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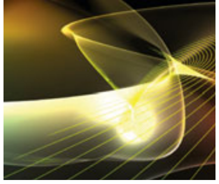

COMMENTARY

Comment on "The challenge of energy-efficient transportation" J. Hermans

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ABSTRACT

It's hard to beat the energy density and convenience of liquid hydrocarbons. The product of energy used and journey time is another way to compare transportation systems. It is more practical to power electric cars from batteries than photovoltaics. Solar can be used to supply some of the energy needed to recharge the batteries. The primary energy used to make food, the fuel for the human cyclist, can be many times the calorific energy derived from the food.

Transportation is a major source of carbon dioxide emissions. Hermans makes some excellent points in his article "The challenge of energy-efficient transportation." However primary energy to produce fuel should also be considered. The embodied energy of liquid hydrocarbon fuels is much less than their energy content. For a cyclist the fuel is food, and, depending on diet, the primary energy can be many times the food's calorific energy. The article is over optimistic on the prospect of cars directly powered by solar photovoltaics. It's more realistic to use batteries in electric cars and generate the electricity from a number of sources. For anything other than trains that run on fixed tracks it's hard to beat the energy density and convenience of liquid hydrocarbons.

Keywords: carbon dioxide; environment; transportation

DISCUSSION POINTS

- Is hydrogen (either as a liquid or a compressed gas) viable as an alternative to liquid hydrocarbons?
- Does cycling necessarily reduce greenhouse gas emissions?

Viewpoint

(See the article, "The challenge of energy-efficient transportation," *MRS Energy & Sustainability, 4*. doi:10.1557/mre.2017.2.)

This article gives an excellent review of the energy options for transportation, based on Chapter 5 of the author's book "Energy A Survival Guide."[1] The conclusion that liquid hydrocarbons from fossil fuels are hard to beat in terms of energy density and convenience for any transportation other than rail is indisputable. Nearly all the liquid hydrocarbons consumed every year are used for transportation, either by land, sea, or air. From the world consumption of crude oil[2] it is then possible to estimate that transportation accounts for almost 30% of annual carbon dioxide emissions.

The article contains many useful observations on energy use in transportation. It is absolutely correct to point out that aerodynamic drag dominates for travel at highway speeds. Trains and buses gain their advantage by being "long thin things," and this overcomes any disadvantage associated with the higher drag coefficient.

Some of the points in the article are more controversial. The larger mass does not adversely affect the train in a journey with frequent stops. A train that has to stop frequently (a commuter train or subway train) is unlikely to reach speeds where aerodynamic drag dominates. Both the energy required to overcome rolling resistance and the energy needed to accelerate to a given speed are proportional to the mass. In stop-start city driving the energy for acceleration is greater than energy to overcome rolling resistance for a car when the stops are more frequent than every 1.0–1.4 km.[3] For a train it would be about 5 times longer due to the reduced coefficient of rolling resistance.

Whilst it is true that almost half the initial mass of an aircraft used for long haul flights is fuel, those who have endured these journeys realize that the aircraft is still fully loaded with passengers. In light planes there is a trade-off between number of passengers and fuel that can be carried, in large commercial aircraft the limit is given by the space allocated. Furthermore large jet aircraft climb to higher altitudes where the air is less dense as the mass is reduced from consumption of fuel.[3,4] The airspeed doesn't change by much, but the lift required to balance the lower mass is reduced since the air density is less.

In the review only the energy required to overcome the combination of air and rolling resistance is mentioned for the bicycle.

The human pedaling away has about the same efficiency as the car, about 20–25%, as mentioned in the book. However one should also consider the energy inputs of the human fuel, or food, as compared to the energy inputs to make gasoline or diesel fuel. The embodied energy of gasoline or diesel is very small compared to its energy content, maybe about 15–20%. For food it all depends on where it comes from, whether fertilizer was used to boost crop yields, and whether meat comes from factory farms where animals are fed on crops that could otherwise have been used to feed people. If the cyclist is a vegetarian only eating what is grown in a local garden, there is a very small energy input, and nearly all of it solar! If, on the other hand, the cyclist stops at hamburger stands there is a massive energy input from fertilizer to grow animal feed, harvesting the crop, fattening the cattle, and distribution of the meat. Coley et al.[5] estimate that five times as much energy is used in making food for the average UK diet as the energy derived from eating it and for the meat in a typical hamburger in the US this may well be up to twice that amount!

