energy cost for HTSM (based on energy required to liquefy nitrogen) is about 0.7kWh per hour for a loaded capsule or 11 cents per hour at \$0.15/kWh. (NOTE: there is a slight increase for HTSM levitation energy as a function of design speed).

(ref. for LN2 energy: <http://hypertextbook.com/facts/2007/KarenFan.shtml>)

2) capsule cooling (removal of waste heat and body heat). A typical human radiates about 100W of heat while at rest, and the capsule lighting and computing emit about 350W for a total of 0.95kWh per hour cooling. This could be supplied with about 10 lb of ice melting. NOTE: this cooling can be supplied at COP much greater

than 1, especially in the winter time.

<http://www.txu.com/en/Business/esource-biz/buying-equipment/refrigeration/ice-makers.aspx> says that energy use per 100 pounds of ice is 3.4 kWh resulting in capsule cooling energy of 0.34kWh. (not needed for most cargo)

3) Supply oxygen and remove CO2 (not required for most cargo);

Our life support energy budget is 0.5kWh per hour per 6 passenger capsule. The following references show this is conservative.

<http://www.petrogen.com/product-breakdown/oxygen-generating-systems-inc/oxygen-generating-systems-inc-faq>

For PSA oxygen generators, the cost for oxygen production, or cylinder filling is normally stated in kilowatt hours (KWH). The reason being that the air is free, but there is a cost of electricity to operate the air compressor. At a sea level site elevation, it will cost about 10 KWH to fill a 6m³ size oxygen cylinder, or 1.5 KWH per M³.

<http://en.oxycock.com/oxygen.php> A human being uses about 400-500 liters of oxygen a day and breathes 12-20 times per minute.

So, for each passengers per day we need 0.5m³ of O₂. And the energy is 0.75kWh / person / day. The per person per hour energy use is: 0.75kWh / 24hr/day = 0.03125kWh per hour per passenger. For 6 passengers (the maximum per capsule) we need 0.1875kWh per hour of trip length. At \$0.15 per kWh the cost is 2.8125 cents per hour for a full passenger capsule.

<http://nextbigfuture.com/2009/01/co2-capture-from-air-for-fuel-or.html> says the cost of artificially removing CO₂ directly from the air is about \$100 per ton of CO₂. Right now the cost of carbon credits (supplied by forests etc.) is about \$6 per ton of CO₂.

www.faiithscience.org/Articles/Articles_Pdfs/HANNA002.pdf This US Department of Agriculture (USDA) study that suggests an average person's respiration generates approximately 900 grams weight (450 liters volume) of CO₂ per day. The publication is: "Your Role in the Greenhouse Effect" by Jerry Hannan. 900g = 0.9kg per person per day.

One metric ton = 1000kg = \$100 or about 10 cents per kg or 9 cents per person per day. That amounts to 2.25 cents per hour for a 6 passenger capsule.

Since a vacuum environment offers excellent thermal insulation, the cooling/heating energy for ET3 will be minimal compared to an automobile.

All total the energy cost of ET3 will typically be less than 1/50th as much as for electric cars or trains.

ET3 energy use for passenger hauls of 400 miles at 400mph:

0.1kWh for airlock, + (2.5kWh for acceleration - 2.25kWh recovered on deceleration =) 0.25kWh, + 0.7kWh for 1hr levitation cooling, + 0.5kWh for 1hr oxygen supply and CO₂ scrubbing, + 0.34kWh for capsule cooling, + .04kWh propulsion energy, + .04kWh vacuum pumping energy, = 1.97kWh total

1.97kWh / 400 miles = .004925kWh per mile (or 6,841 miles per gallon equivalent using EPA 33.7kWh/gallon conversion factor).



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.00493kWh per mile / 6 passengers = 0.000821kWh per passenger mile, this is 0.821 Watt Hour per Passenger Mile. (or 1218 passenger miles per kWh = 41,046 passenger miles per gallon equivalent at the EPA 33.7kWh/gallon conversion factor)

For comparison, <http://www.teslamotors.com/models/features#/performance> says a 7 seat Tesla S is rated at 208 miles using a 60kWh battery, this is 0.2885kWh/mile /7 seats = 0.04121 = 41.2 Watt Hour per Passenger Mile. The Tesla S uses 50 times more energy than ET3 (on a passenger mile basis).

<http://cdm16255.contentdm.oclc.org/cdm/singleitem/collection/p266401coll4/id/1241/rec/4> shows that BART electric passenger train uses 171 Watt Hour per Passenger Mile (Wh/p-m) during peak time 4pm-6pm. Then the author contrives to show that squeezing one more passenger on a rush hour train would require only 41 Wh/p-m additional energy, and this they compare this 41 Wh/p-m to an average car with only a single occupant to claim 52 times better energy efficiency for the train (absolute best case compared to the car's worst case!). (NOTE: a Toyota Prius with all seats full, operated at maximum rated economy gets better passenger miles per gallon than the BART train at rush hour loading.)

