SOME PROSPECTS ON ENERGY AND ENVIRONMENT ISSUES

SUSTAINABILITY?

Yes. This is a wise attitude: do not exhaust your budget today; there is always a tomorrow, at least for your relatives, friends, and fellow beings. Some guidelines may be:

- Control your budget; some sporadic extra expenses may be accepted, but do not squander. And your budget is not only monetary; think also on your time budget, environmental budget, and so on.
- Think with an open mind; use, but not abuse. We know that the only way of living is at the expense of the environment and other people: we need matter, energy, and cooperation, all from outside; we will die if isolated. Time ago, our terrestrial environment was wide enough for providing unlimited supplies of raw matters, and for recovering them from our wastes. Nonetheless, particularly since we went to orbit our Earth, we have realised how delicate a life-support system is, and how limited our planet is for its increasing population and activities.
- Sustainability at a global scale depends on social majorities and common strategies. A person's attitude has little effect on global climate change, for instance. It is society at large that should be convinced (by education and historical knowledge) that war or massive forced migrations are unacceptable, and we must develop global enforcing means to dissuade and stop local offenders. And there is not only the fact that global problems require global support, but the problem of unequal capabilities and unequal development stages: it is unfair to ask for fasting after you have eaten.
- Personal mobility has become nowadays a major resource waste in developed countries. Even if your budget allows, squandering valuable resources is a rejection precedent for general behaviour; e.g. low-cost travel has made some people to know their antipodes better than their neighbourhood (even going far away just to have a drink). Sometimes, personal mobility is demanded by poorly planned housing schemes, and private transport needed by lack of public means.
- Urbanization has provided social synergy and progress, and nowadays more than half the world population lives in cities (and the trend continues). Urban societies are more powerful and efficient, but less resilient to perturbations, and more dependent on a proper circulation of essential matter and energy flows (air, water, food, energy, and people mobility), with associated waste management (air pollution, sewage, garbage...).
- Be cautious on your undertakings, but have some confidence on progress. Trust on future enhancement is inherent to human attitude, and solution to problems that today appear unsolvable may come along tomorrow, after new discoveries by ourselves or by our fellows; go ahead and faith will come along to you (the '*Allez en avant et la foi vous viendra*', proposed by d'Alembert in the Age of Enlightenment).

PHOTOVOLTAIC ENERGY?

Yes. In spite of its low energy density and low conversion efficiency (16..18 % for cheap Si-amorphous cells; around 30 % for expensive multi-junction GaAs cells), solar photovoltaic (PV) systems have great advantages. Solar energy is widespread worldwide and predictable in time (although with wide oscillations, and direct-beam contribution may fluctuate a lot in short times), and photovoltaic energy is already electrical (the most versatile), and affordable (say to 1 €/W of peak power installed; <100 €/m^2).

However, besides the need for energy storage, the major disadvantage of PV-energy is its low concentration: the source, solar irradiance, has a maximum of E_{max}≈1 kW/m^2 on ground, what means a peak electrical power of about $P_{ele,max}$≈0.17×1000=170 W/m^2 and a daily average 170/π=55 W/m^2. And the latter is based on E_{max}≈1 kW/m^2, what is representative of solar irradiance of low and middle latitudes in a clear sky at noon on summer.

STORED ENERGY?

Yes. Buffer storage is a common need to all uncoupled demand/offer systems. Electrical energy is the preferable final-user energy form (the more versatile and clean). Its main handicap is that another energy form is needed for energy storage since only small amounts can be stored on electrical capacitors, or even on electrochemical batteries, and large energy stores require some additional chemical, thermal, mechanical, or hydraulic transformation. For large-capacity energy storage, synthetic fuels (H_2, CH_4O...) or other chemicals (NH_3), seem the best solution.

In a way, civilization has shown a trend from gathering raw materials to cultivating them; i.e. from gathering fruits and animals to agriculture and cattle raising, from fishing to aquiculture, from water supply to water treatment, and from raw fuels (wood, fossil) to synthetic fuels.

Fossil fuels should not be used as in the past, because of its associated massive pollution. In theory, they might be used without contributing to the greenhouse effect, e.g. using natural gas with carbon sequestration, i.e. $CH_4(g)=2H_2(g)+C(s)$; but, in any case, fossil fuels are not renewable, and might be used for better purposes than just burning them.

Even if nuclear fusion becomes mastered and the energy crisis solved, we will still need chemical energy (fuels) for off-rail transportation; e.g. for aviation I cannot envisage any other energy source but a liquid fuel, like present kerosene.

Some details of electrochemical batteries, follow on *Electric cars*.

ELECTRIC CARS?

Yes. For densely populated areas, the best solution to personal mobility is hired electric cars (with driver, without, or self-driven, in the future), and electric buses for public transport. As smoking was banned on must public places around year 2000, I believe that combustion vehicles will be banned in large cities around 2025 or so (at the present ownership of 0.5 car per person, it is not only a pollution problem but of parking-site problem). However, for sparsely populated areas, the internal combustion engine will dominate for road transport for decades. Present worldwide contribution to green-house-gas emissions of cars and light-duty vans is 15 %, IPCC-2015, almost half in large cities. Global transport share (when adding heavy-duty road, maritime, and air transport) is about 28 % of CO_2 emissions.

The battery electric vehicle (BEV) seems presently the best bet for urban mobility, but fuel cells might take over in the future. However, for long distances (say over 300 km in densely-populated areas, or over 500 km in general), other means of transport seem preferable; depending on infrastructures: trains, airplanes, or high-end cars powered by heat engines (or fuel cells in the future).

