The future of electric transportation

(December 2021)

If you represented each human being by a tiny one millimeter square, you would need one and a half NFL regulation football fields to fit everybody, and if you wanted to count them at the rate of one every second the task would take you more than 250 years.

Still, people and politicians alike seem to think that the one size uniform their uninformed intellect was able to design will fit all of mankind.

It would be futile to believe that transportation can be of a single design. Different levels of economic development will require different solutions, and inside each individual country considerations of distance and population density will dictate different designs and solutions.

For example, while high-speed passenger trains can take you from Boston to Washington, DC, via New York City, Philadelphia and Baltimore on electrified railroads, freight trains throughout the country are pulled by diesel locomotives, although power is transmitted to the wheels through a generator and electric motors. Different environments and applications require different designs.

Where relative costs of energy are concerned, the raw cost of energy is not the only factor. For example, while natural gas and coal cost in the U.S. less than 2 cents (before tax) per kWh delivered by a large co-generation power plant, and diesel oil costs 20 cents per mechanical kWh delivered by a large truck engine, the more important issue beside capital and maintenance costs is that of transporting the energy to automotive equipment.

Electric motors existed before internal combustion engines appeared. The reason for the ubiquity of internal combustion vehicles on our roads and streets is simply that liquid hydrocarbon fuels are not only easy to transport in a discrete form, they also pack a very large energy per unit of volume or mass. While heating oil, or diesel, contains nearly 12 kWh of thermal energy per kilogram and can deliver nearly 4 kWh of mechanical energy, the most advanced batteries only contain 0.2 kWh per kg.

The main drawback of batteries in electric transportation is not due to technology; but to simple physics. Not only are batteries nowhere near competing with liquid fuels mass-wise, since their mechanical energy content per unit of mass is but 1/20th of that of liquid fuels (and 1/40th in air transportation applications), but also the transfer of energy to the battery presents an unsurmountable difficulty.

As you know, gas pumps at the service station deliver fuel at a rate of 10 gallons per minute to passenger cars, up to 100 GPM to large trucks, and the rate is even 1,000 GPM when refueling large airplanes in an airport.

You can calculate that a gas pump transfers energy at a rate of 750 kW per GPM equivalent.

To recharge batteries at a rate equivalent to a 10 GPM pump you would need a 7.5 MW power supply for each individual battery operated passenger car being refilled, while a large truck would require 75 MW, and an airplane 750 MW. For reference, the U.S. has a total electric generation capacity of 1,000,000 MW. That's 3 kW per person, so each car being refilled would require an installed power equivalent to that of 2,500 people, while a truck would require 25,000 people equivalent installed power, and an airplane 250,000.

The electrical demand being clearly unsurmountable, the only solution is to increase the time required to recharge the batteries, irrespective of any future improvement to battery design. However, individual people dispose of only about 1.2 residential kW per person, or about 5 kW per family of 4. Even if 50% of that available power were dedicated to charging batteries and batteries held the amount of energy equivalent to that of a 16 gallon diesel tank, the charging time for the corresponding 200 kWh would be 80 hours, while a present day efficient diesel powered car can go 600 miles on a full tank on the highway (10 hours at 60 mph), and 450 miles in the city (also about 10 hours). The disparity between operating and charging times is too large to be ignored, since the impracticability of having to spend 8 hours at the gas pump for each hour driven is quite obvious.

As for going from the power required to drive a gas pump, which is less than half a kW, to the 7.5 MW mentioned above, figures speak for themselves.

Still, considerations of air pollution (other than carbon dioxide, which is anything but a pollutant), of noise, and, above all, of traffic fluidity in very congested metropolitan areas will lead to the adoption of electric vehicles in certain areas and on select thoroughfares, although such electric vehicles will very marginally draw energy from batteries. A limited amount of batteries will still be present, but only as an auxiliary device, not the main or only source.

Numerous and ubiquitous public electric vehicles are in wide operation the world over, although none draw their energy from batteries. Rather, they draw their energy from rails, overhead catenaries, or underground or overhead traction cables, to name a few possibilities. Such systems have been operating in urban areas for over a century. Of the non-rail systems, a few are still operated as trolleybuses or cable cars in San Francisco, Boston, Seattle, or Philadelphia. Trolleybus lines present several advantages, but also several deficiencies, which can and must be addressed.