ET3 used for a cargo haul of 400 miles at 400mph:

0.1kWh for airlock, + (2.5kWh for acceleration - 2.25kWh recovered on deceleration =) 0.25kWh, + 0.7kWh for 1hr levitation cooling, + .04kWh propulsion energy, + .04kWh vacuum pumping energy, = 1.13kWh = 0.002826kWh/capsule*mile = 0.006278kWh per ton mile = 159.3 Ton miles per kWh = less than a tenth of a penny per ton mile. Using the EPA 33.7kWh/gallon results in ET3 at 5368 Ton Miles per gallon.

The best Diesel engines are about 50% heat efficient, so ET3 powered by a Diesel generator would move a ton 3221 miles per gallon of Diesel at 400mph. By contrast a coal train can move a ton 500 miles per gallon of Diesel at about 30mph. ET3 is 6.44 times more energy efficient than a coal train, correcting for the speed difference results in ET3 being 86 times more efficient on an energy and time basis. Applying the EPA method to Diesel's higher energy content would result in 6442 ton miles per gallon.

Longer hauls improve ET3 energy use, as do higher speeds up to a point (especially for passenger use -- less acceleration, levitation, cooling, and life-support cost per mile at higher speed).

Keep in mind that this ignores the energy required to build the tubes, access portals, and capsules; however constructing elevated high-speed-rail requires 35 times more concrete and steel than ET3 tubes. An empty ET3 capsule weighs only 67 lb per seat, while an empty electric train weighs over a ton per seat. For underground use, ET3 requires 1/18th as much energy to dig the tunnel as a HSR tunnel.

Water cycle energy:

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

Water loss via skin and lungs – 800ml/day

<http://www.thenakedscientists.com/forum/index.php?topic=15130.0>

Using 300mls per hour at 20-30% humidity at say 16 breaths per minute gives 5mls evaporative loss per exhale at rest.

http://www.anaesthesiamcq.com/FluidBook/fl3_2.php

Insensible loss from the skin cannot be eliminated. Daily loss is about 400 mls in an adult.

Insensible loss from the respiratory tract is also about 400 mls/day in an unstressed adult. The water loss here is variable: it is increased if minute ventilation increases and can be decreased if inspired gas is fully humidified at a temperature of 37°C (eg as in a ventilated ICU patient).

The minimal insensible loss in an adult is about 800 mls. This is equivalent to a heat loss of about 480 kcals/day which is about 25% of basal heat production. On an 'average' day, activity will increase insensible respiratory water losses so that the overall insensible loss is more than the minimum: an estimate of 50 mls/hr has been suggested for use in unstressed hospitalized patients

Life-cycle Sustainability:

One aspect of sustainability is the ability for everyone in the world to partake on a long term basis without irreparably harming the environment. ET3 AGS takes transportation sustainability to an unprecedented level, and the 'benefit footprint' is in line with the 'cost footprint'. We do not contrive sustainability simply by inappropriately enlarging the boundary of measure via mitigation (coat-tailing on unrelated value), bullying suppliers, or 'greenwashing' mediocre performance. ET3 represents a quantum improvement in many dimensions: energy use, labor efficiency, speed, silence, reliability, ecology, capacity, safety, durability, and material use. Because we virtually eliminate aerodynamic drag and resistance, we use 1/50 as much energy per passenger mile as cars and trains; this results in 1/50th as much carbon footprint. Tons of infrastructure material/capacity is improved by as much as 100 fold. The most important transportation sustainability measures are: energy/passenger mile (or ton mile), labor per passenger mile (or ton mile), material cost/capacity, life-cycle cost/passenger mile (or ton mile), maintenance cost / passenger mile (or ton mile), average speed, cost of accessibility, cargo loss per ton mile, and lives lost per passenger mile.

Construction energy:

ET3 will require about 0.5 tons of concrete per meter (840t/mile) of double tube guideway; and about 0.17 tons of support steel per meter (280t/mile) of typical (18' height) 144 miles of guideway tubes= 40.6TJ;

11t/mile of magnet material for 144mi = 86TJ

5t/mile Al coil mass by 144miles = 101TJ

1400gal/mile diesel fuel to construct by 144 miles = 24.4TJ

144 mile grand TOTAL=252TJ

(2.1M gal diesel equivalent recovered in 2 months savings by ET3 at 6Mtrips/year)

ET3 AGS will use less than 1/50th as much energy per passenger mile (or ton mile) as automobiles (and trucks,) and therefore ET3 produces less than 1/50th as much emissions as automobiles or trucks if using the same energy source. Use of hydro power virtually eliminates emissions.

ET3 will require about 0.5 tons of concrete per meter of double tube guideway; and about 0.15 tons of support steel per meter of typical (18' height) elevated guideway. Over 95% of the steel and concrete can be recycled (and 99.9% of the magnets and coils).