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E T 3 Global Alliance *'Space Travel on Earth'*

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ET3 ENERGY USE OVERVIEW

The most important transportation sustainability measures are: energy/passenger km (or ton-km), labor per passenger km (or ton-km), material cost/capacity, life-cycle cost/passenger km (or ton-km), maintenance cost / passenger mile (or ton mile), average speed, cost of accessibility, cargo loss per ton-km, and lives lost per passenger km. Energy use of ET3 is the focus of this paper.
The energy use calculation of ET3 is not simple as it is with a train, aircraft or 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 other modes; such as energy to: maintain the vacuum, cycle the airlock, and provide breathable air for the occupants. (The proper ET3 terminology is: 'capsulec = 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. (Also reference LIGO.) Capsule leaking is also very low. The main source of pumping loss is from the small (1mm) clearance between the capsule and the airlock resulting in about 18.2 liters of undisplaced volume per airlock cycle. 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 ET3constraints.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 km (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 1.5m (60") diameter tube the force required is Pi*30*30*14.7=18.8 metric tons of force. For one km we have 51.36kWh per single tube. Pumping efficiency is about 60% so we need 86kWh per km of 1.5m diameter tube. This is about $13 worth of electrical energy (at 15 cents per kWh) per km of tube, a very small part of construction cost. A typical freeway will carry more than 30,000 vehicles per day, assuming this use, and that the tube will be serviced once every ten years (it could be once every 100 years) we have a tube vacuum cost of 0.000012 cents per capsule mile. A 550km/h tube will carry 29 times this number of capsules (and a 6500 km/h tube over 300 times more), 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 6500 km/h (worst case) it is about 1kWh per 1600km or about 0.0006kWh per km 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 650km/h, the propulsive energy is less than 1/10th as much.

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Per hour cost:

Some costs depend on time and therefore convert to per km 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 less than 5kg 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 45.3kg 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 6 cubic meter size oxygen cylinder, or 1.5 KWH per cubic meter.
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 0.5m^3 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.faithscience.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 CO_2 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 cost to remove 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 650km at 650km/h:
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 / 650km = 0.003kWh per km (or 6,841 miles per gallon equivalent using EPA 33.7kWh/gallon conversion factor).

.003kWh per mile / 6 passengers = 0.0005kWh per passenger mile, this is 0.5 Watt Hour per Passenger km. (or 1960 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 335 km using a 60kWh battery, this is 0.179kWh/km /7 seats = 0.0256 = 25.6 Watt Hour per Passenger km. 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 106 Watt Hour per Passenger km (Wh/pkm) during peak time 4pm-6pm. Then the author contrives to show that squeezing one more passenger on a rush hour train would require only 25 Wh/pkm additional energy, and this they compare this 25 Wh/pkm 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 petter passenger km per liter of gasoline than the BART train at rush hour loading.)

ET3 used for a cargo haul of 650km at 650km/h:
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 = 0.001756kWh/capsule*km = 0.00390kWh per ton km = 256 Ton km per kWh = less than a tenth of a penny per ton km. (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 km 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 30kg (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 ml/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 ml. 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

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Construction energy:
Compared to elevated HSR infrastructure, ET3 will require less than 1/35th as much concrete and steel, or about 522t/km of double tube guideway = 1.879TJ per km;
and about 174t/km of typical 5m tall supports or 4.00TJ per km;
684t/km of magnet material = 0.371TJ per km;
3t/km Al coil mass = 0.436TJ per km;
3293liter/km diesel fuel to transport and assemble = 0.105TJ per km;
GRAND TOTAL=**6.792TJ per km = 1,886,821kWh per km (= 80,010gal diesel eq. per mile).**
A freeway at 30k trips per day average use =10.95M trips per year at 17km/l (40mpg) per car results in 0.644 MegaLiter/km (273,750 gallons/mile) of Diesel eq.. At 98% savings = 0,631MegaLiter/yr/km (268,275 gallons of Diesel eq. savings per year per mile), so the entire energy investment is recovered in 3.58 months savings by ET3. (NOTE: the capacity of a single ET3 tube at 550km/h is 10 capsules per second or 315M vehicles per year, or about 29 times greater than the use factor assumed for the calculations in this section. This capacity scales with design speed, so for 6,500km/h global routes, the material utilization potential is an order of magnitude greater.)

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 automated system 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.

Conclusions:
ET3 represents a quantum improvement in many dimensions: energy use, labor efficiency, speed, silence, reliability, ecology, capacity, safety, durability, and material use. ET3 will use less than 1/50th as much energy per passenger km (or ton-km) as automobiles (or trucks), therefore ET3 produces less than 1/50th as much emissions as automobiles or trucks if using the same energy source. Infrastructure material mass / capacity is improved by as much as 100 fold. Use of hydro power virtually eliminates emissions. The energy savings is calculated at typical use freeway use factors. Per km energy use diminishes at higher use factors.
Over 95% of the steel and concrete can be recycled (and 99% of the magnets and coils). The entire embodied energy of materials and construction is recovered in less than 1/3rd of a year of savings if used at typical freeway use factors.