I believe that in a first step part of the heavy truck traffic in heavily populated areas, such as the Atlantic seaboard, will be converted to overhead catenary systems on a dedicated lane of major thoroughfares, with limited battery power being used between the freeway exit and a warehouse, for example, or wherever clearance is not sufficient for overhead supply, such as in some tunnels, although the protected nature of a tunnel would allow switching for a limited distance to ground supply. The principal advantage of such a system, though, would be not so much the shift away from liquid fuel, but rather the great benefit of allowing complete automation of vehicle operation on such a dedicated lane.

In a second step the system would be extended to passenger vehicles in urban areas, for such traffic that requires it, perhaps on the basis of rental.

In a third step electrification could extend to cross-country thoroughfares. The undertaking would face the same kind of hurdles faced by freight train companies, although contrary to railroads the owner of freeways is the government and the number of road vehicles greatly exceeds that of locomotives, so the cost would be shared among a multitude of users instead of the only 7 Class I railroad companies, including 2 Canadians. In addition, if and when sufficient electrical power is made available in remote parts of the country railroad electrification would become easier.

Incidentally, if all automotive liquid fuels disappeared in favor of grid electricity, installed electric generation capacity would need to increase by at least 70% to 1,700,000 MW, and the increase could not possibly come from windmills or photovoltaic panels, and neither from natural gas, since even at current consumption levels U.S. proved reserves would only last until 2034, but from nuclear energy. In passing, to go all windmill a number of about 4 million of among the largest would be required, which would cost nearly a year of GDP, and would line quite unattractively 100% of the coasts of the contiguous United States with hundreds of rows of parallel lines of windmills extending a hundred miles or more inland. Furthermore, whatever coasts are not subjected to frequent earthquakes are prone to severe storms and hurricanes, which would further complicate the task.

As it happens, the time allowed between manually operated vehicles on a freeway is currently mandated to be 3 seconds, so the safe maximum traffic capacity of each individual freeway lane is only 1,200 vehicles per hour, irrespective of speed. Whenever the number of lanes decreases, for instance from 4 to 3, the total maximum freeway capacity decreases from 4,800 to 3,600, which requires a 25% slowing down of upstream traffic and an intricate interlacing of traffic into the reduced number of lanes. There is no need for a traffic jam or a pileup, just a slowdown, except if some drivers cheat and attempt to enter the reduced lanes out of turn. Just a few cheats have the capacity to stop and block thousands of cars.

In a fully automated dedicated traffic scheme such out-of-turn occurrences would not happen, and in addition speed could be safely increased while the time interval between vehicles could be reduced from 3 to a fraction of a second, and even to zero, in which case traffic capacity per lane could be increased 40-fold. Likewise, the need for traffic lights would disappear since central but redundant computerization of crisscrossing traffics would allow the seamless concomitance of all perpendicular or merging traffics.

Of course, such a scheme would only be possible in lanes on which all traffic is fully automatic, the mingling of non-automatic and automatic vehicles killing the main purpose of automatization. The solution promoted by some manufacturers today of having automatic battery operated vehicles co-exist with the rest of traffic is therefore clearly disingenuous at best.

In parallel and with regard to airborne traffic, the option recently promoted of electrifying large airplanes is quite bewildering, to say the least, since the combined equivalent energy content of the lightest batteries is currently but 1/40th of that of jet fuel, per unit of mass, which would see the range of large airplanes decrease from a respectable 7,000 miles to a meagre 175.

However, if congested traffic were to be alleviated on the air routes, or even totally eliminated, only total automation could achieve that goal. Current airplanes can land at the touch of a button and it is probable that the only resistance to automatic air transportation will be that of pilots, not of the public, which would get accustomed to it when they realize that no pilot can compete with a computer and that the only way to make sure flights are faster and on time all the time is to automatize airplane operations and also reduce airplane separation. For example, no flight would leave a departure gate that would not be assured not to wait at destination before landing. Of course, such automatically planned flights could not co-exist with manually flown airplanes, the latter becoming confined to recreational air reservations.

You may know that I have hundreds of hours of flight training with commercial pilots who did not display much sympathy for my ideas.

In the end, the principal engineering challenge is either to design from the ground up, or to modify existing energy transmission systems. There is a choice of solutions, from underground or above head traction cables, to catenary electricity supply cables and sliding pantographs, to rail supply, or underground electromagnetic systems, or hydraulic or pneumatic systems, the choice is wide.

Then will come the integration of all different systems and of dedicated and undedicated lanes, the automation of traffic, the coexistence with rail and pedestrian traffic, and other issues.

The main benefit, and the reason why I believe it will eventually happen, is full automation and the subsequent vast improvements to traffic capacity, fluidity, and safety, electrification being part of the scheme, rather than its root.

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