Battery energy density has progressed a lot, with today's value for Li-batteries over 1 MJ/kg (0.3 kWh/kg), but I do not expect this technology to beat a 2 MJ/kg ceiling in the future. Even with more advanced chemicals, I presume it will be difficult to exceed 4 MJ/kg (or 1 kWh/kg). When compared with the work output of a good internal combustion engine (ICE), which may yield 15 MJ/kg (or 4 kWh/kg), the energetic unbalance is clear (more when considering the free heating in wintertime offered by ICE; consumption of BEV in wintertime may double), but one must be always concerned with pollution.

Battery recharge rate is a major concern too, because it is unbearable to use home power (at 5 kW, a 100 kWh battery pack takes 20 h to charge), and even with high-power posts at 300 kW it takes at least 20 min (it really takes half an hour to get 80 % of the charge). Whole battery-pack replacement instead of in-line recharging seems another option in a centralised hire-city-car system.

For the transition from the currently dominating heat-engine car, to the all-electric city-car (which may take more than a decade), hybrid cars (with an electric engine and a heat engine, usually on gasoline) appears as the best solution in the present context of expensive battery-packs, long recharging times, and combined city/road use. Plug-in hybrids, however, are more expensive than fuel-recharge hybrids, almost as full electric cars, and add little advantages.

Autonomous cars require a long development effort (more than a decade), with automated tasks being progressively incorporated, particularly those with low risk like self-parking (call off and call in). Augmented reality gadgets may help a lot during further developments. If the promise of drastic reduction of the present worldwide mortality rate in road-traffic accidents of 19/10000 deaths a year (3900 persons every day!) realises, this goal must be eagerly pursued.

In brief, electric vehicles (EV) will soon replace fuel vehicles (FV) in crowded areas, but not everywhere else. Heavy trucks will follow with the powerful and versatile diesel engine, with post-combustion particle filter and NOx catalytic reduction, perhaps evolving towards dual fuel (e.g. diesel ignition plus natural gas), but should not enter densely-populated areas. Maritime transport already has experience with dual-fuel heat engines (with mechanically or electrically driven propellers), and for aircraft I do not see a better solution than a kerosene-type heat engine, with the advances being on not using these engines on ground operations, and on producing the fuel from renewable sources.

HYDROGEN FUTURE?

Maybe. Hydrogen is the cleanest and more versatile high-capacity storable energy carrier. But it has a small energy density because of its low mass density (either in gas, liquid, or solid form). Higher energy density can be achieved, even at room temperature, by combining it with other substances, e.g. by gas absorption in solid hydrides, or by chemical bonding as in methanol (CH_4O), ammonia (NH_3), or butane (C_4H_{10}); but those combinations introduce additional problems of composition and decomposition. The advantage of hydrogen as a carbon-free fuel is untenable at the moment, since the largest share in hydrogen production will be from fossil fuels (natural gas, and coal) for the near future (so that CO_2 capture will be a long-time need).

Concerning pure hydrogen, I foresee no special difficulty in modifying gas-ducts for piped delivery, or using very-high pressure (up to 100 MPa) bottled gas for movable applications, but I suspect low economical advantage in developing liquid-hydrogen (LH2) carriers similar to LNG carriers for sea transport (let alone LH2 pipelines): even if better thermal insulation were developed, and sloshing were minimized, I guess the cost of boil-off treatment is too high (it is expensive to keep any bulky thing at 20 K). This LH2 handicap points to local production and short-haul transport of pure hydrogen in gas form, in detriment of long-haul hydrogen generation offshore from any renewable (or fossil) source. The simple transition to a future hydrogen economy may be to add hydrogen to natural gas (and later to biomethane) and make use of available natural gas infrastructure. I do not expect an important hydrogen car development in the near future, neither for fuel combustion (too expensive and NO_x) nor even for fuel cell cars.

In brief, I think the future of hydrogen energy more as a stationary local energy storage than as the universal fuel energy carrier. Hydrogen will be used in fuel cells as energy source in stationary and mobile applications in populated areas, and produced more and more from water in electrolysers (or in photoelectrochemical cells) with renewable energy sources (solar and wind). Present drawbacks are high price and short life of fuel cells, and storage and refuelling of hydrogen fuel, with current cost at California service stations of more than 10 €/kg of hydrogen (2017). I do not see hydrogen being used in long-haul transportation, where different synthetic fuels are better solutions (e.g. in aviation, a liquid fuel is a must, so that synthetic kerosene from renewable sources is my bet).

NUCLEAR POWER?

To some extent, minimizing the risks (I know it cannot be fully avoided). Some nuclear power plants, say in a hundred, placed in physical and political stable sites, and well-cared, may help to develop future nuclear fusion plants, and the many current and future non-power applications of nuclear energy (e.g. production of many medical and industrial radioisotopes is linked to the nuclear fuel cycle).

I understand that currently we lack the knowledge for complete nuclear-fuel-waste recycling, and we have to store very dangerous radioactive waste for long (hoping to solve the problem in some reasonable time frame, say centuries, not burying it for aeons). But we too currently lack the knowledge to solve other long-term problems of humankind, like the huge amount of noxious substances released since the Industrial Revolution (among which stands the current 40 000 million tons of CO_2 per annum causing the climate change), or the biological damage to the environment caused by fertilisers, pesticides, antibiotics, species extinction, etc.

To add operational flexibility and efficiency, excess nuclear power might be used to generate hydrogen, but I see cogeneration of district heat too risky.

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