Something that should also be considered when comparing the efficiency of different methods of transportation is the product of energy and time for the journey, or force divided by velocity.[3] In fact this is the measure used to calculate the optimum cruising speed for airplanes that aren't operating near the speed of sound. It's not that flying is inefficient in the energy needed to travel a given distance, it's that flying makes traveling long distances possible.

The article is overly optimistic on the potential of solar, especially in Northern Europe. In Ref. 1 it is claimed that the embodied energy for solar is made back in 3 years. This might be true for Phoenix AZ, but it certainly isn't true for Northern Europe. Depending on the manufacturing process and the efficiency, the energy payback time is more like 8–10 years, and some authors[6] would say the energy is never recovered.

The numbers given for the Eindhoven University car are difficult to understand. The car looks no wider than an average car, less than 2 m, with a solar panel width the same as the car yet in the figure caption it says that the car is equipped with 5.8 m^2 of solar cells. Even if the solar intensity were 1 kW/m^2 (AZ midday in June) a 15% efficient photovoltaic would only give 0.87 kW, not enough to power the 1.5 kW electric motor. In practice the peak solar intensity in Northern Europe is more like 400 W/m^2, and from the image shown the car would need to be traveling in the right direction to capture the maximum intensity. Of course there should also be no clouds in the sky! The range is exaggerated: a 15 kWh battery would give 10 h of use. At the reported low speed of 43 km/h, the range would be 430 km (not 650 km). To put electric cars in perspective the Tesla S has batteries ranging is capacity from 70 to 100 kWh and a 300 kW (peak) electric motor. It should also be noted that the thin bicycle-like tires are needed to cut down on rolling resistance.

A more realistic way to reduce carbon dioxide emissions from ground transportation is to use batteries in the vehicle for storage of electrical energy, rather than try and generate the energy from photovoltaic panels. The low energy density of the battery (by a factor of about in 50 by mass, 30 by volume) is partly compensated by the much higher efficiency of the electric motor as compared to an internal combustion engine. If the electricity is generated by anything other than coal there will be a reduction in carbon dioxide emissions. In practice what has limited the adoption of all-electric vehicles is the cost of the battery. This is now being addressed by Tesla, who are implementing new production processes in their Gigafactory in Nevada.

Ironically solar power is practical for specialized long endurance reconnaissance drone aircraft that circle a point at high altitude above any clouds. It's certainly not practical for passenger carrying aircraft. The Solar Impulse II that recently flew around the world (largely propelled by strong westerly winds at altitude) had about the same wingspan as a Boeing 747 but only carried 1 pilot/passenger!

The discussion on the practicalities of hydrogen storage is especially important, given the interest in using hydrogen as a fuel. The mass of any practical container outweighs the benefits of the high energy density for the hydrogen fuel. The same could have been said for the proposal in the 1950's to use nuclear energy to power airplanes. There's also hydrogen embrittlement to consider which limits the choice of container materials. Although hydrogen has a high energy per unit mass its inferior to liquid hydrocarbons like kerosene in energy per unit volume. That's why it isn't used as the fuel in the 1st stage of rockets. The mass of fuel in a rocket is many times the mass of the payload. The job of the 1st stage is to get the rest of the rocket and payload out of the dense high drag parts of the atmosphere (alternatively one could launch the rocket from an airplane in the stratosphere). To minimize drag it's necessary to minimize volume, which is why 1st stages use kerosene and not liquid hydrogen. The same arguments apply to commercial aircraft.

In summary it's hard to see how liquid hydrocarbons can be displaced as the fuel of choice for transportation systems, except for road transportation where it will depend on both improved battery energy density and lower cost of high performance batteries.

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